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Innovations in measurement and evidence for healthy aging

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Innovations in measurement and evidence for healthy aging

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Editorial: Innovations in measurement and evidence for healthy aging

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Editorial on the Research Topic
Innovations in measurement and evidence for healthy aging

The World Health Organization (WHO) has declared the decade of Healthy Aging (2021–2030), in alignment with the 2030 Sustainable Development Goals (SDO) to ensure that all older people can fulfill their potential with dignity and equality in appropriate environments. Healthy aging represents a continuous process to develop and maintain the functional capacity that allows wellbeing in old age (1). Functional capacity is composed of a person's intrinsic capacity (combination of all physical and mental capacities), the characteristics of the environment (factors in the outside world that form the context of life), and the interactions between the person and these characteristics (2, 3).

Maintaining functional capacity in older people is a public health priority, and some of the greatest challenges are related to measuring and estimating indicators that reflect how people age, the trajectories of functional and intrinsic capacity, and the impacts of policies and actions that promote healthy aging (1–3).

The objective of this Research Topic was to highlight the various ways of seeing and understanding healthy aging in broad and heterogeneous contexts, in such a way that it serves for the transfer of knowledge, evidence for future research, and for the generation of interventions that favor healthy aging and wellbeing in old age.

This Research Topic brought together a total of 18 articles of the highest quality in which 108 authors participated. The works developed provide valuable results, where enriching sources of information and analysis techniques were used. These publications address current issues surrounding the older adult population in different geographic locations and understanding healthy aging, from objective physical and mental measures to aspects of mental health and wellbeing. Below is a summary of each of these works (according to chronological order of publication).

- Pumpho et al. developed a mobile application called Walking Think that allows easy interaction with users to record the Timed Up and Go test (TUG) duration while performing walking simultaneously with a cognitive dual task. The authors demonstrated that the mobile application is a valid tool to measure the TUG and TUG-subtraction duration. The TUG test was able to distinguish between faller and non-faller older peoples, with high sensitivity and specificity.

- Gui et al. aimed to predict metabolic syndrome using obesity- and lipid-related indices in middle-aged and elderly Chinese adults. The authors used a national cohort study that consisted of 3,640 adults (≥45 years) and found that a total of 13 obesity- and lipid-related indices were independently associated with metabolic syndrome risk.
- E et al. explored the mediational effects of social support between internet use and health among older adults in China, from the 2021 Chinese General Social Survey. The authors recommend that the government should take compelling measures to encourage and promote the use of the internet among older adults and to obtain social support to improve their health status.
- Wu et al., based on the China Health and Retirement Longitudinal Study (CHARLS), performed a cohort analysis (2011/2012–2015) with the objective to illustrate the relationship between the waist-to-height ratio and the incidence of hypertension in middle-aged and older adult women in China.
- Guo et al. developed a system of indicators to measure the risk of social disablement in China, which involves complex multidimensional variables. The authors found that the risk of social disability in China is generally at a moderately high level and that the risk of disability varies considerably both between and within regions and provinces.
- De la Vega Martínez et al. performed a secondary analysis of the National Survey on the Effects of COVID-19 on the Wellbeing of Mexican Households. The authors analyzed the prevalence of food insecurity and its association with depressive and anxiety symptoms in older Mexican adults during the COVID-19 pandemic.
- Kozela et al. assessed the predictive performance of the Healthy Aging Scale for all-cause mortality in middle-aged and older adults. Data from the Polish and Czech Health Alcohol and Psychosocial factors in Eastern Europe prospective cohorts (2002–2005) were used.
- Wu et al. conducted the first study to evaluate the relationship between sarcopenia index (SI) and all-cause mortality in middle-aged and older Chinese adults. Among the cohort, patients with a higher SI had lower mortality, indicating that SI could be an effective marker for assessing mortality in middle-aged and older Chinese adults.
- Segura et al. developed research on the demographic, family, social, personal, and health factors associated with the subjective perception of happiness in older adults in five cities in Colombia. The authors observed that happiness was explained by the absence of risk of depression and little hopelessness, strengthened psychological wellbeing, a perception of high quality of life, and living in a functional family.
- Wang et al. developed a short version of the Chinese Resident Health Literacy Scale focused on older adults in China, and further assessed the reliability and validity of this short version. The data was from a cross-sectional community-based older adults (5,829) health survey conducted in 2020.
- Navarrete-Valladares et al. analized the theoretical-methodological characteristics presented by other studies carried out between 2012 and 2022 on the experience and collective memory of older adults in the face of climate change.
- Lee and Lee investigated the effect of obstructive sleep apnea on hearing ability in a sample that included 3,575 participants in the Korean National Health and Nutrition Examination Survey between 1 January 2019 and 31 December 2020.
- Lee et al. conducted a study in Korea where the authors demonstrated that relative handgrip strength (RGS) is associated with the incidence of CKD in both men and women; therefore, RGS can be used in clinical practice to evaluate renal prognosis.
- Luo et al. designed a study to establish the cut-off value and diagnostic utility of the Ishii test, which gauges the odds of severe sarcopenia from the results of an equation based on age, grip strength, and calf circumference among middle-aged and older adults (≥50 years) from the West China Health and Aging Trend study.
- Yeverino-Castro et al. described the cognitive changes in older adults (>60 years of age or older) with healthy aging from the 2012 and 2015 waves of the Mexican Health and Aging Study.
- Gutiérrez-Barreto et al. evaluated the design of Integrated Care for Older People (ICOPE) through Theory of Change to analyze its possible implementation in Mexico City. The authors propose that ICOPE has the potential to be applied to contexts similar to Mexico, for example, in other lower-middle-income countries.
- Bai and Lu focused on studying the gap in primary health care access between planning evaluation and current utilization for older adults. The authors conducted an empirical study in Dalian city area based on the registration and survey data of community health centers during the COVID-19 pandemic.
- Shen et al. explored the associations of intrinsic capacity (IC), fall risk, and frailty in a Total of 703 hospitalized patients aged 75 years or older that were recruited for this retrospective observational study from Zhejiang Hospital.

In summary, this Research Topic constitutes an important advance in the knowledge of new and innovative measures to study healthy aging, and provides useful information to decision makers at different levels. It also raises the need to collect reliable and quality data while improving data analysis to monitor social and health actions, programs, and policies (4).

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Conflict of interest

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Development of a mobile application for assessing reaction time in walking and TUG duration: Concurrent validity in female older adults

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Introduction: The TUG can be used to distinguish between people who fall and people who don't fall. To evaluate cognitive dual-task performance while walking for fall prediction, TUG-dual was frequently employed. A recent study has created a mobile application that enables simple interaction to provide greater convenience for monitoring the duration of TUG, TUG-subtraction, and reaction time.

Objective: The research aim was to ascertain the concurrent validity of the mobile application that was developed for the clinical assessment of TUG, TUG-subtraction, and reaction time.

Methods: Twenty-nine older persons participated in this study. The testing protocol involved the TUG, TUG-subtraction, and reaction time assessment. For TUG and TUG-subtraction, the duration to complete the task was recorded by the APDM Mobility Lab system and the mobile application. For the reaction time tests, the reaction times (msec) were recorded by the Multi Choice Reaction timer and the Mobile application. The TUG durations recorded by the APDM Mobility Lab system were correlated with those recorded by the mobile application to verify the concurrent validity using Pearson's product moment correlation coefficient. Also, the reaction time by the Multi Choice Reaction timer was correlated with the mobile application. Bland-Altman plots were used to explore the existence of any systematic differences between the measurements.

Results: Our results showed very strong correlations between the TUG and TUG-subtraction duration derived from the APDM Mobility Lab system and the mobile application (r = 0.96 and 0.96, respectively). For the reaction time, the results showed a moderate correlation between the reaction time derived from the mobile application and the Multi Choice Reaction Timer (r = 0.67).

Conclusion: The mobile application, which allows measurement in TUG and TUG-subtraction, is a highly valid tool for TUG duration assessment. However, this application is capable for assess the reaction time with moderate validity for reaction time assessment.

KEYWORDS

concurrent validity, mobile, application, reaction time, walking

Introduction

Executive function refers to a group of cognitive abilities that need for complex goal-directed activity to be planned, initiated, sequenced, and monitored (1). Measurement of an executive function yields valuable data for predicting falls (2). According to the dual-task methodology, a person should complete the task that is being assessed for its attention demand (primary task) while concurrently executing a different task (secondary task) (3). The Timed Up and Go test (TUG) is an easy and validated procedure to evaluate functional mobility and may also be useful to monitor clinical changes over time in older individuals (4). The TUG is a reliable assessment with excellent test-retest reliability in older adults ($ICC > 0.98$), and also in patients with Parkinson's disease ($ICC = 0.8$) or patients undergoing hemodialysis ($ICC = 0.96$) (4–6). Utilizing TUG in combination with the cognition task of subtraction by three from a random number between 20 and 100, is known as the Timed Up and Go cognitive (TUG cognitive or TUG-subtraction) (7). During the past two decades, the TUG cognitive has been applied to measure cognitive-motor interference (CMI) during walking in various people (8). Gait deterioration during dual-task testing relative to single-task performance was associated with increased fall risks (9). For identifying older persons who live in the community and are at risk of falling, the TUG cognitive showed 80% sensitivity and 93% specificity (10). In the clinical setting, the administration of TUG-subtraction requires the clinician to work multi-tasking, including measuring the time to complete TUG activity, calculating the number of correct subtraction answers, and guarding the participant during TUG cognitive performance. Therefore, there is a need for a tool that could help the clinician to administer the TUG-subtraction, subsequently leading to the reduction of measurement error. Apart from subtraction, other cognitive tasks are also used for assessing dual-task performance. According to the classification system by Al-Yahya et al. (11), the cognitive task can be classified into five types, including working memory, mental tracking, reaction time, discrimination and decision-making, and verbal fluency. The reaction time test is a useful cognitive ability test that may further search for the cognitive processing components that may explain individual differences in psychometric intelligence (12). The number of stimuli in a task that needs to specific motor reaction can be used to categorize reaction time tasks. The reaction time task is known as a simple reaction time task if there is exactly one stimulus; if there is more than one, it is known as a choice reaction time task (13). In order to complete the necessary operation within a set amount of time, many cognitive operations require speedy sufficient information processing (14). Therefore, it is helpful to understand the nature of the related attention deficit to employ tests of response speed that directly evaluate processing speed (15). For instance, the impaired alertness system, which mostly involves the frontal regions of the brain, is linked to delayed reaction times (16). Reaction time tests are frequently used in computerized cognitive assessment; these are normally performed by displaying a stimulus on a computer monitor and asking the individual to respond as quickly as possible (using a keypad or a computer mouse) (17). However, the reaction time test has not been frequently performed in the clinical setting due to a lack of a standardized measurement tool. Moreover, most of the computerized assessments for reaction time are administered while seated in front of the computer, which limits its use when information about the reaction time during walking is required.

Nowadays, the use of smartphones and the internet has consistently increased markedly in Thailand (18). In Thailand, around 53.57 million people used smartphones in 2020, a significant rise from 2017, when just 42.15 million people used smartphones (18). In particular, mobile applications related to health and fitness are expanding (19). These applications may provide users convenience and are easily accessible for low or no expense. Recently, we developed the mobile application (Walking Think) that allows easy interaction with users to record the duration of a single task (TUG), dual-task walking with the cognitive task, and measurement of reaction during sitting and walking. "Walking Think" also provides past records for comparison purposes that enable the therapist to better plan the intervention accordingly. This application was created with Android Studio 4.2.1 (Google, Mountain View, CA). Also, it is freely available for download with permission. The aim of this study was to determine the concurrent validity of this newly developed mobile application (Walking Think) with the standard laboratory equipment (APDM's Mobility Lab^{TM} and Multi Choice Reaction Timer). In this study, the reaction time function of the Walking Think was validated in sitting due to the protocol of the reference test (Multi Choice Reaction Timer).

Materials and methods

Participants

The participants were recruited from the community based on the following inclusion criteria: (1) Age 60–80 years, (2) medically stable, and (3) able to walk independently without walking aids for at least 10 m. Subjects were excluded if they had (1) neurological disorders that sufficiently disturb the balance, (2) hearing loss, (3) severe visual impairment, (4) orthopedic conditions or pain affecting natural gait, and (5) comprehension issues, indicated by a score of less than 24 on the Thai version of the Mini-Mental State Examination (MMSE) (20).

The sample size calculation for Pearson's product moment correlation coefficient was performed using G*power version 3.1.9.7. For this study, a minimum total of 29 subjects were needed, based on the estimated values of error probability (α) at 0.05 and 80% power.

Measurement tools

Baseline information including age, gender, and underlying disease was collected from all participants by interviewing.

1. Mobile Application (Walking Think). We developed an Android-based mobile application running on version 7 or higher. The application was installed on a Huawei P30 (Huawei Technologies Co., Ltd., Guangdong, China). This application was designed to allow easy interaction with the user to record the walking assessment (e.g., walking test, TUG test, reaction time test, and dual-task assessment). This application achieves three main functionalities:

1.1 Gait duration monitoring. The application was designed such that it could be utilized by either the clinician or the self-administered older adults to manually start and stop

gait recording by pressing the start/stop button. To clarify the concurrent validity of the application to measure the duration of TUG and TUG-subtraction, the rater carried the phone and started the recording while observing the participants get up from a chair and stop when they were sitting down. The rater is a physiotherapist with more than 10 years of experience who has had extensive training in TUG assessment.

1.2 Reaction time. The reaction time modality was designed to generate the vibration randomly every 2–4 s, which deactivates by manually pressing the screen for stop. The reaction time will be recorded in milliseconds. The administration of reaction time assessment *via* this application can be selected to assess either as a simple task (while seated or standing) or dual-task (while walking or performing the TUG test).

1.3 Summary results display. The application stores the information about the previous assessment results and can display it in a graph, allowing the users to follow the progression.

2. APDM's Mobility Lab^{TM} (APDM Inc., Portland, OR, USA). The data was gathered and kept in the APDM Inc., Gait cycles and associated events were identified and calculated using a gyroscope (±400°/s range) and an accelerometer (±5 g range) to record angular movement and acceleration at a sampling rate of 200 Hz. On the participants, four portable initial sensors were positioned at the sternum, 5th lumbar vertebrae, and left and right foot. Each trial is recorded by APDM Inc., based on the configuration of the TUG plug-in.
3. Multi Choice Reaction Timer (Mahidol University) consisted of the following components: (1) A stimulus unit generating auditory stimulus 2,800 Hz, (2) a microswitch keyboard with a press button activated about 5 mm. movement of the finger, and (3) a digital watch counting the time between stimulus "on" and response "off" in 1/1,000 of a second.

Task and procedures

The inertial sensors were placed on the participants when performing the TUG and TUG-subtraction. Participants received standardized verbal instruction about the procedures. After the practice trial, participants performed TUG followed by TUG-subtraction. Next, the sequence of reaction time tests by the Multi Choice Reaction Timer or reaction time test by the Walking Think application was randomized for each participant. The participants were asked to perform two trials of TUG or TUG-subtraction, but one trial of each reaction time test.

The TUG procedure required the participants to rise up from their chairs, walk 3 m at a self-selected speed, turn around, and walk back and seat down. For the TUG-subtraction, a random number between 20 and 100 was chosen to begin the serial subtraction of three, and participants were instructed to recite it aloud. The instruction for performing TUG-subtraction was "please do both tasks as well as you can." There was no instruction to prioritize either gait or subtraction tasks. For the second trial of TUG-subtraction, different digit number, unlike those performed during the first trial, was given to avoid the learning effect. During the TUG performance, two raters scored at the same time: one rater used the APDM Inc., while another rater used the Walking Think application. Digital recorders were used to record participant responses to the subtraction task.

For reaction time assessment using the Multi Choice Reaction Timer, the participants were instructed to take a seat in front of a desk with their forearms resting on it comfortably. They were also instructed to place their index finger lightly on the reaction timer's microswitch key and be prepared to press it as fast as they heard the auditory stimulus. For reaction time assessment using the mobile application, the participants were instructed to hold the mobile in one hand while sitting comfortably on a chair. After feeling the vibration stimulus on their same hand, participants were instructed to quickly push the screen with their thumb. The assessment of reaction time in each instrument was performed for 1 min.

Data analyses

Descriptive statistics (mean and SD) were calculated for TUG duration or reaction time. Agreement between the TUG parameters from APDM and Walking Think, and reaction time between the Muli Choice Reaction Timer and Walking Think were utilized to evaluate Bland-Altman and limits of agreement (LoA), percentage error, and Pearson's and concordance correlation coefficients. Pearson's (r) and concordance correlation coefficients (r_c) were used to analyze the relative and overall agreement between the two methods, respectively (21). Correlation thresholds were set as negligible ($r \leq 0.30$), low ($0.30 < r \leq 0.50$), moderate ($0.5 < r \leq 0.70$), high ($0.70 < r \leq 0.90$), and very high ($0.90 < r \leq 1.00$) (22). Bland-Altman plots were used to explore the existence of any systematic differences between the measurement (23). The NCSS 2022 version 22.0.3 statistic software was used for all statistical analyses.

Results

Twenty-nine elder women (age: 65.90 ± 4.18 years, MMSE score: 26.47 ± 0.88) participated in the study. In relation to the history of

TABLE 1 Distribution of the different diseases involved in the study.

Underlying diseases	Number of occurrences (total of 29 individuals)	Pharmacology
Hypertension	12	Amlopin
Dyslipidemia	8	Simvastatin
Diabetic mellitus	8	Metformin
Asthma	1	Albuterol

TABLE 2 Time Up and Go duration and reaction time using the Walking Think mobile application and other reference devices.

Variables	Walking Think	APDM	Multi choice reaction timer
TUG duration (s)	11.43 ± 2.54	11.90 ± 2.43	–
TUG-subtraction duration (s)	13.70 ± 2.31	13.96 ± 2.17	–
Reaction time (s)	1.23 ± 0.35	–	0.93 ± 0.30

Value is reported as mean ± SD, APDM: APDM Wearable Technologies Inc.

TABLE 3 Mean difference of TUG duration from Walking Think mobile application and APDM system, along with 95% limits of agreement (LoA), Pearson's correlation coefficients (r), and concordance correlation coefficients (r_c).

TUG duration	Mean difference	95% LoA	*r*	*P*-value	r_c (95% CI)
TUG	−0.47	−1.83–0.89	0.96	<0.01	0.94 (0.90–0.97)
TUG cognitive	−0.26	−1.56–1.04	0.96	<0.01	0.95 (0.91–0.98)

TABLE 4 Mean difference of reaction time from Walking Think mobile application and Multi Choice Reaction Timer derived reaction time, along with 95% limits of agreement (LoA), Pearson's correlation coefficients (*r*), and concordance correlation coefficients (r_c).

Reaction time	Mean difference	95% LoA	*r*	*P*-value	r_c (95% CI)
Reaction time	0.30	−0.22–0.82	0.67	<0.001	0.46 (0.27–0.64)

falls, two participants (6.9%) reported falls in the past 6 months with no related injury. The underlying diseases of the participants and their medications were reported (Table 1). There were six individuals with one pathology (HT or DM or Asthma), four individuals with two pathologies (HT and DLP, or HT and DM), and five individuals with three pathologies (HT and DLP and DM). Table 2 displays the Mean (±SD) values for each outcome measure. In Tables 3, 4, agreement values are presented. TUG and TUG-subtraction duration had very high relative and overall agreement between devices (r and r_c values >0.9). The points on the Bland-Altman plot were uniformly and tightly scattered around the horizontal axis (Figures 1, 2). However, reaction time possessed moderate relative agreement and low overall agreement ($r = 0.67$, $r_c = 0.46$). Also, the points on the Bland-Altman plot were widely spread and scattered around the horizontal axis (Figure 3).

Discussion

We devised and developed the mobile application called Walking Think that allows easy interaction with users to record the TUG duration during performing walking simultaneously with performing the cognitive dual task, and this mobile application is also able to summarize the results of the data from previous tests for determining the progression or declination of the TUG or TUG-subtraction performances. In addition, Walking Think aimed to allow the clinician to assess reaction time during walking. Findings from this study demonstrated that the Walking Think mobile application is a valid tool to measure the TUG and TUG-subtraction duration. The TUG test was able to distinguish between fallers and non-fallers in community-dwelling older individuals with high sensitivity

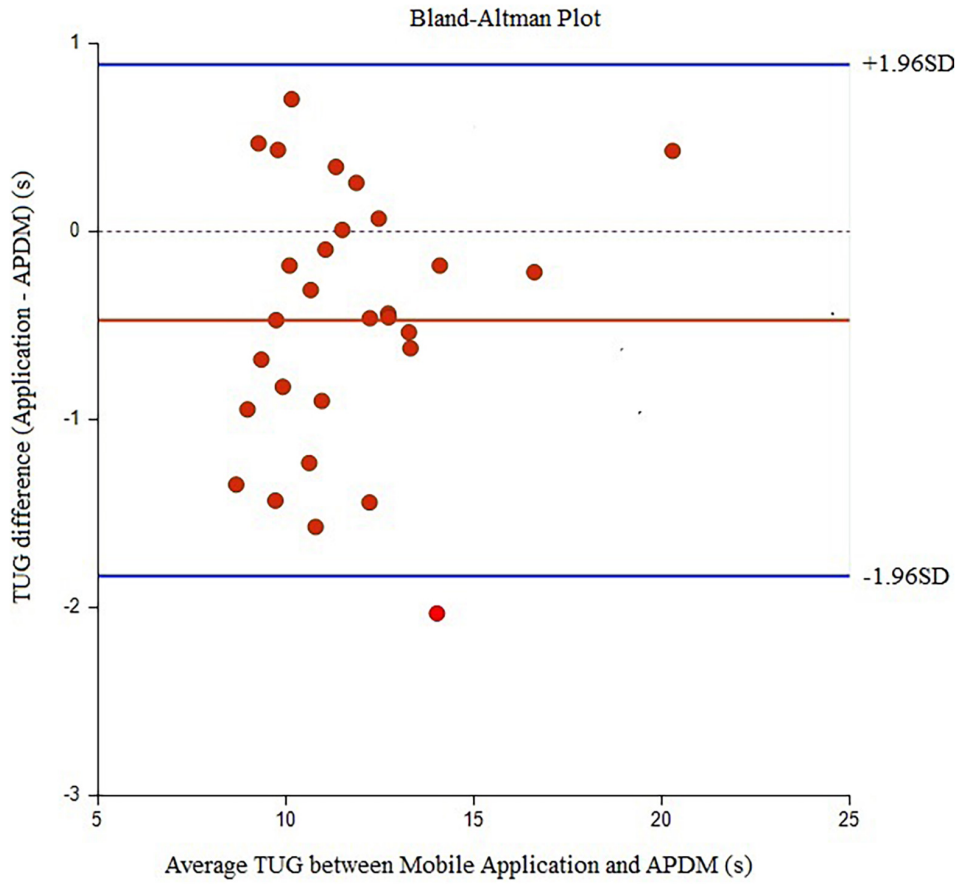

FIGURE 1
Bland-Alman graphs comparing the difference between the average values of TUG duration measured by the Walking Think mobile application and APDM.

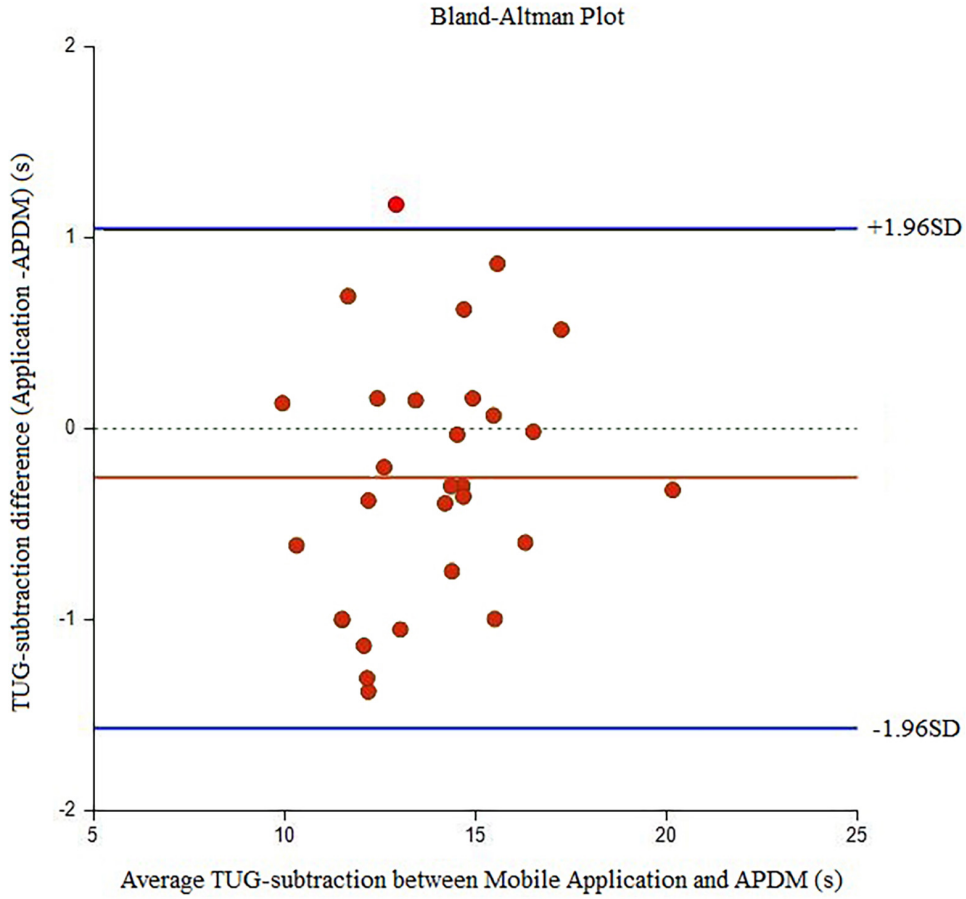

FIGURE 2
Bland-Alman graphs comparing the difference between the mean values of TUG cognitive duration measured by the Walking Think mobile application and APDM.

(80%) and specificity (93%) (10). The TUG-subtraction is helpful for assessing balance while walking. TUG-subtraction has a detrimental effect on functional mobility, and this is demonstrated by the 22–25% longer time required to complete the TUG with an additional secondary task (10). Apart from the traditional paper-based of recording the TUG test, this Walking Think mobile application is appropriate for the screening and follow-up of the TUG and TUG-subtraction performance in routine clinical care.

Nowadays, new technologies, such as wearable sensors or smartphone-embedded inertial sensors, have been created to evaluate the TUG performance of older persons (24). The validity of the unsupervised screening system using sensors (aTUG chair, hip-worn inertial sensor, light barriers, and the Intel® RealSense™ D435 depth image cameras) was examined in a study by Fudickar et al. (25). Their results showed that this system was a valid tool for evaluating TUG, with both light barriers and inertial measurement units demonstrating high correlations with conventional stopwatch measurement (r = 0.73 and 0.78, respectively). The usefulness of mobile applications for TUG assessment for various purposes was also reported in previous studies. Bergquist et al. (26) and Madhushri et al. (27) created smartphone applications for the elderly for self-test functional performance evaluation by extracting data from smartphone-embedded inertial sensors such as accelerometers, gyroscopes, and magnetometers. Bergquist et al. (26) developed smartphone applications for physical self-tests including the TUG, tandem stance, and Five Times Sit-to-Stand tests. This study also assessed the usability problems that affected the test's validity and made adjustments to reduce trial error and update the new instruction. Another study by Madhushri et al. (27) developed mobile health applications including the TUG, 30 s Chair Stand Test, and a 4-stage Balance Test. The TUG application collects and analyzes the incoming signal from the smartphone's gyroscope and accelerometer sensors, extracting parameters, and displaying the outcomes on the screen. Additionally, it may be feasible to monitor the progress of mobility and balance impairment by analyzing the parameters that were gathered over a long period of time. Also, a mobile application was created with the intention of screening and managing fall risks in the elderly as reported in the study by Taheri-Kharameh et al. (28). This application offers education and training recommendations based on an individual's level of fall risk among older adults. Moreover, a mobile device application was also able to detect improvement in kinematics and timing during gait and turning components of TUG. According to a study by Koop et al. (29), gait and turning during the TUG can be quantitatively measured using an inertial measuring unit (IMU) on a mobile device. This device was able to distinguish between changes in total time, gait, and turning performances in patients with Parkinson's disease with on and off-medication conditions.

Apart from the TUG, the Walking Think mobile application was also designed to evaluate the reaction time. Traditionally,

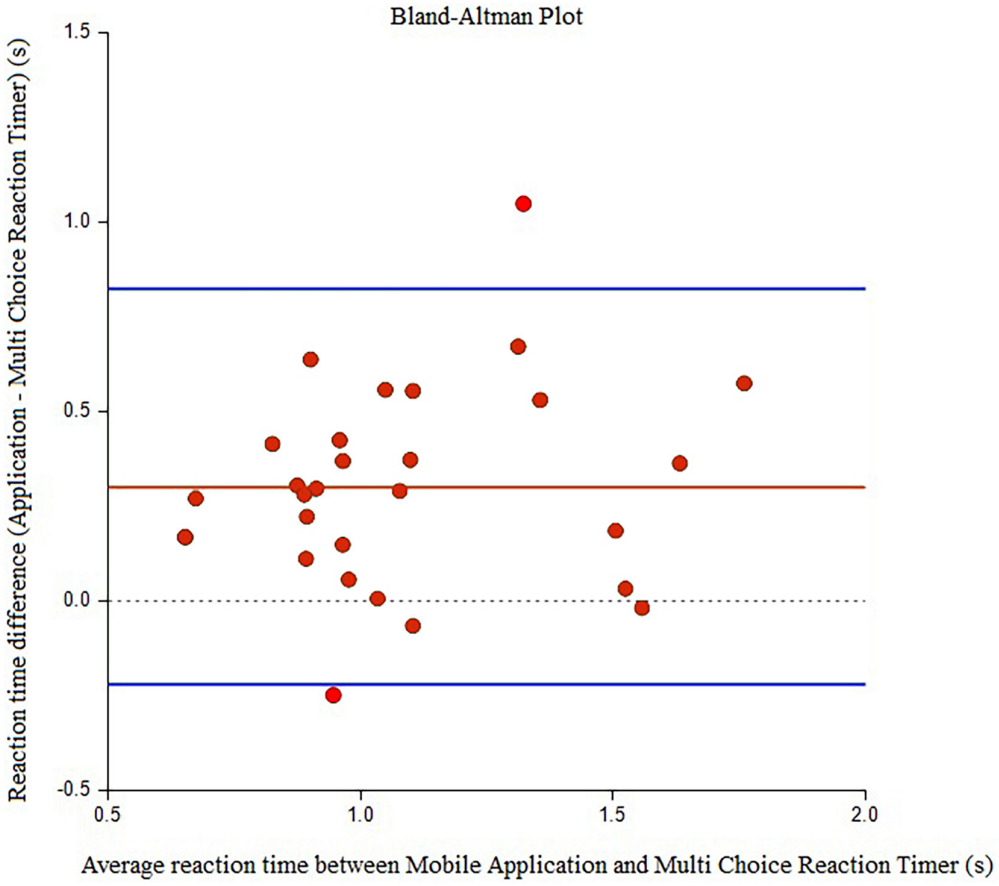

FIGURE 3
Bland-Alman graphs comparing the difference between the mean values of reaction time measured by the Walking Think mobile application and Multi Choice Reaction Timer.

psychogeriatric research frequently uses the computerized cognitive battery for assessing the reaction time (30, 31). When compared to a conventional device, a handheld mobile device offers the advantages of being able to alert users to detect vibrations without requiring a visible display and being applicable in a number of settings, such as in a quiet or noisy environment. However, our results showed a moderate correlation between the reaction time detected by the application and the Multi Choice reaction timer. This is probably due to the different stimulus modalities being transduced through different receptive pathways, i.e., auditory neural pathway and somatosensory neural pathway (32). For the mobile application, the tactile stimuli were produced through a vibration of the mobile phone. Once the participants detected a vibration, they pressed their fingers as quickly as possible. While for the Multi Choice Reaction Timer, the auditory stimuli were generated and the participants pressed their fingers as quickly as possible when they detected a noise. Previous studies reported that different modality stimuli influence reaction time. In the context of the man-machine interaction, the study by Ng and Chan (13) examined finger response time to stimuli in the visual, auditory, and tactile modalities. They demonstrated that the response time to auditory stimuli was significantly longer than the response time to tactile stimuli. While the study by Altinsoy (32) showed that reaction times to auditory stimuli were shorter than tactile stimuli. Our findings were in agreement with the study by Altinsoy (32) which the reaction times to auditory stimulus generated by the Multi Choice Reaction Timer was shorter than the tactile stimulus generated by the application. The findings of the validity of the mobile device to evaluate response time in our study were different from the previous study by Burke et al. (33). They reported that information processing *via* simple reaction time with visual stimuli (a green stimulus light) employed on a mobile device was valid and reliable. To assess the validity of mobile devices, the reaction time data were analyzed using a Welch *t*-test to determine if there were any significant differences between traditional and iPad/iTouch. Their results indicated no significant difference in simple reaction time between devices.

Clinical application

In addition to the traditional use of TUG assessment, this study provided the alternative of using the Walking Think mobile application for recording TUG duration, TUG-dual duration, and reaction time. The TUG and TUG-cognitive duration derived from this mobile application demonstrated excellent correlation in older adults, making them potentially useful in clinical practice.

Conclusion

The results of this study demonstrate that the Walking Think mobile application is a valid tool for TUG duration, TUG-subtraction

duration, and reaction time. The validity of this application for evaluating reaction times may need to be increased by further development.

Study limitation

Some limitations are noted in this study. Firstly, the participants are all female and have a high function of mobility, therefore, the generalization of results is limited. Secondly, the measurement of reaction time in this study was obtained only in sitting, thus further studies investigating the reaction in various positions are required.

Data availability statement

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the Mae Fah Luang University Ethics Committee on Human Research (MFU EC). The patients/participants provided their written informed consent to participate in this study.

Author contributions

AP conceived and designed the project, the function of procurement, data gathering, analysis, and interpretation of data. RB assisted with the critical revision of the manuscript for important intellectual content. SK and PK assisted with the instrumentation. PS helped in the analysis and interpretation of data. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Obesity- and lipid-related indices as a predictor of obesity metabolic syndrome in a national cohort study

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Objective: Metabolic syndrome is a common condition among middle-aged and elderly people. Recent studies have reported the association between obesity- and lipid-related indices and metabolic syndrome, but whether those conditions could predict metabolic syndrome is still inconsistent in a few longitudinal studies. In our study, we aimed to predict metabolic syndrome by obesity- and lipid-related indices in middle-aged and elderly Chinese adults.

Method: A national cohort study that consisted of 3,640 adults (≥45 years) was conducted. A total of 13 obesity- and lipid-related indices, including body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHtR), conicity index (CI), visceral adiposity index (VAI), Chinese visceral adiposity index (CVAI), lipid accumulation product (LAP), a body shape index (ABSI), body roundness index (BRI), and triglyceride glucose index (TyG-index) and its correlation index (TyG-BMI, TyG-WC, and TyG-WHtR), were recorded. Metabolic syndrome (MetS) was defined based on the criteria of the National Cholesterol Education Program Adult Treatment Panel III (2005). Participants were categorized into two groups according to the different sex. Binary logistic regression analyses were used to evaluate the associations between the 13 obesity- and lipid-related indices and MetS. Receiver operating characteristic (ROC) curve studies were used to identify the best predictor of MetS.

Results: A total of 13 obesity- and lipid-related indices were independently associated with MetS risk, even after adjustment for age, sex, educational status, marital status, current residence, history of drinking, history of smoking, taking activities, having regular exercises, and chronic diseases. The ROC analysis revealed that the 12 obesity- and lipid-related indices included in the study were able to discriminate MetS [area under the ROC curves (AUC $>$ 0.6, $P < 0.05$)] and ABSI was not able to discriminate MetS [area under the ROC curves (AUC $<$ 0.6, $P > 0.05$)]. The AUC of TyG-BMI was the highest in men, and that of CVAI was the highest in women. The cutoff values for men and women were 187.919 and 86.785, respectively. The AUCs of TyG-BMI, CVAI, TyG-WC, LAP, TyG-WHtR, BMI, WC, WHtR, BRI, VAI, TyG index, CI, and ABSI were 0.755, 0.752, 0.749, 0.745, 0.735, 0.732, 0.730, 0.710, 0.710, 0.674, 0.646, 0.622, and 0.537 for men, respectively. The AUCs of CVAI, LAP, TyG-WC, TyG-WHtR, TyG-BMI, WC, WHtR, BRI, BMI, VAI, TyG-index, CI, and ABSI

were 0.687, 0.674, 0.674, 0.663, 0.656, 0.654, 0.645, 0.645, 0.638, 0.632, 0.607, 0.596, and 0.543 for women, respectively. The AUC value for WHtR was equal to that for BRI in predicting MetS. The AUC value for LAP was equal to that for TyG-WC in predicting MetS for women.

Conclusion: Among middle-aged and older adults, all obesity- and lipid-related indices, except ABSI, were able to predict MetS. In addition, in men, TyG-BMI is the best indicator to indicate MetS, and in women, CVAI is considered the best hand to indicate MetS. At the same time, TyG-BMI, TyG-WC, and TyG-WHtR performed better than BMI, WC, and WHtR in predicting MetS in both men and women. Therefore, the lipid-related index outperforms the obesity-related index in predicting MetS. In addition to CVAI, LAP showed a good predictive correlation, even more closely than lipid-related factors in predicting MetS in women. It is worth noting that ABSI performed poorly, was not statistically significant in either men or women, and was not predictive of MetS.

KEYWORDS

metabolic syndrome, lipids, obesity, national cohort study, middle-aged and elderly Chinese

Introduction

Metabolic syndrome (MetS) is a common condition among middle-aged and elderly people. The prevalence was 19.2% in men and 27.0% in women in China (1). The MetS consists of five major components, namely, central obesity, elevated triglyceride (TG) levels, low high-density lipoprotein cholesterol (HDL-C) levels, elevated BP, and elevated fasting plasma glucose (FPG) levels (2). Central obesity (3) and insulin resistance are considered the main pathogenesis of MetS, while chronic inflammation (4, 5) and stress response (6) also play important roles. Various pathological damages, such as glucose and lipid dysfunction in the liver, free fatty acid (FFAs) release from adipose tissues, impaired glucose uptake in muscle, and defective insulin secretion in the pancreas, can lead to central obesity or insulin resistance. At the same time, chronic inflammation and stress reaction also play an important role in this process. Figure 1 shows the main physiological changes of MetS.

Several studies (7, 8) have shown that MetS causes different degrees of damage to the cardiovascular system, digestive system, and endocrine system. Obesity can result in a significantly increased risk of death from other conditions such as cardiovascular disease, digestive tract diseases, endocrine diseases, or cancer (9). A cross-sectional analysis of 59 studies in the Middle East in 2017 found that the comprehensive estimated prevalence of MetS was 25%, and it was also a significant cause of stroke, coronary heart disease, and cardiovascular diseases (10). Gluvic et al. (11) found that for patients with cardiovascular disease, the mortality rate of patients with MetS is much higher than that of patients without MetS. Meanwhile, MetS may lead to cancer (12).

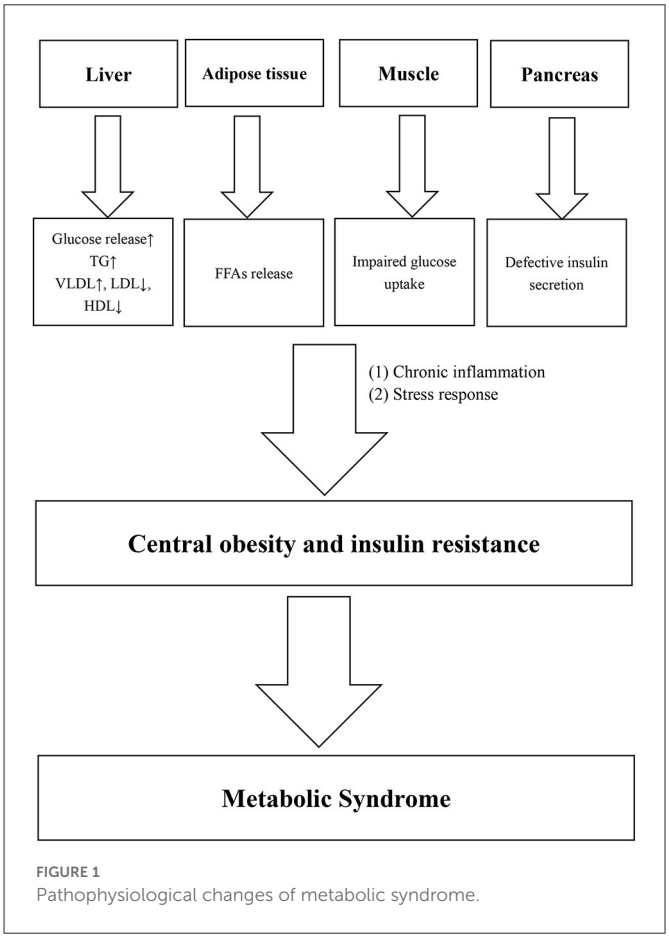

FIGURE 1
Pathophysiological changes of metabolic syndrome.

Abbreviations: MetS, metabolic syndrome; BMI, body mass index; WC, waist circumference; WHtR, waist-height ratio; CI, conicity index; VAI, visceral adiposity index; CVAI, Chinese visceral adiposity index; LAP, lipid accumulation product; ABSI, a body shape index; BRI, body roundness index; TyG, triglyceride glucose; TyG-BMI, triglyceride glucose-body mass index; TyG-WC, triglyceride glucose-waist circumference; TyG-WHtR, triglyceride glucose-waist-height ratio; ROC, receiver operator curve; AUC, area under curve; TG, triglyceride; HDL-C, high density lipoprotein cholesterol; BP, blood pressure; FPG, fasting plasma glucose blood glucose; CHARLS, China Health and Retirement Longitudinal Study; CAPI, computer-aided personal interview; IDF, international diabetes federation; OR, odds ratio; ES, effect size; FFA, free fatty acid; IR, insulin resistance; NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III.

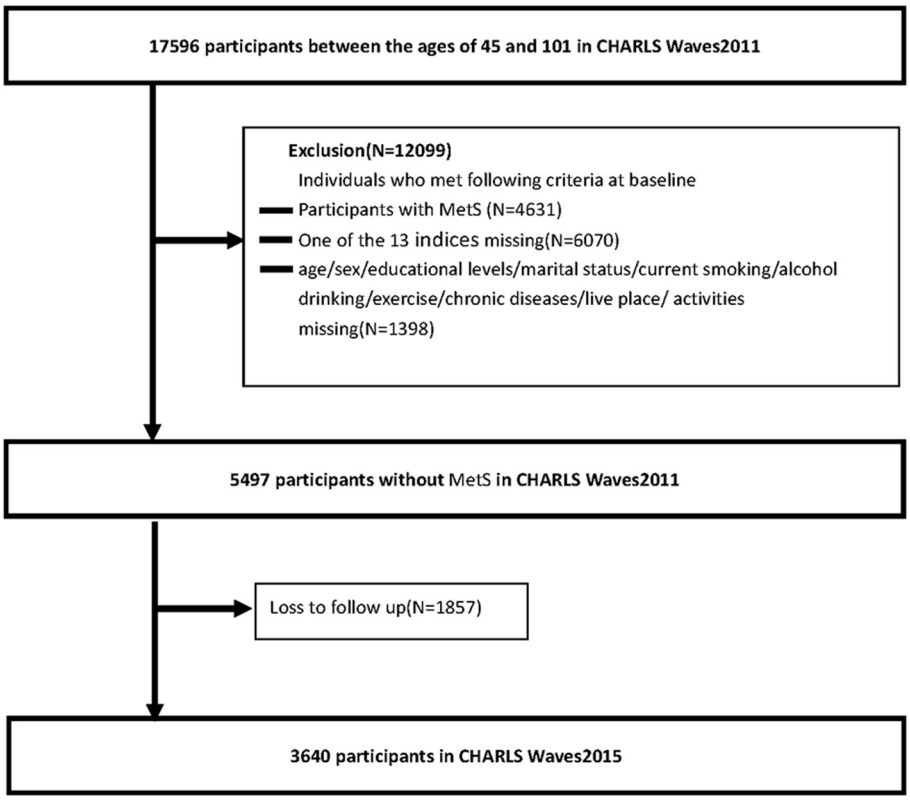

FIGURE 2
Flowchart of the study participants.

A meta-analysis of global data from 28 million subjects showed that the worldwide prevalence of MetS ranged from 12.5 to 31.4%, with the Eastern Mediterranean region and the Americas showing significantly higher prevalence than other regions (13). Among Europeans between the ages of 30 and 89 years, the incidence of MetS in men is 41%, while that in women is 38% lower than that in men (14). Adult white men were more likely to have abdominal obesity than other races, whereas white women lacked the opposite, which may explain this phenomenon (15). In the Asia Pacific region, the Philippines reported a minimum prevalence of 11.9%, while Pakistan reported a MetS prevalence of 49.0% (16). Possible factors that affect the large difference in the incidence of MetS in the Asia-Pacific region include smoking, alcohol consumption, lack of physical activity, and unhealthy diet (17). We also observed an increasing trend in the prevalence of MetS in China (13.7% in 2000–2001 and 21.3% in 2009) (18, 19). A cross-sectional study of 8,040 community residents in Jiangsu Province, China, showed that the prevalence of MetS was 35.2% in 2014 (20).

Middle-aged and older adults often suffer from a variety of chronic diseases. At the same time, their body immunity was low. Therefore, MetS was more likely to cause more serious consequences or even death. Consequently, it was necessary to find a practical index for predicting MetS. Mounting evidence demonstrates that obesity- and lipid-related indices could be associated with MetS. The current meta-analysis attempts to estimate the strength of the relationship between obesity- and lipid-related indices and MetS. A recent meta-analysis conducted with 155 patients by Ecder and Sasak (21) found that waist-to-height ratio (WHtR) in women [area under the ROC curve (AUC) = 0.815, 95% CI = 0.687–0.942] and waist circumference (WC) in men (AUC = 0.826, 95% CI = 0.741–0.911) prove to be better than other anthropometric measures for predicting MetS in renal transplant recipients. Another meta-analysis performed for the 232 participants by Khan et al. (22) found that WHtR and AVI performed best in predicting MetS. In addition, a number of meta-analysis studies (23–25) also proved the association between obesity- and lipid-related indices and MetS. Although the meta-analysis used cohort and cross-sectional studies to confirm the potential association between obesity- and lipid-related indicators and MetS, the strength of the prediction of obesity- and lipid-related indicators for MetS was not analyzed in the same field. In addition, most meta-analyses included only Western participants, and some studies considered other ethnic groups, such as Asians. Therefore, further studies in middle-aged and older adults in China are needed to determine the strength of the association between obesity- and lipid-related indices in predicting MetS in Chinese participants.

To fill these gaps, we used longitudinal data from a nationally representative sample of participants of community residents in China who were ≥45 years old and explored to examine the relationship between obesity- and lipid-related indices and incidence of MetS. In addition, this study explored the stability of the association between components of obesity- and lipid-related indicators and MetS by controlling for potential confounders.

TABLE 1 Characteristics of participants with full samples in baseline ($N = 3,640$).

Variables	Male	Female	Total	t/X^2	P
N	$N = 1,968$	$N = 1,672$	$N = 3,640$		
Age (years)				130.285	0.000
45–54	547 (27.79)	734 (43.90)	1,281 (35.19)		
55–64	810 (41.16)	637 (38.10)	1,447 (39.75)		
65–74	486 (24.70)	236 (14.11)	722 (19.84)		
≥75	125 (6.35)	65 (3.89)	190 (5.22)		
Education				366.202	0.000
Illiterate	274 (13.92)	700 (41.87)	974 (26.76)		
Less elementary	1,476 (75.00)	872 (52.15)	2,348 (64.51)		
High school	148 (7.52)	77 (4.61)	225 (6.18)		
Above vocational	70 (3.56)	23 (1.38)	93 (2.55)		
Marital status				9.547	0.002
Married	1,794 (91.16)	1,472 (88.04)	3,266 (89.73)		
Single	174 (8.84)	200 (11.96)	374 (10.27)		
Current residence				0.916	0.339
Rural	1,868 (94.92)	1,575 (94.20)	3,443 (94.59)		
Urban	100 (5.08)	97 (5.80)	197 (5.41)		
Current smoking				1,805.457	0.000
No	459 (23.32)	1,564 (93.54)	2,023 (55.58)		
Former smoke	285 (14.48)	17 (1.02)	302 (8.30)		
Current smoke	1,224 (62.20)	91 (5.44)	1,315 (36.13)		
Alcohol drinking				821.328	0.000
No	820 (41.67)	1,459 (87.26)	2,279 (62.61)		
Less than once a month	221 (11.23)	80 (4.78)	301 (8.27)		
More than once a month	927 (47.10)	133 (7.95)	1,060 (29.12)		
Taking activities				3.174	0.075
No	994 (50.51)	894 (53.47)	1,888 (51.87)		
Yes	974 (49.49)	778 (46.53)	1,752 (48.13)		
Having regular exercises				1.011	0.603
No exercise	1,213 (61.64)	1,004 (60.05)	2,217 (60.91)		
Less than exercises	400 (20.33)	358 (21.41)	758 (20.82)		
Regular exercises	355 (18.04)	310 (18.54)	665 (18.27)		
Chronic diseases (counts)				0.544	0.762
0	704 (35.77)	584 (34.93)	1,288 (35.38)		
1–2	974 (49.49)	848 (50.72)	1,822 (50.05)		
3–14	290 (14.74)	240 (14.35)	530 (14.56)		
WC	81.47 ± 7.67	80.91 ± 9.00	81.22 ± 8.32	1.988	0.047
BMI	21.91 ± 3.05	22.64 ± 3.65	22.25 ± 3.36	−6.471	0.000
WHtR	0.50 ± 0.05	0.53 ± 0.06	0.51 ± 0.05	−17.260	0.000
VAI	2.43 ± 1.58	3.27 ± 1.76	2.82 ± 1.71	−15.184	0.000
ABSI	8.18 ± 0.54	8.22 ± 0.59	8.20 ± 0.56	−2.238	0.025
BRI	3.39 ± 0.88	4.00 ± 1.20	3.67 ± 1.08	−17.310	0.000

(Continued)

TABLE 1 (Continued)

Variables	Male	Female	Total	t/X^2	*P*
N	*N* = 1,968	*N* = 1,672	*N* = 3,640		
LAP	17.93 ± 13.12	24.27 ± 13.42	20.84 ± 13.62	−14.351	0.000
CI	1.25 ± 0.08	1.27 ± 0.09	1.26 ± 0.08	−4.567	0.000
CVAI	75.67 ± 34.77	79.31 ± 31.81	77.34 ± 33.49	−3.291	0.001
TyG index	8.37 ± 0.47	8.36 ± 0.42	8.37 ± 0.45	0.936	0.349
TyG-BMI	183.58 ± 28.10	189.3 ± 32.26	186.21 ± 30.21	−5.661	0.000
TyG-WC	682.62 ± 78.37	676.48 ± 82.91	679.8 ± 80.53	2.294	0.022
TyG-WHtR	4.19 ± 0.47	4.43 ± 0.54	4.30 ± 0.52	−14.516	0.000

The data are presented either as the mean ± SD or *n* (%).
WC, waist circumference; BMI, body mass index; WHtR, waist-to-height ratio; VAI, visceral adiposity index; ABSI, a body shape index; BRI, body roundness index; LAP, lipid accumulation product; CVAI, cardio-ankle vascular index; CI, conicity index; TyG, triglyceride and glucose index; TyG-BMI, TyG related to BMI; TyG-WC, TyG related to WC; TyG-WHtR, TyG related to WHtR.

Materials and methods

Participants

Participants in this national cohort study were Chinese community residents aged older than 45 years who participated in the China Health and Retirement Longitudinal Study (CHARLS) survey. CHARLS is a nationally representative longitudinal survey of middle-aged and elderly Chinese adults and their spouses. The CHARLS began in 2011 with a cohort of 17,596 participants between 45 and 101 (Waves1) years and collected data in 2013 (Waves2) and 2015 (Waves3). Participants will undergo face-to-face, computer-assisted personal interviews (CAPIs), and structured questionnaires every 2 years. The study used data from participants in Waves1 and Waves3. We excluded individuals who met any of the following criteria at baseline: (1) participants with MetS, (2) one of the 13 indices missing, and (3) age/sex/educational level/marital status/current smoking/alcohol drinking/exercise/chronic diseases/live place/activities missing. In addition, we excluded participants with no follow-up data. The numbers of individuals who completed both the baseline and follow-up surveys were 3,640 for the long term (2011–2015). Figure 2 shows a flow diagram of the study individuals, follow-up, and missed follow-up.

Metabolic syndrome symptom

The NCEP ATP III (2005) (26, 27) proposed the definition and diagnostic criteria of MetS. According to the standard Chinese definition (28, 29), components of MetS are divided into five categories:

(1) The waist circumference (WC) of central obesity is defined as ≥80 cm for women and ≥90 cm for men.
(2) Elevated TG levels: TG levels of ≥150 mg/dl.
(3) Low HDL-C levels: HDL-C levels of <40 mg/dl for men and <50 mg/dl for women.
(4) Elevated BP: systolic blood pressure (SBP) of ≥130 mmHg and/or diastolic blood pressure (DBP) of ≥85 mmHg or using antihypertensive therapy.
(5) Elevated FPG levels: FPG levels of ≥100 mg/dl or using antidiabetic medications or self-reported medical history of diabetes.

When three of the five listed characteristics are present, a diagnosis of MetS can be made.

Covariates

In this study, we classified the participants into two groups according to gender. According to the International Diabetes Federation (IDF) (30), age, obesity, and a lack of exercise are all risk factors for MetS. Yang et al.'s (31) research shows that there is a strong link between MetS and age and place of residence. At the same time, smoking and drinking alcohol have also been confirmed to lead to MetS (32, 33). According to the previous standards (34, 35), we classified 14 chronic diseases, which were divided into three categories according to the number of chronic diseases: 0, 1–2, and 3–14. Referring to our previous research (34, 36–42), we formulated the basis for choosing the 13 obesity- and lipid-related indices. These bases included age, education, marriage, residence, drinking, smoking, activities, exercise, and chronic diseases. The classification of nine covariates is shown as follows:

(1) Age: (1) below 45–54 years, (2) 55–64 years, (3) 65–74 years, and (4) above 75 years.
(2) Education level: (1) illiterate, (2) less than elementary school, (3) high school, and (4) above vocational school.
(3) Marital status: (1) single (divorced, never married, widowed, or separated) and (2) married.
(4) Current residence: (1) rural and (2) urban.
(5) Current smoking: (1) current smokers, (2) former smokers, and (3) never smokers.
(6) Alcohol drinking: (1) never drinker, (2) less than once a month, and (3) more than once a month.
(7) Taking activities: (1) yes and (2) no.
(8) Having regular exercises: (1) no physical exercise, (2) less than regular physical exercise, and (3) regular physical exercise.
(9) Chronic diseases: (1) 0, (2) 1–3, and (3) 4–16.

TABLE 2 Follow-up characteristics of the study participants with and without MetS by sex in 2015.

Variables	Male ($N = 1,968$)		t/X^2	P	Female ($N = 1,672$)		t/X^2	P
	With MetS	Without MetS			With MetS	Without MetS		
	$N = 253$	$N = 1,715$			$N = 418$	$N = 1,254$		
Age (years)			3.512	0.319			14.133	0.003
45–54	79 (31.23)	468 (27.29)			167 (39.95)	567 (45.22)		
55–64	104 (41.11)	706 (41.17)			158 (37.80)	479 (38.20)		
65–74	52 (20.55)	434 (25.31)			65 (15.55)	171 (13.64)		
≥75	18 (7.11)	107 (6.24)			28 (6.70)	37 (2.95)		
Education			7.024	0.071			1.107	0.775
Illiterate	32 (12.65)	242 (14.11)			168 (40.19)	532 (42.42)		
Less elementary	184 (72.73)	1,292 (75.34)			227 (54.31)	645 (51.44)		
High school	21 (8.30)	127 (7.41)			18 (4.31)	59 (4.70)		
Above vocational	16 (6.32)	54 (3.15)			5 (1.20)	18 (1.44)		
Marital status			0.008	0.930			4.362	0.037
Married	231 (91.30)	1,563 (91.14)			356 (85.17)	1,116 (89.00)		
Single	22 (8.70)	152 (8.86)			62 (14.83)	138 (11.00)		
Current residence			2.489	0.115			1.317	0.251
Rural	235 (92.89)	1,633 (95.22)			389 (93.06)	1,186 (94.58)		
Urban	18 (7.11)	82 (4.78)			29 (6.94)	68 (5.42)		
Current smoking			4.020	0.134			0.184	0.912
No	58 (22.92)	401 (23.38)			390 (93.30)	1,174 (93.62)		
Former smoke	47 (18.58)	238 (13.88)			5 (1.20)	12 (0.96)		
Current smoke	148 (58.5)	1,076 (62.74)			23 (5.50)	68 (5.42)		
Alcohol drinking			4.050	0.132			1.770	0.413
No	103 (40.71)	717 (41.81)			370 (88.52)	1,089 (86.84)		
Less than once a month	20 (7.91)	201 (11.72)			15 (3.59)	65 (5.18)		
More than once a month	130 (51.38)	797 (46.47)			33 (7.89)	100 (7.97)		
Taking activities			0.416	0.519			1.696	0.193
No	123 (48.62)	871 (50.79)			212 (50.72)	682 (54.39)		
Yes	130 (51.38)	844 (49.21)			206 (49.28)	572 (45.61)		
Having regular exercises			0.323	0.851			0.393	0.821
No exercise	156 (61.66)	1,057 (61.63)			251 (60.05)	753 (60.05)		
Less than exercises	54 (21.34)	346 (20.17)			86 (20.57)	272 (21.69)		
Regular exercises	43 (17.00)	312 (18.19)			81 (19.38)	229 (18.26)		
Chronic diseases (counts)			2.387	0.303			3.767	0.152
0	100 (39.53)	604 (35.22)			130 (31.10)	454 (36.20)		
1–2	114 (45.06)	860 (50.15)			222 (53.11)	626 (49.92)		
3–14	39 (15.42)	251 (14.64)			66 (15.79)	174 (13.88)		
WC	87.01 ± 8.09	80.65 ± 7.26	−12.798	0.000	84.52 ± 9.02	79.71 ± 8.68	−9.703	0.000

(Continued)

TABLE 2 (Continued)

Variables	Male ($N = 1,968$)		t/X^2	P	Female ($N = 1,672$)		t/X^2	P
	With MetS	Without MetS			With MetS	Without MetS		
	$N = 253$	$N = 1,715$			$N = 418$	$N = 1,254$		
BMI	23.84 ± 3.02	21.63 ± 2.95	−11.099	0.000	23.87 ± 3.73	22.23 ± 3.53	−8.081	0.000
WHtR	0.53 ± 0.05	0.50 ± 0.04	−11.478	0.000	0.55 ± 0.06	0.52 ± 0.06	−9.275	0.000
VAI	3.15 ± 1.83	2.32 ± 1.51	−6.884	0.000	3.82 ± 2.01	3.09 ± 1.62	−6.691	0.000
ABSI	8.22 ± 0.53	8.17 ± 0.54	−1.331	0.183	8.28 ± 0.60	8.20 ± 0.58	−2.404	0.016
BRI	3.97 ± 0.93	3.31 ± 0.83	−10.726	0.000	4.46 ± 1.28	3.85 ± 1.14	−8.677	0.000
LAP	27.54 ± 16.43	16.51 ± 11.92	−10.289	0.000	30.53 ± 15.00	22.18 ± 12.15	−10.307	0.000
CI	1.28 ± 0.08	1.25 ± 0.08	−5.376	0.000	1.29 ± 0.09	1.26 ± 0.09	−5.537	0.000
CVAI	103.07 ± 33.98	71.63 ± 33.02	−14.083	0.000	95.43 ± 31.37	73.93 ± 30.11	−12.512	0.000
TyG index	8.56 ± 0.45	8.35 ± 0.46	−6.702	0.000	8.46 ± 0.43	8.33 ± 0.42	−5.609	0.000
TyG-BMI	203.92 ± 27.27	180.57 ± 26.96	−12.842	0.000	201.90 ± 33.12	185.10 ± 30.85	−9.460	0.000
TyG-WC	744.31 ± 78.26	673.52 ± 74.19	−14.069	0.000	714.95 ± 84.11	663.65 ± 78.44	−11.369	0.000
TyG-WHtR	4.53 ± 0.46	4.13 ± 0.45	−13.028	0.000	4.67 ± 0.56	4.35 ± 0.51	−10.940	0.000

The data are presented either as the mean ± SD or *n* (%).
WC, waist circumference; BMI, body mass index; WHtR, waist-to-height ratio; VAI, visceral adiposity index; ABSI, a body shape index; BRI, body roundness index; LAP, lipid accumulation product; CVAI, cardio-ankle vascular index; CI, conicity index; TyG, triglyceride and glucose index; TyG-BMI, TyG related to BMI; TyG-WC, TyG related to WC; TyG-WHtR, TyG related to WHtR.

Measurements

At the end of exhalation and before inhalation, the circumference of the midpoint line is measured between the lowest point of the rib and the upper edge of the iliac crest with a soft ruler, which is called WC (43). It is worth noting that the remaining 12 indicators need to be calculated. BMI is calculated as the body mass (kg) divided by the square of the body height (m) (44). WHtR is defined as the WC (m) divided by the height (m) (45). The visceral adiposity index (VAI), Chinese visceral adiposity index (CVAI), lipid accumulation product (LAP), and triglyceride glucose index (TyG-index) are calculated to obtain TG and HDL through invasive examination. VAI is calculated by four indices, namely, WC, BMI, TG, and HDL (46). It is worth noting that the figures in the calculation formulas of VAI for men and women are slightly different, but they are all completed by these four same measurement indices. A body shape index (ABSI) is determined by a comprehensive calculation of WC, BMI, and height (47). Body roundness index (BRI) is calculated using two basic metrics, i.e., WC and height (48). LAP is calculated slightly differently by subtracting a number (males: 65 cm, females: 58 cm) from WC and multiplying by TG (49). The measurement method of CI is completed by WC, weight, and height (50). CVAI is calculated based on VAI to develop a more suitable measurement of the Chinese people (51). The calculation result with TG and glucose is defined as the TyG index (52). At the same time, TyG-BMI, TyG-WC, and TyG-WHtR are obtained by multiplying TyG with BMI, WC, and WHtR (53–55). The 12 indices except WC are calculated as follows:

(1) $\text{BMI} = \text{Weight}/\text{Height}^2$
(2) $\text{WHtR} = \text{WC}/\text{Height}$
(3) Males: $\text{VAI} = \frac{WC}{39.68+(1.88\times BMI)} \times \frac{TG}{1.03} \times \frac{1.31}{HDL}$
Females: $\text{VAI} = \frac{WC}{36.58+(1.89\times BMI)} \times \frac{TG}{0.81} \times \frac{1.52}{HDL}$
(4) $\text{ABSI} = \frac{WC}{Height^{\frac{1}{2}} \times BMS^{\frac{2}{3}}}$
(5) $\text{BRI} = 364.2 - 365.5\sqrt{1 - \left(\frac{WC\div(2\pi)^2}{(0.5\times Height)^2}\right)}$
(6) Males: LAP = [WC (cm) – 65] × TG (mmol/L)
Females: LAP = [WC (cm) – 58] × TG (mmol/L)
(7) $\text{CI} = \frac{WC(m)}{0.019\sqrt{\frac{\text{weight(kg)}}{\text{height(m)}}}}$
(8) Males: CVAI = −267.93 + 0.68 × age + 0.03 × BMI (kg/m^2) + 4.00 × WC (cm) + 22.00 × Log_{10}TG (mmol/L) – 16.32 × HDL-C (mmol/L)
Females: CVAI = −187.32 + 1.71 × age + 4.32 × BMI (kg/m^2) + 1.12 × WC (cm) + 39.76 × Log_{10}TG (mmol/L) – 11.66 × HDL-C (mmol/L)
(9) TyG index = Ln [(TG (mg/dl) × glucose (mg/dl)/2)]
(10) TyG-BMI = TyG × BMI
(11) TyG-WC = TyG × WC
(12) TyG-WHtR = TyG × WHtR.

Statistical analysis

All data were analyzed using the SPSS software, version 25.0 (IBM SPSS, Armonk, NY, USA). The chi-square test was used to classify variables, and the *t*-test was used to determine the significant differences between continuous variables. Using these two methods, we tested the degree of correlation between covariates and 13 obesity- and lipid-related indices and gender in Table 1. In Table 2, the degree of association between these indices and the presence or absence of MetS was examined. The receiver operating characteristic (ROC) curve was drawn and AUC was calculated to check the ability of these indices to identify the MetS. The cutoff points were

TABLE 3 Cutoff value between area under curve, sensitivity, and specificity for obesity- and lipid-related indices to detect metabolic syndrome (CHARLS2011–2015) by sex.

$N = 3,088$	WC	BMI	WHtR	VAI	ABSI	BRI	LAP	CI	CVAI	TyG index	TyG-BMI	TyG-WC	TyG-WHtR
Male ($N = 1,968$)													
Area under curve	0.730	0.732	0.710	0.674	0.537	0.710	0.745	0.622	0.752	0.646	0.755	0.749	0.735
Std. error	0.018	0.017	0.017	0.017	0.019	0.017	0.016	0.019	0.016	0.018	0.016	0.016	0.017
95% CI	0.695, 0.764	0.698, 0.766	0.675, 0.744	0.641, 0.708	0.500, 0.575	0.675, 0.744	0.713, 0.777	0.586, 0.659	0.721, 0.784	0.611, 0.682	0.723, 0.787	0.717, 0.781	0.703, 0.768
P-value	0.000	0.000	0.000	0.000	0.055	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Optimal cutoffs	83.950	22.569	0.509	2.030	8.054	3.523	16.896	1.264	85.284	8.493	187.919	705.405	4.342
J-Youden	0.400	0.384	0.336	0.283	0.079	0.335	0.402	0.208	0.402	0.282	0.395	0.399	0.399
Sensitivity (%)	0.715	0.692	0.692	0.751	0.672	0.692	0.775	0.613	0.727	0.625	0.735	0.715	0.668
Specificity (%)	0.685	0, 692	0.644	0.532	0.407	0.644	0.627	0.595	0.675	0.657	0.660	0.683	0.694
(+) Likelihood ratio	2.270	2.247	1.944	1.605	1.133	1.942	2.079	1.514	2.239	1.821	2.162	2.260	2.183
(−) Likelihood ratio	0.416	0.445	0.478	0.468	0.806	0.479	0.359	0.650	0.404	0.571	0.402	0.416	0.478
Female ($N = 1,672$)													
Area under curve	0.654	0.638	0.645	0.632	0.543	0.645	0.674	0.596	0.687	0.607	0.656	0.674	0.663
Std. error	0.015	0.015	0.015	0.015	0.016	0.015	0.015	0.016	0.015	0.016	0.015	0.015	0.015
95% CI	0.624, 0.683	0.608, 0.667	0.616, 0.675	0.602, 0.662	0.511, 0.575	0.616, 0.675	0.644, 0.703	0.565, 0.626	0.658, 0.716	0.576, 0.637	0.627, 0.685	0.645, 0.703	0.633, 0.692
P-value	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Optimal cutoffs	82.700	21.923	0.517	3.244	7.918	3.680	23.723	1.275	86.785	8.297	187.164	644.630	4.265
J-Youden	0.240	0.224	0.231	0.225	0.089	0.231	0.264	0.175	0.276	0.203	0.233	0.252	0.235
Sensitivity (%)	0.574	0.708	0.725	0.589	0.775	0.725	0.644	0.574	0.603	0.711	0.656	0.821	0.773
Specificity (%)	0.666	0.516	0.506	0.636	0.313	0.506	0.620	0.601	0.673	0.492	0.577	0.431	0.462
(+) Likelihood ratio	1.719	1.463	1.468	1.618	1.129	1.468	1.695	1.439	1.844	1.400	1.551	1.443	1.437
(−) Likelihood ratio	0.640	0.566	0.543	0.646	0.718	0.543	0.574	0.709	0.590	0.587	0.596	0.416	0.491

WC, waist circumference; BMI, body mass index; WHtR, waist to height ratio; VAI, visceral adiposity index; ABSI, a body shape index; BRI, body roundness index; LAP, lipid accumulation product; CVAI, cardio-ankle vascular index; CI, conicity index; TyG, triglyceride and glucose index; TyG-BMI, TyG related to BMI; TyG-WC, TyG related to WC; TyG-WHtR, TyG related to WHtR.

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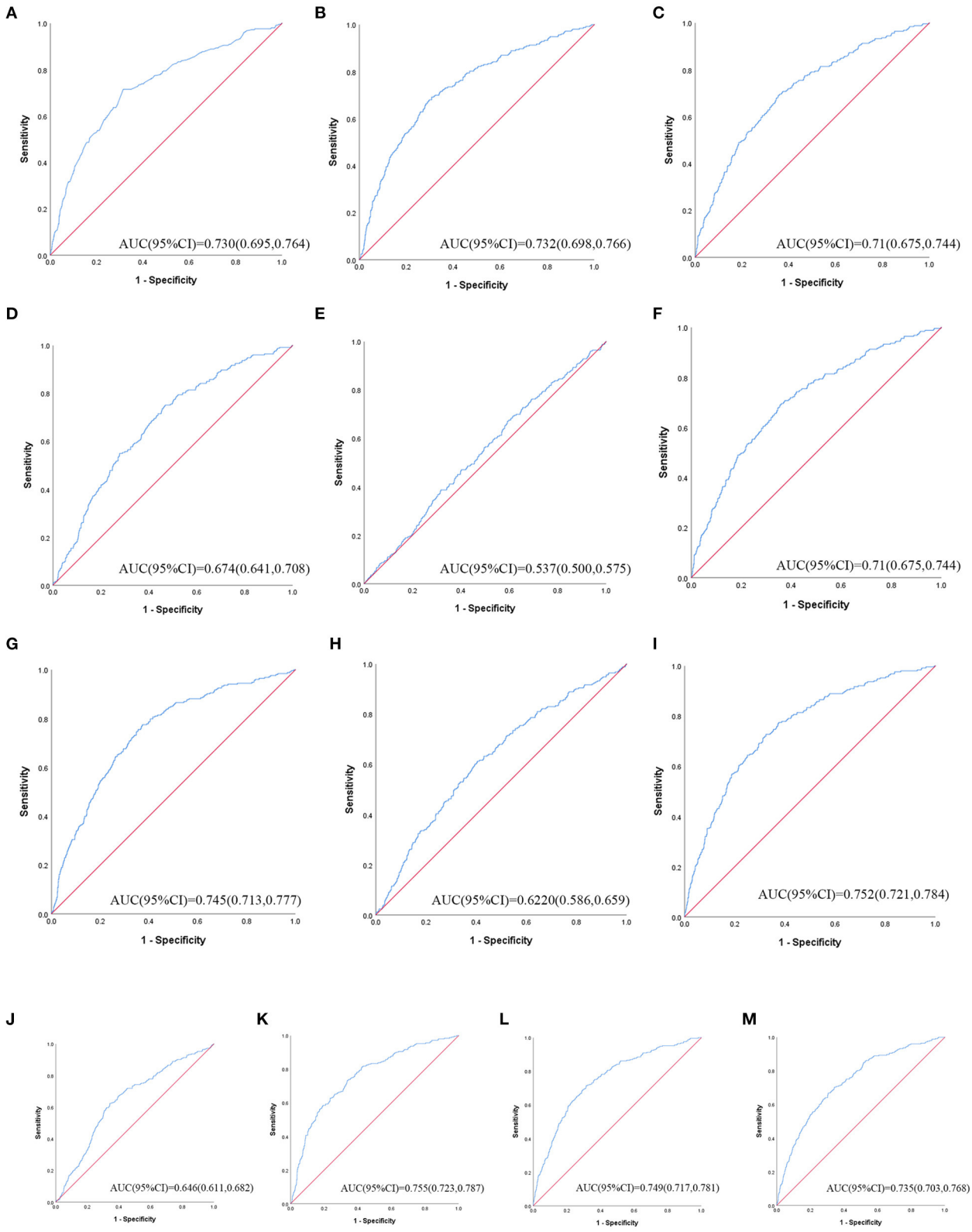

FIGURE 3
The ROC curves of each indicator in the prediction of MetS risk in male. **(A)** = WC, **(B)** = BMI, **(C)** = WHtR, **(D)** = VAI, **(E)** = ABSI, **(F)** = BRI, **(G)** = LAP, **(H)** = CI, **(I)** = CVAI, **(J)** = TyG-index, **(K)** = TyG-BMI, **(L)** = TyG-WC, **(M)** = TyG-WHtR.

selected using the Youden index (sensitivity + specificity − 1). The likelihood ratio was determined, and the effect size (ES) and odds ratio (OR) for each metric were calculated to determine the predictor for each metric. The *p*-value obtained by the statistical significance test was generally considered statistically significant when $P < 0.05$ and extremely significant when $P < 0.001$. According

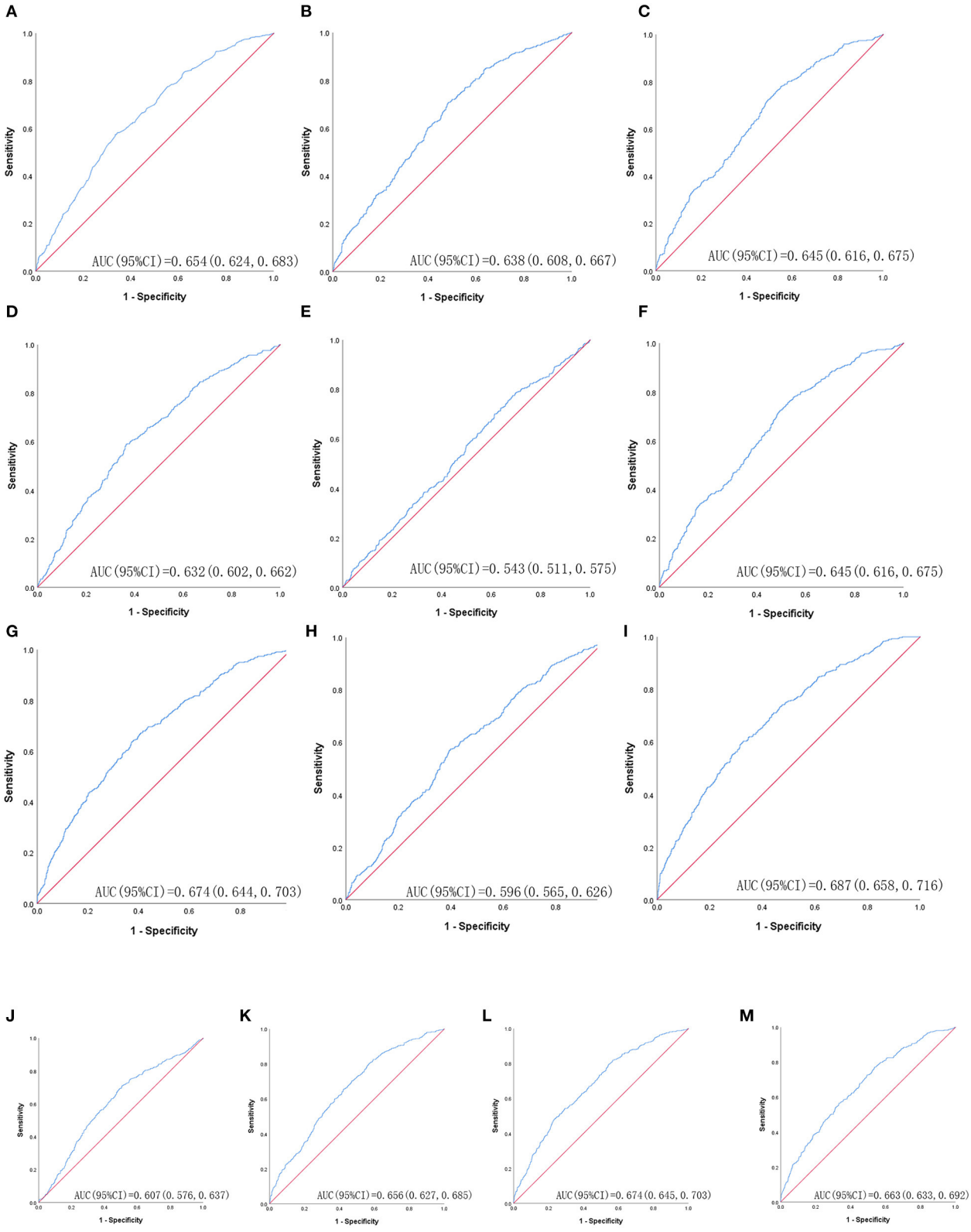

FIGURE 4
The ROC curves of each indicator in the prediction of MetS risk in female. **(A)** = WC, **(B)** = BMI, **(C)** = WHtR, **(D)** = VAI, **(E)** = ABSI, **(F)** = BRI, **(G)** = LAP, **(H)** = CI, **(I)** = CVAI, **(J)** = TyG-index, **(K)** = TyG-BMI, **(L)** = TyG-WC, **(M)** = TyG-WHtR.

to optimal cutoff values of the 13 obesity- and lipid-related indices, they were divided into two categorical variables, and OR and 95% CI of each obesity- and lipid-related indices with MetS components were recalculated. After adjusting for age, education level, marital status, current residence, current smoking, alcohol drinking, taking activities, doing regular exercise, and chronic diseases, OR and 95% CI of each obesity- and lipid-related indices with MetS components were calculated.

TABLE 4 Associations of obesity- and lipid-related indices with MetS (CHARLS2011–2015) and its components.

MetS and its components	WC	BMI	WHtR	VAI	ABSI	BRI	LAP	CI	CVAI	TyG index	TyG-BMI	TyG-WC	TyG-WHtR
Male													
MetS													
Unadjusted OR (95% CI)	5.470 (4.087, 7.321)**	5.030 (3.780, 6.694)**	3.947 (2.975, 5.238)**	3.425 (2.537, 4.625)**	1.402 (1.060, 1.855)*	4.054 (3.050, 5.388)**	5.790 (4.244, 7.901)**	2.310 (1.762, 3.028)**	5.544 (4.129, 7.443)**	3.188 (2.425, 4.190)**	5.390 (4.007, 7.251)**	5.426 (4.054, 7.262)**	4.548 (3.434, 6.024)**
P-value	0.000	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Adjusted OR (95% CI)	5.574 (4.133, 7.518)**	5.137 (3.820, 6.907)**	4.004 (3.006, 5.332)**	3.426 (2.528, 4.642)**	1.514 (1.136, 2.019)*	4.110 (3.081, 5.481)**	5.841 (4.256, 8.016)**	2.391 (1.817, 3.145)**	5.893 (4.351, 7.979)**	3.167 (2.405, 4.169)**	5.522 (4.064, 7.504)**	5.570 (4.129, 7.512)**	4.601 (3.460, 6.118)**
P-value	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Elevated triglycerides													
Unadjusted OR (95% CI)	2.234 (1.770, 2.818)**	2.278 (1.805, 2.875)**	2.011 (1.595, 2.535)**	3.930 (3.022, 5.111)**	1.303 (1.025, 1.657)*	2.035 (1.614, 2.565)**	4.074 (3.179, 5.223)**	1.392 (1.106, 1.752)*	2.886 (2.282, 3.651)**	4.185 (3.281, 5.336)**	2.998 (2.367, 3.798)**	3.453 (2.722, 4.380)**	3.294 (2.601, 4.172)**
P-value	0.000	0.000	0.000	0.000	0.031	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000
Adjusted OR (95% CI)	2.178 (1.714, 2.766)**	2.127 (1.672, 2.706)**	2.069 (1.633, 2.621)**	3.830 (2.934, 4.999)**	1.526 (1.190, 1.957)**	2.090 (1.650, 2.647)**	3.981 (3.090, 5.130)**	1.508 (1.193, 1.907)**	3.115 (2.440, 3.977)**	4.089 (3.199, 5.225)**	2.844 (2.228, 3.630)**	3.466 (2.713, 4.430)**	3.395 (2.667, 4.323)**
P-value	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Reduced HDL-C													
Unadjusted OR (95% CI)	1.579 (1.209, 2.063)**	1.619 (1.239, 2.116)**	1.242 (0.951, 1.623)	2.478 (1.864, 3.293)**	0.990 (0.755, 1.298)	1.294 (0.991, 1.689)	1.356 (1.040, 1.769)*	1.104 (0.846, 1.441)	1.874 (1.436, 2.446)**	1.254 (0.958, 1.640)	1.324 (1.014, 1.730)*	1.428 (1.092, 1.867)*	1.348 (1.029, 1.766)*
P-value	0.001	0.000	0.112	0.000	0.943	0.058	0.024	0.467	0.000	0.099	0.039	0.009	0.030
Adjusted OR (95% CI)	1.709 (1.296, 2.252)**	1.762 (1.333, 2.329)**	1.309 (0.997, 1.719)	2.404 (1.801, 3.208)**	1.037 (0.784, 1.372)	1.364 (1.040, 1.790)*	1.400 (1.065, 1.838)*	1.169 (0.892, 1.533)	2.031 (1.543, 2.674)**	1.232 (0.939, 1.617)	1.404 (1.063, 1.853)*	1.528 (1.158, 2.015)*	1.407 (1.069, 1.853)*
P-value	0.000	0.000	0.053	0.000	0.797	0.025	0.016	0.258	0.000	0.133	0.017	0.003	0.015
Elevated blood pressure													
Unadjusted OR (95% CI)	1.513 (1.258, 1.819)**	1.520 (1.263, 1.830)**	1.774 (1.479, 2.130)**	1.082 (0.907, 1.292)	1.217 (1.015, 1.458)*	1.759 (1.466, 2.110)**	1.372 (1.147, 1.641)**	1.346 (1.126, 1.610)*	1.499 (1.248, 1.801)**	1.417 (1.180, 1.701)**	1.474 (1.229, 1.768)**	1.480 (1.231, 1.779)**	1.642 (1.363, 1.978)**
P-value	0.000	0.000	0.000	0.380	0.034	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000
Adjusted OR (95% CI)	1.676 (1.380, 2.036)**	1.794 (1.472, 2.186)**	1.803 (1.492, 2.178)**	1.173 (0.976, 1.410)	1.040 (0.860, 1.258)	1.792 (1.484, 2.164)**	1.493 (1.237, 1.803)**	1.248 (1.038, 1.501)*	1.478 (1.221, 1.790)**	1.507 (1.248, 1.820)**	1.718 (1.415, 2.086)**	1.576 (1.298, 1.912)**	1.671 (1.378, 2.027)**
P-value	0.000	0.000	0.000	0.088	0.682	0.000	0.000	0.018	0.000	0.000	0.000	0.000	0.000
Elevated fasting glucose													
Unadjusted OR (95% CI)	1.375 (1.129, 1.673)*	1.211 (0.993, 1.476)	1.348 (1.110, 1.637)*	1.208 (0.997, 1.463)	1.284 (1.053, 1.566)*	1.362 (1.122, 1.654)*	1.368 (1.128, 1.660)*	1.287 (1.062, 1.560)*	1.382 (1.136, 1.680)*	1.658 (1.364, 2.016)**	1.423 (1.172, 1.729)**	1.475 (1.212, 1.794)**	1.468 (1.205, 1.788)**
P-value	0.002	0.058	0.003	0.054	0.013	0.002	0.001	0.010	0.001	0.000	0.000	0.000	0.000

(Continued)

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TABLE 4 (Continued)

MetS and its components	WC	BMI	WHtR	VAI	ABSI	BRI	LAP	CI	CVAI	TyG index	TyG-BMI	TyG-WC	TyG-WHtR
Adjusted OR (95% CI)	1.424 (1.163, 1.743)**	1.272 (1.036, 1.563)*	1.347 (1.105, 1.640)*	1.255 (1.032, 1.527)*	1.222 (0.996, 1.499)	1.364 (1.120, 1.661)*	1.418 (1.163, 1.730)**	1.246 (1.025, 1.514)*	1.392 (1.139, 1.702)*	1.722 (1.413, 2.098)**	1.510 (1.232, 1.849)**	1.526 (1.246, 1.868)**	1.477 (1.208, 1.806)**
P-value	0.001	0.022	0.003	0.023	0.055	0.002	0.001	0.027	0.001	0.000	0.000	0.000	0.000
Female													
MetS													
Unadjusted OR (95% CI)	2.687 (2.142, 3.370)**	2.586 (2.038, 3.282)**	2.648 (2.082, 3.367)**	2.494 (1.989, 3.127)**	1.567 (1.210, 2.030)**	2.703 (2.123, 3.441)**	2.931 (2.328, 3.690)**	2.033 (1.625, 2.545)**	3.125 (2.486, 3.928)**	2.377 (1.873, 3.018)**	2.591 (2.057, 3.263)**	3.470 (2.639, 4.563)**	2.916 (2.262, 3.761)**
P-value	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Adjusted OR (95% CI)	2.764 (2.195, 3.480)**	3.045 (2.363, 3.925)**	2.619 (2.055, 3.337)**	2.552 (2.029, 3.209)**	1.485 (1.135, 1.943)*	2.669 (2.092, 3.404)**	2.999 (2.374, 3.788)**	1.945 (1.542, 2.452)**	3.072 (2.416, 3.906)**	2.332 (1.834, 2.967)**	2.932 (2.300, 3.737)**	3.547 (2.690, 4.678)**	2.895 (2.241, 3.741)**
P-value	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Elevated triglycerides													
Unadjusted OR (95% CI)	1.491 (1.182, 1.88)**	1.581 (1.248, 2.001)**	1.549 (1.223, 1.962)**	3.063 (2.413, 3.888)**	1.367 (1.050, 1.780)*	1.580 (1.246, 2.002)**	2.770 (2.182, 3.516)**	1.338 (1.063, 1.685)*	2.066 (1.637, 2.606)**	3.162 (2.436, 4.104)**	1.992 (1.575, 2.519)**	2.199 (1.692, 2.859)**	2.183 (1.694, 2.814)**
P-value	0.001	0.000	0.000	0.000	0.020	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000
Adjusted OR (95% CI)	1.464 (1.159, 1.849)*	1.536 (1.203, 1.961)**	1.544 (1.217, 1.958)**	3.069 (2.415, 3.901)**	1.494 (1.135, 1.966)*	1.578 (1.243, 2.002)**	2.733 (2.15, 3.473)**	1.417 (1.116, 1.799)*	2.300 (1.798, 2.942)**	3.224 (2.478, 4.193)**	1.955 (1.536, 2.487)**	2.174 (1.670, 2.829)**	2.183 (1.691, 2.819)**
P-value	0.001	0.001	0.000	0.000	0.004	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Reduced HDL-C													
Unadjusted OR (95% CI)	1.466 (1.189, 1.807)**	1.542 (1.25, 1.903)**	1.272 (1.032, 1.567)*	2.702 (2.186, 3.34)**	0.989 (0.788, 1.241)	1.273 (1.033, 1.568)*	1.702 (1.383, 2.096)**	1.079 (0.877, 1.327)	1.662 (1.348, 2.048)**	1.416 (1.147, 1.748)*	1.497 (1.217, 1.842)**	1.444 (1.16, 1.797)*	1.346 (1.087, 1.666)*
P-value	0.000	0.000	0.024	0.000	0.925	0.024	0.000	0.474	0.000	0.001	0.000	0.001	0.006
Adjusted OR (95% CI)	1.456 (1.179, 1.797)**	1.509 (1.214, 1.876)**	1.272 (1.031, 1.570)*	2.697 (2.18, 3.338)**	1.052 (0.83, 1.332)	1.275 (1.033, 1.573)*	1.687 (1.369, 2.080)**	1.145 (0.924, 1.419)	1.851 (1.483, 2.310)**	1.438 (1.163, 1.778)**	1.462 (1.182, 1.809)**	1.436 (1.1520, 1.791)*	1.350 (1.088, 1.674)*
P-value	0.000	0.000	0.025	0.000	0.677	0.024	0.000	0.217	0.000	0.001	0.000	0.001	0.006
Elevated blood pressure													
Unadjusted OR (95% CI)	1.360 (1.109, 1.667)*	1.108 (0.906, 1.355)	1.437 (1.173, 1.762)**	0.934 (0.762, 1.145)	1.172 (0.937, 1.464)	1.452 (1.185, 1.781)**	1.197 (0.979, 1.464)	1.487 (1.215, 1.819)**	1.859 (1.515, 2.28)**	1.121 (0.916, 1.372)	1.048 (0.858, 1.281)	1.219 (0.988, 1.503)	1.259 (1.025, 1.547)*
P-value	0.003	0.318	0.000	0.512	0.164	0.000	0.079	0.000	0.000	0.269	0.646	0.064	0.028
Adjusted OR (95% CI)	1.505 (1.212, 1.870)**	1.563 (1.250, 1.953)**	1.44 (1.161, 1.785)**	0.937 (0.756, 1.160)	0.814 (0.638, 1.039)	1.445 (1.165, 1.791)**	1.285 (1.038, 1.589)*	1.142 (0.920, 1.417)	1.439 (1.154, 1.795)*	1.015 (0.82, 1.257)	1.347 (1.084, 1.675)*	1.304 (1.044, 1.629)*	1.227 (0.987, 1.525)
P-value	0.000	0.000	0.001	0.549	0.098	0.001	0.021	0.229	0.001	0.890	0.007	0.019	0.066

(Continued)

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TABLE 4 (Continued)

MetS and its components	WC	BMI	WHtR	VAI	ABSI	BRI	LAP	CI	CVAI	TyG index	TyG-BMI	TyG-WC	TyG-WHtR
Elevated fasting glucose													
Unadjusted OR (95% CI)	1.088 (0.872, 1.359)	1.056 (0.848, 1.314)	1.164 (0.935, 1.451)	1.12 (0.899, 1.395)	1.277 (0.998, 1.633)	1.197 (0.961, 1.492)	1.257 (1.011, 1.564)*	1.255 (1.009, 1.562)*	1.407 (1.129, 1.753)*	1.609 (1.285, 2.014)**	1.162 (0.935, 1.445)	1.368 (1.086, 1.724)*	1.45 (1.155, 1.821)*
P-value	0.455	0.626	0.175	0.311	0.052	0.109	0.040	0.041	0.002	0.000	0.177	0.008	0.001
Adjusted OR (95% CI)	1.099 (0.878, 1.376)	1.164 (0.926, 1.463)	1.145 (0.917, 1.43)	1.14 (0.913, 1.424)	1.147 (0.887, 1.483)	1.175 (0.94, 1.468)	1.28 (1.026, 1.596)*	1.131 (0.902, 1.418)	1.27 (1.007, 1.602)*	1.575 (1.255, 1.977)**	1.261 (1.006, 1.581)*	1.38 (1.092, 1.744)*	1.439 (1.143, 1.81)*
P-value	0.410	0.195	0.233	0.247	0.296	0.156	0.029	0.288	0.043	0.000	0.044	0.007	0.002

The obesity- and lipid-related indices (WC, BMI, WHtR, VAI, ABSI, BRI, LAP, CVAI, CI, TyG, TyG-BMI, TyG-WC, and TyG-WHtR) used data from participants in 2011. The MetS components (elevated triglycerides, reduced HDL-C, elevated blood pressure, elevated fasting glucose) used data from participants in 2015.

Adjusted OR: adjusted for age, educational levels, marital status, live place, current smoking, alcohol drinking, activities, exercises, chronic diseases.

$^{*}P < 0.05$, $^{**}P < 0.001$.

WC, waist circumference; BMI, body mass index; WHtR, waist-to-height ratio; VAI, visceral adiposity index; ABSI, a body shape index; BRI, body roundness index; LAP, lipid accumulation product; CVAI, cardio-ankle vascular index; CI, conicity index; TyG, triglyceride and glucose index; TyG-BMI, TyG related to BMI; TyG-WC, TyG related to WC; TyG-WHtR, TyG related to WHtR.

Results

Table 1 shows the baseline characteristics of participants according to gender differences. The number of participants was 3,640; 54.07% were men and 45.93% were women. Notably, 10.27% were single; 94.59% were living in rural areas; 8.30% were former smokers and 36.13% were current smokers; 8.27% were drinking less than once a month and 29.12% were drinking more than once a month; 48.13% were taking activities; 50.05% had 1–2 chronic diseases and 14.56% had 3–14 chronic diseases. Meanwhile, the current residence, taking activities, doing regular exercises, and chronic disease counts were not statistically significant between the male and female subgroups ($P > 0.05$).

Table 2 shows the baseline characteristics of the study participants with and without MetS by sex. A total of 3,640 participants were classified into two groups according to sex. A total of 1,968 men, robust with MetS (12.86%) and without MetS (87.14%) at baseline, were included in the national cohort analysis. A total of 1,672 women, robust with MetS (25.00%) and without MetS (75.00%) at baseline, were included in the national cohort analysis. There was no significant difference in ABSI between subgroups of patients with and without MetS, whether in men or women ($P > 0.05$). At the same time, the remaining 12 indicators differed between subgroups of patients with and without MetS ($P < 0.05$).

Table 3 shows ROC analysis and AUC results of obesity- and lipid-related indices. We observed the predictive value of obesity- and lipid-related indicators for MetS by sex using the ROC. The ROC curves of each indicator in the prediction of MetS risk in men and women are shown in Figures 3, 4, respectively. In men, the largest AUC was observed for the TyG-BMI index (AUC = 0.755, Std. Error = 0.016, 95% CI = 0.723–0.787, and optimal cutoff value = 187.919). The prediabetes predictive values were similar to the CVAI (AUC = 0.752, Std. Error = 0.016, 95% CI = 0.721–0.784, and optimal cutoff value = 85.284), TyG-WC (AUC = 0.749, Std. Error = 0.016, 95% CI = 0.717–0.781, and optimal cutoff value = 705.405), and LAP (AUC = 0.745, Std. Error = 0.016, 95% CI = 0.713–0.777, and optimal cutoff value = 16.896) indices. In contrast, the AUC of ABSI did not reach statistical significance ($P = 0.055$). In women, the largest AUC was observed for the CVAI index (AUC = 0.687, Std. Error = 0.015, 95% CI = 0.658–0.716, and optimal cutoff value = 86.785). The prediabetes predictive values were similar to the LAP (AUC = 0.674, Std. Error = 0.015, 95% CI = 0.644–0.703, and optimal cutoff value = 23.723), TyG-WC (AUC = 0.674, Std. Error = 0.015, 95% CI = 0.645–0.703, and optimal cutoff value = 644.630), and TyG-WHtR (AUC = 0.663, Std. Error = 0.015, 95% CI = 0.633–0.692, and optimal cutoff value = 4.265) indices. As in men, the AUC of ABSI in women was not statistically significant ($P = 0.009$).

Table 4 shows that MetS and its components increase gradually with the increase of obesity- and lipid-related indices in both sexes. For instance, in men, a unit increase in WC was associated with a 5.574-fold increased odds of metabolic syndrome (aOR: 5.574; 95% CI: 4.133–7.518), and a unit increase in BMI was associated with a 5.137-fold increase in odds of metabolic syndrome (aOR: 5.137; 95% CI: 3.820–6.907). In women, a unit increase in WC was associated with a 2.764-fold increase in odds of metabolic syndrome (aOR: 2.764; 95% CI: 2.195–3.480), and a unit increase in BRI was associated

with a 3.045-fold increased odds of metabolic syndrome (aOR: 3.045; 95% CI: 2.363-3.925). The OR and 95% CI of Table 4 are used to draw Figures 5, 6. It is interesting that OR values were generally higher in men than in women for risk factors of MetS. Meanwhile, the OR value of ABSI was much lower than that of the other 13 indices.

Discussion

According to the diagnostic criteria of MetS issued in 2006, this study evaluated the predictive power of 13 obesity- and lipid-related parameters to identify the risk of MetS in middle-aged and elderly Chinese adults. This article is an original study. To the best of our knowledge, no previous study has compared the ability of these 13 obesity- and lipid-related factors to predict MetS in middle-aged and elderly Chinese populations. There are 3,640 participants in this study. Among 3,640 individuals, the prevalence of MetS was 18.43%. Among 1,968 male participants, 253 (12.86%) were diagnosed with MetS. Among 1,672 female participants, 418 (25.00%) were diagnosed with MetS. According to the meta-analysis report (1), the prevalence of MetS in China was 24.5% in 2016, among which the prevalence of MetS increases with age (15–39 years: 13.9%; 40–59 years: 26.4%; 60 years: 32.4%). Ranasinghe et al.'s (16) research report says that the prevalence of MetS in China is increasing yearly. Based on these studies, further studies are needed to establish a single index for predicting the occurrence of MetS in the middle-aged and elderly population in China.

This national cohort study found that the correlation between ABSI and MetS was far lower than the other 12 obesity- and lipid-related indices. Through ROC analysis of obesity- and blood lipid-related indicators, the results for the ABSI AUC did not reach statistical significance ($P = 0.055$) in men, similar to the results ($P = 0.009$) obtained in women. At the same time, some studies (56–58) also show that BRI is better than ABSI in predicting MetS. According to Ji et al. (59), this result can be explained by the following viewpoints: ABSI is highly clustered around the mean value with relatively slight variance, which makes ABSI perform poorly in predicting chronic diseases.

Among the other 12 indices, BMI, WHtR, WC, LAP, and CVAI have received special attention. Ashwell et al. (60) reported that WHtR outperformed WC and BMI in detecting cardiac metabolic risk factors in both men and women. Similarly, in a systematic literature review in 2016, Corrêa et al. (61) also shows that WHtR has better performance than WC and BMI in evaluating MetS. Alves et al.'s (62) study shows that LAP, WC, and WHtR indicators identify MetS in older women and can be used to assess and monitor MetS individually or collectively.

Tyg-related factors such as the TyG index, TYG-BMI, TYG-WC, and TYG-WHTR values may provide a broader basis for assessing the association between MetS and obesity- and lipid-related indicators. Thus, TyG-related factors have also recently been suggested as a method for estimating metabolic disorders. Ahn et al.'s (63) study shows that the TyG index provided a good standard for identifying people with pre-diabetes/diabetes. In the meantime, most of the studies (64–66) also showed a significant correlation between TyG-related factors and pre-diabetes/diabetes. As mentioned earlier, elevated FPG levels were one of the diagnostic criteria for MetS, and pre-diabetes/diabetes leads to elevated FPG levels. Therefore, there must be an association between TyG-related factors and MetS. Ferreira et al. (67) identified the TyG-related factors as an important tool for predicting MetS.

Indeed, in this study, the TyG-related factors were more efficient compared to these other markers. According to the results of this study, obesity- and lipid-related indices are different in predicting MetS because of gender differences. In general, an AUC closer to 1 indicates better predictive power, while an AUC of 0.55 or less indicates no better predictive power than chance. Among men, TyG-BMI performed best, followed by CVAI, TyG-WC, and LAP. TyG-BMI is a surrogate marker used to identify insulin resistance (68). In the ROC analysis of obesity- and blood lipid-related indicators, the largest AUC was observed for the TyG-BMI index (AUC = 0.755, Std. Error = 0.016, 95% CI = 0.723–0.787, and optimal cutoff value = 187.919). Raimi et al. (69) suggested that the product of TyG-related factors and the anthropometric index could improve the identification and prediction of MetS. This view is consistent with this article.

In contrast, according to the report (70), VAI has moderate to high accuracy in screening MetS diagnostic tests. VAI was a reliable index to evaluate the visceral fat function, as proposed by Amato et al. (46). A multi-center cross-sectional study (58) was conducted in Guizhou Province in southwest China, and it was found that LAP and VAI, the visceral obesity markers, were the most effective predictors of MetS, while ABSI and CI were the weakest indicators for screening MetS. Interestingly, many studies (71, 72) have also demonstrated that VAI performs well in predicting MetS.

Considerable evidence suggests that VAI plays a significant role in predicting MetS (73, 74). However, there were significant differences in body fat distribution between ethnic groups. According to the distribution characteristics of Asian body fat, Xia et al. developed CVAI to evaluate the visceral fat area of the Chinese people (51). CVAI is better than VAI in predicting the MetS in middle-aged and older adults in China. Among women, CVAI performed best, followed by LAP, TyG-WC, and TyG-WHtR. In the ROC analysis of obesity- and blood lipid-related indicators, the largest AUC was observed for the CVAI index (AUC = 0.687, Std. Error = 0.015, 95% CI = 0.658–0.716, and optimal cutoff value = 86.785).

Similarly, LAP performed well in predicting metabolic synthesis. LAP was used as an indicator to predict insulin resistance (75, 76), so there is also a significant association between LAP and MetS. In this study, for men, the AUC of LAP (AUC = 0.745, Std. Error = 0.016, 95% CI = 0.713–0.777, and optimal cutoff value = 16.896) was the largest of the other factors in the ROC analysis of obesity- and lipid-related measures, except for the TyG-related factors and CVAI. For women, the AUC of LAP (AUC = 0.674, Std. Error = 0.015, 95% CI = 0.644–0.703, and optimal cutoff value = 23.723) was second only to that of CVAI among the other factors. The rest of the studies (77–79) also showed that LAP works well in predicting MetS.

In this study, 13 obesity- and lipid-related indices were converted into two-category variables according to the values in Table 3. Table 4 is based on the transformed variables. In general, a higher OR indicates a greater risk factor. In Table 4, the OR value of ABSI is much lower than that of the remaining 12 indices in both sexes, which is consistent with the conclusion drawn in Table 3. ABSI is not suitable as a predictor of MetS. Stefanescu A showed in the study that ABSI is much inferior to other indicators for predicting MetS in Peruvian adults (80). Khan et al.'s study showed that WHtR and VAI outperformed ABSI in predicting MetS (22). At the same time, many studies (22, 81, 82) are consistent with the viewpoint of this study. It

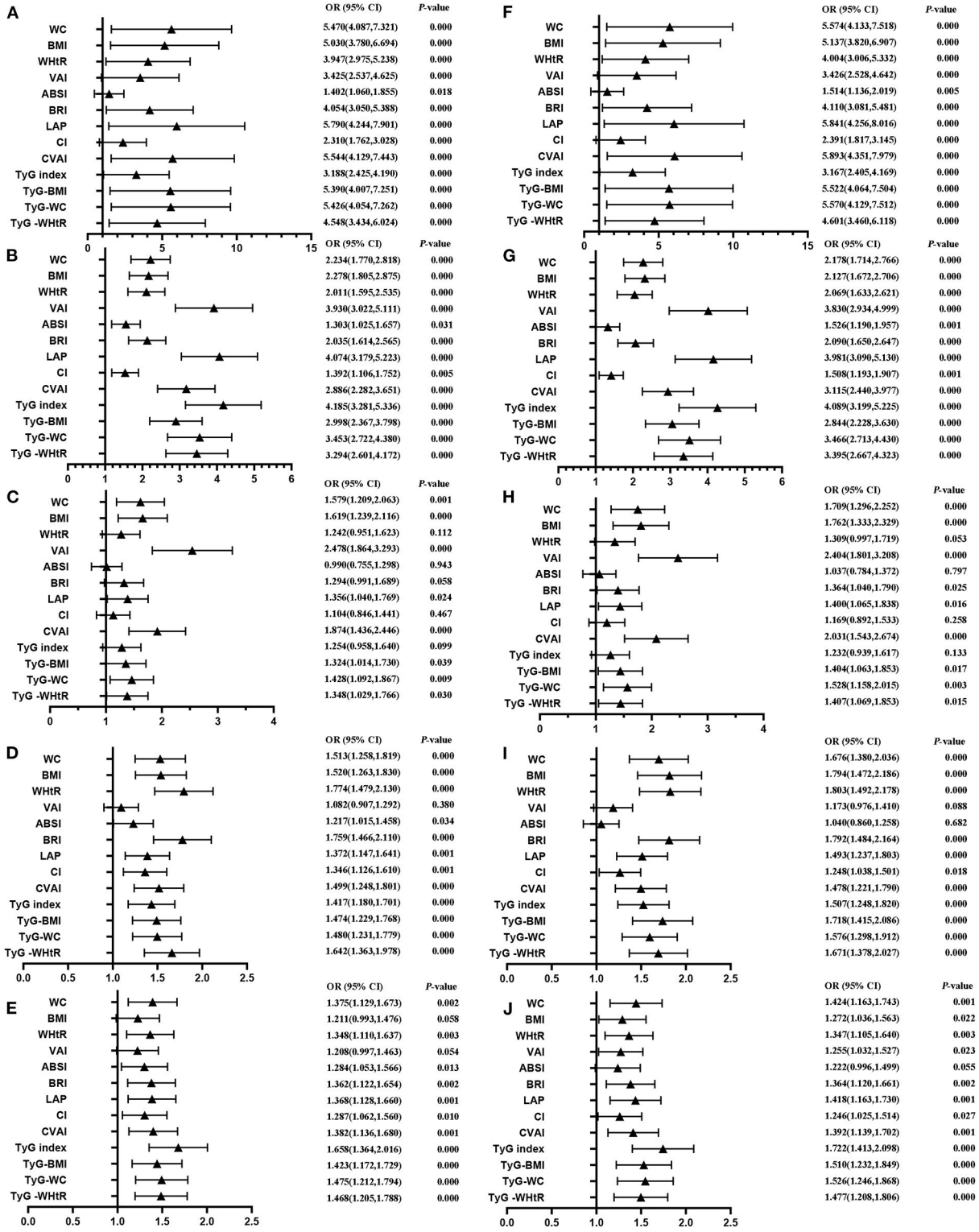

FIGURE 5
Forest diagram of OR before and after adjustment of confounding factors for male. **(A)** Mets unadjust, **(B)** Elevated triglycerides unadjusted, **(C)** Reduced HDL-C unadjusted, **(D)** Elevated blood pressure unadjusted, **(E)** Elevated fasting glucose unadjusted, **(F)** Mets adjusted, **(G)** Elevated triglycerides adjusted, **(H)** Reduced HDL-C adjusted, **(I)** Elevated blood pressure adjusted, **(J)** Elevated fasting glucose adjusted.
Adjusted OR: Adjusted for age, educational levels, marital status, live place, current smoking, alcohol drinking, activities, exercises, chronic diseases.

is interesting that the OR value of men is greater than that of women before and after adjustment. This suggests that an increase in obesity factors may make men more susceptible to MetS. There are many reasons for this. Men are more vulnerable to tobacco damage than women. Many studies (83, 84) have shown that tobacco is more likely to cause sugar and lipid metabolism disorders in the elderly. This may

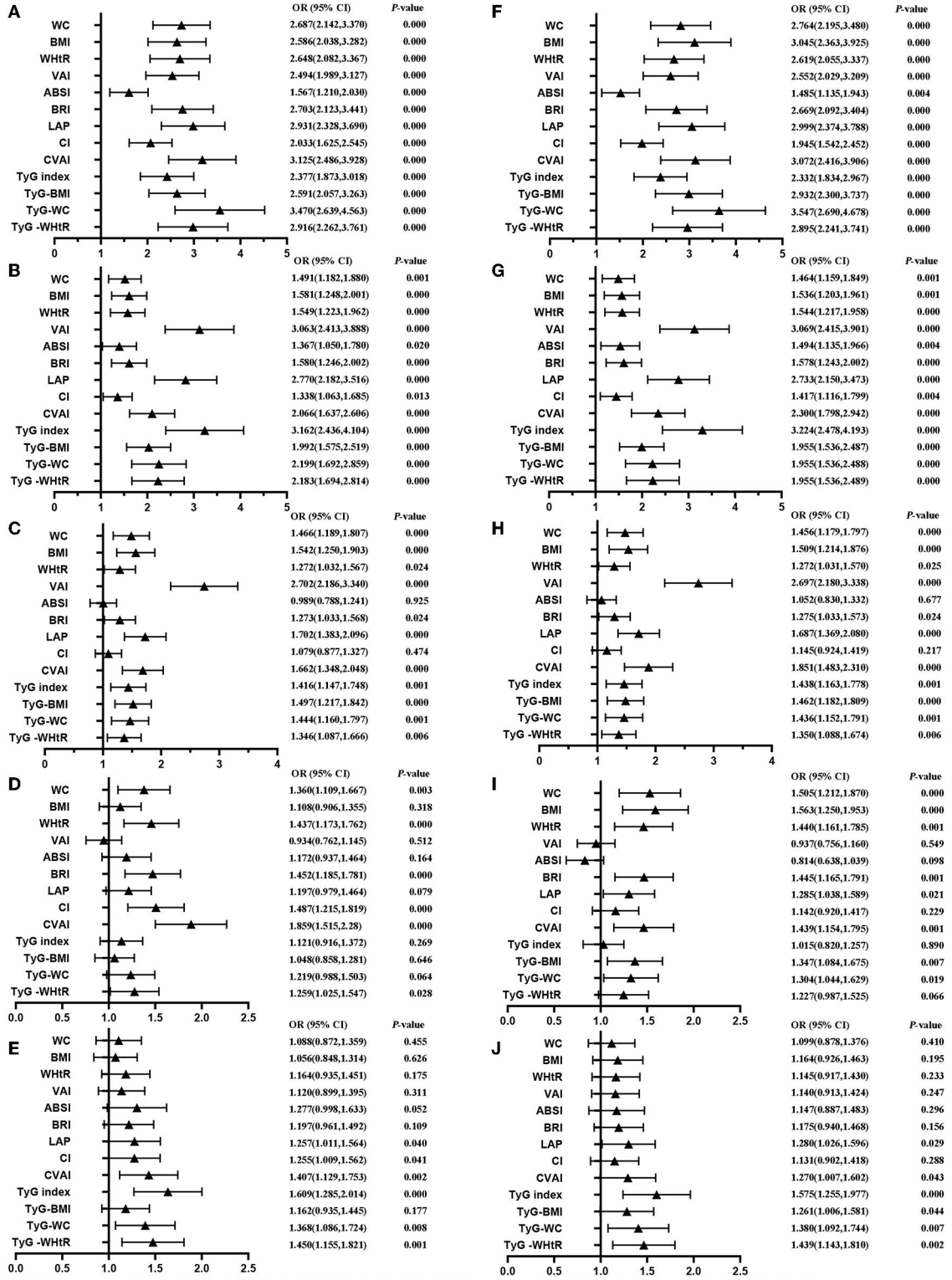

FIGURE 6
Forest diagram of OR before and after adjustment of confounding factors for female. **(A)** Mets unadjust, **(B)** Elevated triglycerides unadjusted, **(C)** Reduced HDL-C unadjusted, **(D)** Elevated blood pressure unadjusted, **(E)** Elevated fasting glucose unadjusted, **(F)** Mets adjusted, **(G)** Elevated triglycerides adjusted, **(H)** Reduced HDL-C adjusted, **(I)** Elevated blood pressure adjusted, **(J)** Elevated fasting glucose adjusted.
Adjusted OR: Adjusted for age, educational levels, marital status, live place, current smoking, alcohol drinking, activities, exercises, chronic diseases.

be associated with cigarette smoke impairing the reverse transport of cholesterol (85). At the same time, men are more prone to alcohol abuse than women in daily life. Excessive drinking can significantly increase the risk of MetS (86).

Strengths and limitations of the study

This study has several advantages. This study was based on a nationwide cohort study of middle-aged and older community residents, with participants aged 45 years or older. It compared the effect of different obesity- and lipid-related indices of the MetS and its component symptom. Previous studies have used only a set of single indices to predict the incidence of MetS. It helped us to understand the different obesity- and lipid-related indices on the incidence of MetS. There are several limitations to this study. Many participants were excluded due to missing data, and further studies should gather more complete data.

Conclusion

Among middle-aged and older adults, all obesity- and lipid-related indices, except ABSI, were able to predict MetS after adjustment for age, sex, educational status, history of smoking, taking activities, doing regular exercises, and chronic diseases. In addition, in men, TyG-BMI is the best indicator to predict MetS, and in women, CVAI is considered the best indicator to predict MetS. LAP had performed well in predicting MetS in both men and women.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

All data are openly published as microdata at http://charls.pku.edu.cn/ with no direct contact with all participants. Approval for this study was given by the Medical Ethics Committee of Wannan Medical College (approval number 2021–3). The patients/participants provided their written informed consent to participate in this study.

Author contributions

LZ: conceived the research. JG: wrote the paper and analyzed the data. JG, YLi, HL, LG, JinlL, YLe, XL, LS, LY, TY, CW, DZ, HW, JingL, ML, YH, and LZ: revised the paper. All authors reviewed the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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The impact of internet use on health status among older adults in China: The mediating role of social support

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Background: With the popularization of the Internet, the use of the Internet is becoming more and more important in the daily life of older adults. However, previous research mainly focuses on Internet use and health in general, and the mechanism of this effect remains to be studied. To bridge this gap, this study aims to explore the mediational effects of social support between Internet use and health among older adults in China.

Methods: The data used in this article are from the 2021 Chinese General Social Survey (CGSS). Social support is divided into two aspects and four dimensions: informal social support (relatives support, friends support, neighbors support) and formal social support (social insurance). This article uses the nested multivariate OLS regression models to analyze the impact of Internet use on health. Furthermore, Finally, SPSS macro PROCESS is applied to test their mediation effects.

Results: Informal social support positively influenced the health status among older adults, while formal social support did not. Among the three types of informal social support, relatives support and friends support significantly affected health status among Chinese older adults. Regarding social support differences between urban and rural areas, it was found that relatives support is a positively significant factor for rural older adults, while friends support is significant for urban older adults.

Conclusions: Since Internet use has many ways of impacting health status, social support only plays a partial mediating role in this study. It recommends that the government should take compelling measures to encourage and promote the use of the Internet among older adults and obtain various social support to improve their health status.

KEYWORDS

internet use, social support, health status, older adults, mediation analysis

Introduction

China's population has been rapidly aging over the last few decades. By the end of 2020, China had 264 million people over the age of 60, accounting for 18.9% of the total population; this figure is expected to rise to more than 300 million by the end of 2025 (1). The World Health Organization (WHO) has defined active aging as "the process of optimizing the opportunities for health, participation, and safety to improve the quality of life as the person ages" (2). Consequently, improving the health of older adults has emerged as a priority for health policymakers. On the other hand, the arrival of the Internet era has greatly

changed the lives of older adults. According to the 45th Statistical Report on China's Internet Development, the number of Internet users in China had reached 904 million by 2020, with 6.7% being over the age of 60 (3). Especially during the COVID-19 pandemic, Internet use has become a trend. Compared to the pre-lockdown period, Internet usage among older adults has increased significantly (4). By December 2021, the Internet penetration rate of the older adults reached 43.2% (5). Therefore, with China's aging population, widespread Internet use has emerged as a new factor that may have an impact on their health status.

Researchers have recently begun to focus on the relationship between Internet use and the health of older adults. Studies have shown that older adults can not only search for health information through the Internet, but also help them build new social networks and reduce social isolation (6, 7). For example, Bretherton conducted a survey of 214 older Australians and found that higher levels of social support mean not using mental health services (8). Researchers have also investigated the role of social support on the health of older adults, and their findings showed that social support has a direct or indirect impact on the health of older adults (9, 10). For example, a prospective repeated measurement cohort study on participants aged 60 and over showed that the higher the social support, the lower the psychological distress (11).

While previous studies have demonstrated that Internet use is associated with health status, few studies have explored the impact mechanism and path of Internet use on health status among older adults. Social support may be a very important mediating factor in this process. Internet use may not only have a direct effect on the health of older adults, but also have an indirect effect on the health of older adults through the mediating variables of social support. However, many previous studies have focused on the direct effects of social support on the physical and mental health of older adults, little is known about their underlying mechanisms. Furthermore, the correlation between social support and personal health has been analyzed in existing studies (12), and Internet use may have effects on social support (13–15). Therefore, whether and how social support mediates the relationship between Internet use and older adults' health status remains to be further tested.

On this basis, this study aims to study the impact of Internet use on the health status of older adults in China, focusing on the mediating role of social support in this process. By using a nationally representative survey and multiple mediating models, this study empirically tests whether different types of social support are potential mediation mechanisms for the relationship between Internet use and health status. In addition, we try to discover whether such impact mechanisms differ significantly between rural and urban areas based on the Chinese context to enrich the existing studies.

Literature review and research hypotheses

Internet use and health

At present, the Internet is now widely used around the world and has become a way of life for an increasing number of people. Scholars have conducted numerous empirical studies on the impact of Internet use on health outcomes. On the one hand, Internet use by older adults has an impact on their physical health. The Internet provides a platform for people to communicate and help them acquire more health knowledge, which is of great significance for improving their health (16–19). For example, Flynn Kathryn and his colleagues pointed out in the study that one-third of the respondents searched their health or medical care information on the Internet (20). In terms of disease intervention, Internet interventions have been widely adopted to aid disease management in a variety of areas, such as HIV and AIDS, malaria, tuberculosis, diabetes, asthma, obesity, and smoking (21), thus reducing mortality (22). Besides, some scholars' research showed that the use of smartphones can effectively improve the elderly's self-health evaluation (23). On the other hand, it is also closely related to their mental health. As it is known to all, with the growth of age, the social interaction of the elderly gradually shrinks, and the sense of loneliness of the elderly increases significantly. It is precisely because the Internet has brought about an increase in social interaction, which can effectively reduce the loneliness of the elderly, have a positive impact on their emotions, enable older adults to obtain a better psychological state, and reduce their mental diseases, such as depression, anxiety, post-traumatic stress disorder (PTSD) and stress (24), so older adults can use the Internet to expand social interaction, reduce loneliness, and improve mental health (25, 26). For example, Atsushi found that when compared with the elderly who do not use the Internet at all, the elderly using the Internet every day can keep close contact with society, meet friends more frequently, and effectively improve their subjective well-being (27); Some researchers have also revealed the relationship between Internet use and subjective well-being of older adults through path analysis, and their findings suggest that the use of the Internet can enhance the ability of older adults to maintain close intergenerational relationships and thus contribute to their subjective well-being (28). In short, although considerable studies have confirmed the effects of internet use on older adults' heath and explained them from the perspectives of social relationships and lifestyles, there are still some gaps in existing research. First, since most of the above content comes from western culture, it is necessary to identify this phenomenon in the Chinese context to understand the differences between these empirical studies and those reported in the previous literature. Second, the direct effect of internet use on older adults' health has been well confirmed, while the possible mediating mechanism is not clear.

Social support and health

In the early 1970s, social support was formally put forward as an academic concept and a professional term. Scholars in various research fields put forward different definitions of social support, and there are two main perspectives. First, in the perspective of social interaction, social support is not only one-way care and help, but also a social exchange and a social interaction between people in most situations (29, 30). Bernard believes that social support is a collection of families, friends, and social institutions that people rely on to meet their social, physical, and psychological needs (31). Second, in the perspective of social resources, social support refers to a kind of behavior or information that individuals feel is concerned, respected, and valued by the members of their social

network, and also comes from the help of social relations and the resource exchange of members in the social network (32). House and Turner demonstrated that there were meaningful groups around individuals, such as family members, friends, colleagues, relatives, and neighbors, who had positive support and effects on individuals, including practical help, social emotional help, and information help (33, 34). Cullen defines social support as a variety of material and spiritual information that can be received by individuals from communities and social networks (35). In general, social support refers to the process by which individuals receive and use help from the government, social organizations, and others (36).

Social support can be divided into formal social support and informal social support. Formal social support is defined as the support provided by the government, institutions, communities, and other formal organizations for vulnerable groups, such as endowment insurance and the system of medical safety and security (37). In recent decades, China's social security has made phenomenal progress, with the widespread establishment and dramatic expansion of the social insurance system. Since 2003, China has established a basic social insurance system that covers almost all rural and urban residents till now, which is divided into two parts: health insurance and endowment insurance. For health insurance, the three pillars of the system are the New Rural Cooperative Medical Scheme (NCMS), Urban Resident Basic Medical Insurance (URBMI), and Urban Employees' Basic Medical Insurance (UEBMI); For endowment insurance, the new rural endowment insurance and the urban endowment insurance were included in the basic endowment insurance for urban and rural residents (38). In our study, we used Zhang and Shen's research framework, that is, social insurance as a key indicator for measuring formal social support (39, 40). Unlike formal support from official organizations, in Berkman and Cantors' research, informal social support mainly refers to emotional, behavioral support, which is provided by family members, neighbors, friends, and colleagues (41, 42). For older adults, social support is a known contributor to health in the general (43, 44). As they withdraw from the main areas of social life, social interaction is greatly reduced, which will lead to their mental health problems such as loneliness and depression. At this time, social support and its network members can help the elderly actively seek help, and can also serve as internal support to promote their mental health (45). For example, Adams found in his research that the elderly living alone may rely on friends and neighbors to establish similar relationships with their families (46). Using a sample survey from Chengdu, Sichuan Province, China, Tang et al. found that informal social support had significant positive health effects, especially on those with high age and agricultural household registration (47). However, studies have not examined the independent effects of the two types of social support on the health of older adults separately. In the following sections, we elaborate on these two lines of research.

Internet use, social support, and health

Recently, with the widespread use of the Internet, scholars began to focus on the relationship between Internet use, social support, and health. On the one hand, there was a significant correlation between specific Internet use (including online chat, game, and entertainment use) and social support (48, 49). For example, a study in Finland found that as a source of social support, the Internet can help people obtain emotional and informational support (50). According to a study based on seven European countries, researchers believe that the use of the Internet is more closely related to social support and subjective health than the use of other media (51). Meanwhile, other scholars further pointed out that the main purpose of people accessing the Internet is to maintain the existing social support network in real life, rather than to develop online virtual social networks (52). Moreover, research on older adults in China also found that the main purpose of older adults use the Internet is to keep in touch with relatives and friends, which enables them to expand or maintain social contacts and increase access to information. A high level of Internet use means the elderly have more opportunities to interact and connect with relatives, friends, and society, thus promoting social support (53). On the other hand, many scholars further pointed out the relationship between Internet use, informal social support, and health. Kang pointed out that online chat can improve social support and reduce depression (54). Some scholars found in the survey that the use of the Internet can reduce the loneliness of elderly Polish males, increase social support, and have a better quality of life (55).

To conclude, although scholars recently have started to examine the relationship between Internet use, social support, and health, they have not used the same research framework, and have only considered the relationship between the two of them. Therefore, this study will investigate how different types of social support affect the relationship between Internet use and older adults' health status.

Research purposes and hypotheses

The main purpose of this study is to explore the relationships among Internet use, social support, and health status among older adults in the Chinese context, and examine whether different forms of social support play mediating roles between Internet use and health. Therefore, the current study has the following three steps. First of all, the nationally representative CGSS survey data is used to comprehensively measure two types of social support (formal social support and informal social support) through four indicators: social insurance, relatives, friends and neighbors; Secondly, the multiple mediation analysis is applied to explore the path of Internet use influencing the health status of older adults in China through social support. Finally, on the basis of existing research, it is believed that social support has a positive impact on older adults' health status, which is helpful to provide policy references for improving older adults' health in China. The hypothesis proposed are as follows (Figure 1).

H1: Internet use has positive effects on the health status of older adults.

H2: Internet use has an indirect effect on the health status of older adults through relatives support.

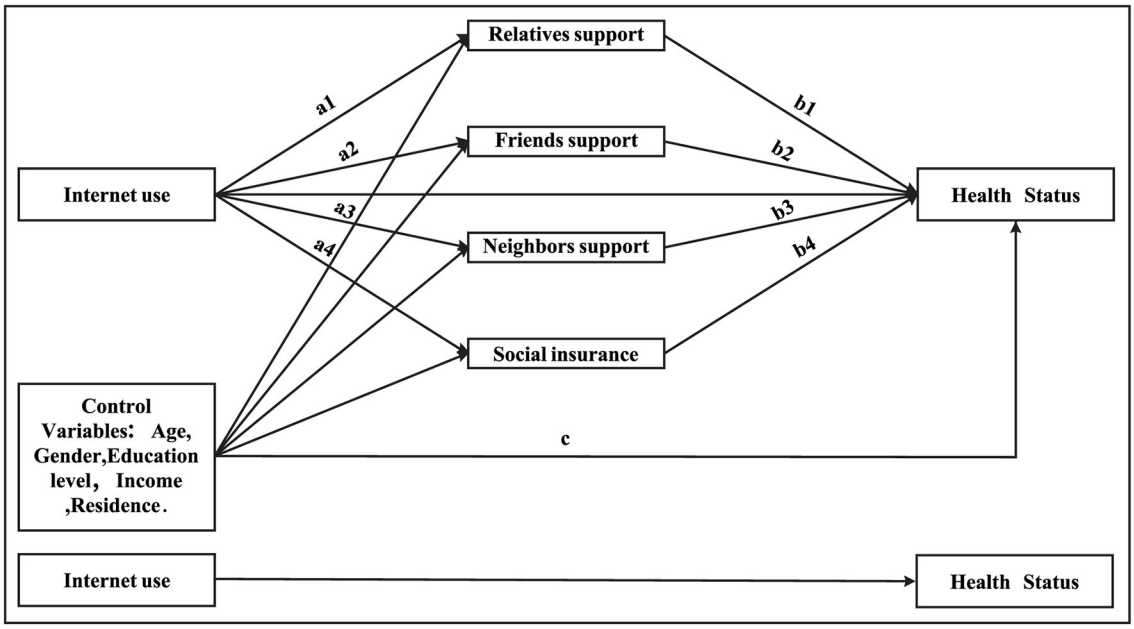

FIGURE 1
The hypothesized model.

H3: Internet use has an indirect effect on the health status of older adults through friends support.
H4: Internet use has an indirect effect on the health status of older adults through neighbors support.
H5: Internet use has an indirect effect on the health status of older adults through formal support.

Methods

Data sources

We use data from the 2021 Chinese General Social Survey (CGSS). This survey project mainly focuses on the major theoretical and practical issues in the changing social structure of China. It comprehensively collects some basic information on residents' behavior patterns, thinking patterns, lifestyles, and social changes. A total of 8,148 valid samples were completed in the 2021 CGSS. Currently, these data are suitable for this study because they collect rich information about Internet use, health, social support, and sociodemographic characteristics. Finally, a total of 2,929 older adults aged between the ages of 60 and 99 in urban and rural areas were included in this study.

Measures

Dependent variable

This paper analyzed the health status of older adults. According to the definition of health by WHO, health included "physical health, mental health, social adaptation, and moral health" (56), we used three questions to describe the health status. Consistent with the measurement of health in the study by Wang et al. (57), the question "What do you think of your current health?" was selected to measure the variable of self-rated health. Respondents' answers ranged from "very unhealthy" (=1), "relatively unhealthy" (=2), "average" (=3), "relatively healthy" (=4), and "very healthy" (=5). The question "In the past four weeks, how often has your work or other daily activities been affected because of the health issues?" was selected to measure the variable of physical health. The question "In the past four weeks, how often have your felt depressed?" For physical health and mental health, the rating regarding the frequency on a 5-point scale ranged from "always" (=1), "often" (=2), "sometimes" (=3), "rarely" (=4), and "never" (=5). We sum up the above questions and generate a new variable "health". Considering the accuracy of the study, we use factor analysis to show the strength of the inter-correlation between the items and also test the reliability of the data through the Kaiser-Meyer-Olkin (KMO) index range from 0 to 1 and through the Cronbach's alpha. From Table 1, we can see that the KMO value is 0.67 and the Cronbach's alpha is 0.76, suggesting that the above measurements have high reliability.

Independent variable

The independent variable is Internet use. According to a study by Han et al. in 2021 (58), We chose the question "In the past year, what was your use of the internet (including mobile internet)?" to measure the use of the Internet in CGSS. Based on the respondents' answers, the rating in terms of the frequency on a 5-point

TABLE 1 Factor analysis of items of health.

	Variable	Uniqueness	Kmo	Kmo-overall	Cronbach α
1	Subjective evaluation on their current physical health	0.493	0.654	0.667	0.762
2	The frequency of health problems affecting work or other daily activities over the past 4 weeks	0.427	0.627		
3	The frequency of depression over the past 4 weeks	0.651	0.760		

scale ranged from "never"(=1), "rarely"(=2), "sometimes"(=3), "often"(=4) and "very frequently"(=5).

Mediating variables

The mediating variable in this paper is social support. It could be divided into two aspects: informal social support and formal social support. As for informal social support, we apply Berkman and Cantor's conceptual framework (41), which describes informal social support along three key dimensions: relatives support, friends support and neighbors support. In CGSS, we use these questions in the questionnaire: "In the past year, have you often gathered with relatives who do not live together in your spare time?", "How often do you socialize with your neighbors?", "How often do you socialize with other friends?", "In the past year, you gathered with friends in your spare time". The rating in terms of frequency on a 5-point scale ranged from "never" (=1), "several times a year or less" (=2), "several times a month" (=3), "several times a week" (=4) and "every day" (=5). We sum the last two questions together and form a new variable "friends support". All the respondents' answers to these questions reflect the informal social support of older adults.

Formal social support, as mentioned earlier, which divided into two parts: health insurance and endowment insurance in the Chinese context. In the CGSS questionnaire, respondents were asked to answer these two questions "Are you currently enrolled in any of the following social insurance programs? –Urban Employee Basic Medical Insurance (UEBMI), Urban Resident Basic Medical Insurance (URBMI), or New Rural Cooperative Medical Scheme (NCMS)" and we dichotomized their answers into "yes" = 1 and "no" = 0; "Are you currently enrolled in any of the following social insurance programs? –the rural endowment insurance or the urban endowment insurance" and we dichotomized their answers into "yes" = 1 and "no" = 0. We sum the above two together to form a new variable "social insurance" to measure formal social support.

Control variables

Five variables are included: age, gender, education level, income, and residence. Gender is coded as 0 for females and 1 for males. Education is structured based on residents' educational attainment. It is categorized into primary education or below, primary school education, middle school education, high school education, and university education or above (education =0, 1, 2, 3, and 4). To correct for the positive skewness of income, we used the natural log transformation. The residence type is coded as 0 for rural areas and 1 for urban areas.

Statistical analysis

Descriptive statistics and Pearson correlation analyses were performed using STATA17.0 software (two-sided test $p < 0.05$ was considered to be significantly correlated); We then performed an OLS regression controlling for gender, age, education, and income to examine the relationship between Internet use, social support, and health status. All control variables were assumed to have an impact on health. At last, in SPSS25.0, Model 4 in the process plugin compiled by Hayes (2017) was used for the multiple mediation effect analysis, and the bootstrap test was used to estimate direct effects and indirect effects according to repeated sampling from sample data, so as to establish confidence intervals for each effect. When the confidence interval does not contain 0, the corresponding effect is significant.

Results

Descriptive statistics and correlation analyses

Table 2 presents the descriptive statistics of key variables. The average age of the sample was 70.2 years old. About 51% were female.15.4% of the elderly have a senior high school education level. More than half of the participants came from rural areas (59.4%). After using the natural log transformation of income, the value range is 0 to 16.12. The average score of health was 10.4 (SD = 3.0). Notably, among the participants, more than half of the elderly have never used the Internet (61.4%). The mean score of friends support was 4.55 (SD =2.07). More than half of the participants (56.18%) showed that interactions with relatives were several times a year or less. However, 28.54% of the participants had never interacted with their neighbors. The average score of formal social support obtained by the sample was 1.74.

Table 3 presents the correlation matrix of the core studied variables. In general, positive correlations were found between the health status of older adults in China and Internet use, informal social support, formal social support, gender, age, residence, income, and education level, while age was negatively correlated with it. Internet use was significantly positively related to interaction with relatives and friends, formal social support, and other sociodemographic characteristics but negatively associated with age. There is a positive correlation between the three different types of informal social support. For formal social support, residence, income, and education level were all positively correlated with it.

TABLE 2 Basic variable description statistics table.

Variable	Mean/percentage	SD	Min	Max	Details
Health	10.44	3.01	3	15	Continuous variables
Internet use	2.08	1.53	1	5	Multi-categorical variables
Never	61.43%				
Rarely	7.52%				
Sometimes	5.98%				
Often	11.51%				
Always	13.56%				
Relatives support	1.91	0.78	1	5	Multi-categorical variables
Never	28.83%				
Several times a year or less	56.18%				
Several times a month	10.78%				
Several times a week	3.25%				
Every day	0.96%				
Friends support	4.55	2.07	2	10	Continuous variables
Neighbors support	2.93	1.50	1	5	Multi-categorical variables
Never	28.54%				
Several times a year or less	9.55%				
Several times a month	24.42%				
Several times a week	15.73%				
Every day	21.77%				
Social insurance	1.74	0.52	0	2	Continuous variables
Income	8.34	4.41	0	16.12	Natural log transformation.
Gender	0.49	0.50	0	1	Binary variables
Female	51.31%				
Male	48.69%				
Education	1.50	1.12	0	4	Multi-categorical variables
Illiteracy	21.00%				
Primary school	32.70%				
Junior high school	26.32%				
senior high school	15.37%				
college or above	4.60%				
Residence	0.41	0.49	0	1	Binary variables
Rural	59.37%				
Urban	40.63%				
Age	2,929 (100.00)	70.23 (6.88)	60	99	Continuous variables

Relationship between internet use and health

The main results showed that all nested regression models are statistically significant between models (Table 4). As the baseline model, Model 1 only examined the effects of control variables on health. We can obviously see that gender, age, education level, and income have a significant impact on the health of older adults. Model 2 analyzed the impact of Internet use on health. The results showed that the regression coefficient of Internet use to health is 0.2, and it is significant at the level of 0.001. This finding indicates that these two variables are highly correlated. That is, the more their use of the Internet, the higher level of their health. Model 3, Model 4, and Model 5 analyzed the three dimensions of

TABLE 3 Pearson's correlations among relevant study variables.

Variables	1	2	3	4	5	6	7	8	9	10	11
1. Health	1										
2. Internet use	0.207***	1									
3. Relatives support	0.140***	0.143***	1								
4. Friends support	0.117***	0.142***	0.350***	1							
5. Neighbors support	0.0140	−0.0260	0.161***	0.493***	1						
6. Social insurance	0.052***	0.101***	0.038**	0.035*	−0.0100	1					
7. Gender	0.140***	0.0210	0.0190	0.0080	−0.083***	0.045**	1				
8. Age	−0.083***	−0.255***	−0.0140	−0.0100	0.0210	−0.055***	0.00500	1			
9. Residence	0.211***	0.314***	0.161***	0.110***	−0.092***	0.142***	0.0110	0.076***	1		
10. Income	0.134***	0.174***	0.072***	0.073***	−0.033*	0.097***	0.126***	0.00900	0.332***	1	
11. Education	0.243***	0.446***	0.134***	0.081***	−0.109***	0.144***	0.232***	−0.174***	0.451***	0.259***	1

*p < 0.05; ** < 0.01; ***p < 0.001.

TABLE 4 Impacts of Internet use on Chinese older adults' health status: based on OLS model.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Gender	0.613***	0.649***	0.651***	0.669***	0.669***	0.667***
	(0.112)	(0.112)	(0.112)	(0.112)	(0.113)	(0.114)
Age	−0.033***	−0.024**	−0.024**	−0.025**	−0.025**	−0.024**
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Education	0.358***	0.266***	0.258***	0.257***	0.260***	0.260***
	(0.058)	(0.061)	(0.060)	(0.061)	(0.061)	(0.061)
Residence	0.871***	0.770***	0.695***	0.685***	0.687***	0.682***
	(0.130)	(0.131)	(0.131)	(0.132)	(0.133)	(0.134)
Income	0.030*	0.027*	0.026*	0.026*	0.027*	0.027*
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Internet use		0.200***	0.184***	0.175***	0.174***	0.167***
		(0.041)	(0.041)	(0.041)	(0.041)	(0.042)
Relatives support			0.345***	0.262***	0.262***	0.260***
			(0.070)	(0.075)	(0.075)	(0.075)
Friends support				0.088**	0.082*	0.082*
				(0.028)	(0.032)	(0.032)
Neighbors support					0.017	0.018
					(0.042)	(0.043)
Social insurance						0.004
						(0.107)
_Cons	11.307***	10.430***	9.877***	9.700***	9.686***	9.633***
	(0.594)	(0.618)	(0.626)	(0.632)	(0.636)	(0.668)
N	2,845	2,845	2,838	2,812	2,802	2,768
R^2	0.089	0.097	0.104	0.107	0.107	0.105

*p < 0.05; ** < 0.01; ***p < 0.001.

informal social support, including the effects of relatives support, friends support, and neighbors support on health. The results showed that relatives support ($\beta = 0.34$, $p < 0.001$), and friends support ($\beta = 0.09$, $p < 0.01$) were positively associated with health, while neighbors support had no significant impact on health. Furthermore, the result of Model 6 showed that formal social support had no significant impact on health. In addition, regression analysis indicated that among the control variables, gender, age, education, residence, and income all passed the significance test in the six models, indicating that all five variables were significantly associated with health. For example, in Model 1, gender ($\beta = 0.61$, $p < 0.001$), education ($\beta = 0.36$, $p < 0.001$), residence ($\beta = 0.87$, $p < 0.001$), and income ($\beta = 0.03$, $p < 0.05$) were positively associated with health. In contrast, age was negatively associated with health ($\beta = -0.03$, $p < 0.01$). Therefore, based on the regression coefficients for the three dimensions of informal support, relatives support had the largest impact on health, followed by support from friends. Neighbors support and formal social support had no significant correlation with health.

Mediation effect analysis

The results of the first and second parts in Table 5 showed that the coefficient of Internet use to social support were 1.634, 3.474,2.681, and 1.829, and a 95% confidence interval (CI) did not include 0. Meanwhile, the coefficient of social support to health were 0.260, 0.083, 0.018, and 0.004, and the 95% confidence interval (CI) did not include 0 among the two of them. Combining the results of Internet use on health, social support was considered to play a partial mediating role in the relationship between Internet use and health.

Model 4 of PROCESS was used to test the multiple mediating effects of social support. From the total effects in Table 6, Internet use had a significant positive effect on health [Bootstrap 95% CI:0.111, 0.274]. The direct effect results showed that Internet use had a significant positive effect on health [Bootstrap 95% CI:0.085, 0.248]. Thus, H1 was fully supported. Regarding the effects of social support on health status, the indirect effect results showed that among the three types of informal social support, two of them (relatives support and friends support) had significant and positive effects on the health of older adults in China ([Bootstrap 95% CI: 0.004, 0.022]; [Bootstrap 95% CI:0.002, 0.026]), whereas the other support had no significant effects. These findings fully supported H2 and H3, but H4 was not. With regards to formal social support, social insurance had no significant effect on this mechanism [Bootstrap 95% CI:−0.003, 0.003], and similarly, H5 was not verified. Among all indirect paths via social support, two mechanisms were significant: Internet use → relatives support → health; Internet use → friends support → health. Therefore, relatives support and friends support were mediators between Internet use and health. Moreover, the effect of formal social support on health did not have a mediation effect, but some informal support did. Thus, we can conclude that informal social support may play a more significant mediating role than formal social support.

Difference between rural and urban areas in social support

We also used PROCESS to test for differences between rural areas and urban areas (Tables 7, 8). We found significant differences between rural areas and urban areas in social support. When social support was used as a mediating variable, relatives support was considered to play a partial mediating role in the relationship between Internet use and health status [Bootstrap 95% CI: 0.005, 0.040] in rural areas. However, this path was not significant in the urban sample. In urban areas, the results showed that friends support partially mediates the effect of Internet use on health status [Bootstrap 95% CI: 0.002, 0.034].

Discussion

Using the 2021 wave of CGSS data, the present study examined the impact of Internet use on health status among Chinese older adults. Despite the large number of studies on the association between Internet use and health status, the potential mechanisms underlying this process remain to be explored. Therefore, we proposed a multiple mediation model to examine the role of social support. The results of this study show that Internet use was positively associated with health status by promoting social support. Several important conclusions can be drawn from this study.

The first finding is that Internet use has direct effects on health among Chinese older adults, which is in line with most prior work (59, 60). The mechanism of the effect of Internet use on the health status of older adults is that Internet use is conducive to expanding the scale of personal social networks, including communication with family and friends, access to effective information, and participation in leisure activities (61). On this basis, the Internet can provide individuals with more emotional comfort, alleviate negative emotions, provide them with more health information and medical resources, and improve their health (62), thus reducing their depression and loneliness and achieving higher life satisfaction (63). Our results are a good extension of previous studies that have simply separated Internet use into "use or not" (64, 65) to draw the general conclusion that Internet use has a positive effect on health status.

Second, this study distinguished three types of informal social support and examined the effect of each type on health separately. Our results show that not all types of informal social support have significant effects on the relationship between Internet use and health status, which is in line with prior studies. When compared to other types of informal social support, only relatives support and friends support significantly affected health status among Chinese older adults, which is consistent with previous research. For example, informal social support has been found to have a significant effect on health outcomes in a large number of studies, people with a higher level of informal social support have lower social pressure and higher health status (66, 67). For older adults, regular contact with relatives and friends can effectively promote health (68). Krause found that informal social support established through voluntary activities has a positive impact on the health of the elderly (69). Meanwhile, we found that relatives support and

TABLE 5 Path-coefficients of the mediating models.

Variables	*B*	BC95%LL	BC95%UL	R^2	*F*
Internet use vs. informal social support					
Internet use → relatives support	1.634	1.306	1.962	0.035	16.738
Internet use → friends support	3.474	2.596	4.352	0.027	12.619
Internet use → neighbors support	2.681	2.046	3.316	0.021	9.858
Internet use vs. formal social support					
Internet use → social insurance	1.829	1.612	2.046	0.033	15.685
Social support vs. health					
Relatives support → health	0.260	0.112	0.408		
Friends support → health	0.083	0.019	0.146		
Neighbors support → health	0.018	−0.066	0.102		
Social insurance → health	0.004	−0.207	0.214		
Internet use vs. health					
Internet use → health	0.167	0.085	0.248		

TABLE 6 Mediating effects of social support.

Paths	Standardized coef.	Bootstrap 95%CI	
		Lower	Upper
Total effect			
Internet use → health	0.193	0.111	0.274
Direct effects			
Internet use → health	0.167	0.085	0.248
Indirect effects (total)	0.026	0.013	0.041
Internet use→ relatives support → health	0.012	0.004	0.022
Internet use→ friends support → health	0.014	0.002	0.026
Internet use→ neighbors support → health	0.001	−0.004	0.006
Internet use→ social insurance → health	0.001	−0.003	0.003
Indirect effects contrast			
Relatives support vs. Friends support	−0.002	−0.017	0.014
Relatives support vs. Neighbors support	0.011	0.002	0.022
Relatives support vs. Social insurance	0.012	0.004	0.023
Friends support vs. Neighbors support	0.013	−0.001	0.027
Friends support vs. Social insurance	0.014	0.003	0.026
Neighbors support vs. Social insurance	0.001	−0.004	0.006

friends support significantly mediated the effect of Internet usage on health. This is consistent with previous research, suggesting that social support from relatives and friends partially mediated the relationship between Internet use and self-rated health. The reason may be that the Internet can increase the frequency of interaction between older adults and their relatives and friends, from which they can obtain social support (53). Social support means getting emotional encouragement, information, and help from relatives and friends they get along with. When older adults perceive higher levels of social support, they are more inclined to show better adjustment, thus resulting in better health. Therefore, the mediating role of relatives and friends support suggests that older adults can not only use the Internet to promote health but also use more relatives and friends support resources through the Internet to promote their health.

We also found that neighbors support did not have a significant influence on health status, which was contrary to our expectations. Prior research has empirically supported that neighborhood support can not only provide instant information, but also provide help at the first time in case of emergency. Therefore,

TABLE 7 Mediating effects of social support in rural areas.

Paths	Standardized coef.	Bootstrap 95%CI	
		Lower	Upper
Total effect			
Internet use → health	0.064	0.104	0.354
Direct effects			
Internet use → health	0.064	0.071	0.321
Indirect effects (total)	0.011	0.013	0.056
Internet use→ relatives support → health	0.009	0.005	0.040
Internet Use→ friends support → health	0.008	−0.005	0.028
Internet use→ neighbors support → health	0.005	−0.005	0.014
Internet use→ social insurance → health	0.002	−0.004	0.003

TABLE 8 Mediating effects of social support in urban areas.

Paths	Standardized coef.	Bootstrap 95%CI	
		Lower	Upper
Total effect			
Internet use → health	0.052	0.057	0.260
Direct effects			
Internet use→ health	0.052	0.035	0.240
Indirect effects (Total)	0.009	0.005	0.041
Internet use→ relatives support → health	0.005	−0.003	0.016
Internet use→ friends support → health	0.008	0.002	0.034
Internet use→ neighbors support → health	0.002	−0.006	0.004
Internet use→ social insurance → health	0.004	−0.007	0.008

neighborhood support helps to improve the mental health of older adults (70, 71). This inconsistent finding could be due to the difference in the Chinese situation. Unlike traditional society, rapid urbanization has brought about modern urban lifestyles and dramatic changes to traditional neighborhoods. In particular, the development of network technology has freed people from face-to-face and proximity forms of interaction, and people can reach the needs of social interaction without leaving their homes. Meanwhile, the diversification of modern life and leisure styles has greatly weakened the importance of neighborhood relations. Moreover, neighbors support did not significantly mediate the role between Internet use and self-rated health, this may be due to COVID lockdowns, people generally go out less and have less opportunity to contact their neighbors, which also affects the impact of neighbor support on health to some extent.

Third, our results show that the mediating pathway of Internet use on the health status of older adults through social insurance is not significant. That is, the underlying mechanism between Internet use and health status among older adults in China was informal social support only, which is contrary to our expectations. The critical role of social insurance in motivating health outcomes and promoting health equity has been empirically supported by a strand of previous research (72, 73). This inconsistent finding could be due to the difference in the measurement of social insurance, as well as whether to control the use of the Internet. Previous studies have generally focused on social insurance alone, so there is a need to consider the factors of Internet use to conduct more empirical studies and compare their effects on health status together.

The last and also most important finding in the current study is that regarding social support differences between urban and rural areas. For the rural elderly, relatives support has a significant mediating effect between Internet use and health status, while for the urban elderly, friends support has a significant mediating effect between Internet use and health status. The analysis is based on the following reasons: on the one hand, Chinese society is an "acquaintance society" characterized by relationship orientation (74, 75), and older adults have a higher consistency of family networks in rural areas of China. In line with past research, informal social support is also the main source of social support for rural residents (76). Compared with other social support, relatives of rural people are close. Relatives support can provide higher interpersonal trust and reciprocity, which will help to generate positive emotional experiences and improve the health status of older adults. On the other hand, with the reduction of urban family size and the diversity and convenience of urban social space, it is easier for older adults to establish ties with friends. When

the elderly can no longer obtain continuous and sufficient family support, the support of friends' network, as the second source of social support in the social interaction of the elderly, has become more important for health (77, 78).

There are still some limitations in this article. First, due to the limitation of existing data, the Internet use of the elderly only measures the frequency of use, which cannot fully show the diversity of Internet use of the elderly, such as the time of use, psychological motivation, browsing items, etc. Second, in this paper, we analyze CGSS data only in 2021, without considering the survey data of other years, and cannot obtain the dynamic changes of the impact of social support on health status. Third, causal interpretation cannot only rely on path analysis, and future research should introduce longitudinal design or experimental research design. Last but not least, future studies should further explore the stories behind research findings through qualitative research methods such as interviews to enhance the richness of results.

Conclusion

To sum up, this paper analyzed the influence mechanism of Internet use on the health status of older adults by focusing on the mediating role of social support. To be more specific, through the Internet, older adults in China can keep in touch with geographically dispersed relatives and friends, and establish new contacts with the outside world, which not only strengthens their connection with external social networks, but also increases communication with relatives, which is conducive to their health status. Overall, as there are many pathways for the Internet to affect health, social support only plays a partial mediating role in our study. That is, informal social support positively influenced the health status among older adults, while formal social support does not. These findings suggest that government should take effective steps to encourage and improve Internet use among older adults and obtain various social support to improve their health status.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization: YE and JY. Data curation, methodology, and writing—original draft: YE. Formal analysis: CL. Writing—review and editing: CL and LN. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Waist-to-height ratio and new-onset hypertension in middle-aged and older adult females from 2011 to 2015: A 4-year follow-up retrospective cohort study from the China Health and Retirement Longitudinal Study

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Background: Central obesity was closely associated with hypertension. Middle-aged and older adult females, defined as those aged 45 and above, were more likely to suffer from central obesity. For waist-to-height ratio (WHtR) was used as central obesity assessment, the object of this study was to illustrate the relationship between WHtR and the incidence of hypertension in middle-aged and older adult females in China.

Methods: Data used in this prospective cohort study was derived from the China Health and Retirement Longitudinal Study (CHARLS) in a baseline survey from 2011 to 2012 with a follow-up duration of 4 years. The waist-to-height ratio was calculated as waist circumstance divided by height, and the cohort was divided into different groups based on WHtR level. The outcome variable was new-onset hypertension.

Results: Of the 2,438 participants included in the study, 1,821 (74.7%) had high WHtR levels (WHtR $\geq$ 0.5). As WHtR was closely related to new-onset hypertension in a multivariable logistics regression mode [OR: 7.89 (95% CI: 2.10–29.67)], individuals with high WHtR were also more likely to suffer from hypertension compared with low WHtR levels [OR: 1.34 (95% CI: 1.06–1.69)].

Conclusion: WHtR is positively related to the risk of hypertension incidents among middle-aged and older adult females. Individuals with WHtR $\geq$ 0.5 were more likely to suffer from hypertension.

KEYWORDS

WHtR, CHARLS, hypertension, central obesity, female

Background

In recent years, the problem of global aging has continued to intensify. As individuals get older, organ function and metabolism levels decreased significantly, both of which led to metabolic-related disease. Several studies illustrated the positive relationship between aging and hypertension incidence (1). Besides these, physiological changes during menopause made a great role in regulating blood pressure (2, 3). Middle-aged and older adult females, defined as females aged 45 and above, were at high risk of suffering from hypertension.

Central obesity, manifesting as extra fat collected in the abdomen and stomach, raised attention worldwide for its rapidly increased incidence. However, the growth of age was also closely related to central obesity (4, 5). For a higher proportion of body fat and sex hormones difference, the incidence of central obesity was higher among females than males (6–8). As general obesity showed little relationship, higher relevance between central obesity and different metabolic-related diseases was illustrated (9–11). Moreover, the positive relationship between central obesity and hypertension was also revealed (12).

As middle-aged and older adult females were at high risk of suffering from hypertension, which often led to a bad outcome. There was an urgent need for risk evaluation. Waist-to-height ratio (WHtR), a proxy index for central obesity assessment, has been widely accepted as a valuable tool for a health assessment with a cut-off point of 0.5 (13). Though there were some investigations that revealed the relationship between WHtR and the incidence of metabolism-related disease (14–16), few studies explored the association between WHtR and the incidence of hypertension among middle-aged and older adult females in China. Therefore, in this study, we aimed to explore the relationship between WHtR and the incidence of hypertension and testing the usefulness of the cut-off points for health assessment in WHtR.

Methods

Study design and population

The cohort of this study originated from the China Health and Retirement Longitudinal Study (CHARLS) from 2011 to 2015, which is in charge of the National Development Institute of Peking University. CHARLS is an ongoing representative survey targeting individuals aged 45 and above from 450 villages and 150 counties or districts within 28 provinces in mainland China. The baseline wave was conducted between June 2011 and March 2012 and 17,708 individuals were involved. Among all the participants, 13,013 provided venous blood. All the participants were followed every 2 years. Previous research papers (17) have shown information about this.

Individuals: (1) with complete information of venous blood sample in wave 1; (2) followed up at least once in wave 2, 3; (3) with complete information on WHtR met inclusion criteria. Individuals: (1) who were male; (2) combined with hypertension in wave 1; (3) with missing data on age or age <45; (4) who were not interviewed in 2015 were excluded from the study. A total of 2,438 individuals were enrolled in the study. As WHtR = 0.5 was used as a cut-off point for health assessment in the previous study, the cohort was divided into two groups based on WHtR level (Figure 1).

Follow-up duration and new-onset hypertension

As all the baseline characteristic was collected from 2011 to 2012 in wave 1, all the participants followed two waves every 2 years (wave 2 and 3) until 2015. During the follow-up in waves 2 and 3, new-onset hypertension was assessed by the following criteria: (1) an SBP higher than 140 mm Hg or a DBP higher than 90 mmHg; (2) self-report of a doctor diagnosis; and (3) self-report of antihypertensive treatment.

Other covariates

The interviewers trained by CHARLS collected information on demographic background, health status, and biomarkers according to the questionnaire. Demographic background including age, gender (male/female), education level (illiteracy, primary school, middle school, high school, and above), residence (urban/rural), marital status (married/single) were recorded, Health status consisting of 14 comorbidities (hypertension, diabetes, dyslipidemia, cancer, kidney disease, stroke, heart problem, liver disease, chronic lung disease, digestive disease, nervous problem, memory-related diseases, arthritis, and asthma) and comorbidity-related treatment taken by respondents. The options used to assess the history of alcohol drinking during the interview included: (1) I never had a drink; (2) I used to drink less than once a month; and (3) I used to drink more than once a month. In our study, option 2 and option 3 were regarded as a history of alcohol drinking. Biomarkers, including weight, height, waist circumstance, systolic pressure, and diastolic pressure, were all tested standardly by the interviewer. The blood collection, transported at 4°C temperature and sent to the local laboratory, was executed by the staff of the Chinese Center for Disease Control and Prevention (China CDC) during baseline survey. Then the plasma and buff coat were both frozen at −20°C, transported to Beijing within 2 weeks, and they would be placed in a deep freezer and stored at −80°C until assay before all the serum markers were assayed. eGFR was calculated using the CKD-EPI creatinine formula.

WHtR was calculated as waist circumstance divided by height. Height was measured by the height measuring instrument vertically. Training surveyors circled a soft tape at the navel level to measure waist circumstance. Diabetes was diagnosed as one of the following criteria: (1) self-report of a diagnosis by a doctor; (2) HbA1c $\geq$ 6.5%; (3) plasma glucose $\geq$ 11.1 mmol/L (casual) or plasma glucose $\geq$ 7.0 mmol/L (fasting); (4) self-report of the diabetes-related treatment. Dyslipidemia was diagnosed as one of the following criteria: (1) self-report of a diagnosis by a doctor; (2) total cholesterol (TC) $\geq$ 240 mg/dl; (3) high-density lipoprotein cholesterol (HDL) $\leq$ 40 mg/dl; (4) low-density lipoprotein cholesterol (LDL) $\geq$ 160 mg/dl; (5) triglycerides (TG) $\geq$ 150 mg/dl; (6) self-report of the anti-dyslipidemia treatment. Kidney disease was diagnosed as one of the following criteria: (1) self-report of a diagnosis by a doctor; (2) self-report of the kidney disease-related treatment; (3) Estimated glomerular filtration rate (eGFR) <60 ml/min/1.73 m^2.

Statistical analysis

All variables were shown as follows: continuous variables with median (IQR) and counts percentages for categorical variables. Mann-Whitney U and Chi-squared tests were used to compare baseline characteristics among cohorts with different levels of WHtR. Univariable and multivariable logistics regression was used to estimate the relationship between WHtR and new-onset hypertension. Four models were constructed, including model 1

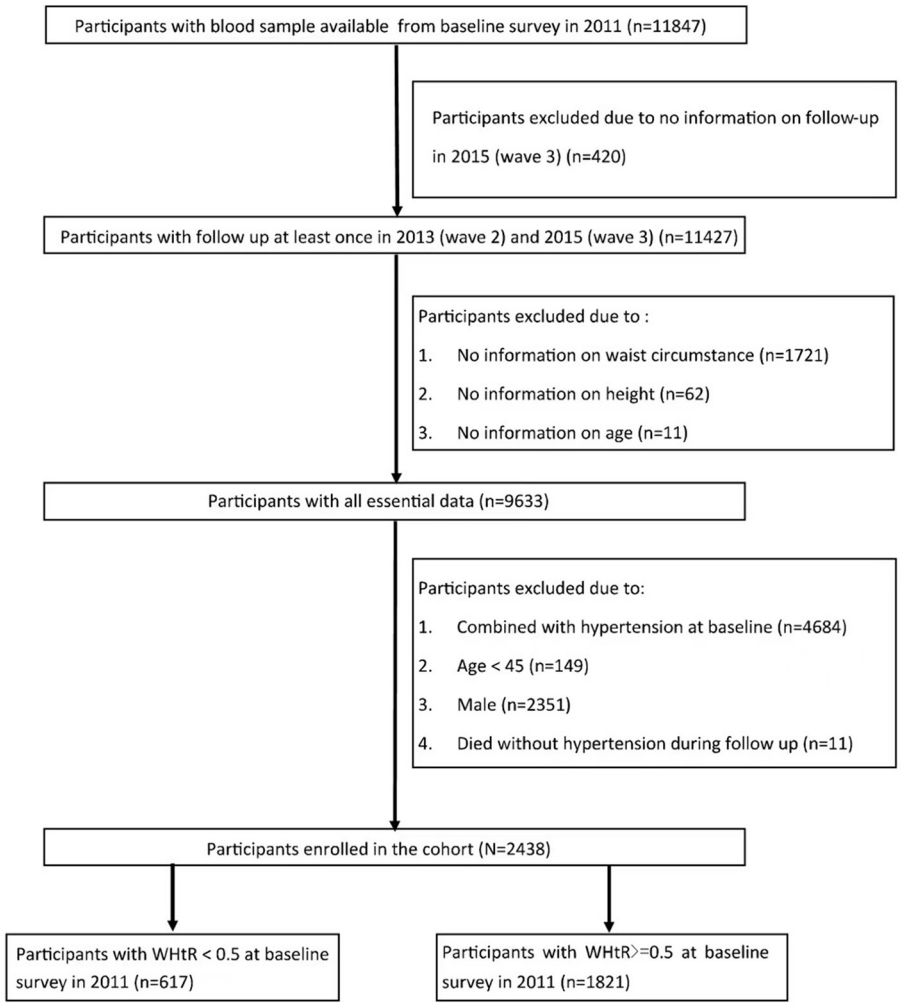

FIGURE 1
Flow chart of the study.

(crude), model 2 (adjusted for age), model 3 (adjusted by age, SBP, DBP, residence, education level, digestive disease, smoking) and model 4 (adjusted by age, SBP, DBP, residence, education level, marital status, diabetes, dyslipidemia, kidney disease, cancer, chronic lung disease, liver disease, heart problem, stroke, digestive disease, nervous problems, memory-related disease, arthritis, asthma, smoking, and alcohol drinking). The interaction of different variables on new-onset hypertension was also calculated in model 4. Restrict cubic spline (RCS) functions and smooth curve fitting (penalized spline method) were used to assess the dose-response relationship and the potential non-linear relationship between WHtR and new-onset hypertension. Receiver Operating Characteristic (ROC) analyses were used to compare the effectiveness of new-onset hypertension prediction between WHtR and BMI. As the age of 60 was regarded as criterion for older people, so cut-off of age at 60 was chosen to assess the relationship between WHtR and new onset hypertension in different age groups. Both sensitivity and subgroup analysis were used to test the robustness of our findings.

Statistical analyses were performed using the R package (version 4.2.1), and $p < 0.05$ was considered statistically significant.

Results

Baseline characteristics of study participants

There were 2,438 individuals included in the final cohort. As the baseline characteristics were shown in Table 1, the median age was 55.5 years old. Individuals with WHtR $\geq$ 0.5 accounted for 1,821 (74.7%) of the cohort. Compared to individuals with WHtR $<$ 0.5, individuals with WHtR $\geq$ 0.5 were older (56.0 vs. 55.0, $p = 0.022$), had a higher level in both systolic pressures (121.0 vs. 118.0 mmHg; $p < 0.001$) and diastolic pressure (72.0 vs. 70.0 mmHg; $p < 0.001$) at baseline. Besides these, individuals with low WHtR had a significantly lower prevalence of diabetes (7.1% vs. 13.0%, $p < 0.001$) and dyslipidemia (30.8% vs. 47.2%, $p < 0.001$).

Relationship between WHtR and new-onset hypertension

The relationship between WHtR and new-onset hypertension was assessed in logistics regression. As the result showed, WHtR

TABLE 1 Baseline characteristic of cohort.

	Overall $n = 2,438$	WHtR < 0.5 $n = 617$	WHtR ≥ 0.5 $n = 1,821$	*p*
Age	55.50 (49.00, 61.00)	55.00 (49.00, 60.00)	56.00 (49.00, 62.00)	0.022
WHtR	0.54 (0.50, 0.59)	0.47 (0.45, 0.49)	0.56 (0.53, 0.60)	<0.001
eGFR (ml/min/1.73 m^2)	97.71 (87.15, 104.60)	97.91 (87.72, 105.08)	97.66 (87.07, 104.45)	0.466
SBP (mmHg)	120.00 (112.00, 129.00)	118.00 (109.00, 126.75)	121.00 (112.00, 129.00)	<0.001
DBP (mmHg)	72.00 (66.00, 78.00)	70.00 (64.00, 76.00)	72.00 (66.00, 78.00)	<0.001
BMI (kg/m^2)	23.08 (20.88, 25.42)	20.11 (18.47, 21.57)	24.11 (22.13, 26.09)	<0.001
Residence, *n* (%)				0.027
Urban	314 (12.9)	63 (10.3)	251 (13.8)	
Rural	2,113 (87.1)	551 (89.7)	1,562 (86.2)	
Education level, *n* (%)				0.04
Illiteracy	1,422 (58.3)	374 (60.6)	1,048 (57.6)	
Primary school	443 (18.2)	89 (14.4)	354 (19.4)	
Middle school	395 (16.2)	103 (16.7)	292 (16.0)	
High school and above	178 (7.3)	51 (8.3)	127 (7.0)	
Marital status, *n* (%)				0.925
Alone	406 (16.7)	104 (16.9)	302 (16.6)	
Married	2032 (83.3)	513 (83.1)	1,519 (83.4)	
Dyslipidemia, *n* (%)	1,049 (43.0)	190 (30.8)	859 (47.2)	<0.001
Diabetes, *n* (%)	280 (11.5)	44 (7.1)	236 (13.0)	<0.001
Cancer, *n* (%)	31 (1.3)	8 (1.3)	23 (1.3)	1
Chronic lung disease, *n* (%)	203 (8.4)	64 (10.5)	139 (7.7)	0.037
Liver disease, *n* (%)	98 (4.0)	22 (3.6)	76 (4.2)	0.588
Heart problem, *n* (%)	217 (8.9)	49 (8.0)	168 (9.3)	0.381
Stroke, *n* (%)	27 (1.1)	7 (1.1)	20 (1.1)	1
Kidney disease, *n* (%)	186 (7.6)	45 (7.3)	141 (7.7)	0.783
Digestive disease, *n* (%)	684 (28.2)	195 (31.9)	489 (27.0)	0.021
Nervous problems, *n* (%)	41 (1.7)	14 (2.3)	27 (1.5)	0.259
Memory related disease, *n* (%)	13 (0.5)	2 (0.3)	11 (0.6)	0.613
Arthritis, *n* (%)	936 (38.5)	214 (34.8)	722 (39.7)	0.034
Asthma, *n* (%)	72 (3.0)	20 (3.3)	52 (2.9)	0.728
Smoking, *n* (%)	195 (8.0)	57 (9.3)	138 (7.6)	0.217
Alcohol drinking, n (%)	174 (7.7)	47 (8.4)	127 (7.5)	0.572
Glu (mg/dl)	100.62 (93.60, 109.26)	98.82 (92.16, 107.19)	101.34 (93.96, 110.34)	<0.001
Creatinine (mg/dl)	0.67 (0.60, 0.76)	0.67 (0.60, 0.76)	0.67 (0.60, 0.76)	0.847
Total cholesterol (mg/dl)	193.30 (169.33, 217.27)	188.66 (165.66, 211.86)	195.23 (170.88, 219.59)	<0.001
Triglycerides (mg/dl)	104.43 (74.34, 146.02)	86.73 (65.49, 127.44)	108.86 (78.76, 153.10)	<0.001
HDL (mg/dl)	104.43 (74.34, 146.02)	86.73 (65.49, 127.44)	108.86 (78.76, 153.10)	<0.001
LDL (mg/dl)	117.53 (95.49, 139.95)	112.11 (93.56, 133.76)	119.07 (95.88, 141.50)	<0.001
Hb1Ac (%)	5.10 (4.90, 5.40)	5.10 (4.80, 5.30)	5.10 (4.90, 5.47)	<0.001

WHtR, waist to height ratio; eGFR, estimated glomerular filtration rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, Body mass index; Glu, glucose; HDL, high density lipoprotein; LDL, low density lipoprotein; Hb1Ac, glycated hemoglobin.

TABLE 2 Risk factors for new-onset hypertension in univariable logistics regression.

Characteristics	OR (95% CI)	*p*
WHtR	21.34 (6.49–72.93)	<0.001
Age (per year)	1.04 (1.03–1.05)	<0.001
SBP (per mmHg)	1.06 (1.05–1.07)	<0.001
DBP (per mmHg)	1.04 (1.03–1.05)	<0.001
Dyslipidemia		
Without	1.00 (Ref.)	
With	1.22 (1.03–1.45)	0.024
Education level		
Illiteracy	1.00 (Ref.)	
Primary school	0.91 (0.72–1.14)	0.401
Middle school	0.87 (0.68–1.10)	0.244
High school and above	0.50 (0.34–0.72)	<0.001
Digestive disease		
Without	1.00 (Ref.)	
With	0.80 (0.66–0.97)	0.022
Residence		
Urban	1.00 (Ref.)	
Rural	1.43 (1.10–1.89)	0.009
Smoking		
Without	1.00 (Ref.)	
With	1.44 (1.06–1.94)	0.018

OR, odds ratio; CI, confidential interval; WHtR, waist to height ratio; SBP, systolic blood pressure; DBP, diastolic blood pressure.

showed a positive relationship with new-onset hypertension [OR: 21.34 (95% CI: 6.49–72.93)] (Table 2) in logistics regression. The restricted cubic spline model showed a U-shape relationship between WHtR and new-onset hypertension (Figure 2) with the lowest relationship of hypertension at WHtR = 0.49.

As WHtR was used as a marker of health assessment with the cut-off point at 0.5, the relationship between different level of WHtR and new-onset hypertension were further analyzed. Different models were also used to assess the relationship between WHtR and new-onset hypertension. Individuals with WHtR ≥ 0.5 were 1.34 times higher in suffering from hypertension [OR: 1.34 (95% CI: 1.06–1.69)] (Table 3).

Subgroup and sensitivity analysis

As is shown, participants with WHtR ≥ 0.5 were more likely to suffer from hypertension when age ≥60 [OR: 1.64 (95% CI: 1.09–2.47)], living in rural [OR: 1.32 (95% CI: 1.03–1.69)], not combined with diabetes [OR: 1.33 (95% CI: 1.04–1.70)], combined with dyslipidemia [OR: 1.61 (95% CI: 1.08–2.39)] and not combined with kidney disease [OR: 1.30 (95% CI: 1.03–1.66)] (Figure 3). WHtR was also more positively related to new-onset hypertension

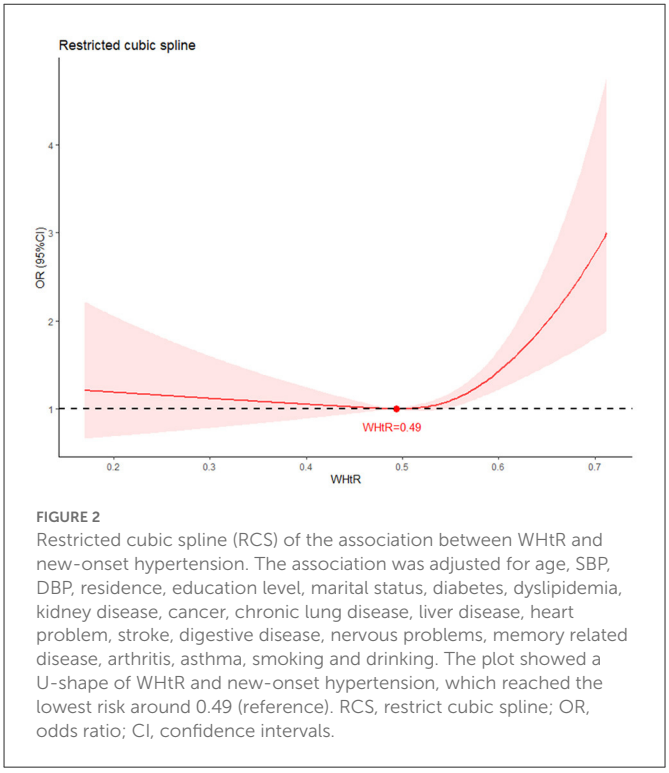

FIGURE 2
Restricted cubic spline (RCS) of the association between WHtR and new-onset hypertension. The association was adjusted for age, SBP, DBP, residence, education level, marital status, diabetes, dyslipidemia, kidney disease, cancer, chronic lung disease, liver disease, heart problem, stroke, digestive disease, nervous problems, memory related disease, arthritis, asthma, smoking and drinking. The plot showed a U-shape of WHtR and new-onset hypertension, which reached the lowest risk around 0.49 (reference). RCS, restrict cubic spline; OR, odds ratio; CI, confidence intervals.

(Supplementary Figure 1). Sensitivity analysis was in accordance with the results (Supplementary Tables 1–3).

Discussion

We investigated the relationship between WHtR and new-onset hypertension among middle-aged and older women in China. As the results showed, WHtR showed a positive relationship with new-onset hypertension. Besides these, the cut-off point at 0.5 was practical for health assessment. Individuals with WHtR more than 0.5 had a significantly higher incidence of hypertension when compared to others.

Though the relationship between obesity and the risk of hypertension was well-established, the mechanism of this relation was quite complex. Several mechanisms were contributing to hypertension development. As adipose tissue accumulated, the renin–angiotensin–aldosterone system (RAAS) was highly promoted, leading to high sodium and water retention (18, 19). Besides these, changes in endocrine level also played an important role (20). Decreased adiponectin secretion could also lead to insulin resistance. A high level of leptin could also result in the inflammatory response upregulating. Moreover, fatty acid accumulation was typical among obesity combined with dyslipidemia. All of these endocrine transformations could result in increased blood vessel stiffness, which is the early histology change in hypertension. Decreased estrogen levels in middle-aged and older women also played an important role in hypertension development. The level of ANP and Ang II were elevated for the reason estrogen decreased, both of which could increase the activity of RAAS (21). However, a low level of estrogen could also lead to a reduction in lipid clearance, accelerating dyslipidemia formation (22). Decreased levels of

TABLE 3 Association between WHtR and new-onset hypertension in logistics regression.

		Model 1		Model 2		Model 3		Model 4	
		OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
WHtR as continuous		21.34 (6.37–71.51)	<0.001	16.06 (4.82–53.51)	<0.001	6.92 (2.01–23.81)	0.002	7.89 (2.1–29.67)	0.002
WHtR as categorical	<0.5	1.00 (Ref.)		1.00 (Ref.)		1.00 (Ref.)		1.00 (Ref.)	
	≥0.5	1.55 (1.26–1.9)	<0.001	1.51 (1.23–1.86)	<0.001	1.34 (1.08–1.67)	0.009	1.34 (1.06–1.69)	0.014

WHtR, waist to height ratio; HR, hazard ratio; CI, confidential interval; SBP, systolic blood pressure; DBP, diastolic blood pressure.
Model 2: adjusted by age.
Model 3: adjusted by age, SBP, DBP, residence, education level, dyslipidemia, digestive disease, smoking.
Model 4: adjusted by age, SBP, DBP, residence, education level, marital status, diabetes, dyslipidemia, kidney disease, cancer, chronic lung disease, liver disease, heart problem, stroke, digestive disease, nervous problems, memory related disease, arthritis, asthma, smoking and alcohol drinking.

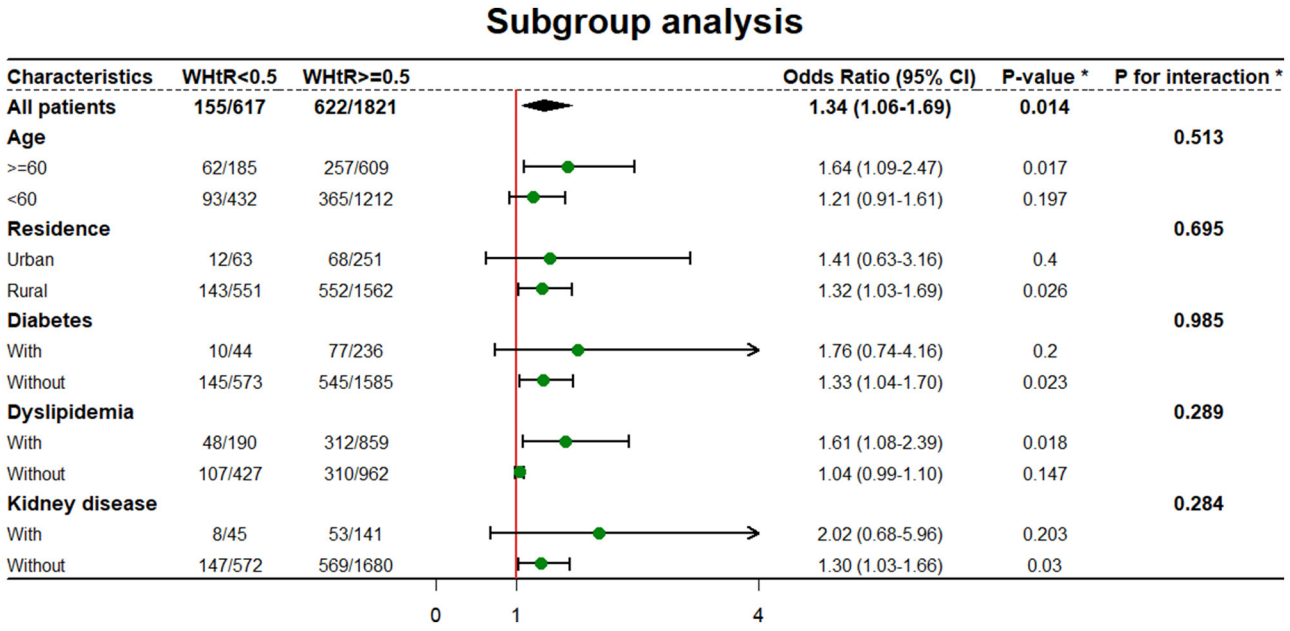

FIGURE 3
Subgroup analysis of relationship between WHtR and new-onset hypertension. *WHtR as categorical. *All model was adjusted by age, SBP, DBP, residence, education level, marital status, diabetes, dyslipidemia, kidney disease, cancer, chronic lung disease, liver disease, heart problem, stroke, digestive disease, nervous problems, memory related disease, arthritis, asthma, smoking and drinking unless the variable was used as a subgroup variable.

estrogen and endocrine dysfunction contributed significantly to hypertension development.

As global aging has been accelerating in recent years, age-related diseases raised more attention from all around the world. For the low level of metabolism, obesity and overweight were one of the most common comorbidities threatening the quality of life among the aged. Different obesity subtypes were further studied in recent years. The relationship between abdominal fat accumulation and increased endocrine dysfunction led to a higher incidence of cardiovascular risk among central obesity (23, 24). Besides these, central obesity was also related to a reduction in quality of life and an increment in health expenses. As the incidence of central obesity raised rapidly during recent years (7, 25), several studies indicated a higher proportion of central obesity among females than males (6, 8), which could be attributed to fertility and decreased estrogen levels. The relationship between obesity and hypertension was well-studied. Yuri et al. (26) revealed the relationship between obesity and hypertension among women in Indonesia. In a cross-section study held by Wang et al. (27), a synergistic effect of BMI and waist circumstance on the incidence of HBP (defined as SBP ≥ 140 mmHg/or DBP ≥ 90 mmHg or use of antihypertensive medication within 2 weeks) was confirmed in the aged.

Though BMI was recognized as an obesity-related marker for a long time, some investigators argued its limitation on not considering the adverse effect of intra-abdominal fat (28). WHtR was highly recommended for central obesity assessment for its easy measurement, elimination of the impact of height, and universality among different gender, and races. The effectiveness of metabolism-related disease prediction, including metabolic syndrome, hypertension, diabetes, dyslipidemia, and cardiovascular diseases, was compared among different obesity markers (29–31). According to a multicenter cross-section study held by Akbari et al. (30), WHtR performed better in hypertension prediction than WHR and BMI. Lee et al. compared the influence of different anthropometric indices on metabolic risk. WHtR was more strongly associated with hypertension in females (32). Our study used the ROC curve to assess the predicate ability and WHtR showed a

higher predictive ability than BMI (Supplementary Figure 2), BMI was associated with a lower increment in new-onset hypertension when compared with WHtR (Supplementary Table 4). Besides these, our study also showed a significantly lower tendency of suffering from hypertension in WHtR < 0.5 groups, which supports the usage of WHtR $= 0.5$ as a cut-off point for health assessment.

Obesity was closely related to the incidence of hypertension, which brought a heavy burden to public health. Our study showed a close relationship between WHtR and new-onset hypertension. Though WHtR showed a better ability for hypertension prediction than other markers among middle-aged and older females, new markers or formulas were urgently needed for much more precise prediction. Besides this, how to prevent hypertension among middle-aged and older females was also an essential factor that needs further research.

One significant advantage of our study was that this was the first study to analyze the relationship between WHtR and new-onset hypertension among middle-aged and older adult females in China. However, there were still some limitations that should be noticed. First, all the health information was collected according to self-report by participants. However, some participants might be unaware of their diseases, which could lead to bias in baseline information and the outcome variable. Second, some participants had no information about WHtR, leading to being excluded from the final cohort. These might make an impact on results.

Conclusion

This study explored the relationship between WHtR and new-onset hypertension among middle-aged and older adult females in China. As the result shows, WHtR was positively related to hypertension. More attention should be paid to individuals with high WHtR.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Biomedical Ethics Review Committee of Peking University (IRB00001052-11015). The patients/participants provided their written informed consent to participate in this study.

Author contributions

YW, HW, and YT: methodology, writing, and revision. XZ, YL, QL, and JR: data curation and investigation. CL: supervision, reviewing, and editing the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1122995/full#supplementary-material

SUPPLEMENTARY TABLE 1
Sensitivity analysis excluded individuals combined with kidney disease for association of WHtR and new-onset hypertension in CAHRLS (2011–2015).

SUPPLEMENTARY TABLE 2
Sensitivity analysis excluded individuals combined with diabetes for association of WHtR and new-onset hypertension in CAHRLS (2011–2015).

SUPPLEMENTARY TABLE 3
Sensitivity analysis excluded individuals combined with dyslipidemia for association of WHtR and new-onset hypertension in CAHRLS (2011–2015).

SUPPLEMENTARY TABLE 4
Association between BMI and new-onset hypertension in logistics regression.

SUPPLEMENTARY FIGURE 1
Subgroup analysis of relationship between WHtR level and new-onset hypertension. *WHtR as continuous; *All model was adjusted by age, SBP, DBP, residence, education level, marital status, diabetes, dyslipidemia, kidney disease, cancer, chronic lung disease, liver disease, heart problem, stroke, digestive disease, nervous problems, memory related disease, arthritis, asthma, smoking and drinking unless the variable was used as a subgroup variable.

SUPPLEMENTARY FIGURE 2
ROC curves for new-onset hypertension by WHtR and BMI.

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What is the degree of social disability risk in China under the background of the aging population? Social disability risk measurement index system design and evaluation research based on China

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Objective: The impact of the aging population in China varies between regions. It is because regions with different resource endowments, such as those related to economy, population, and medical care, have different degrees of disability risk in the face of the increases in the disabled and semi-disabled older population caused by the overall aging of the population. This study aimed to construct an evaluation system to monitor and measure the degree of social disability risk in different regions in China and to evaluate and compare the degree of social disability risk in different regions using empirical data.

Method: This study used the Delphi method to construct a social disability risk measurement index system with macro, meso, and micro dimensions. At the same time, based on the data of CHARLS2018, an AHP-entropy method was used to calculate the index's total weight, and the standard deviation classification method was used to classify the total and criterion-level measurement scores of 28 provinces.

Results: The regional degree of social disability risk was analyzed in subdimensions. Our research indicates that China's social disability risk situation is not promising, with a general medium to high-risk level. The score of degree of social disability risk among provinces is consistent with the regional economic development level to a large extent. The risk of social disability varies significantly among the eastern and central, and western regions of China and the provinces within the three regions.

Discussion: Currently, the situation facing the degree of social disability risk in China is that the overall risk level of the country is higher, and the difference between regions is significant. It is necessary to take measures to meet better the needs of the aging population and the disabled and semi-disabled older populations in a large-range, large-scale, multilevel way.

KEYWORDS

demographic aging, risk of social disability, evaluation system, analytic hierarchy process, entropy method, China

1. Introduction

The universal trend of increased human longevity is leading to an aging population. Due to the decline in bodily function accompanying aging alongside the appearance of functional disorders, an aging society will inevitably show a significant increase in the number of

disabled and semi-disabled older people. The risk of disability and semi-disability of older people will become increasingly prominent as the aging process continues.

In 2006, the World Health Organization (WHO) believed that a disabling disease afflicted only around 500 million people worldwide (1). Six years later, however, the WHO gave the World Disability Report, which soared to one billion—15% of the world's population (2). That is twice the 2006 value. The latest WHO figure is that 1.3 billion people worldwide today—16% of the global population—have a severe disability, and the number is growing as people live longer (3). In East Asia, according to statistics published by Japan's Ministry of Health, Labor, and Welfare, the number of disabled people over 18 in Japan in 1996 was 2.933 million (4). 2001 saw 3.245 million disabled people (5), an increase of 10.6% over 1996, and in 2006 the figure rose to 3.483 million (6). In South Korea, also an East Asian country, 2.4% of the country's population was registered with a disability in 2001, gradually increasing to 4.9% in 2016 (7). Since 2013, over 40% of registered persons with disabilities in Korea are aged 65 or over (8). As one of the fastest-aging countries (9) with the largest older population (10), the double burden of an aging population and an increased chronic disease has led to a continuous increase in China's disability burden (11). Data from two national sample surveys of people with disabilities show that China's disabled population was 51.64 million in 1987 (12) and increased to 82.96 million in 2006 (13), an increase of 60.65% in 20 years and accounting for 6.34% of the country's total population. Scholars predict there will be between 108.67 million and 108.79 million disabled people in China in 2020 (14). By 2030, this number is expected to grow to 136.24 million and 136.74 million (14). In 2020, China's disabled, the older population reached 43.75 million (15). They were expected to reach 614.44 million by 2030 (15), accounting for over 57% of the total disabled population (14), with the total number of disabled older people rapidly increasing to 91.4 million in 2050 (15).

In response to the continuing increase in the number of people with disabilities due to the aging of the population and the rising prevalence of non-communicable diseases worldwide (16), the United Nations and other international organizations have taken many actions. To ensure that persons with disabilities are afforded the same rights and opportunities as others (17), the UN adopted the Convention on the Rights of Persons with Disabilities in 2006 to make visible the 'invisible' community of persons with disabilities in the traditional UN human rights protection arena. To promote the health and wellbeing of persons with disabilities (18) and the implementation of the Convention on the Rights of Persons with Disabilities (19, 20), the World Health Organization and the World Bank jointly published the World Report on Disability in 2011, which provides a comprehensive analysis of disability issues and recommendations for national and international action. The UN's 2030 Agenda for Sustainable Development commits to "leaving no one behind" (21) and recognizes disability as a cross-cutting issue that must be considered in implementing all its goals (22).

In this context, disability has become a new social risk (23). In pre-industrial or agricultural societies, where the population's life expectancy was low, disability did not form an overall social risk. As we enter an aging population, the probability of disability rises due to the decline in older people's physical and psychological functions as they age. When older people become disabled, the demand for medical and senior care services generally increases.

In contrast, the established supply system of medical and healthcare services is not yet able to meet the needs of disabled older people. There is a severe imbalance between supply and demand, especially in developing and less developed countries. As a result, in a society with a high degree of aging, where disability leads to economic poverty for the families of disabled older people, an undersupply of health care services, and an inability of the health insurance fund to cover its expenses and other difficulties, then disability becomes a new social risk for the country or region. Internationally, in societies characterized by aging populations, it has been determined that when the proportion of the total population over 60 years old reaches 10% and the proportion of the total population over 65 years old reaches 7%, a country or region is considered an aging society. Furthermore, the proportion of the total population over 60 is taken to measure the degree of aging. A proportion of 10% is called a mildly aging society, 20% is a moderately aging society, 30% is a severely aging society, and more than 35% is a deeply aging society. However, the risk of social disability induced by aging and hyper-aging has, to date, not been explored by Chinese and international academics. Existing research has looked only at the assessment of the disability level of individuals with disabilities (24–30) or, based on the natural population growth rate, average life expectancy, and other factors, used measurement methods and the existing number of the disabled older population to predict the number of disabled older people at a certain point of time in the future (14, 15, 31–33). To date, there has been no research on the degree of risk of social disability at a national or regional level among Chinese and international academics.

In recent years, significant changes have occurred in China's population structure. The aging and hyper-aging population trend are increasing, and the rate is constantly accelerating, resulting in a severe structural imbalance (34). In order to effectively deal with the risk and challenges associated with the aging population, China established and implemented the "respond positively to population aging" strategy. In November 2021, the State Council issued Opinions on Strengthening the Work of Aging in the New Era, which put forward the strategic concept of "aging risk echelon response." The reason for this is that an aging population, as a long-term development process, creates unbalanced risks for economic and social development, which is reflected in the fact that the impact of an aging population is not the same across all regions, areas and links, but presents characteristics of varying severity (35). This means that regions with different levels of economic, population, and medical care resources, among other factors, have different degrees of disability risk in the face of increases in the disabled and semi-disabled older population caused by an aging population. Therefore, it is necessary to construct an evaluation system to monitor and measure the degree of social disability risk in different regions and to evaluate and compare the degree of social disability risk in different regions using empirical data.

This study borrowed the Delphi method to determine an index system based on national conditions with Chinese characteristics to measure national and regional older population disability risk, and, based on a combination of the analytic hierarchy process (AHP) and entropy method (EM) empowerment method, calculated

various combinations weights in the index system to synthesize the empirical data to analyze further the level of social disability risk in different areas of China.

2. Materials and methods

2.1. The measurement index system of social disability risk

The level of social disability risk depends on many factors. Any one factor is only a part of this risk and cannot reflect the whole of the risk. Given the lack of Chinese and international academic research on the degree of social disability risk in different countries or regions, no Chinese or international literature can be directly referenced in this study. Based on this, when determining the construction of the index system and formulating the index framework, this study drew on macro-, meso- and micro-level analysis perspectives in economic research to fill and enrich specific indicators of three dimensions: macro-system level, mesosystem level, and micro-system level. The principle of indicator determination was as follows: macro indicators strive to reflect the degree of aging of the population in a country or region and the total quantitative support and assistance available for the older disabled population. The meso index tries to reflect the supply and demand of medical resources for the older disabled population in a meso society. The micro index mainly reflects the degree of disability of older disabled people at the micro-individual level, using the degree of individual disability in a probability sample within a region to represent the degree of disability of the group within the area. Based on the above ideas, when initially formulated the measuring and evaluation indicators of the degree of social disability risk, the primary considerations in this study were as follows: we strove to reflect social security (36, 37), economic development level, aging population (38, 39), medical resource allocation (40), medical service provision (40, 41), education level, economic status, health status (42–44), health care expenditure, psychological status (45) and social adaptation capacity (46) and other aspects indicators suitable for Chinese national conditions; interviews were conducted with relevant personnel of government departments and experts in the field of social security and social medicine to summarize the evaluation indicators for monitoring the degree of risk of disability in China; the criteria and indicator variables for assessing the degree of individual disability were extracted from existing policy documents, especially the Long-term Care Disability Grade Assessment Criteria (Trial) jointly issued by the National Medical Insurance Administration and the Ministry of Civil Affairs in 2021. Since there has been no similar research in China or internationally, this research is exploratory. Therefore, the indicators were intended to be scientific, refined, and operable, and the data were made available without omission.

2.1.1. The macro-system level

The macro level is mainly measured at the national or regional level. It is the main index used to measure the degree of social disability risk in a country or region. It includes three criteria: social security, economic development level, and degree of population aging.

1. Criteria for social security. Social security is an essential index in measuring the risk of older people's disability in a region or country. The establishment of the modern industrial society, the collapse of the natural economy, and the transformation of the commodity economy into the market economy, the socialization of production and the marketization of the economy led to land security and family security in the traditional agricultural society could no longer provide a survival foundation. Thus, laborers could no longer rely on family and land to guarantee their livelihoods, and these individual risks of workers were concentrated and transferred to society, becoming social risks. As the highest authority in the management of society, the state or government is duty-bound to assume the primary responsibility of social security and alone can implement living security for the whole society through the redistribution of national income. As an economical category, finance is a kind of economic activity with the state as the main body, used to safeguard and improve people's livelihoods, promote economic and social development, protect state security, etc. It is associated with a centralized national revenue, and the expenditure activity for part of this national income is used to meet the needs of the public in order to achieve the optimized allocation of resources, fair distribution, and economic stability and development goals. The quantitative support and assistance of the country or region provided to older disabled persons reflect the function of social management and the degree of risk of the disabled older people in the country/region. Generally, regions that spend more on social security for older disabled people have a greater social disability risk than regions that spend less on social security for older disabled people. This study selected three indicators to measure this risk: the per capita social health expenditure on disabled persons, the per capita government health expenditure on disabled persons, and the proportion of social security in the regional general public budget expenditure.
2. Criteria for the level of economic development. The regional economic development level reflects the region's degree and stage of social development. It is generally believed that a region with a high economic level, early development, and a higher degree of social development will have a higher degree of social disability. As the most effective tool and crucial index used to grasp and compare the economic development levels of different countries or regions, per capita regional GDP is often used to compare the macroeconomic operational status of different regions. Therefore, this study selected per capita regional GDP to measure regional economic development.
3. Criteria for population aging. Aging and the degree of aging continuing to increase are the initial signs of a disabled society. When longevity is shared in an aging population, the length and cycle of human life are increasingly extended, the proportion of the old-age period in the life cycle increases, the number of older people and very old people gradually increases, and the top of the "pyramid" of the population age structure constantly expands. Meanwhile, combined with the inevitable decline in bodily function as people enter old age, the continuous increase of aging leads to an increased population of disabled and semi-disabled older people, a large-scale and multilevel increase in disabled and semi-disabled older people, and an increased risk

of social disability. The basic situation of an aging population can be measured *via* the population's average life expectancy, the proportion of older people in the total population, the dependency ratio of the older population, and the proportion of older disabled people in the total older population. The higher the degree of aging, the higher the social disability risk.

2.1.2. The mesosystem level

The meso level is also an essential aspect of the degree of social disability risk in a region. The allocation of medical social resources to potential older disabled people and the demand for medical services for older disabled people also reflect the degree of risk of social disability in a country or region.

1. Criteria for medical resource allocation. Health resource allocation refers to the distribution and transfer of health resources collected by a country or region in different health industries or departments (47), mainly including health institutions, human resources, material resources, and other elements. As relatively scarce resources, the distribution, quantity, and structure of medical resources for older people with disabilities also reflect the basic situation of regional health services for older people, which directly relates to the health rights and interests of older people with disabilities and the degree of social disability risk. Based on the China Health Statistical Yearbook of medical and health institutions, health facilities, and the classification of health personnel, this study selected three indicators to measure the allocation of medical resources for older disabled people in different regions: the number of nursing homes and sanitariums per million older population, number of beds in nursing homes and nursing stations per million older population and number of health technicians per 1,000 older population.
2. Criteria for the provision of medical services. Based on health needs and health status, the number of health services available to disabled older people reflects their health status. The number of health services received by disabled older people in a given region reflects the degree of disability risk of the older population in that region to a certain extent. According to the availability of data and the setting of the questions on medical use in the CHARLS2018 household questionnaire, the number of outpatient visits per capita older population in the past month and the number of hospital admissions per capita older population in the past year were selected as indicators to measure the supply of medical services.

2.1.3. The micro-system level

The micro level, which uses the older people's disability degree in a probability sample in the area of older population groups to represent the entire area of the degree of disability, is central to measuring the degree of risk in the regional social disability index system, comprising six aspects: level of education, economic status, health conditions, health care spending, psychological status, and social adaptability.

1. Education criterion. Many epidemiological studies have shown that education level negatively correlates with disability risk (48); people with a higher education level are significantly less likely to have a disability. Education is represented by the highest level of education the respondent has received.
2. Financial situation criterion. Economic status is an index used to measure respondents' financial income and living consumption expenditure, mainly measured by per capita disposable income, which is the primary individual factor affecting the degree of disability in older people. It is generally assumed that older people with higher income levels and better economic conditions are less likely to be disabled.
3. Health status criterion. What is a disability? The typical academic definition is the partial or complete loss of some bodily functions due to old age, disease, injury, and so on so that the ability to engage in regular activity is limited or missing (49). From this definition, it is not difficult to see that regardless of what causes a disability, its direct representation must be partial or complete bodily function damage and health problems. The fact that physical function inevitably declines in old age measures health status as a vital measurement criterion, including the activities of daily living, cognitive ability, and the number of chronic diseases. According to the relevant standards in the Long-term Care Disability Grade Assessment Criteria (Trial) jointly issued by the National Medical Insurance Administration and the Ministry of Civil Affairs in 2021, poor ability to engage in daily activities, low cognitive ability, and more types of chronic disease in the older people surveyed generally indicated a high disability grade and a profound degree of disability.
4. Criterion for healthcare expenditure. Population studies have empirically shown that medical expenditure is directly related to disability status among older people. Older people in different states of disability have different amounts of medical care expenditure, and the more severe the disability status, the greater the medical expenditure (50). Therefore, this study selected per capita healthcare expenditure to measure this criterion.
5. Psychological status criterion. With the intensification of China's aging, mental problems among older people have become increasingly prominent and the focus of academic discussion. Depression has become a common mental illness among the older population, affecting the incidence of chronic diseases and the ability to engage in daily activities and further affecting the degree and grade of disability. In this study, psychological depression was selected to measure the psychological status of the older population.
6. Social adaptability criterion. The ability to adapt socially is not only a dynamic reflection of people's responses in the face of external environmental changes. However, it is also a kind of health capital of respondents, reflecting a better physical and psychological state. It can be subdivided into three aspects: social communication, social support, learning, and adaptability.

According to the selection and description of the above indicators, based on the initial index system, following the Delphi expert consultation method and after two rounds of expert consultation, this study constructed a social disability risk measurement index system which was divided into three levels of indicators: three system-level indicators, 11 criteria-level indicators, and 21 indication-level indicators, as shown in Table 1.

TABLE 1 Measurement index system of social disability risk.

Target layer	System layer	Criteria layer	Index layer	Unit
Comprehensive measurement index of social disability risk	Macro-system (A1)	Social security (B1)	Per capita social health expenditure of disabled persons (C1)	Yuan
			Per capita government health expenditure of disabled persons (C2)	Yuan
			Proportion of social security in older people regional general public budget expenditure (C3)	%
		Economic development (B2)	Per capita regional GDP (C4)	Yuan
		Aging of the population (B3)	Average life expectancy of the population (C5)	Year
			Proportion of the older people in the total population (C6)	%
			Dependency ratio of the older population (C7)	%
			Proportion of the older disabled population in the older population (C8)	%
	Mesosystem (A2)	Allocation of medical resources (B4)	Number of nursing homes and sanitariums per million older population (C9)	So
			nuMber of beds in nursing homes and nursing stations per million older population (C10)	Bed
			number of health technicians per 1,000 older population (C11)	Person
		Provision of medical services (B5)	number of outpatient visits per capita older population in the past month (C12)	Times
			number of hospital admissions per capita older population in the past year (C13)	Times
	Micro-system (A3)	Education (B6)	Education level of the older people per capita (C14)	–
		Financial situation (B7)	Per capita disposable income (C15)	Yuan/person
		Health status (B8)	Activities of daily living per capita older population (C16)	–
			Cognitive ability of per capita older population (C17)	–
			Number of chronic diseases per capita in the older population (C18)	Types
		Healthcare expenditure (B9)	Per capita healthcare expenditure (C19)	Yuan
		Psychological status (B10)	Psychological status of the per capita older population (C20)	–
		Social adaptability (B11)	Social adaptability of the per capita older population (C21)	–

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The determination of the measurement index system was based on the initial indicator system, strictly following the process and paradigm of the Delphi expert consultation method, after two rounds of written consultation with 15 experts, screening of the initially proposed indicators according to the boundary value method, and making additions, deletions, and corrections according to the opinions expressed in the experts' written consultations. The expert authority coefficient and Kendall coordination coefficient of the two rounds of correspondence consultation were 0.72 and 0.174, and 0.74, and 0.137, respectively, with P-values < 0.001 and 0.004, which passed the consistency test.

The Delphi research design method follows the "Guidelines for Conducting and Reporting Delphi Studies" (51). Moreover, the Delphi panel members were carefully selected for their diversity and "richness of information" (52).

In this study, 15 social security, health management, health policy, and social medicine experts were invited to collect information using a Delphi expert consultation form supplemented by unstructured interviews. Fifteen experts, all of whom had a master's degree or higher, including 10 with a Ph.D. (66.67%), 10 with a senior title (66.7%), and nine with more than 10 years of experience (60%; Table 2).

TABLE 2 Demographic characteristics of the Delphi panel ($N = 15$).

Characteristics	*n*	Percentage (%)
Gender		
Male	2	13.3
Female	13	86.7
Age (years)		
≤30	1	6.7
31–40	11	73.3
41–50	2	13.3
51–60	1	6.7
≥61	0	0
Experience in profession (years)		
≤5	1	6.7
6–10	5	33.3
11–15	7	46.7
16–20	1	6.7
21–25	0	0
≥26	1	6.7
Professional title		
Professor	4	26.7
Associate professor	6	40.0
Lecturer	5	33.3
Education degree		
Master degree	5	33.3
Doctorate	10	66.7
Specialty		
Social medicine	6	40.0
Health management	1	6.7
Public administration	1	6.7
Social security	2	13.3
Public service management	5	33.3
Research direction		
Health policy and management	1	6.7
Health economics and health policy	3	20.0
Health policy and health management	4	26.7
Medical security	1	6.7
Health services management	1	6.7
Social security	3	20.0
Health management	2	13.3

2.2. Data sources and index assignment

The data used in this study to measure the risk of regional social disability were taken from the 2018 China Health and Retirement Longitudinal Study (CHARLS2018), the 2019 China Health Statistical Yearbook, the 2019 China Statistical Yearbook, the Seventh National Census and the 2018 National Sample Survey on Population Changes, which was partially used to ensure data for the current year of 2018.

CHARLS, a large-scale interdisciplinary survey project hosted by the National Institute of Development at Peking University, is a tracking and longitudinal survey aimed at collecting a set of high-quality microdata representing households and individuals aged 45 and above in mainland China. To ensure international comparability and best practice, CHARLS draws on international experience in the design and measurement of specific questions, aligning with similar international studies such as the US Health and Retirement Study (HRS), the English Longitudinal Study of Aging (ELSA) and the Survey of Health, Aging, and Retirement in Europe (SHARE). To ensure a representative sample, the CHARLS National Baseline Study carried out in 2011 covered 28 provinces (municipalities and autonomous regions) and 150 county-level units, involving 450 village-level units (villages and urban communities) and covering more than 17,000 respondents from more than 10,000 households.

Since this study investigated the 28 provinces (municipalities and autonomous regions) included in the CHARLS database and used probability sampling data in the region covered by CHARLS to represent the situation of groups in the region, the 21 indicators at the index level were used as the units for the research samples. The 21 indicators were not all included in the screening conditions at one time for sample screening. The reasons are as follows: (1) The 21 index-layer indicators determined by the Delphi expert consultation method came from macro-, meso- and micro-system layers, and CHARLS cannot provide all empirical data. (2) The degree of social disability risk in 28 provinces (municipalities, autonomous regions) was analyzed and compared, with provinces

TABLE 3 Partial measure index of social disability risk and its assignment.

Index layer	Index assignment	Unit
Proportion of the older disabled population in the older population (C8)	Physical Self-Maintenance Scale (PSMS) of the CHARLS household questionnaire was used to determine whether the older respondent was disabled, which corresponded to the six questions DB010-DBA015 in the questionnaire. Four options: "No difficulty" or "have difficulty but can still do," were considered "non-disability," and "have difficulty and need help" or "cannot do" were considered "disability." If one of the six questions was scored "disability," the respondent was considered disabled	%
Education level of the older people per capita (C14)	The degree of education was measured by BD001_W2_4 in the CHARLS questionnaire and adopted a reverse assignment, with a total of 11 discrete variables: "Doctoral degree" = 1, "Master's degree" = 2, …, "not finish primary school" = 10, "no formal education" = 11	–
Activities of daily living per capita older population (C16)	The ADL scale in CHARLS was used to measure the activities of daily living (ADL), including six items of a physical self-maintenance scale (PSMS) and six items related to instrumental activities of daily living corresponded to DB010-DB015, DB016-DB020, and DB035 in the questionnaire. Among the options were "no difficulty" = 1, "difficulty but can still do" = 2, "difficulty and need help" = 3, "cannot do" = 4, and the older respondents who answered "no telephone" in question DB035 were excluded	–
Cognitive ability of per capita older population (C17)	Cognitive ability is measured by the simple mental state in CHARLS and consists of three parts: DC001_W4-DC012_W4, DC014_W4_DC014_W4_5, and DC016_W4-DC024_W4. There are 24 questions in total. Each correct answer is marked with 1 point, and the score ranges from 0 to 24 points	–
Number of chronic diseases per capita in the older population (C18)	The self-reported diagnosis of chronic diseases by doctors of the respondents was used as a measurement. Among the 14 chronic diseases listed in the questionnaire, one respondent was diagnosed with one, and the score ranged from 0 to 14, corresponding to the 14 questions under DA007 in CHARLS	-
Psychological status of the per capita older population (C20)	Psychological status was measured by CESD in the CHARLS questionnaire, corresponding to 10 questions DC009-DC018. Among the options were "rarely or none of the time" = 0, "some or a little of the time" = 1, "occasionally or a moderate amount of the time" = 2, and "most or all of the time" = 3, with the score ranging from 0 to 30	–
Social adaptability of the per capita older population (C21)	One point is scored for each of the 11 social interaction activities, measured by the DA056 question in CHARLS. The score ranges from 0 to 11	–

as the comparison unit. There was no need to screen samples in a unified way and then classify them. (3) CHARLS's research is authoritative within China concerning older people's health data; the data quality is high, and the loss of samples is minimal, but there is still a loss of data in the database and bumping, especially for older respondents. The questionnaire involves 21 indicator problems without a complete answer, especially in the age of the sample of this study, which was higher, being 65 years old and above. If the 21 indicators were uniformly covered as the screening criteria, too many samples would have been excluded, resulting in the problem of insufficient representation. The empirical data of indicators C8, C12, C13, C14, C16, C17, C18, C20, and C21 in the third-level indicator layer were from CHARLS2018, and the specific values are shown in Table 3.

The China Health Statistical Yearbook is an annual publication reflecting the development of health undertakings and the health status of residents in China. It is also a national authoritative data source that can be used to study the development of health undertakings and the health level of residents in China. The empirical data of C1, C2, C9, C10, and C11 indicators in this study were obtained from or collated by the 2019 China Health Statistical Yearbook.

The 2019 China Statistical Yearbook systematically collected the economic and social statistics of all provinces, autonomous regions, and municipalities in 2018. It comprehensively reflects China's economic and social development during that period. The empirical data of the four indicators of C3, C4, C15, and C19 in this study were obtained from the 2019 China Statistical Yearbook.

Designed to accurately depict changes in the new era of national population development, strengthen population development strategy research, and provide a basis for promoting this research to realize long-term and balanced population development, the 2018 National Sample Survey on Population Changes was an annual nationwide sample survey organized by the National Bureau of Statistics (NBS) on November 1, 2018, with a sampling ratio of 0.820‰. The empirical data for the "Proportion of the older people in the total population (C6)" and "dependency ratio of the older population (C7)" used in this study were compiled from the sample data of the 2018 National Sample Survey on Population Changes.

It is worth noting that the "average life expectancy of the population (C5)" index could only use the national census data to ensure that the statistical methods, statistical caliber, and statistical time of the data of the 28 provinces were consistent. The national census is conducted every 10 years, wherein years ending with 0 are census years. In order to ensure the credibility of the data, the average life expectancy of each province used in this study was taken from the Seventh Census conducted in 2020.

2.3. A comprehensive evaluation of AHP combined with the entropy method

After synthesizing the existing relevant measurement research data from China and internationally and consulting relevant experts, this study adopted a comprehensive weighting method combining subjective and objective weighting to evaluate the index system comprehensively and combined the index weights calculated using the analytic hierarchy process (AHP) and entropy method (EM) with a Lagrange multiplier formula. The final

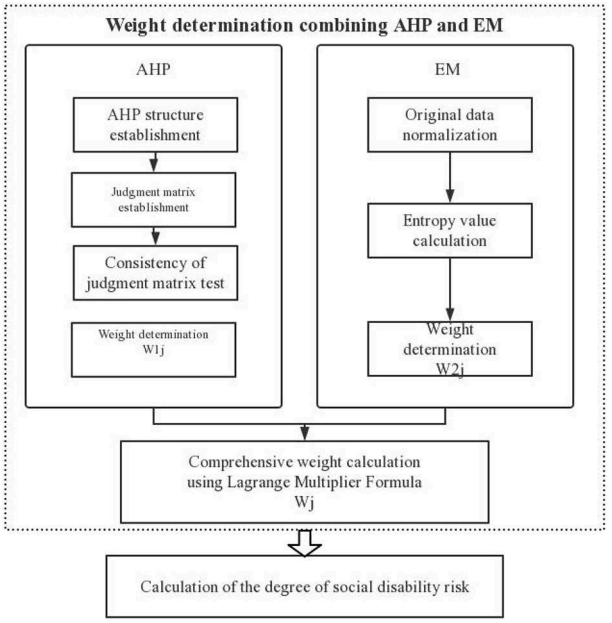

FIGURE 1
Flowchart of comprehensive evaluation combining the entropy method (EM) and analytic hierarchy process (AHP).

combined weight of the regional social disability risk index was obtained to comprehensively analyze the respective degrees of social disability risk of 28 provinces (municipalities and autonomous regions) covered by the CHARLS2018 database. A flowchart of the comprehensive evaluation combining AHP and EM is presented in Figure 1.

2.3.1. Weight determination using AHP

The analytic hierarchy process (AHP) is one solution to the problem of the complex multi-objective combination of qualitative and quantitative methods to calculate weights in decision-making research. Professor T. L. Saaty, an American operations research scientist, developed it. The method combines quantitative analysis with qualitative analysis, using the experience of experts and scholars to judge whether it is possible to determine the relative importance of various measured items. In addition, the weight of each index under each decision-making scheme is reasonably given, and the order of advantages and disadvantages of each scheme is calculated using that weight so that it can be more effectively applied to those topics that are difficult to address simply by using quantitative methods (53). Because the application of AHP requires less objective data, a complex monitoring and evaluation index system can still be given a better weight through subjective evaluation when the evaluation index data are difficult to collect or cannot be ultimately collected. Therefore, this method is often used to evaluate index systems in social sciences.

As part of applying the Delphi method to construct the measurement index system, 15 experts in related fields were brought together to score the importance of 21 indicators in the third-level index layer, and the value of each score itself included the relative importance of pairwise indicators in each level. Thus, this study directly used measuring software to rate the importance of 21 indicators in the index layer to calculate the average values and used the average value information to obtain the relative importance and establish the judgment matrix required by AHP (see Table 4). Thus, we calculated 21 tertiary index weights using AHP, and the results can be seen in Table 5. After consistency testing, the maximum characteristic root $\lambda max = 21$, the RI value was 1.636, and the CR value of the consistency judgment index was <0.001. Therefore, the weighting results of the index layer analytic hierarchy process of the social disability risk measurement index system passed the consistency test.

2.3.2. Weight determination using EM

AHP based on subjective evaluation can easily produce significant inaccuracies and even errors. In particular, when a subjective evaluation based on experience, intuition, and understanding significantly differs from objective facts, this judgment thinking method's calculation process and results show low accuracy. Therefore, this study also applied the entropy method, an objective weighting method with high objectivity and rationality, reducing human factors' interference. Entropy is a measure of uncertainty. The entropy method borrows the physical concept of entropy in thermodynamics, using the information carried by entropy, combined with the degree of variation of each index, and uses the tool of information entropy to calculate the objective weight of each index. Generally, the greater the amount of information, the smaller the uncertainty and entropy, the higher the degree of aggregation of the index, the more significant the role of the index in representing the entire evaluation system, and the greater the weight (54).

Due to the inconsistency of data direction and unit among indicators, before using the entropy method, it was necessary to carry out dimensionless processing on all data, that is, to adopt the normalization method: forward index forward, reverse index reverse. Since the value range of normalized data is 0∼1, and a zero value cannot be used to calculate a logarithm in an entropy algorithm, non-negative translation was selected for dimensionless data. The coordinate translation formula was as follows:

$$Y_{ij} = Z_{ij} + 0.0001 \tag{1}$$

where i is the number of the province to be measured ($i = 1, 2, ..., 28$), j is the number of the indicator layer indicator ($j = 1, 2, ..., 21$), Y_{ij} is the value of the normalized data shifted by 0.0001 units to the right, and 0.0001 is the translation amplitude.

According to the definition of entropy, the proportion of the jth index in the ith province in the calculation of entropy value can be obtained as follows:

$$p_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{28} Y_{ij}} \tag{2}$$

The information entropy value of item j can be expressed as follows:

$$E_j = -\frac{1}{\ln 28} \sum_{i=1}^{28} p_{ij} \cdot \ln p_{ij} \tag{3}$$

TABLE 4 AHP judgment matrix.

Average value	Item	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
8.533	C1	1	0.928	0.985	1	1.049	1	1.016	1.032	1	1	0.985	1.143	1.306	1.049	0.955	0.914	0.928	0.941	0.941	1	1.123
9.2	C2	1.078	1	1.062	1.078	1.131	1.078	1.095	1.113	1.078	1.078	1.062	1.232	1.408	1.131	1.03	0.986	1	1.015	1.015	1.078	1.211
8.667	C3	1.016	0.942	1	1.016	1.066	1.016	1.032	1.048	1.016	1.016	1	1.161	1.327	1.066	0.97	0.929	0.942	0.956	0.956	1.016	1.14
8.533	C4	1	0.928	0.985	1	1.049	1	1.016	1.032	1	1	0.985	1.143	1.306	1.049	0.955	0.914	0.928	0.941	0.941	1	1.123
8.133	C5	0.953	0.884	0.938	0.953	1	0.953	0.968	0.984	0.953	0.953	0.938	1.089	1.245	1	0.91	0.871	0.884	0.897	0.897	0.953	1.07
8.533	C6	1	0.928	0.985	1	1.049	1	1.016	1.032	1	1	0.985	1.143	1.306	1.049	0.955	0.914	0.928	0.941	0.941	1	1.123
8.4	C7	0.984	0.913	0.969	0.984	1.033	0.984	1	1.016	0.984	0.984	0.969	1.125	1.286	1.033	0.94	0.9	0.913	0.926	0.926	0.984	1.105
8.267	C8	0.969	0.899	0.954	0.969	1.016	0.969	0.984	1	0.969	0.969	0.954	1.107	1.265	1.016	0.925	0.886	0.899	0.912	0.912	0.969	1.088
8.533	C9	1	0.928	0.985	1	1.049	1	1.016	1.032	1	1	0.985	1.143	1.306	1.049	0.955	0.914	0.928	0.941	0.941	1	1.123
8.533	C10	1	0.928	0.985	1	1.049	1	1.016	1.032	1	1	0.985	1.143	1.306	1.049	0.955	0.914	0.928	0.941	0.941	1	1.123
8.667	C11	1.016	0.942	1	1.016	1.066	1.016	1.032	1.048	1.016	1.016	1	1.161	1.327	1.066	0.97	0.929	0.942	0.956	0.956	1.016	1.14
7.467	C12	0.875	0.812	0.862	0.875	0.918	0.875	0.889	0.903	0.875	0.875	0.862	1	1.143	0.918	0.836	0.8	0.812	0.824	0.824	0.875	0.982
6.533	C13	0.766	0.71	0.754	0.766	0.803	0.766	0.778	0.79	0.766	0.766	0.754	0.875	1	0.803	0.731	0.7	0.71	0.721	0.721	0.766	0.86
8.133	C14	0.953	0.884	0.938	0.953	1	0.953	0.968	0.984	0.953	0.953	0.938	1.089	1.245	1	0.91	0.871	0.884	0.897	0.897	0.953	1.07
8.933	C15	1.047	0.971	1.031	1.047	1.098	1.047	1.063	1.081	1.047	1.047	1.031	1.196	1.367	1.098	1	0.957	0.971	0.985	0.985	1.047	1.175
9.333	C16	1.094	1.014	1.077	1.094	1.148	1.094	1.111	1.129	1.094	1.094	1.077	1.25	1.429	1.148	1.045	1	1.014	1.029	1.029	1.094	1.228
9.2	C17	1.078	1	1.062	1.078	1.131	1.078	1.095	1.113	1.078	1.078	1.062	1.232	1.408	1.131	1.03	0.986	1	1.015	1.015	1.078	1.211
9.067	C18	1.063	0.986	1.046	1.063	1.115	1.063	1.079	1.097	1.063	1.063	1.046	1.214	1.388	1.115	1.015	0.971	0.986	1	1	1.063	1.193
9.067	C19	1.063	0.986	1.046	1.063	1.115	1.063	1.079	1.097	1.063	1.063	1.046	1.214	1.388	1.115	1.015	0.971	0.986	1	1	1.063	1.193
8.533	C20	1	0.928	0.985	1	1.049	1	1.016	1.032	1	1	0.985	1.143	1.306	1.049	0.955	0.914	0.928	0.941	0.941	1	1.123
7.6	C21	0.891	0.826	0.877	0.891	0.934	0.891	0.905	0.919	0.891	0.891	0.877	1.018	1.163	0.934	0.851	0.814	0.826	0.838	0.838	0.891	1

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TABLE 5 The indicator weight of the social disability risk measurement index.

Target layer	System layer	Weight	Criteria layer	Weight	Index layer	Attribute	Weight		
							AHP	EM	Comprehensive
Comprehensive measure index of social disability risk	Macro-system (A1)	0.39808	Social security (B1)	0.18643	C1	Positive	0.04798	0.0991	0.07454
					C2	Positive	0.05172	0.0627	0.06155
					C3	Positive	0.04873	0.0445	0.05034
			Economic development (B2)	0.05404	C4	Neutral	0.04798	0.0521	0.05404
			Aging of the population (B3)	0.15761	C5	Positive	0.04573	0.0201	0.03277
					C6	Positive	0.04798	0.0242	0.03683
					C7	Positive	0.04723	0.0302	0.04082
					C8	Positive	0.04648	0.041	0.04719
	Mesosystem (A2)	0.30567	Allocation of medical resources (B4)	0.23029	C9	Positive	0.04798	0.0873	0.06996
					C10	Positive	0.04798	0.2201	0.11108
					C11	Positive	0.04873	0.0426	0.04925
			Provision of medical services (B5)	0.07539	C12	Positive	0.04198	0.0335	0.04054
					C13	Positive	0.03673	0.0283	0.03485
	Micro-system (A3)	0.29624	Education (B6)	0.02181	C14	Positive	0.04573	0.0089	0.02181
			Financial situation (B7)	0.06303	C15	Neutral	0.05022	0.0677	0.06303
			Health status (B8)	0.09307	C16	Positive	0.05247	0.0093	0.02388
					C17	Reverse	0.05172	0.0203	0.03502
					C18	Positive	0.05097	0.0196	0.03417
			Healthcare expenditure (B9)	0.0465	C19	Positive	0.05097	0.0363	0.0465
			Psychological status (B10)	0.04747	C20	Positive	0.04798	0.0402	0.04747
			Social adaptability (B11)	0.02437	C21	Reverse	0.04273	0.0119	0.02437

The index weight of the criterion layer is obtained by simply adding the weights of each index layer under the combination method. The index weight of the system layer is obtained by simply adding the index weights of the criterion layer.

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The objective weight of the jth index can then be calculated as follows:

$$W_{2j} = \frac{1 - E_j}{\sum_{j=1}^{21}(1 - E_j)} \quad (4)$$

2.3.3. Comprehensive weight determination using the Lagrange multiplier formula

Combined weighting was carried out according to the Lagrange multiplier formula using the following Equation:

$$W_j = \frac{\sqrt{W_{1j} \cdot W_{2j}}}{\sum_{j=1}^{21}\sqrt{W_{1j} \cdot W_{2j}}} \quad (5)$$

where W_{1j} is the emotional weight in the analytic hierarchy process, W_{2j} is the objective weight for the entropy method, and W_j is the combined weight after combining the main objective weights. The final weighting results are shown in Table 5.

The combined weight and dimensionless translation data were combined for calculation. Finally, the comprehensive social disability risk score of the *i*th province in 2018 could be obtained, as shown in Equation (6):

$$V_i = \sum_{j=1}^{21} W_j \cdot Y_{ij} \quad (6)$$

where i is the number of the province to be measured ($i = 1, 2, ..., 28$).

3. Results

3.1. Contribution of each index to the degree of social disability risk

Based on the macro-level, meso-level, and micro-level analysis perspectives in economic research, a theoretical framework for measuring the social disability risk was constructed with three essential elements as the primary evaluation dimensions: the macro-national or regional level, the meso medical industry resource allocation level and the micro individual disability level of the older people. In this study, the weight coefficients of the three first-level indicators were 0.39808, 0.30567, and 0.29624, with relatively similar values, indicating that these three aspects are essential for monitoring the degree of risk of social disability. Among the second-level indicators, the weights of "social security," "population aging," and "medical resource allocation" were all above 0.15, which were significantly higher than other second-level items, indicating that these three items had the most extraordinary relationship with the risk of social disability. The scores of 21 three-level indicators were relatively well-proportioned, and the weight coefficients of 50% of the indicators ranged from 0.03485 to 0.05404. Among them, the two indexes with the highest coefficients were "number of beds in nursing homes and nursing stations per million older population (C10)" (0.11108) and "per capita social health expenditure of disabled persons (C1)" (0.07454).

3.2. Empirical analysis of measurement of social disability risk in China

By applying the above research methods, comprehensive measurement scores of the degree of social disability risk in 28 provinces (municipalities and autonomous regions) in China in 2018 could be obtained, as shown in Table 6. The higher the total score, the higher the degree of risk of social disability in the region. To more intuitively show the spatial distribution of provinces with different degrees of social disability risk, according to the standard deviation classification method ($\bar{x}$ is the average value, S is the standard deviation), the 28 provinces in this study were classified and divided into four levels: low-risk area ($0, \bar{x} - s$), medium-risk area ($\bar{x} - s, \bar{x}$), higher-risk area ($\bar{x}, \bar{x} + s$) and highest-risk area ($\bar{x} + s$,1). The results are shown below.

3.2.1. Overall analysis

It can be seen from Figure 2 that Jiangxi and Guangxi are two provincial-level regions with a low risk of social disability, accounting for 7.14% of the studied regions. There were 16 provinces (57.14%) in the medium disability risk range. There were seven provinces with high risk, accounting for 25%. Three provinces were in the highest-risk zone, Shanghai, Beijing, and Jiangsu, accounting for 10.71%. The average degree of social disability risk in 28 provinces was 0.32218, and the median degree of social disability risk was 0.302765. The proportion of provinces with a moderate or above risk was as high as 92.86%. Therefore, China's social disability risk is generally moderately high.

According to the regional division, all 12 provinces in the east covered by the survey were defined as medium or higher-risk areas, especially Shanghai, Beijing, and Jiangsu provinces, with the top three social disability risks in China. In the central region, Jiangxi was a low-risk area, and the other five provinces were all medium-risk areas. The degrees of disability risk in the western provinces spanned an extensive range, including low-, medium- and high-risk areas. It can be seen that the social disability risk scores of provinces were consistent with the regional economic development level to a large extent.

3.2.2. System layer comparison and analysis

The scores and distribution of the comprehensive measurement of the degree of social disability risk shown in Table 6 and Figure 3 were synthesized by summing the evaluation scores of 21 indicators at the index layer, which was too general. In order to further compare and analyze the scores of different dimensions within each province, it was necessary to conduct a more detailed analysis of the 28 provinces, as shown in Table 7 and Figures 4–6.

3.2.2.1. Macro-system measurement

As shown in Table 7, the score ranking at the macro level was similar to the comprehensive ranking: of the top 10 provinces in the macro ranking, Jilin was an exception (ranked 14th in the comprehensive ranking); the total scores of the other nine provinces were all in the top 10 and Shanghai and Beijing were ranked first and second in both the macro ranking and comprehensive ranking. The standard deviation classification

TABLE 6 The score of comprehensive measurement of the degree of social disability risk for 28 provinces (municipalities and autonomous regions) in China in 2018.

Province	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	Comprehensive scores	Ranking
Shanghai	0.05435	0.04196	0.00449	0.05145	0.03277	0.03587	0.03165	0.01868	0.04856	0.11109	0.01052	0.02677	0	0.00851	0.06303	0.0108	0.00274	0	0.04232	0	0.00379	0.59938	1
Beijing	0.07454	0.06156	0.00452	0.05405	0.03254	0.01886	0.01369	0.00747	0.00894	0.00255	0.04925	0.04054	0.01992	0	0.06058	0.01312	0	0.01943	0.0465	0.00153	0	0.5296	2
Jiangsu	0.02058	0.00861	0.00482	0.04162	0.02037	0.03285	0.03159	0.01221	0.06996	0.0851	0.00849	0.01541	0.00914	0.0185	0.02782	0.01293	0.01013	0.007	0.02078	0.00658	0.01907	0.48356	3
Zhejiang	0.02213	0.0098	0.00287	0.03342	0.02371	0.02683	0.02456	0	0.03845	0.03235	0.01901	0.01245	0.00586	0.0186	0.03827	0.0103	0.01297	0.00807	0.02166	0.00156	0.01449	0.37738	4
Xinjiang	0.01416	0.01843	0.00555	0.00901	0.00627	0	0	0.03774	0.00553	0.00012	0.0445	0	0.03485	0.01321	0.00542	0.02388	0.0224	0.03417	0.01212	0.04748	0.02355	0.3584	5
Liaoning	0.00888	0.00007	0.05034	0.01324	0.01791	0.03598	0.03204	0.02442	0.01284	0.00432	0.00485	0.00523	0.01356	0.01401	0.01649	0.01501	0.01144	0.01018	0.0257	0.01446	0.02082	0.3518	6
Chongqing	0.01051	0.01346	0.02094	0.01718	0.01745	0.03366	0.0356	0.01203	0.01273	0.00628	0.00501	0.01195	0.01616	0.0188	0.01202	0.0129	0.01938	0.0109	0.0135	0.02831	0.02154	0.35031	7
Tianjin	0.01877	0.0187	0.01892	0.04437	0.02797	0.01732	0.01196	0.01176	0.00329	0.00001	0.01609	0.01427	0.00048	0.01608	0.02973	0.01542	0.01745	0.01297	0.03428	0.00789	0.01181	0.34954	8
Shandong	0.01102	0.00315	0.00799	0.02231	0.01983	0.03684	0.04083	0.02609	0.0193	0.00941	0.00638	0.00678	0.00674	0.01815	0.01582	0.01617	0.01446	0.00915	0.01283	0.00647	0.02181	0.33152	9
Sichuan	0.00813	0.00835	0.02075	0.00872	0.01449	0.03604	0.03802	0.01933	0.00098	0.0014	0.00379	0.01987	0.01675	0.02008	0.00672	0.01656	0.02449	0.01131	0.01163	0.02166	0.0207	0.32975	10
Inner Mongolia	0.00734	0.01524	0.01426	0.01835	0.0136	0.0124	0.00856	0.03566	0.01734	0.00339	0.02661	0.00599	0.01772	0.01538	0.0147	0.01946	0.01147	0.01556	0.01733	0.01397	0.01658	0.32092	11
Qinghai	0.0047	0.05026	0.01249	0.00812	0.00623	0.00197	0.00076	0.00409	0.0077	0.00667	0.04323	0.00862	0.01275	0.02138	0.00442	0.01916	0.0223	0.01003	0.01722	0.03328	0.0222	0.31757	12
Hubei	0.0069	0.00574	0.01852	0.01752	0.01529	0.02456	0.02326	0.01142	0.00231	0.00186	0.01175	0.00867	0.01435	0.01777	0.01124	0.01593	0.02505	0.01227	0.01856	0.02452	0.02031	0.30782	13
Jilin	0.00689	0.00951	0.02018	0.01206	0.01687	0.024	0.02035	0.03889	0.01638	0.00253	0.01124	0.00336	0.00495	0.01394	0.00717	0.01875	0.01357	0.00872	0.02069	0.01142	0.02324	0.30471	14
Guangdong	0.01308	0.01472	0.00001	0.02734	0.02033	0.0051	0.00278	0.00231	0.01859	0.00701	0.0305	0.02718	0.01764	0.01791	0.02474	0.01233	0.01812	0.00611	0.01065	0.00588	0.01851	0.30082	15
Gansu	0.00072	0.01277	0.01071	0.00001	0.00623	0.01915	0.01872	0.04585	0.00402	0.00001	0.00958	0.01641	0.01711	0.01984	0.00001	0.02115	0.01738	0.01245	0.01174	0.02592	0.02091	0.29066	16
Hebei	0.00414	0.00386	0.01451	0.00816	0.01433	0.02545	0.02691	0.03051	0.00001	0.00126	0.00614	0.02693	0.01249	0.01506	0.00805	0.01828	0.01031	0.01523	0.01105	0.01699	0.01656	0.28625	17
Anhui	0.00185	0.00613	0.01395	0.00813	0.01514	0.02782	0.02992	0.01167	0.00966	0.00815	0	0.01039	0.01461	0.02181	0.00877	0.01747	0.02153	0.01386	0.00458	0.01892	0.02076	0.28514	18
Shanxi	0.00236	0.00539	0.0172	0.00695	0.01495	0.01458	0.01225	0.04719	0.00838	0.00209	0.0182	0.00779	0.00582	0.01712	0.00608	0.0219	0.01468	0.00878	0.01299	0.02016	0.01702	0.28187	19
Shaanxi	0.01083	0.01252	0.01521	0.01596	0.01453	0.01842	0.01568	0.01242	0.00525	0.0018	0.02711	0.01515	0.01139	0.01469	0.00681	0.01418	0.00995	0.01319	0.01532	0.00819	0.01817	0.27675	20
Heilongjiang	0.00768	0.00001	0.03475	0.00593	0.01625	0.02328	0.01839	0.03227	0.00291	0.00162	0.00758	0.00244	0.01028	0.01178	0.00708	0.01819	0.00761	0.01411	0.02526	0.01483	0.01272	0.27498	21
Hunan	0.004	0.00641	0.01429	0.01073	0.01483	0.02453	0.02669	0.00843	0.00274	0.00219	0.00812	0.01189	0.0143	0.01577	0.01047	0.01553	0.01787	0.0122	0.01443	0.01405	0.01258	0.26204	22
Henan	0.00168	0.00516	0.0127	0.00935	0.01376	0.01794	0.02009	0.02651	0.0027	0.00165	0.01399	0.01555	0.01422	0.01785	0.00605	0.01553	0.01565	0.01189	0.01107	0.01042	0.017	0.26077	23
Fujian	0.00949	0.01053	0.00029	0.02972	0.01718	0.01073	0.00872	0.0067	0.01447	0.00261	0.0197	0.0239	0.00683	0.02066	0.02046	0.01398	0.00981	0.00593	0.0048	0.00198	0.02159	0.26007	24
Yunnan	0.00235	0.01285	0.01226	0.00288	0	0.01113	0.00996	0.01873	0.00571	0.00036	0.01903	0.01891	0.01436	0.02161	0.00351	0.01629	0.02276	0.00984	0.00548	0.02343	0.02438	0.25584	25
Guizhou	0.00131	0.01746	0.00312	0.00492	0.00454	0.01926	0.02251	0.01842	0.00459	0.00193	0.01519	0.00578	0.00357	0.02121	0.00128	0.01343	0.03503	0.00801	0.00171	0.01541	0.01935	0.23801	26
Jiangxi	0.00001	0.01491	0.01085	0.008	0.01391	0.01187	0.01215	0.00532	0.00396	0.00058	0.01106	0.01514	0.01495	0.01785	0.0089	0.01393	0.01196	0.00825	0	0.01724	0.01738	0.21821	27
Guangxi	0.00176	0.01011	0.01385	0.00505	0.01552	0.01321	0.0148	0.00751	0.00612	0.00331	0.01883	0.01603	0.01135	0.01748	0.0054	0	0.01093	0.00875	0.00746	0.01667	0.01333	0.21748	28

The CHARLS survey covered only 28 provincial-level administrative regions, excluding Hainan, Tibet, Ningxia, Taiwan, Hong Kong, and Macao.

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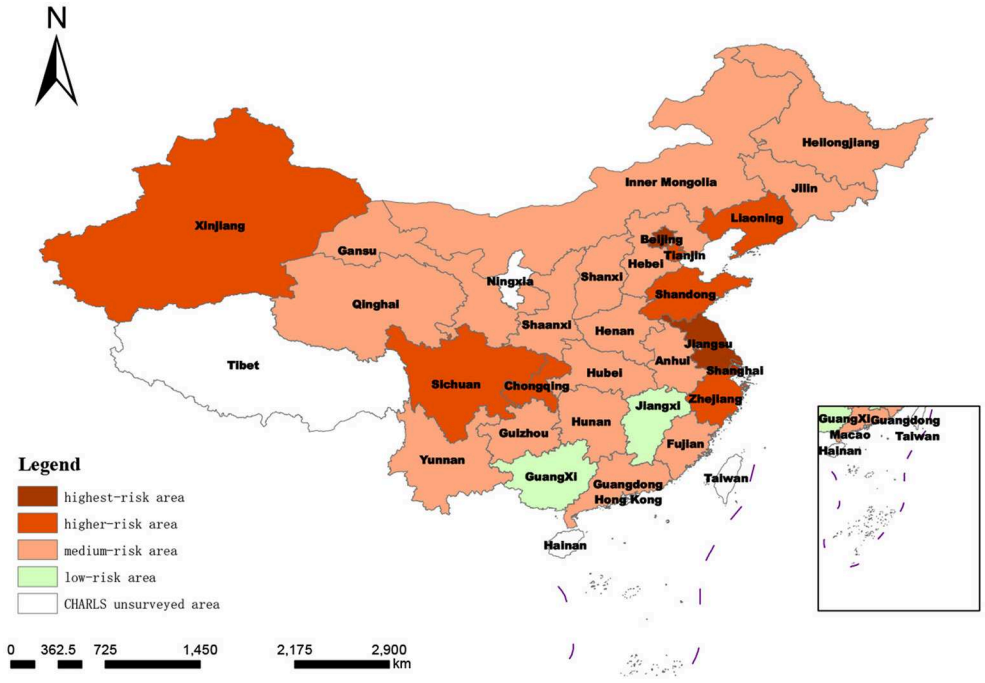

FIGURE 2
Spatial distribution of degree of regional social disability risk based on target-layer score.

FIGURE 3
The eastern, central, and western regions of China.

TABLE 7 Scores of system-layer measures of the degree of social disability risk for 28 provinces (municipalities and autonomous regions) in China in 2018.

Province	Macro-system	Ranking	Meso-system	Ranking	Micro-system	Ranking	Target layer	Ranking
Shanghai	0.27122	1	0.19695	1	0.13121	8	0.59938	1
Beijing	0.26723	2	0.12121	3	0.14116	5	0.5296	2
Liaoning	0.18289	3	0.0408	22	0.12812	10	0.3518	6
Jiangsu	0.17264	4	0.18811	2	0.12281	15	0.48356	3
Tianjin	0.16977	5	0.03415	26	0.14562	4	0.34954	8
Shandong	0.16804	6	0.04861	14	0.11486	19	0.33152	9
Chongqing	0.16083	7	0.05214	13	0.13735	6	0.35031	7
Sichuan	0.15382	8	0.04279	20	0.13314	7	0.32975	10
Jilin	0.14873	9	0.03846	25	0.11752	17	0.30471	14
Zhejiang	0.14332	10	0.10813	4	0.12592	13	0.37738	4
Heilongjiang	0.13857	11	0.02483	28	0.11158	22	0.27498	21
Hebei	0.12788	12	0.04683	17	0.11153	23	0.28625	17
Inner Mongolia	0.12542	13	0.07105	8	0.12445	14	0.32092	11
Hubei	0.12321	14	0.03894	24	0.14567	3	0.30782	13
Shanxi	0.12087	15	0.04228	21	0.11873	16	0.28187	19
Shaanxi	0.11556	16	0.06069	10	0.1005	25	0.27675	20
Anhui	0.11461	17	0.04281	19	0.12772	11	0.28514	18
Gansu	0.11414	18	0.04713	16	0.12939	9	0.29066	16
Hunan	0.10991	19	0.03923	23	0.1129	21	0.26204	22
Henan	0.10718	20	0.04811	15	0.10548	24	0.26077	23
Fujian	0.09335	21	0.06751	9	0.09921	26	0.26007	24
Guizhou	0.09154	22	0.03105	27	0.11542	18	0.23801	26
Xinjiang	0.09117	23	0.085	6	0.18223	1	0.3584	5
Qinghai	0.08862	24	0.07897	7	0.14998	2	0.31757	12
Guangdong	0.08567	25	0.10092	5	0.11423	20	0.30082	15
Guangxi	0.08182	26	0.05564	12	0.08002	28	0.21748	28
Jiangxi	0.07701	27	0.04569	18	0.09551	27	0.21821	27
Yunnan	0.07018	28	0.05837	11	0.12729	12	0.25584	25

results of the measurement score at the macro system level showed that compared with the comprehensive score of degree of risk classification, the number of provinces defined as highest-risk areas remains the same (Jiangsu province moved from highest risk to higher risk, while Liaoning province moved from higher risk to highest risk), the number of provinces in the higher-risk category increased from seven to eight (Jilin and Heilongjiang provinces moved to higher risk; Xinjiang from higher to medium risk). The number of medium-risk provinces was reduced by 2 to 14, and the number of low-risk provinces increased to three by including Yunnan province in the western region.

3.2.2.2. Meso-system measurement

At the meso level, the risk of social disability in the 28 provinces (municipalities and autonomous regions) covered by CHARLS2018 no longer included low-risk areas after classification according to the standard deviation of this dimension. This indicates that if the risk of social disability in the region is measured only by the dimension of the demand and supply of medical resources for the older disabled population, then the national risk of disability investigated in this study will be upgraded and increased, and the focus will be on the medium-risk level. In this subdivision, the number of provinces at medium risk increased from 16 to 19. In contrast, the number of provinces defined as higher risk and highest risk areas did not change much, and the number of provinces with higher risk decreased from 7 to 6.

3.2.2.3. Micro-system measurement

From the micro-system standard deviation classification features, three areas in China were included as risk areas. This

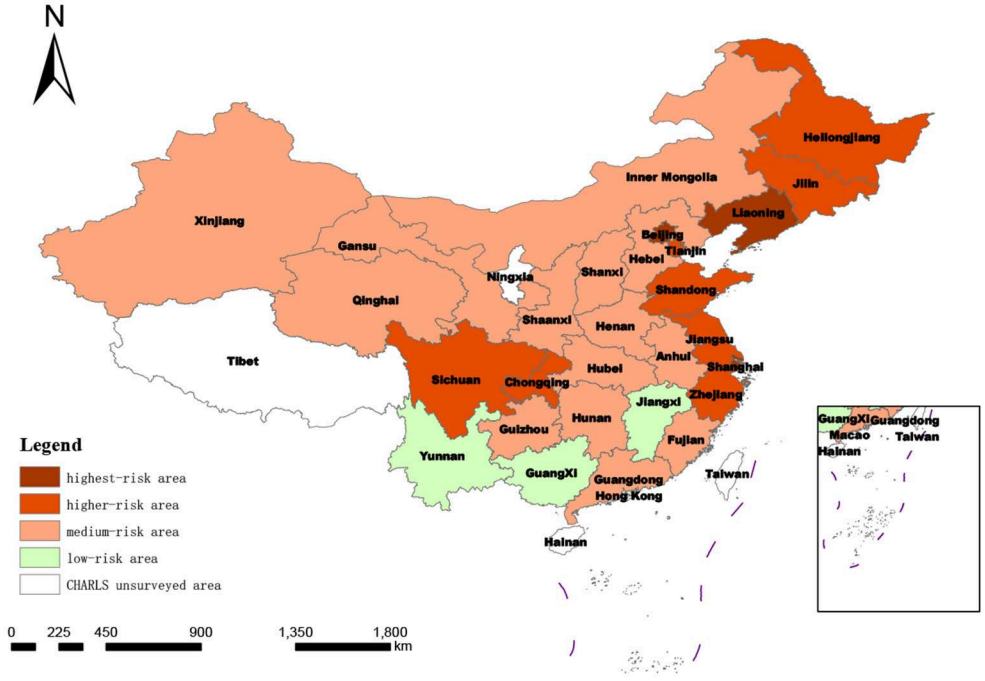

FIGURE 4
Spatial distribution of degree of regional social disability risk according to macro-system score.

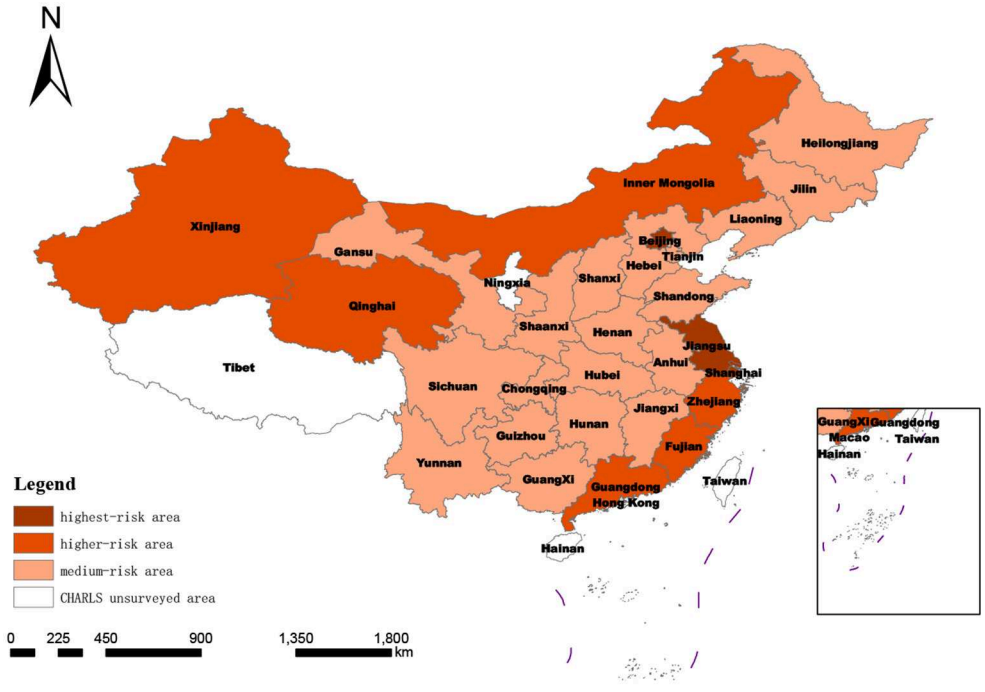

FIGURE 5
Spatial distribution of degree of regional social disability risk under mesosystem score.

indicates that the regional differences in the degree of social disability risk measured at the micro level are more evident in China than in other scales. The differences among provinces in the eastern, central, and western regions are significant.

4. Discussion

Looking back at the history of human societies, the development of longevity, fewer children, and urbanization

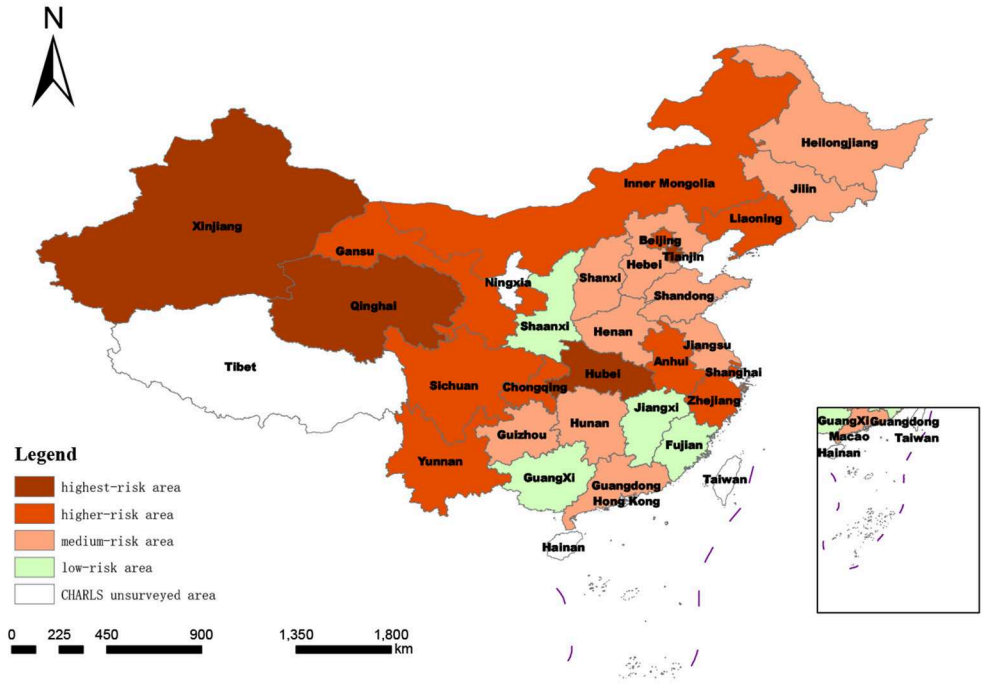

FIGURE 6
Spatial distribution of degree of regional social disability risk based on micro-system score.

has led to an aging trend in society. European scholars first began to explore the economic impact of changing age structures. Then the international community paid increasing attention to the aging phenomenon and its impact on human societies, and aging research emerged, grew, and flourished. The risk of aging under the phenomenon of population aging, which marks the arrival of an aging society, has evolved gradually as forms of aging have developed. As aging progresses, the population's life expectancy generally increases, the older population gradually grows, and the top of the population age pyramid continues to expand. At the same time, the deepening of aging presents an increase in the number of disabled and semi-disabled older people due to the physiological rule that people's physical functions inevitably decline when they enter old age. According to the results of the seventh census, there are 264 million people aged 60 and above in China, accounting for 18.7% of the total population, making it the country with the largest older population in the world. At the same time, there are currently 43.75 million disabled, older people in China. With such a severely aging population and many disabled, older people, what is the risk of social disablement in China? How is it measured? What tools are used to measure it?

This study first constructs a system of indicators to measure the risk of social disablement in China, which involves complex multi-dimensional variables such as social security, healthcare resource supply and demand, and the health status of the older population. It is an extensive system with dimensions including the country or region at the macro level, the healthcare allocation at the meso level, and the individual disabled older people at the micro level.

Secondly, after constructing the measurement index system, this study used a comprehensive weighting method combining hierarchical analysis and the entropy method to calculate the weights of each indicator. The study results show that, among the three system-level indicators, the macro system has the highest weight, followed by the mesosystem, and the microsystem has the lowest weight. It shows that the quantitative national or governmental support and assistance for social security for the older population also reflects the level of risk of old age disability in the region. The importance of public programs in improving the situation of people with disabilities is highlighted in line with previous reports (55, 56). Regions with high spending on social security for older disabled people are at greater risk of social disablement than regions with low spending on social security for older disabled people. However, the three values are relatively close, suggesting that these three areas are crucial for monitoring the level of risk of social disablement. Previous studies all support the importance of health resource utilization (57, 58) in improving the situation of people with disabilities and the geographical differences (59) in the prevalence of disability among older people.

Among the indicators in the criteria layer, the highest overall weighting coefficient is for "allocation of medical resources (B4)" at 0.23029, the lowest is for "education (B6)" at 0.02181, and the median is for "financial situation (B7)" at 0.6303. The top three coefficients are "allocation of medical resources (B4)," "social security (B1)," and "aging of the population (B3)." These, which all weigh 0.15 or more, are significantly higher than the other criteria layer indicators, indicating that these three indicators have the most significant relationship with the risk of social disablement and present a higher coefficient. Two of the top three indicators belong to the macro level, confirming our discussion above that national or regional actions significantly impact social disablement risk.

The 21 indicators scored relatively evenly in the indicator tier with a standard deviation of 0.020544. Regarding relative values, the highest weighting coefficient was C10 at 0.11108, and the lowest was C14 at 0.02181, a difference of nearly five times. This indicates that in this study, the "number of beds in nursing homes and nursing stations per million older population (C10)" has the most significant impact on the level of social disablement risk in the region. In contrast "education level of the older people per capita (C14)" has the slightest effect. Previous research (60) has suggested that the more educated older person is, the more knowledgeable they are about primary health care compared to less educated older people. When health problems arise, more educated older people are more likely to be proactive in their treatment (61), thus avoiding a significant reduction in their ability to take care of themselves. However, the results of this study show that the education level of the older population has less impact on the level of risk of social disablement. This may be because older Chinese people, whose standard of living and economic income have increased significantly due to health education, are more physically active, take care of their health seriously, regardless of their education level, and receive treatment when they are unwell.

Afterward, the combined weights of the indicators and the dimensionless processed empirical data were multiplied to derive the risk level of social disablement in 28 provincial administrative regions in China. In order to visualize the magnitude of risk in different provinces, the standard deviation grading method was used to classify the risk scores of the 28 provinces studied above into four levels: low risk, medium risk, higher risk, and high-risk zones, concerning relevant studies (62). Then, the analysis was carried out in the overall and system-level dimensions. The spatial distribution of social disablement risk in Chinese provinces under different dimensional analyses was mapped using ArcGIS version 10.2 software.

In this study, the overall analysis includes all 21 indicator layers indicators. The results show that at this time, except for Jiangxi and Guangxi, all other 26 provinces are in the medium and above risk zone for social disablement risk, accounting for 92.86%. This indicates that the overall risk of social disablement in China is at a moderate to high-risk level, and the situation is not optimistic. The reason for this may be the rising life expectancy of China's population due to improved living standards and medical technology, which has led to a continuous increase in the degree of aging and a rise in the size and proportion of potentially disabled older people. This, coupled with the lagging change in health concepts, unhealthy living and eating habits, and the lack of fitness facilities, as well as the natural pattern of physical decline in old age, has led to a rapid increase in the number of disabled and semi-disabled people in China's aging population, resulting in a high risk of disability in Chinese society. Through a more detailed analysis, it was found that Jiangxi and Guangxi provinces have a higher risk of social disability in terms of "economic development (B2)," "aging of the population (B3)," "health status (B8)" and "healthcare expenditure (B9)." We believe combining these factors has contributed to the low risk of social disablement in Jiangxi and Guangxi provinces. Lower levels of economic development and lower levels of social development also result in a smaller size and share of the older, more senior population. The higher number of younger older people means that older people are in relatively good health and have higher levels of activity in daily living and cognitive ability. In surveying the prevalence of chronic diseases in the older population, CHARLS uses respondents' self-reported doctor-diagnosed chronic diseases. With a low level of economic development, older people have less disposable income and are less willing to be treated by doctors when they are ill, so naturally, there are fewer doctor-diagnosed chronic diseases, and the health status of the older population collected from the survey is relatively good.

By region, the results show that all five provinces in the central region, except for Jiangxi, are in the medium risk zone, while all 12 eastern provinces are in the medium and higher risk zone, especially in Shanghai, Beijing, and Jiangsu, the three most economically developed provinces in China, which are among the top three in the country. This suggests that the level of social disablement risk in Chinese provinces coincides to a greater extent with the level of regional economic development. This may be because regions with higher levels of economic development are also regions with earlier development and higher levels of social development; where medical technology is advanced, life expectancy is relatively high. The older population is also more extensive, with a higher degree of population aging and naturally higher levels of social disablement risk. Previous studies (63, 64) confirm China's positive correlation between economic development and population aging.

When only the macro-system level is measured in the system level dimension analysis, the results show that the macro-system level social disablement risk scores of the 28 measured provinces in China are the most similar to the overall analysis ranking. This indicates the highest weighting of the macro-system level indicators, reflecting the combined weighting of the subjective Delphi expert consultation method and the objective entropy value method. The mesosystem indicators measure healthcare resource allocation and healthcare service provision. When only the mesosystem level is measured, social disablement risk in China will escalate and increase. There will no longer be provinces with low levels of social disablement risk. This may be because disabled older people receive more outpatient or inpatient treatment than non-disabled people, and social healthcare resources are rationed higher for the older disabled. When only the microsystem level is measured, provinces in the three regions of East, West, and Central China cover low, medium, higher, and high-risk zones. This reflects that provinces within the three regions of East, West, and Central China vary more significantly when the level of disablement of the sampled older people is used to reflect the regional level of risk of social disablement. This may be because even within the same region, there are still considerable differences in socio-economic development (65) and demographic differences (66, 67) between provinces, resulting in different levels of disability among older people in different provinces within the same region.

As seen from the above, currently, the situation facing the degree of social disability risk in China is that the overall risk level of the country is higher, and the difference between regions is significant. It is necessary to take some measures to meet better the needs of the aging population and the disabled and semi-disabled older populations in a large-range, large-scale, multilevel way.

First, it is necessary to change our ideas and reshape our cognition. As the initiating factor of disability risk in the older population, population aging is the current trend (68), and the risks and challenges it brings are global (69), long-term (70), and irreversible (71). Therefore, in the face of the challenge of social disability risk, we must abandon the unsuitable concepts of "partial war," "quick decision war," and "temporary war." This is an inevitable historical turning point in the development of human society from the perspectives of both the evolution of research disciplines and our understanding of the causes of aging. Based on this, in order to realize the transformation from problem-based research to social-form research and from solving problems to constructing a new social form, research perspectives should also expand from simply focusing on the problem of disabled and semi-disabled older people to structural problems and social form problems and explore the rise and fall of an aging society.

Second, institutional guarantees are required. Establishing and improving the old-age security system, especially the multilevel old-age service system based at home, supported by the community and supplemented by institutions, will be the foundation for ensuring the quality of life among the disabled and semi-disabled older population. The establishment and improvement of old-age social security, medical security, and long-term care service systems are the three pillars of old-age security and old-age service. Legal measures should be adopted to protect every citizen's fundamental rights and interests, including the disabled and semi-disabled older people.

Third, it is necessary to adhere to the "all-round considerations and arrangements for the nation as a whole" and "give full play to the initiative of both the central and local governments." Because of the high social disability risk across the whole country and the significant differences in risk between regions, it is necessary, on the one hand, to strengthen the top-level design at the national level—that is, all regions and departments functioning under the unified leadership of a central, overall arrangement, and collaborating and focusing on priorities to provide a guarantee for urgent fundamental problems. On the other hand, western provinces' local fiscal construction funds are limited due to their inability to cope effectively with their finances. This requires the transfer of central government support, strengthening of economically underdeveloped regions in terms of social disability risk to cope with the financial support, and efforts to promote the equalization of public service, gradually narrowing the gap between measures and the strength of a region, in order to promote an overall reduction in social disability risk. Again, concerning regions with different degrees of social disability risk and risk performance dimension scores, enthusiasm, and initiative, regions must be encouraged, according to their respective social disability risks, to rely on their resource endowment, utilizing their advantages and taking targeted measures to establish their ways of dealing with social disability risk.

This study has several strengths. Firstly, we break through the existing research on the plight of disabled, older people and the lack of social support, and explore the construction of an evaluation system to assess and measure the degree of risk of disability among the older population in a country or region, bridging the research gap on the degree of risk of disability in regional societies and beginning to explore this area of research. Secondly, when assigning the indicators, we adopt a combination of subjective and objective assignments to eliminate the disadvantages of using only one assigning method. Third, after the evaluation system and indicator weights were determined, we also conducted an empirical study using authoritative data to analyze the degree of social disablement risk in China and make recommendations.

There are still some things that could be improved in this study. First, the regional degree of social disability caused by the significant risk of disability and semi-disability in the older population has not been studied by Chinese and international academics. This study is exploratory, and due to the limitation of team capacity, no clear definition and concept of disabled society and risk of social disability have been given. In the future, we will continue the theoretical research in this area and carry out further theoretical and conceptual clarification. Second, due to data availability, we only studied the regional degree of social disability risk caused by the extension of life expectancy and physical function decline in China's older population aged 65 years and above. However, severe disabilities and intellectual disabilities of newborns will also lead to an increase in regional social disability risk. In the future, we will continue to expand the research indicators related to the regional risk of social disability for further exploration and interpretation.

5. Conclusions

To sum up, population aging, as a long-term development process (70), is characterized by gradualness, hierarchy, and unevenness in the risk of economic and social development. Based on these characteristics and the objective fact that the increase in the number of disabled and semi-disabled older people in an aging society has different degrees of impact on different regions, this study constructs a regional social disability risk measurement index system. It also combines empirical data to measure the degree of social disability risk in 28 provinces in China. It was found that the risk of social disability in China is generally at a moderately high level and that the risk of disabling disability varies considerably between and within regions and provinces. As an exploratory study, this study has great significance and value as an exploratory study due to the lack of previous academic research on the degree of risk of such social disability.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization, methodology, and writing—review and editing: QG and YS. Software, formal analysis, resources, data curation, writing—original draft preparation, and visualization:

QG. Validation and investigation: MF and ZL. Supervision, project administration, and funding acquisition: YS. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Prevalence of food insecurity and its association with depressive and anxiety symptoms in older adults during the COVID-19 pandemic in Mexico: A secondary analysis of ENCOVID-19 survey

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Introduction: COVID-19 infection has caused high rates of morbi-mortality in older adults (OAs). In addition, conditions such as depression, anxiety, unemployment, and poverty frequently contribute to this population being at higher risk of food insecurity (FI) during the COVID-19 pandemic.

Objective: This study aimed to analyze the prevalence of FI and its association with depressive and anxiety symptoms in Mexican OAs during the COVID-19 pandemic.

Methods: This study involved a secondary analysis of the National Survey on the Effects of COVID-19 on the Wellbeing of Mexican Households (ENCOVID-19), a series of cross-sectional telephone surveys conducted between April and October 2020. The OA subsample was 1,065. FI was measured by using the Latin American and Caribbean Food Security Scale (ELCSA), and depression and anxiety symptoms were measured by using the Depression Scale of the Center for Epidemiological Studies (CESD-7) and the Generalized Anxiety Disorder Scale (GAD-2), respectively. Socioeconomic status (SES), occupation, schooling, and pension were also evaluated. ANOVA was used to compare the variables between the different FI groups, and logistic regression was used to analyze the risk between FI and the anxiety and depression variables.

Results: The mean age of the participants was 67.31±6.4years, and FI was classified as mild, moderate, and severe, with prevalences of 38.6, 15.04, and 8.16%, respectively. Overall, 28.01% of the OAs presented symptoms of anxiety and 39.09% of depression. In the comparison between groups, a higher prevalence of depressive symptoms was observed with a higher degree of FI, with 65.75% in moderate-to-severe, 10.39% in mild, and 9.40% without FI, $p \leq 0.000$. Regarding anxiety symptoms, 48% of the OAs showed moderate-to-severe, 30.05% showed mild, and 15.38% were without FI, $p \leq 0.000$. Using multiple logistic regression, an OR of 5.50 (95% CI 2.74–11.04) was observed for depressive symptoms when moderate-to-severe FI is present. In the case of the risk of anxiety symptoms, it was significant in all degrees of FI, in mild (OR=2.43, 95% CI 1.66–3.59) and in moderate-to-severe (OR=5.32, 95% CI 3.45–8.19).

Conclusion: There is a high prevalence of FI in Mexican OAs during the COVID-19 pandemic. FI increases the risk of other conditions such as depression and anxiety. It is important to design and implement programs aimed at OAs with these conditions to reduce or prevent FI.

KEYWORDS

COVID-19, depression, anxiety, food insecurity, older adults

Introduction

The pandemic caused by the COVID-19 virus has caused the death of almost 6 million people in the world until February 2022 (1). Several studies have shown that age is an important predictor of adverse outcomes among patients with COVID-19 (2–4). A study published in Mexico in 2021 showed that the main predictors of severity and mortality in 220,804 confirmed cases of COVID-19 were age (adults 60 years of age or older) and high social lag indexes (2). In addition to comorbidities, high social lag indexes were identified as a predictor of mortality from COVID-19 adjusted for age and sex (HR 1.13, 95% CI 1.054–1.21).

In many countries of the world, social determinants of health have been observed to influence morbidity and mortality from COVID-19. These include poverty, physical environment, race, or ethnicity (5). OAs are usually a population with multiple risk factors such as chronic morbidity, lack of social support, living without company, and presenting greater effects on mental health such as anxiety or depression, reaching a range of 8.3 to 49.7% and 14.6 to 47.2%, respectively, according to a review by Sepulveda-Loyola et al. that included 42 articles with a total sample of 20,069 OAs from Asia, Europe, and America (6).

Gaitán-Rossi et al. through data from the National Survey on the Effects of COVID-19 on the Wellbeing of Mexican Households (ENCOVID-19) and the National Health and Nutrition Survey (ENSANUT 2018) in people over 18 years of age showed that the pandemic was also associated with a reduction in food security (households that did not report concerns or difficulties in accessing food), decreasing from 38.9% in 2018 to 24.9% in 2020 in Mexican households. At the lowest level of socioeconomic status, moderate-to-severe FI reached its highest prevalence, with 28.9 and 20.9%, respectively. Anxiety was also associated with higher FI scores; for example, 57.1% of people living with severe FI reported symptoms of anxiety (7).

Pourmotabbed et al. in a meta-analysis included 19 studies with 372,143 participants from 10 countries. The results showed that there was a positive relationship between FI and the risk of depression (OR = 1.40; 95% CI: 1.30–1.58) and stress (OR = 1.34; 95% CI: 1.24–1.44), but not anxiety. A subgroup analysis by age showed that adults older than 65 years had a higher risk of depression (OR = 175; 95% CI: 120, 256) than younger participants (OR = 1.34; CI 95%: 1.20–1.50). This study shows the relationship between FI and mental health status, such as depression and anxiety, and as previously stated, these conditions increased during the COVID-19 pandemic (8).

It is important to know the effects of the pandemic on the Mexican population, mainly in vulnerable populations such as OAs in a situation of poverty, high social lag indexes, greater comorbidity, and FI. There are still few published studies on FI in OAs in Mexico during the pandemic and the factors that could be associated with it. Therefore, the objective of this study is to analyze the prevalence of FI and its association with depressive and anxiety symptoms in Mexican OAs during the COVID-19 pandemic.

Methods

Study population and data sources

Secondary analysis of ENCOVID-19, which is a series of cross-sectional telephone surveys, is a national representative of people over 18 years of age who have a mobile phone. This survey provides data in four main domains: work, income, mental health, and food security, and began in April 2020 and continued monthly until October 2021, after which it was extended in frequency (9, 10).

The monthly surveys were compiled with probabilistic samples of mobile phone numbers using the national numbering plan, which is publicly available, as a sampling frame. To correct for slight deviations in the demographic composition of the ENCOVID-19 sample, post-stratification sample weights were used. Weights were calculated using data from the 2015 INEGI census to adjust the sample for geographic distribution (state), gender, age, and socioeconomic status (SES) (11).

For the present study, the rounds from April to October 2020 were used, including only people aged 60 years or older and who had data from the FI, depression, anxiety, and scales. A final sample of 1,065 participants was obtained.

Measurements

Household FI was measured with the eight-item adult version of the Latin American and Caribbean Food Security Scale (ELCSA) (12), an instrument that has been validated for its use in Mexico (13). The adapted version of the scale (telephone) was used, which proved to be reliable and valid, and the alpha coefficients in the April, May, and June rounds varied between 0.87 and 0.89. Correlations between items were above the cutoff point of 0.60 in all surveys. Furthermore, the Rasch models showed that the high reliability of the telephone version of the scale was comparable to the face-to-face application in ENSANUT 2018 (10).

The ELCSA asks if, in the last 3 months, due to lack of money or other resources, the respondent or any other adult in the household: (i) worried that they might run out of food (worried); (ii) they were unable to eat healthy and balanced and nutritious (healthy) food; (iii) ate only a few types of food (few foods); (iv)

skipped breakfast, lunch, or dinner (omitted); (v) ate less than he thought he should have eaten (without eating); (vi) the food is over (it is over); (vii) were hungry but did not eat (hungry); and (viii) went without eating for a whole day. Responses to all items are dichotomous (Yes/No).

After calculating the total summative score for the eight items, FI was classified into four levels: food secure (total score = 0), mildly food insecure (1–3), moderately food insecure (4–6), and food insecure severe (7, 8). For purposes of regression analysis, food insecurity was coded as no FI (0), mild FI (1), and moderate-to-severe FI (2). This is due to the number of severe OAs FI, which was only 75, so it was decided to join these two categories.

Anxiety symptoms. Anxiety was measured with the two-item generalized anxiety disorder scale (GAD-2) (14–16) which asks about how often the respondent felt during the last 2 weeks: (i) nervous, anxious, or borderline and (ii) not being able to stop or control the worry. Response options are "Never"; "several days"; "More than half the days"; and "almost daily." The scale was validated in Spanish with the neuropsychiatric interview and was found to be reliable (alpha = 0.93) and with predictive validity with a sensitivity of 0.91, a specificity of 0.85, a positive predictive value of 86.6%, a negative predictive value of 91%, and an area under the curve of 0.937 (14–16).

Depression symptoms. The depression scale of the Center for Epidemiological Studies, abbreviated version (CESD-7) (17) was used. It consists of seven items that indicate the probable presence of depressive symptoms during the last week in which they were presented: (i) rarely or never (less than 1 day), (ii) rarely or sometimes (1–2 days), (iii) a considerable number of times (3–4 days), and (iv) all or most of the time (5–7 days). It has a minimum score of 0 and a maximum of 21 points, without symptoms <5 points and with the presence of depressive symptoms ≥5 points.

Socioeconomic status. The SES of the household was measured with the Mexican Association of Market Intelligence and Opinion Agencies (AMAI) index (18). It combines six indicators from the National Household Income and Expenditure Survey (2): (i) educational level of the household head; (ii) number of complete bathrooms; (iii) number of cars or vans; (iv) have an internet connection; (v) number of household members 14 years or older who are working; and (vi) number of bedrooms. Based on a summative score and standard cutoff points, the socioeconomic level is classified into seven mutually exclusive categories, ranging from "A/B" to "E," where E represents the lowest value.

Other sociodemographic variables were also included, such as sex (male and female), age (years), level of schooling (basic (≤6 years), upper secondary, higher and postgraduate (>6 years), and no education (0 years)), occupation (active or not economically), welfare pension, and consumption of food groups (fresh fruits, vegetables, milk, eggs, meat, and beans), where the number of servings consumed per day is asked.

Statistical analysis

A descriptive analysis of the characteristics of the population, presented with means±SD and absolute and relative frequencies, was carried out. Similarly, an ANOVA was performed to compare the study variables between the FI categories. In a third analysis, logistic regression models were adjusted according to the variables that were significant in the ANOVA and previously reported in the literature associated with FI, depression, and anxiety (sex, age, SES, and schooling) to identify the variables associated with terms of measures of association with odds ratios (ORs). Statistical power was calculated based on the prevalence of depression by FI level, giving a power greater than 80. The models were evaluated checking that there was no collinearity or interaction. Statistical significance was verified through the construction of 95% confidence intervals (95% CI). The statistical software used was Stata/SE, version 15.0 (Stata Corp., TX, United States).

Results

The average age of the participants was 67.31 ± 6.4 years (60–99), 47.75% were women, and most of the participants had basic level education (≤6 years) (54.14%). The prevalence of FI in mild, moderate, and severe was 38.56, 15.04, and 8.16%, respectively, and 38.24% with food security. In relation to the consumption of different food groups, 23.79% reported that they stopped consuming fresh fruits, 21.52% vegetables, 32.79% meats, 24.12% dairy products, 12.66% eggs, and 6.11% beans. In relation to anxiety symptoms, a prevalence of 25.52 and 39.02% of depression symptoms was shown. Regarding the economic variables, 65.9% were within the economically inactive population, and when the participants were classified by SES, the levels with the highest prevalence were D and E (45.92%) and C, C−, and D+ (38.59%) (see Table 1).

In the comparison of the variables between the degrees of (in) food security, a higher prevalence of depression symptoms was observed at a higher degree of FI, 65.75% in moderate-to-severe FA, 10.39% in mild FI, and 9.40% without FI, $p = 0.000$. Regarding anxiety symptoms, 48% showed moderate-to-severe FI, 30.05% in mild FI, and 15.38% without FI, $p = 0.000$. Regarding the socioeconomic level, there was a higher prevalence of moderate-to-severe FI in the lowest status of SES, level D with 51.54% in severe FI, 40.84% in moderate FI, 37.91% in mild FI, and 25.48% without FI, level E with 19.49% in severe FI, 19.71% in moderate FI, 10.16% in mild FI, and 3.32% without FI ($p = 0.000$) (see Table 2).

In the final adjusted regression model, a significant association was observed for depressive symptoms with moderate-to-severe FI (OR = 5.50, 95% CI 2.74–11.04). In the case of the risk of anxiety symptoms, it was significant in all degrees of FI, in mild FI, an OR of 2.43 (95% CI 1.66–3.59) was observed, and in moderate-to-severe FI, an OR of 5.32 (95% CI 3.45–0.199) was observed.

Discussion

The objective of this study was to analyze the prevalence of FI and its association with depression and anxiety symptoms in OAs in Mexico. With the results, we can observe that more than 60% of the participants are under some degree of FI, these data were similar to those reported by the different ENCOVID-19 surveys, for example, Gaitán-Rossi et al. reported that food security was 24.9% in Mexican households where a child lived, that is, 75% had an FI degree (7). Ponce-Alcala et al. according to data from the ENSANUT MC (2016) reported in 5456 adults aged 20 to 59 years that 70.8% had some degree of food insecurity at home (19).

TABLE 1 Description of the characteristics of the study population.

Characteristics of participants	Means±SD or n (%)	*N*
Sociodemographic		
Age	67.31 ± 6.4	1,065
Gender (Women)	521 (47.75%)	511
(Men)	570 (52.25%)	554
Schooling (No education)	43 (7.73%)	556
(≤ 6 years)	301 (54.14%)	
(> 6 years)	212 (38.13%)	
Food insecurity		
Food insecurity scale (ELCSA-8)	2.01 ± 2.07	918
ELCSA with food safety	351 (38.24%)	
ELCSA mild FI	356 (38.56%)	
ELCSA moderate FI	136 (15.04%)	
ELCSA severe FI	75 (8.16%)	
Food consumption		
(Fruit)	3.03 ± 1.09	720
(Vegetable)	3.24 ± 2.0	
(Meat or egg)	3.67 ± 2.5	
(Milk and dairy products)	3.68 ± 2.9	
Less food consumption		
(Fresh fruit)	113 (23.79%)	473
(Vegetables)	61 (21.52%)	
(Meats)	75 (32.79%)	
(Dairy products)	55 (24.12%)	
(Eggs)	29 (12.66%)	
(Beans)	14 (6.11%)	
Mental health		
Anxiety symptoms (GAD-2 ≥ 3)	306 (25.52)	1,056
Depressive symptoms (CESD-7 ≥ 5)	119 (39.02)	303
Economy and occupation		
Occupation (Economically active)	160 (32.19)	497
(Economically inactive)	236 (65.9)	
Pension	272 (36.41)	272
SES		
1 (A/B and C+)	165(15.49)	1,065
2 (C, C− and D +)	411(38.59)	
3 (D and E)	489 (45.92)	

Values expressed as mean ± SD and/or n (%). ELCSA, the Latin American and Caribbean Food Security Scale; FI, Food insecurity; SES, Socioeconomic status; GAD-2, Generalized Anxiety Scale; CESD-7, Center for Epidemiological Studies.
A/B (Households in which the head of the family has professional education and has fixed internet at home. It is the level that invests the most in education and less in spending on food).
C+ (Most households at this level have at least one vehicle, 93% have access to fixed internet, and they spend just under a third on food purchases).
C (Most of the households at this level, the head, have education higher than primary school, 77% have a fixed internet connection, and allocate 35% of spending to food and 7% to education).
C− (Nearly three out of four households (74%) at this level have a head of household with higher than primary education. Just over half (52%) have a fixed internet connection at home. In relation to spending, 38% is dedicated to food and spending on transport and communication reaches 24%).
D+ (In just over 6 out of 10 households at this level (62%), the head of the household has higher than primary education. Only 22% of households have a fixed internet connection at home. Expenditure on food increases to 42% and spending on education is 7%).
D (In 56% of households at this level, the head of the household has education up to primary school. Internet access at home in these households is very low, only 4%. Close to half of the expenditure (46%) is devoted to food and only 16% to transportation and communication).
E (The vast majority of households at this level (95%) are headed by the head of the family with education up to primary school. Homeownership of fixed internet is practically zero (0.2%). Just over half of the household expenditure (52%) is used for food and only 11% is used for transportation and communication, a percentage similar to that used for housing).

TABLE 2 Comparison of the variables by the level of food insecurity.

Characteristics of participants	Food safety 351 n (%)	Mild FI 356 n (%)	Moderate-to-severe FI 211 n (%)	*p*-value
Gender (Women)	136 (38.75)	185 (51.97)	124 (58.77)	**0.000**
(Men)	215 (61.25)	171 (48.03)	87 (41.23)	
Schooling (No education)	7 (1.99)	14 (3.93)	19 (14.84)	**0.000**
(≤ 6 years)	88 (25.07)	122 (34.26)	84 (65.63)	
(> 6 years)	209 (59.54)	70 (19.66)	25 (19.53)	
Anxiety symptoms (GAD-2 ≥ 3 points)	54 (15.38)	107 (30.05)	100 (48.08)	**0.000**
Depression symptoms (CESD-7 ≥ 5 points)	33 (9.40)	37 (10.39)	48 (65.75)	**0.000**
Occupation (Economically active)	84 (39.44)	70 (32.86)	59 (27.70)	0.078
(Economically inactive)	118 (38.06)	129 (41.61)	63 (20.32)	
Pension (Yes)	85 (39.53)	93 (43.36)	37 (27.82)	0.0586
Socioeconomic status				
1 (A/B and C+)	38 (69.09)	14 (25.46)	9 (4.27)	**0.000**
2 (C, C− and D +)	60 (65.22)	26 (28.26)	58 (27.49)	
3 (D and E)	61 (57.55)	33 (31.33%)	144 (68.25)	

FI, Food insecurity.
Bold values refers to the fact that they were significant values, however, it is suggested that it is quite bold.

TABLE 3 Logistic regression on the association between food insecurity and depression symptoms.

	Depression symptoms							
	No adjustment				Adjusted			
	OR	CI 95%		*P*	OR	CI 95%		*P*
FI mild	1.67	0.92	8.40	0.092	1.67	0.92	3.05	0.092
FI moderate-to-severe SES	**9.34**	3.09	28.23	**0.000**	**5.50**	2.74	11.04	0.000
2 (C, C− and D +)	1.09	0.31	3.78	0.886	**0.98**	0.40	2.35	0.967
3 (D and E)	1.92	0.55	6.69	0.304	0.640	0.19	2.16	0.479
Schooling								
≤6 years	1.14	0.47	2.77	0.757	1.36	0.49	3.80	0.570
>6 years	0.50	0.19	1.25	0.141	0.64	0.19	2.16	0.479
Woman	1.41	0.85	2.52	0.178	1.52	0.91	2.53	0.107
Age, years	0.97	0.35	5.08	0.255	0.97	0.94	1.01	0.292

FI, Food insecurity; SES, Socioeconomic status.
Bold values refers to the fact that they were significant values, however, it is suggested that it is quite bold.

In relation to the prevalences reported in other countries during the pandemic, Giacoman et al. through a longitudinal study based on two population-based surveys in Chile (CASEN 2017 and COVID 2020) found that FI levels went up significantly ($p < 0.001$) between 2017 (30%) and 2020 (49%) mainly in those with economically dependent people (that is, children, adolescents, and older adults). In this last population group, it was found that mild FI went from 12.7% in 2017 to 16.3% in 2020 and moderate-to-severe FI from 14 to 20.6% (20).

In the present study, it was shown that during the COVID-19 pandemic, at a higher degree of FI, there is a greater risk that OAs present anxiety and depression symptoms. This can be explained given the situation of the OAs since they were the ones who were in the greatest confinement due to their high risk of morbidity and mortality. In addition to these adverse effects associated with the pandemic, there was an increase in those OAs with the highest rate of social backwardness (3).

Few studies have analyzed the impact that the pandemic had on the mental health of OAs. Gaitán-Rossi et al. also found that anxiety was associated with higher FI scores during the pandemic, for example, symptoms of anxiety reported in people living in households with FI were 19.3% while in people living in households with severe FI were 57.1% (14). Sepúlveda-Loyola et al. (21) showed through a review that included 20,069 OAs, from Asia, Europe, and America during isolation due to the pandemic, presented a high prevalence of anxiety and depression, with a range of 8.3 to 49.7% and 14.6 to 47.2%, respectively. These results confirm the expected psychoemotional impact and the complex syndemic interaction of mental health and the FI experience during the pandemic (Table 3).

Moreover, in the descriptive analysis, we can observe that 20% of the population reported having stopped consuming fruits, vegetables, and dairy products and more than 30% reported having stopped eating meat, the latter being higher than that reported by Federik et al.

TABLE 4 Logistic regression on the association between food insecurity and anxiety symptoms.

Anxiety symptoms								
	No adjustment				Adjusted			
	OR	CI 95%		*p*	OR	CI 95%		*p*
FI mild	2.437	1.66	3.59	**0.008**	**2.43**	1.66	3.59	**0.000**
FI moderate-to-severe SES	5.323	3.45	8.19	**0.000**	**5.32**	3.45	8.19	**0.000**
2 (C, C− and D +)	0.961	0.44	2.08	0.922	0.88	0.55	1.41	0.609
3 (D and E)	0.685	0.28	1.67	0.407	0.67	0.49	1.09	0.115
Schooling								
≤6 years	0.754	0.32	1.79	0.376	0.70	0.32	1.52	0.376
>6 years	0.963	0.27	2.07	0.586	0.70	0.24	2.07	0.456
Woman	**1.82**	1.25	3.45	**0.030**	1.60	1.18	2.18	**0.020**
Age,years	1.850	1.02	1.35	0.560	0.99	0.96	1.01	0.421

FI, Food insecurity; SES, Socioeconomic status.
Bold values refers to the fact that they were significant values, however, it is suggested that it is quite bold.

(22), who reported less meat consumption in only 11.5% of young adults during the pandemic (Table 4).

The present study has the strength of having used the ENCOVID-19 data source, which has a representative sample of OAs from the 32 states of the Mexican Republic and the survey was carried out month-by-month. However, a limitation of ENCOVID-19 was the insufficient inclusion of people living in rural and isolated locations due to lower mobile phone coverage (9, 10).

Another variable studied was socioeconomic status, which was measured through a reliable asset-based scale suitable for implementation in brief telephone surveys. It has previously been shown, in face-to-face interviews, to be highly associated with income deciles across all states in Mexico and across localities with different population sizes (13). One limitation, however, is that this scale cannot capture changes in economic circumstances and only reflects pre-pandemic SES. However, in the present analysis, there was a higher prevalence of severe FI in households with lower levels of SES and it was associated with a higher risk of FI.

For future analyses, it is important to monitor the interaction of these factors (depression, anxiety, and SES) over time on the effects of FI and health in the older population during the pandemic. Furthermore, comparing these associations with pre-pandemic databases, we were able to measure the impact and incorporate other variables such as functional status, nutritional status, such as diet quality, and anthropometric and health data, such as comorbidity, and access to health services.

Conclusion

There is a high prevalence of food insecurity during the COVID-19 pandemic, occurring in particularly vulnerable populations, such as older adults, in whom being food insecure has a higher risk of anxiety and depression symptoms. Interventions to increase access to healthy foods, especially among minorities and low-income people, and mitigate the socio-emotional effects are crucial to alleviating the economic stress of this pandemic.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The study was reviewed and approved by the Universidad Iberoamericana Research Ethics Committee (CONBIOETHICS-09—CEI-008-2016060). Verbal Informed consent was obtained from all participants.

Author contributions

DA contributed to data and analysis, collection and manuscript writing. L-TM contributed to statistic analysis and manuscript writing. R-CO collaborated in statistic analysis and manuscript review. G-RP contributed to database and manuscript review. A-MM manuscript review. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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ATHLOS Healthy Aging Scale score as the predictor of all-cause mortality in Poland and Czechia

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Background: The ATHLOS consortium (Aging Trajectories of Health–Longitudinal Opportunities and Synergies) used data from several aging cohorts to develop a novel scale measuring healthy aging comprehensively and globally (ATHLOS Healthy Aging Scale). In the present study, we assessed the predictive performance of the ATHLOS Healthy Aging Scale for all-cause mortality in middle-aged and older adults.

Methods: Data from the Polish and Czech HAPIEE (Health Alcohol and Psychosocial factors In Eastern Europe) prospective cohorts were used. There were 10,728 Poles and 8,857 Czechs recruited. The ATHLOS Healthy Aging Scale score was calculated for all participants using data from the baseline examination carried out from 2002 to 2005. The follow-up for all-cause mortality was completed over 14 years. The associations between quintiles of the ATHLOS Healthy Aging Scale and all-cause mortality were estimated using Cox proportional hazards models.

Results: A total of 9,922 Polish and 8,518 Czech participants contributed ATHLOS Healthy Aging Scale and mortality data with 1,828 and 1,700 deaths, respectively. After controlling for age, the ATHLOS Healthy Aging Scale score was strongly associated with mortality in a graded fashion for both genders and countries (hazard ratios for lowest vs. highest quintile were 2.98 and 1.96 for Czech and Polish women and 2.83 and 2.66 for Czech and Polish men, respectively). The associations were only modestly attenuated by controlling for education, economic activity, and smoking, and there was further modest attenuation after additional adjustment for self-rated health.

Conclusion: The novel ATHLOS Healthy Aging Scale is a good predictor of all-cause mortality in Central European urban populations, suggesting that this comprehensive measure is a useful tool for the assessment of the future health trajectories of older persons.

KEYWORDS

healthy aging, scale, mortality, Central and Eastern Europe (CEE), aging

1. Introduction

Populations around the world are aging faster than ever before. The ongoing process is the result of the favorable phenomenon of increasing life expectancy and is exacerbated by the low fertility rate. Achieving healthy aging is an important challenge worldwide. Many initiatives have attempted to operationalize the concepts of healthy aging (1, 2). However, international consensus regarding how healthy aging should be measured, while acknowledging the diversity between populations, has not been fully achieved (3–5).

In 2015, the World Health Organization (WHO) defined healthy aging as "the process of developing and maintaining the functional ability that enables well-being in older age" (6). Functional abilities are health-related attributes that allow people to do what they have reason to value. They can be determined by intrinsic capacities (the composite of all the physical and mental capacities that an individual can draw on) and social environment, as well as the interactions between them. The WHO suggested that building and maintaining intrinsic capacity is the fundamental way of enhancing functional ability. Agreement on metrics, measures and analytical approaches to healthy aging was recognized as an urgent need (6). This has led to attempts to develop common metrics of healthy aging that would allow for comprehensive comparisons of healthy aging profiles globally (6). Developing common metrics of healthy aging would also facilitate cross-country analyses of healthy aging and its determinants within the different societal contexts of older adults (4).

The ATHLOS (Aging Trajectories of Health–Longitudinal Opportunities and Synergies) consortium (7) harmonized aging cohorts worldwide and developed a novel scale to measure healthy aging comprehensively and globally. The ATHLOS Healthy Aging Scale was constructed based on 41 characteristics referring to intrinsic capacity and functional ability (6) using integrated data from over 411,000 individuals from 16 independent aging cohorts, covering 38 countries from all continental regions, which has been believed to be universally applicable for evaluating healthy aging at an individual level (8).

A well-designed index of healthy aging should reflect an individual's biological age and predict mortality independently of calendar age. So far, the ATHLOS Healthy Aging Scale has been found to be inversely and progressively related to 10-year all-cause mortality across six waves of data collection in a sample of nearly 11,000 participants from England (9). This study also found that the older the participants, the stronger the protective effect of the higher scores from the ATHLOS Healthy Aging Scale observed. As the performance of the ATHLOS Healthy Aging Scale may differ across populations, potentially reflecting different stages of social, demographic, and epidemiological transition, more analyses of the scale should be performed in diverse population samples to assess the predictive ability in terms of all-cause mortality.

In this context, Central and Eastern Europe provide interesting settings for a study of healthy aging. In the 1990s and early 2000s, Central and Eastern European countries were experiencing political and economic transitions. After a long period of stagnating or falling life expectancy, which led to a large mortality gap between Eastern and Western Europe, life expectancy has increased dynamically (10).

In this report, we used two Central European prospective population-based cohorts to assess the relationships between the ATHLOS Healthy Aging Scale and all-cause mortality in middle-aged and older adults.

2. Methods

2.1. Data

The Polish and Czech cohorts of the Health, Alcohol and Psychosocial factors In Eastern Europe (HAPIEE project) were established in Krakow (Poland) and six Czech towns between 2002 and 2005 (11). Both cohorts included random samples of men and women aged 45–69 years at baseline, stratified by gender and 5-year age groups. In total, we recruited 10,728 Poles and 8,857 Czechs (the response rate was 61% in Poland and 55% in Czechia). All participants gave written consent. At baseline, participants were interviewed by trained nurses using a standardized questionnaire. Detailed information on health, including physical functioning assessment and mental health and cognitive functioning tests, was collected. Information on education, marital status, occupational status, smoking, and self-rated health was also obtained.

2.2. Mortality information

The Czech cohort was followed up for mortality until 31 December 2018. In Poland, the follow-up was completed by 25 August 2017. In Poland, mortality data from the Central Registry of Residents and the Central Statistical Office were used. In the Czechia, mortality data from the National Death Register was used.

2.3. ATHLOS Healthy Aging Scale

The ATHLOS Healthy Aging Scale was constructed using harmonized data from 16 international cohorts. The harmonization aimed to convert study-specific variables into a priori defined variables and their possible values to provide the same variables format across studies. A list of 41 characteristics referring to intrinsic capacity and functional ability assessed in the studies, covered domains such as vitality, sensory skills, locomotion/mobility, cognition and activities and instrumental activities of daily living. The ATHLOS Healthy Aging Scale was constructed using a two-parameter logistic item response theory model with characteristics related to intrinsic capacity and functional ability, and heterogeneities in the cohort-specific datasets. The item response theory approach targets the explanation of the relationship between latent traits and their manifestations, by establishing a link between the individuals' responses to specific items and the underlying trait, on an assumed continuum. This approach aims at the assessment of the individual's position on the continuum scale (8, 12). The IRT models presented high reliability (>0.90) (8). The obtained score is normally distributed with a mean of 50 and a standard deviation of 10, with higher values indicating better health (8). The ATHLOS Healthy Aging Scale scores were

made for all ATHLOS individuals, including the HAPIEE cohorts, and the estimation took into account non-responses and imputed missing data. The harmonization algorithms of each item per study can be found at URL: https://github.com/athlosproject/athlos-project.github.io. A detailed description of the harmonization procedure and the delivery of the ATHLOS Healthy Aging Scale have been published by Sanchez-Niubo et al. (7, 8).

2.4. Covariates

Based on a previous study (9), age (continuous), gender (binary: men vs. women), marital status (binary: married/cohabiting vs. single/widowed/divorced), education (binary: university vs. lower), occupational status (binary: employed vs. not in work), smoking (binary: ever-smoker vs. never-smoker), and self-rated health (binary: good vs. lower) were considered as potential confounding factors.

2.5. Statistical analyses

All HAPIEE cohort participants who provided consent for mortality follow-up and had complete data for the ATHLOS Healthy Aging Scale and covariates were included in statistical analyses ($N = 9{,}922$ in Poland and 8,518 in Czechia; 94% of the full sample). The distributions of the ATHLOS Healthy Aging Scale and other covariates in men and women were examined separately in each country. Cohorts were divided into five subgroups according to gender-specific quintiles of the ATHLOS Healthy Aging Scale, assessed for the countries combined. The ranges of quintiles for women were: Q1 $\leq$ 40.11; Q2:40.12–45.68; Q3:45.69–51.66; Q4:51.67–57.86; Q5 $>$ 57.86 and for men were: Q1 $\leq$ 43.07; Q2:43.08–50.08; Q3:50.09–55.98; Q4:55.99–60.06; Q5 $>$ 60.06. The reference category was the highest quintile (P5).

Firstly, country differences in sample characteristics at baseline and follow-up time were examined in men and women separately. Secondly, the associations between ATHLOS Healthy Aging Scale scores and all-cause mortality were assessed using four country- and gender-specific Cox proportional hazards models: (1) adjusted for age; (2) additionally adjusted for education; (3) additionally adjusted for marital status, occupational status, and smoking; and (4) additionally adjusted for self-rated health. The proportional hazard assumptions were verified using graphs of the log(-log(survival)) vs. the log of survival time. The timescale was the follow-up time in the study. Pooled analysis (of cohorts and genders) was not performed, since the interactions between the ATHLOS Healthy Aging Scale and country and gender, respectively, were statistically significant Statistical analyses were conducted using Stata version 14.1 (StataCorp LP, TX, USA), and IBM® SPSS, with a *P*-value threshold of $\alpha < 0.05$ for statistical significance.

3. Results

Table 1 shows distributions of age, the ATHLOS Healthy Aging Scale score, and follow-up time by country and gender. In both men and women, Czech participants tended to be older than Polish participants (57.4 vs. 56.9; $p = 0.001$ in women and 58.0 vs. 57.4; $p < 0.001$ in men). The mean ATHLOS Healthy Aging Scale score was higher for Czech women (50.3) than for Polish women (46.7; $p < 0.001$). No significant difference in the mean values of the ATHLOS Healthy Aging Scale score by country was found in men. The median values of follow-up time were approximately 5,500 days in Czechia and 5,000 days in Poland.

Table 2 presents the proportions of deaths by quintile of the ATHLOS Healthy Aging Scale score, country and sex. The differences in numbers within quintiles in Czechia and Poland were mainly a consequence of combining the two countries. In women, 656 and 674 deaths occurred, respectively, in Czechia and Poland. In men, there were 1,044 deaths in Czechia and 1,154 in Poland. The proportion of deaths in both genders and countries increased with the decreased quintile of the ATHLOS Healthy Aging Scale. Between-country differences in the proportion of deaths are largely dependent on the differences in the follow-up time. The distribution of covariates by country and gender is presented in Supplementary Table 1.

The associations between quintiles of the ATHLOS Healthy Aging Scale score and all-cause mortality in women are shown in Table 3. For the Czech women, after adjusting for age, the risk of death for those in the lowest quintile of the ATHLOS Healthy Aging Scale (Q1) was approximately three times higher than those in the highest quintile (Q5). Significant increases in the risk of death were also observed in Q2 (HR = 2.04; 95% CI = 1.59–2.61) and Q3 (HR = 1.39; 95% CI = 1.07–1.80). A dose-response relationship between quintiles of the ATHLOS Healthy Aging Scale score and all-cause mortality was observed. Additional adjustment for education hardly changed the results. Further adjustments for marital status, occupational status, and smoking slightly attenuated the associations in the two lowest quintiles by ~12%. The association in the Q3 group became insignificant. In the final model, after additionally controlling for self-rated health, only a slight reduction in the estimates was observed. Ultimately, compared to women in the Q5 group, women in the Q1 group had over 2.5 times higher risk of death and women in the Q2 group had an ~80% higher risk of death. For the Polish women, significant unadjusted associations between quintiles of the ATHLOS Healthy Aging Scale score and all-cause mortality were observed only in those in the Q1 and Q2 groups. After controlling for age, compared to those in the Q5 group, women in the Q1 group had a nearly twice higher risk of death (HR = 1.96; 95% CI: 1.52–2.52). Further adjustments contributed to the attenuation of the magnitude of the observed association, with the greatest reduction observed in the final model. Eventually, compared to Polish women in the Q5 group, women in the Q1 group had a nearly 40% higher risk of death (HR = 1.38; 95% CI 1.05–1.81).

The associations between quintiles of the ATHLOS Healthy Aging Scale score and all-cause mortality in men are presented in Table 4. In the age-adjusted model for participants from Czechia, compared to men in the Q5 group, men in the Q3, Q2 and Q1 groups had a significantly higher risk of death by 34%, 88% and nearly 3 times, respectively. Further adjustment for covariates slightly attenuated the estimates. The greatest reduction in values of HR was observed in the Q1 group in the fully adjusted model. Nevertheless, the graded associations between

TABLE 1 Distribution of age, ATHLOS Healthy Aging Scale score, and follow-up time by country and gender.

	Czechia					Poland					
	x	SD	Me	Min	Max	*x*	SD	Me	Min	Max	*p*
Women	$N = 4,570$					$N = 5,097$					
Age (years)	57.4	7.1	58.0	44	72	56.9	7.0	56.0	45	70	0.001
ATHLOS Healthy Aging Scale (points)	50.3	8.6	50.3	25.8	63.9	47.5	9.0	46.7	25.8	63.9	<0.001
Follow-up time (days)			5,522	39	6,152			5,004	22	5,656	<0.001
Men	$N = 3,948$					$N = 4,825$					
Age (years)	58.0	7.2	58.0	44	72	57.4	7.0	57.0	45	70	<0.001
ATHLOS Healthy Aging Scale (points)	51.7	8.3	52.6	25.8	63.9	51.3	8.9	53.2	25.8	63.9	0.160
Follow-up time (days)			5,457	20	6,124			4,971	26	5,390	<0.001

x, mean; SD, standard deviation; Me, median; min, lowest value; max, highest value.

TABLE 2 Proportions of deaths by quintiles of ATHLOS Healthy Aging Scale score, country and gender.

	Czechia			Poland		
	N	Died (*n*)	Died (%)	*N*	Died (*n*)	Died (%)
Women						
Q1 ≤ 40.11	615	181	29	1,309	289	22
Q2 40.12–45.68	857	178	21	1,072	130	12
Q3 45.69–51.66	1,046	132	13	922	97	11
Q4 51.67–57.86	772	69	9	859	79	9
Q5 > 57.86	1,280	96	8	935	79	8
Total	4,570	656	14	5,097	674	13
Men						
Q1 ≤ 43.07	667	301	45	1,070	436	41
Q2 43.08–50.08	887	289	33	875	235	27
Q3 50.09–55.98	862	198	23	888	186	21
Q4 55.99–60.06	766	144	19	999	164	16
Q5 > 60.06	766	112	15	993	133	13
Total	3,948	1,044	26	4,825	1,154	24

the ATHLOS Healthy Aging Scale score and all-cause mortality remained significant. Compared to the Czech men in the Q5 group, men from the three lowest quintile groups had a higher risk of death by 20% (P3), 42% (P2) and 85% (P1), respectively. For the men from Poland, after adjusting for age, as well as for age and education, the results of the main associations were similar to those of the Czech men. Adjusting for more covariates contributed to a slight decrease in the estimates. In the final model, the association for Polish men in the Q3 group was insignificant. Ultimately, compared to Polish men in the Q5 group, the men in the two lowest quintile groups had a higher risk of all-cause mortality by 40% and over 2-fold, respectively.

4. Discussion

In a 14-year follow-up, the inverse associations between quintiles of the ATHLOS Healthy Aging Scale and all-cause mortality were found in both men and women in each country. These associations were independent of age, education, marital status, occupational status, smoking and self-rated health. For the Polish women, the strength of the association was lower than for the Czech women and lower than for the men from both countries. The pattern of association may depend to some extent on the baseline distribution of the ATHLOS Healthy Aging Scale scores, which for the Polish women was the lowest.

The results of our study are consistent with the previous analysis of data from England (9). Older people's life expectancy does not depend on health status at older age alone but rather depends on the long-term interaction between individuals' intrinsic capacities and the environment they live in (6). It is therefore an important observation that the ATHLOS Healthy Aging Scale had a similar ability to predict mortality in both Western European and Central and Eastern European countries, i.e., populations exposed to different social contexts during their lives.

TABLE 3 Association between quintiles of ATHLOS Healthy Aging Scale score and all-cause mortality by country for the women.

Women	Czechia					Poland				
ATHLOS Healthy Aging Scale	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
Q5 > 57.86	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q4 51.67–57.86	1.21 (0.89–1.64)	1.08 (0.79–1.46)	1.06 (0.78–1.44)	1.05 (0.77–1.42)	1.04 (0.76–1.42)	1.10 (0.81–1.50)	1.01 (0.74–1.38)	1.00 (0.74–1.37)	0.97 (0.71–1.33)	0.92 (0.68–1.27)
Q3 45.69–51.66	1.82 (1.41–2.35)	1.39 (1.07–1.80)	1.36 (1.05–1.76)	1.27 (0.97–1.65)	1.23 (0.93–1.62)	1.24 (0.93–1.67)	1.04 (0.77–1.40)	1.02 (0.76–1.37)	0.99 (0.73–1.33)	0.87 (0.64–1.18)
Q2 40.12–45.68	3.01 (2.36–3.85)	2.04 (1.59–2.61)	1.96 (1.53–2.53)	1.82 (1.41–2.35)	1.78 (1.35–2.34)	1.45 (1.10–1.91)	1.06 (0.80–1.41)	1.03 (0.77–1.36)	0.98 (0.74–1.30)	0.83 (0.62–1.11)
Q1 ≤ 40.11	4.58 (3.59–5.85)	2.98 (2.32–3.82)	2.80 (2.18–3.61)	2.59 (2.00–3.36)	2.52 (1.90–3.36)	2.80 (2.18–3.58)	1.96 (1.52–2.52)	1.88 (1.46–2.42)	1.70 (1.32–2.20)	1.38 (1.05–1.81)
Age		1.10 (1.08–1.11)	1.10 (1.08–1.11)	1.09 (1.07–1.11)	1.09 (1.07–1.11)		1.09 (1.07–1.10)	1.09 (1.07–1.10)	1.07 (1.06–1.08)	1.07 (1.06–1.08)
University education			0.66 (0.47–0.93)	0.70 (0.49–0.98)	0.70 (0.50–0.99)			0.79 (0.65–0.95)	0.90 (0.74–1.10)	0.92 (0.75–1.12)
Marital status (married or cohabiting)				1.28 (1.10–1.50)	1.29 (1.10–1.51)				1.33 (1.14–1.56)	1.33 (1.14–1.55)
Occupational status (employed)				1.39 (1.11–1.75)	1.40 (1.11–1.76)				2.13 (1.68–2.71)	2.03 (1.60–2.59)
Smoking (ever smoked)				1.49 (1.27–1.74)	1.50 (1.28–1.75)				1.72 (1.48–2.01)	1.74 (1.48–2.03)
Self-rated health (good)					0.96 (0.78–1.17)					0.63 (0.50–0.79)

HR, hazard ratio; CI, confidence interval.

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TABLE 4 Association between quintiles of ATHLOS Healthy Aging Scale score and all-cause mortality by country for the men.

Men	Czechia					Poland				
ATHLOS Healthy Aging Scale	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
Q5 > 60.06	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Q4 55.99–60.06	1.26 (0.99–1.60)	1.21 (0.95–1.54)	1.21 (0.95–1.54)	1.21 (0.94–1.55)	1.18 (0.92–1.51)	1.26 (1.001–1.57)	1.14 (0.91–1.43)	1.14 (0.91–1.43)	1.08 (0.86–1.36)	1.06 (0.84–1.33)
Q3 50.09–55.98	1.60 (1.28–2.00)	1.34 (1.07–1.69)	1.30 (1.03–1.63)	1.29 (1.02–1.62)	1.20 (0.94–1.52)	1.62 (1.30–2.02)	1.31 (1.05–1.63)	1.26 (1.01–1.58)	1.14 (0.91–1.43)	1.12 (0.89–1.40)
Q2 43.08–50.08	2.49 (2.02–3.08)	1.88 (1.52–2.33)	1.78 (1.44–2.21)	1.59 (1.27–1.99)	1.42 (1.12–1.79)	2.18 (1.76–2.70)	1.68 (1.36–2.08)	1.64 (1.33–2.04)	1.45 (1.17–1.80)	1.40 (1.12–1.75)
Q1 ≤ 43.07	3.81 (3.09–4.70)	2.83 (2.29–3.50)	2.68 (2.16–3.32)	2.19 (1.75–2.74)	1.85 (1.45–2.36)	3.67 (3.02–4.45)	2.66 (2.18–3.24)	2.46 (2.02–3.00)	2.14 (1.75–2.62)	2.04 (1.64–2.53)
Age		1.10 (1.09–1.11)	1.10 (1.09–1.11)	1.08 (1.07–1.10)	1.08 (1.07–1.10)		1.08 (1.07–1.09)	1.08 (1.07–1.09)	1.07 (1.06–1.08)	1.07 (1.06–1.08)
University education			0.75 (0.63–0.89)	0.86 (0.71–1.03)	0.87 (0.72–1.04)			0.65 (0.57–0.75)	0.75 (0.64–0.87)	0.76 (0.65–0.88)
Marital status (married or cohabiting)				1.58 (1.36–1.84)	1.58 (1.36–1.84)				1.74 (1.51–2.01)	1.75 (1.51–2.02)
Occupational status (employed)				1.60 (1.37–1.88)	1.57 (1.34–1.84)				1.29 (1.11–1.50)	1.28 (1.10–1.48)
Smoking (ever smoked)				1.87 (1.61–2.17)	1.88 (1.62–2.18)				1.97 (1.69–2.30)	1.97 (1.69–2.29)
Self-rated health (good)					0.75 (0.64–0.88)					0.91 (0.78–1.05)

HR, hazard ratio; CI, confidence interval.

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Our results are consistent with the findings of other studies on particular domains such as mobility, cognition, and activities of daily living. For physical functioning, including locomotion and activities of daily living, several studies found a negative association between objective measures of physical functioning and all-cause mortality. A recent meta-analysis concluded that physical capability is a predictor of all-cause mortality in older adults (13). Further studies have reinforced the conclusion that limitations in physical functioning, defined as having the inability to complete at least one of the performance-based tests (grip strength, timed walk, chair stands, and peak expiratory flow), are associated with approximately twice higher risks of subsequent 4-year mortality (14). For cognitive functions, there is also well-established evidence indicating the inverse relationship between cognitive functions (15–17) and psychosocial factors with mortality (18, 19).

Studies on the relationships between single exposures related to daily functioning and mortality are numerous, and they have provided clear evidence of an adverse relationship between functional limitations and the risk of death in older people. However, the focus on single exposures (of functional domains) might be somewhat detached from "normal life". For example, some older people with physical limitations may still be able to achieve healthy aging if they maintain good levels of cognitive performance and psychosocial wellbeing in their social and natural environment (2, 20). We confirmed the relation between morality and the ATHLOS Healthy Aging Scale which combines both intrinsic capacities and functional abilities in different domains. The advantage of this assessment is that it reflects an overall functioning comprehensively.

Compared to the commonly used frailty index, the ATHLOS Healthy Aging Scale includes more information on functional capabilities. The frailty index focuses more on age-related health deficits. It is considered a proxy measure of biological aging (21, 22) and was also found to be associated with elevated mortality risk (23).

The strengths of our study include using two population-based representative samples to investigate an important yet under-researched epidemiological question in a geographical region with a high risk of total mortality since the late 1990s. Using cohort data, we examined time trends over a period of up to 14 years after baseline data collection. We confirmed a good predictive performance of the ATHLOS Healthy Aging Scale for all-cause mortality in a different socio-economic context from Western Europe. Our results can contribute to a wider acceptance of this standardized healthy aging index.

There are also some limitations that should be considered. First, the ATHLOS Healthy Aging Scale has some limitations in the interpretation of the results, which has been widely discussed by Sanchez-Niubo (8). One important limitation is that data used for the development of the ATHLOS Healthy Aging Scale were among community dwellings. Therefore, this scale might under-represent older people with greater dependency, such as those living in nursing homes, other institutionalized persons, or those with greater cognitive impairments.

Second, the procedure for calculating the score of the ATHLOS Healthy Aging Scale might be difficult to replicate on a smaller scale. The large number of variables used to calculate an individual's ATHLOS Healthy Aging Scale score may not always be available, and this may affect the accuracy of the Healthy Aging Scale estimates. Given the number of measurements required, the tool's usefulness may be limited for large population-based assessments but be less useful for everyday practice. Finally, in the Czech and Polish HAPIEE samples, the response rate was ∼ 60% and it is known that less healthy individuals are less likely to participate in studies such as the HAPIEE study (24). Furthermore, participants who had missing data for the ATHLOS Healthy Aging Scale, mortality information, and covariates were excluded from the analyses. Thus, the studied groups may not be fully representative of the target populations from Czechia and Poland and the associations found in the healthier parts of these populations might be underestimated.

Nevertheless, the ATHLOS Healthy Aging Scale has shifted the approach to measuring healthy aging from "being away from diseases only" to "considering the interaction between persons' intrinsic capacities and the environments they live in". Demonstrating the significant relationship between the ATHLOS Healthy Aging Scale and mortality risk also opens the door to intervention studies that may target strengthening the functional ability in older people by improving their intrinsic capacities and creating aging-friendly environments to enable good functioning for individuals with some functional limitations.

5. Conclusion

In conclusion, the ATHLOS Healthy Aging Scale was a good predictor of all-cause mortality in urban populations of Poland and Czechia. This composite indicator of intrinsic capacity and functional ability may be an important contribution to a better assessment of healthy aging.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by National Institute of Public Health Ethics Committee (Prague, the Czech Republic) and Jagellonian University Medical College Bioethics Committee (Krakow, Poland). The patients/participants provided their written informed consent to participate in this study.

Author contributions

AP, JA-M, MB, HP, AS-N, and JH contributed to the conception and design of the study. MK, KS, and MP organized

the database. KS and MP performed the statistical analysis. MK wrote the first draft of the manuscript. WL and US wrote sections of the manuscript. All authors contributed to the revision of the manuscript and read and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1114497/full#supplementary-material

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Sarcopenia index based on serum creatinine and cystatin C is associated with mortality in middle-aged and older adults in Chinese: A retrospective cohort study from the China Health and Retirement Longitudinal Study

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Background: The sarcopenia index (SI, serum creatinine/serum cystatin C × 100) is recommended for predicting sarcopenia. There were several studies showing that lower SI is associated with poorer outcomes in the older adults. However, the cohorts studied in these researches were mainly patients hospitalized. The aim of this study was to evaluate the correlation between SI and all-cause mortality among middle-aged and older adults from the China Health and Retirement Longitudinal Study (CHARLS).

Materials and methods: A total of 8,328 participants meeting the criteria were enrolled in this study from CHARLS between 2011 and 2012. SI was calculated as [serum creatinine (mg/dL)/cystatin C (mg/L)] × 100. Mann-Whitney *U*-test and Fisher's exact test were used to assess balance in baseline characteristics. Kaplan-Meier, log-rang analysis, univariate and multivariate Cox hazard ratio regression models were used to compare the mortality between different SI levels. The dose relationship between sarcopenia index and all-cause mortality was further assessed by the cubic spline functions and smooth curve fitting.

Results: After adjustment for potential covariates, we found SI was significantly correlated with all-cause mortality [Hazard Ratio (HR) = 0.983, 95% confidence interval (CI) 0.977–0.988, $P < 0.001$]. Similarly, as SI was used as a categorical variable according to quartiles, higher SI was associated with lower mortality [Hazard Ratio (HR) = 0.44, 95% CI 0.34–0.57, $P < 0.001$] after adjustment for confounders.

Conclusions: Lower sarcopenia index was associated with higher mortality among middle-aged and older adults in China.

KEYWORDS

sarcopenia, middle-aged, all-cause mortality, older adults, CHARLS

Introduction

Sarcopenia, which often exacerbates during the aging process, manifests as reduced skeletal muscle mass and weakness of mass strength and/or physical performance (1), Individuals diagnosed with sarcopenia are often associated with function decline, decreased quality of life, even increased risk of mortality (2–5). As the aging of the population poses considerable social challenges, the adverse effect bought by sarcopenia is becoming much more profound.

While several ways were recommended for assessing sarcopenia during hospitalization, the standard criteria for evaluating sarcopenia include low skeletal muscle mass (SMM) and low muscle function. The golden standard of SMM assessment is the medical imaging afforded by computed tomography (CT), magnetic resonance imaging (MRI), and so on. Besides these, low muscle function was evaluated by gait speed. All ways of assessment could be both time-consuming and expensive.

Recently, a novel sarcopenia index (SI) was developed by Kashani et al., which is calculated as [serum creatinine (mg/dL)/cystatin C (mg/dL)] × 100. The SI showed a positive relationship with muscle mass and strength. Besides these, this index also showed a good ability to diagnose sarcopenia in critically ill patients (6). There were also other studies that showed that low SI was associated with poor long-term prognosis in adult ICU patients and hospitalized older patients (6–9). However, most of these studies were based on patients treated in hospitals, while there is a little study investigating the relationship between SI and long-term prognosis among middle-aged and older adults people in the general person.

In this study, we aim at clarifying the relationship between SI and all-cause mortality using data from the China Health and Retirement Longitudinal Study (CHARLS), which was a nationally representative survey.

Methods

Study design and population

The cohort enrolled in this study was obtained from the China Health and Retirement Longitudinal Study (CHARLS), which is held by the National Development Institute of Peking University. More details about this cohort were described in other research papers (10).

Individuals: (1) aged not <45 years old at wave 1; (2) with complete information about serum creatinine and cystatin C in wave 1; (3) followed up at least one time in wave 2, 3, and 4 were included in the cohort. Individuals with eGFR < 30 ml/min/1.73 m^2 were excluded from the study. A total of 8,328 individuals meeting these criteria were enrolled in the final cohort (Figure 1).

All-cause mortality and onset time of death assessment

During the follow-up in wave 2, 3, and 4, the mortality of the participants was assessed by the interview status (alive or dead). While the exact date of death could be extracted from wave 2, there was little information about the exact date of death in wave 3 and 4. Once the death events happened, the survival time was calculated from the date of wave 1 to the death date in wave 2, or the median time from the first interview to the wave that records the death.

Blood sample

The blood collection was executed by the staff of the Chinese Center for Disease Control and Prevention (China CDC) basing on the standard protocol. The fresh venous blood samples were transported at 4°C temperature and sent to the local laboratory, where the whole blood was collected to obtain plasma and buff coat. Then the plasma and buff coat were both frozen at −20°C, transported to Beijing within 2 weeks, and they would be placed in a deep freezer, and stored at −80°C until assay. The creatinine would be measured using the rate-blanked and compensated Jaffe creatinine method, while a particle-enhanced turbimetric assay was used to analyze the cystatin C. Other blood metrics, including Glucose, total cholesterol (TC), TG, low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), Glycated hemoglobin (HbA1c), and so on, were also assayed.

Other covariates

Based on the well-designed questionnaire, the CHARLS-trained interviewers collected information on demographic background, health status, and biomarkers. Demographic background including age, gender (male/female), education level (illiteracy, primary school, middle school, high school, and above), marriage status (married/along), Residence (urban/rural) were collected, Health status including fourteen comorbidities (hypertension, diabetes, dyslipidemia, cancer, kidney disease, stroke, heart problem, chronic lung disease, liver disease, digestive disease, nervous problem, memory-related diseases, arthritis, and asthma) diagnosed by doctor and treatment taken by respondents.

SI was calculated as (serum creatinine divided by serum Cystatin C) × 100. To give a more precise definition, hypertension was re-diagnosed as one of the following criteria: (1) an SBP higher than 140 mm Hg or a DBP higher than 90 mmHg; (2) self-report of a doctor's diagnosis; (3) self-report of the antihypertensive treatment. Diabetes was re-diagnosed as one of the following criteria: (1) self-report of a doctor diagnosis; (2) HbA1c ≥ 6.5%; (3) plasma glucose ≥ 7.0 mmol/L (fasting), or plasma glucose ≥ 11.1 mmol/L (casual); (4) self-report of the glucose-lowering or insulin treatment. Dyslipidemia was re-diagnosed as one of the following criteria: (1) self-report of a doctor diagnosis; (2) total cholesterol (TC) ≥ 240 mg/dL; (3) high-density lipoprotein cholesterol (HDL) ≤ 40 mg/dL; (4) low-density lipoprotein cholesterol (LDL) ≥ 160 mg/dL; (5) triglycerides (TG) ≥ 150 mg/dL; (6) self-report of the anti-dyslipidemia treatment. Kidney disease was re-diagnosed as one of the following criteria: (1) self-report of a doctor diagnosis; (2) self-report of the kidney

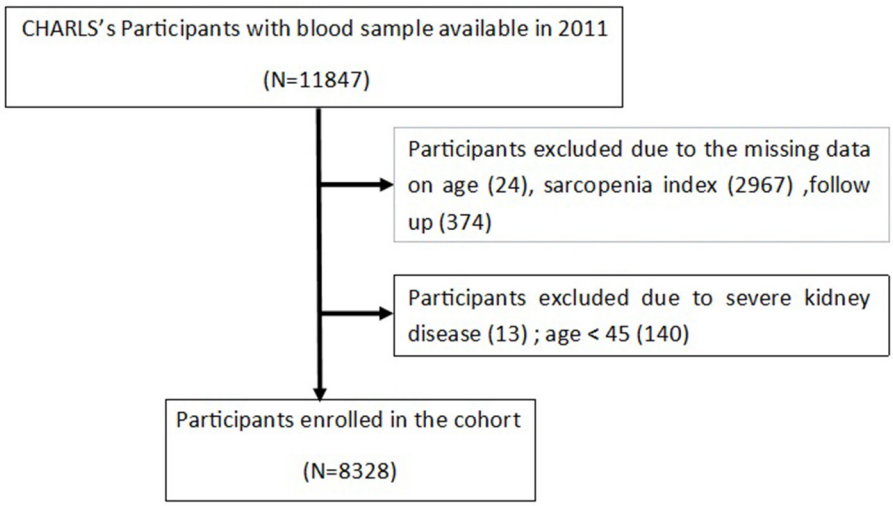

FIGURE 1
The flowchart of study participants.

disease treatment; (3) eGFR <90 ml/min/1.73m^2. Estimated glomerular filtration rates were calculated using the CKD-EPI creatinine formula.

Statistical analysis

Based on the quartile of SI, Participants were divided into four groups (Q1, 8.33–66.53; Q2, 66.53–76.84; Q3, 76.84–89.16; Q4, 89.16–274.43), with quartile 1 as the reference group. All variables were shown as follows: median (IQR) for continuous variables and counts with percentages for categorical variables. Mann-Whitney *U*-test and Fisher's exact test were used to assess balance in baseline characteristics among cohorts with different sarcopenia index levels. The survival curve was plotted with Kaplan-Meier analysis, and the difference in survival was tested by log-rank test. Univariate and multivariate Cox proportional-hazards regression model analyses were used. Variables that showed a significant relationship ($p < 0.1$) with the outcome were included in the step-wise multivariate analysis. Finally, three models were constructed, including a non-adjusted model, a minimally adjusted model (only adjusted for age and gender), and a fully adjusted model (adjusted for age, gender, BMI, education level, marriage status, hypertension, diabetes, eGFR, cancer, chronic lung disease, memory related disease, and smoking). The dose relationship between sarcopenia index and all-cause mortality was further assessed by the cubic spline functions and smooth curve fitting (penalized spline method). Subgroup analyses by gender (male vs. female), age (<60 vs. ≥60 years), BMI (<18.5; 18.5–24; ≥24), residence (rural vs. urban areas), combined with comorbidities or not (hypertension, diabetes, and dyslipidemia), eGFR (< 90; ≥90) were further performed to test the robustness of the results. As SI was calculated through two serum markers, both of which were used to assess the kidney function, Sensitivity analysis was utilized: (1) in participants without a history of cancer and eGFR > 60 ml/min/1.73 m^2; (2) in participants without a history of cancer and eGFR > 90 ml/min/1.73 m^2; (3) in the participants, without a history of kidney disease and cancer; to test the robustness of our findings.

Statistical analyses were performed using SPSS 26.0 (SPSS Inc., Chicago, IL, USA) and R package (version 4.2.1), $P < 0.05$ was considered statistically significant.

Results

Baseline characteristics of study participants

A total of 8,328 individuals were included in the study, of whom 934 (11.2%) died at follow-up. The cohort was categorized into four groups (Q1, Q2, Q3, Q4) based on the quartile of the sarcopenia index. The baseline characteristics are summarized in Table 1. The median age of the cohort was 59 years old, and males accounted for 47.3%. Compared to other groups, participants in Q4 were younger, had a higher proportion of males, with a higher educated level. Besides these, the mortality was 18.0, 11.3, 8.7, and 6.8% in quartiles 1–4.

Relation between sarcopenia index level and all-cause mortality

As is shown in Figure 2, participants with high SI had low mortality during follow-up. Significant differences in the all-cause mortality were shown by Kaplan–Meier curves (log-rank test, $p < 0.001$) among different SI levels. The relationship between SI and all-cause mortality was further assessed in the univariate and multivariate hazard ratio Cox regression model

TABLE 1 Baseline characteristics of the study participants ($N = 8,328$).

	Overall	Q1	Q2	Q3	Q4	
	$n = 8,328$	$n = 2,082$	$n = 2,073$	$n = 2,091$	$n = 2,082$	p
Age	59.00 [53.00, 68.00]	64.00 [56.00, 73.00]	61.00 [54.00, 69.00]	58.00 [51.00, 65.00]	56.00 [50.00, 63.00]	<0.001
Gender, *n* (%)						<0.001
Female	4,386 (52.7)	1,523 (73.2)	1,248 (60.2)	954 (45.6)	661 (31.7)	
Male	3,942 (47.3)	559 (26.8)	825 (39.8)	1,137 (54.4)	1,421 (68.3)	
BMI	23.03 [20.70, 25.68]	22.54 [20.02, 25.38]	22.85 [20.54, 25.42]	23.21 [20.92, 25.70]	23.57 [21.38, 26.12]	<0.001
Education level, *n* (%)						<0.001
Illiteracy	4,075 (49.0)	1,311 (63.0)	1,115 (53.9)	937 (44.9)	712 (34.2)	
Primary school	1,862 (22.4)	413 (19.8)	441 (21.3)	475 (22.7)	533 (25.6)	
Middle school	1,543 (18.5)	237 (11.4)	341 (16.5)	438 (21.0)	527 (25.3)	
High school and above	841 (10.1)	120 (5.8)	173 (8.4)	239 (11.4)	309 (14.8)	
Residence, *n* (%)						<0.001
Rural	6,869 (82.5)	1,827 (87.8)	1,742 (84.1)	1,697 (81.2)	1,603 (77.0)	
Urban	1,455 (17.5)	255 (12.2)	330 (15.9)	392 (18.8)	478 (23.0)	
Marriage status, *n* (%)						<0.001
Unmarried	1,565 (18.8)	543 (26.1)	388 (18.7)	327 (15.6)	307 (14.7)	
Married	6,763 (81.2)	1,539 (73.9)	1,685 (81.3)	1,764 (84.4)	1,775 (85.3)	
Hypertension, *n* (%)	3,690 (44.5)	1,000 (48.2)	931 (45.2)	889 (42.7)	870 (42.0)	<0.001
Diabetes, *n* (%)	1,245 (15.1)	268 (13.0)	281 (13.8)	317 (15.3)	379 (18.3)	<0.001
Dyslipidemia, *n* (%)	4,014 (48.3)	857 (41.2)	579 (28.4)	988 (47.3)	857 (41.3)	<0.001
Kidney disease, *n* (%)	842 (10.2)	190 (9.2)	189 (9.2)	224 (10.8)	239 (11.6)	0.022
Stroke, *n* (%)	208 (2.5)	59 (2.8)	55 (2.7)	49 (2.4)	45 (2.2)	0.502
eGFR (ml/min/1.73 m^2)	93.00 [82.00, 101.00]	96.00 [87.00, 104.00]	94.00 [84.00, 102.00]	93.00 [82.00, 100.50]	89.00 [77.00, 98.00]	<0.001
Cancer, *n* (%)	83 (1.0)	24 (1.2)	24 (1.2)	21 (1.0)	14 (0.7)	0.348
Chronic lung diseases, *n* (%)	904 (10.9)	252 (12.2)	224 (10.9)	221 (10.6)	207 (10.0)	0.158
Liver disease, *n* (%)	315 (3.8)	78 (3.8)	78 (3.8)	75 (3.6)	84 (4.1)	0.889
Heart problem, *n* (%)	1,069 (12.9)	295 (14.3)	283 (13.8)	253 (12.2)	238 (11.5)	0.025
Stomach or digestive disease, *n* (%)	1,939 (23.4)	487 (23.5)	498 (24.1)	496 (23.8)	458 (22.1)	0.444
Nervous problems, *n* (%)	127 (1.5)	42 (2.0)	38 (1.8)	27 (1.3)	20 (1.0)	0.02
Memory related disease, *n* (%)	119 (1.4)	42 (2.0)	31 (1.5)	24 (1.2)	22 (1.1)	0.04
Arthritis or Rheumatism, *n* (%)	2,954 (35.6)	839 (40.4)	734 (35.6)	704 (33.8)	677 (32.7)	<0.001
Asthma, *n* (%)	320 (3.9)	108 (5.2)	82 (4.0)	66 (3.2)	64 (3.1)	0.001
Smoking, *n* (%)	3,293 (39.7)	584 (28.1)	739 (35.8)	930 (44.6)	1,040 (50.1)	<0.001
Drinking, *n* (%)	2,661 (32.1)	660 (31.7)	650 (31.4)	677 (32.5)	674 (32.5)	0.828

BMI, Body mass index; eGFR, estimated glomerular filtration rate.

(Table 2). After adjusting for covariates, the SI showed a negative relationship with all-cause mortality (HR, 0.98; 95% CI, 0.98–0.99) in the cohort. The influence of different SI levels on all-cause mortality was further studied (Table 3). Q4 showed a significantly lower risk of death (HR, 0.36; 95% CI, 0.30–0.43; p for trend < 0.001), this correlation still exists after adjusting for

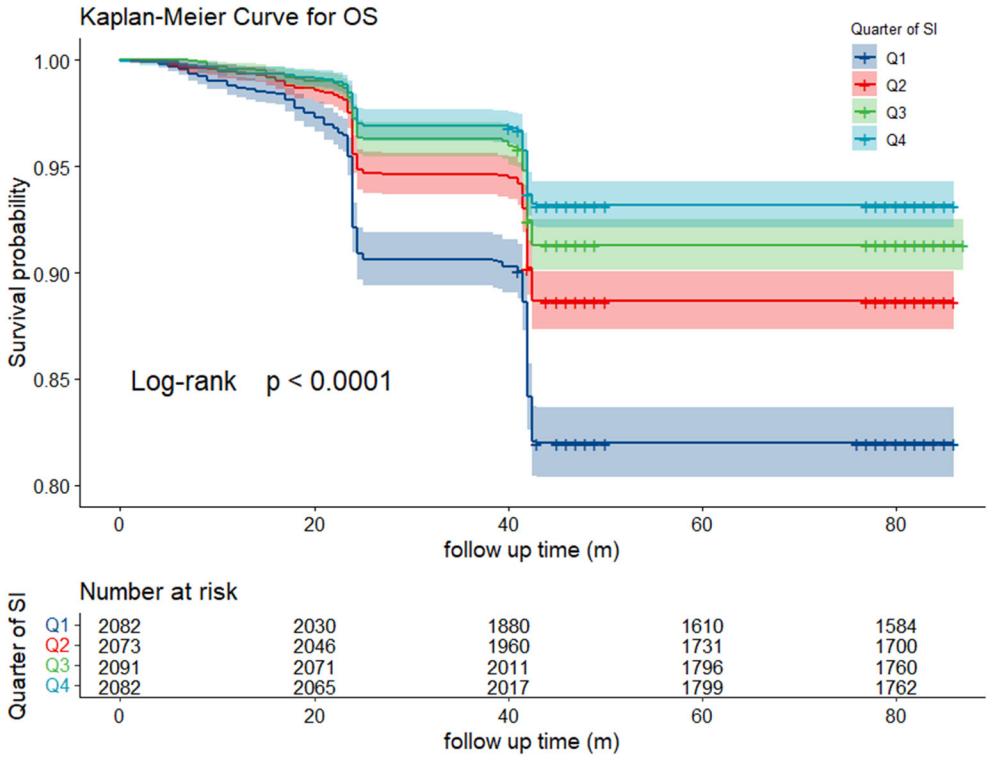

FIGURE 2
Kaplan-Meier curve of survival rate among different SI level.

multiple confounding factors. The restricted cubic spline model showed an L-shaped association between SI and all-cause mortality (Figure 3), with an infection point (SI = 102.72) after adjusting for multiple variables.

Subgroup analyses and sensitive analysis

Subgroup analysis was utilized to clarify the relationship between different levels of SI and all-cause mortality by potential risk factors. As is shown in Table 4, participants with high SI levels showed decreased risk in all-cause mortality among all the analyses. However, as SI was calculated through serum creatinine and cystatin C, both of which are important markers in evaluating kidney function, sensitivity analysis was conducted. The results were consistent with previous analysis (Supplementary Tables 1–3).

Discussion

Though the correlation between SI and all-cause mortality was studied in several studies, our study was the first to evaluate this relationship in middle-aged and older adults Chinese. As the result shows, SI level showed a positive relationship with survival rate. Differences in survival rate were further compared among different levels of SI. Participants with the lowest SI level showed the highest mortality compared to other groups, which was after multivariate adjustment. Among the cohort, patients with higher SI had lower mortality, meaning SI could be an effective marker for assessing mortality in middle-aged and older adults Chinese.

Serum creatinine (SCr) and cystatin C (CysC) is serum markers used to evaluate the glomerular filtration rate (GFR) and renal function (11, 12). As the SCr was mainly generated in muscle from phosphocreatine and creatine, the amount of skeletal muscle mass had a profound impact on SCr secreted into circulation. The concentration of SCr is often maintained as the muscle mass is stable. However, such factors, including aging, gender, chronic illness, and augmented renal clearance, could lead to a fluctuation in SCr (13, 14). Though there were some studies clarifying the relationship between low SCr and adverse events (6, 13, 15, 16), the fluctuation of SCr often limits the wide usage of Scr. CysC, which is metabolized by the proximal tubular cells, is excreted by all nucleated cells. CysC often keeps at a stable level without any fluctuation, leading to a conclusion that the impact of muscle mass on CysC is significantly <SCr. Considering the characteristic of SCr and CysC, SI was developed by (SCr / Cysc) *100 to assess sarcopenia (17). Our study shows the relationship between low SI and all-cause mortality. Patients with low SI often suffer from losing SMM. Patients with a low level of SMM often suffer from different kinds of diseases. Many studies indicated the relationship between SMM loss and reduction of life quality. For the correlation between SI and SMM, it is not surprising to make

TABLE 2 Univariate and multivariate analysis the relationship between SI and all-cause mortality.

Characteristics	Univariate		Multivariate	
	HR (95% CI)	*P*	HR (95% CI)	*P*
Sarcopenia index	0.98 (0.98–0.98)	<0.001	0.98 (0.98–0.99)	<0.001
Age	1.10 (1.09–1.11)	<0.001	1.06 (1.05–1.07)	<0.001
Gender	1.66 (1.46–1.89)	<0.001	1.80 (1.46–2.23)	<0.001
BMI	0.90 (0.88–0.91)	<0.001	0.96 (0.94–0.98)	<0.001
Education level	0.69 (0.64–0.74)	<0.001	0.87 (0.79–0.95)	0.003
Residence	0.78 (0.65–0.94)	0.009		
Marriage status	0.49 (0.43–0.56)	<0.001	0.82 (0.70–0.98)	0.026
Hypertension	1.73 (1.51–1.96)	<0.001	1.26 (1.08–1.47)	0.004
Diabetes	1.49 (1.27–1.75)	<0.001	1.45 (1.20–1.75)	<0.001
Dyslipidemia	0.94 (0.83–1.07)	0.058		
Kidney disease	2.63 (2.29–3.01)	<0.001		
Stroke	2.74 (2.09–3.58)	<0.001		
eGFR	0.97 (0.96–0.97)	<0.001	0.98 (0.98–0.99)	<0.001
Cancer	1.75 (1.05–2.92)	0.031	2.52 (1.45–4.37)	0.001
Chronic lung diseases	2.00 (1.70–2.36)	<0.001	1.46 (1.21–1.76)	<0.001
Liver disease	1.24 (0.92–1.69)	0.163		
Heart problem	1.29 (1.08–1.54)	0.005		
Stomach or digestive disease	0.83 (0.70–0.97)	0.018		
Nervous problems	1.55 (1.00–2.39)	0.048		
Memory related disease	3.17 (2.27–4.42)	<0.001	1.66 (1.10–2.53)	0.017
Arthritis or Rheumatism	0.92 (0.81–1.06)	0.252		
Asthma	2.00 (1.56–2.57)	<0.001		
Smoking	1.67 (1.47–1.90)	<0.001	1.30 (1.07–1.58)	0.007
Drinking	0.91 (0.79–1.04)	0.165		

HR, hazard ratio; CI, confidence interval; BMI, Body mass index; eGFR, estimated glomerular filtration rate.

a conclusion that low SI could be a good marker of predicting the patients' prognosis.

As SI was developed in recent years, there were several studies evaluating the relationship between SI and all-cause mortality. In a retrospective study shown by Kashani et al. (6), 226 high-risk adults in ICU were recruited, and lower SI was a risk factor for in-hospital and 90-day mortality. Tang et al. explored the relationship in hospitalized older patients (9), SI showed a significant association with all-cause mortality after 3-year follow-up. Ren et al. further investigated this in a prospective study (8). After the median follow-up period of 212 days, the SI showed a close relationship with long-term mortality, malnutrition, and sarcopenia in older Chinese patients. Our results were in consists with these previous studies, which indicated the predictive effect of SI on all-cause mortality. There were also some studies exploring the relationship between SI and adverse events in clinical patients. According to the study held by Suzuki et al. (12), SI was correlated with chemotherapy-related adverse effects in patients diagnosed with lung cancer. A multicenter prospective study held by Komorita et al. showed a close relationship between lower SI and fractures in patients with T2DM (18). Among these studies, participants with abnormal kidney dysfunction were excluded. To further testify to the effectiveness of our results, sensitivity analysis and subgroup analysis were both put into practice, both of which were consistent with the previous conclusion. Though the accuracy of SI in predicting sarcopenia was confirmed in a previous study, other studies argued that the relationship between SI and SMM was debatable (19), and needed further study. For the limited information given by CHARLS database, the relationship between SI and sarcopenia was not testified in this study. However, for the promise of SI in predicting adverse events, further prospective study was needed to confirm the relationship between SI and sarcopenia and adverse events.

One major strength of our study was that this was the most significant cohort enrolled to analyze the relationship between sarcopenia index and all-cause mortality. Besides this, this study also brought the sarcopenia index more clinically possess

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TABLE 3 Association between SI and all-cause mortality in different model.

Quintiles of sarcopenia index		No. of events/No. of participants	Model 1		Model 2		Model 3		Non-linear *p*-value
			HR (95% CI)	*p*	HR (95% CI)	*p*	HR (95% CI)	*p*	
Sarcopenia index (continue)			0.98 (0.97–0.98)	<0.001	0.99 (0.98–0.99)	<0.001	0.98 (0.98–0.99)	<0.001	<0.001
Sarcopenia index (quartile)									
	Q1	375/2,082	Ref.	-	Ref.	-	Ref.	-	
	Q2	235/2,073	0.61 (0.52–0.71)	<0.001	0.70 (0.59–0.83)	<0.001	0.63 (0.52–0.76)	<0.001	
	Q3	182/2,091	0.46 (0.39–0.55)	<0.001	0.61 (0.51–0.74)	<0.001	0.50 (0.40–0.63)	<0.001	
	Q4	142/2,082	0.36 (0.30–0.43)	<0.001	0.55 (0.45–0.68)	<0.001	0.44 (0.34–0.57)	<0.001	
	P for trend		-	<0.001	-	<0.001	-	<0.001	

HR, hazard ratio; CI, confidence interval.
Model 2: adjusted by age and gender.
Model 3: adjusted by age, gender, BMI, education level, marriage status, hypertension, diabetes, eGFR, cancer, chronic lung disease, memory related disease, and smoking.

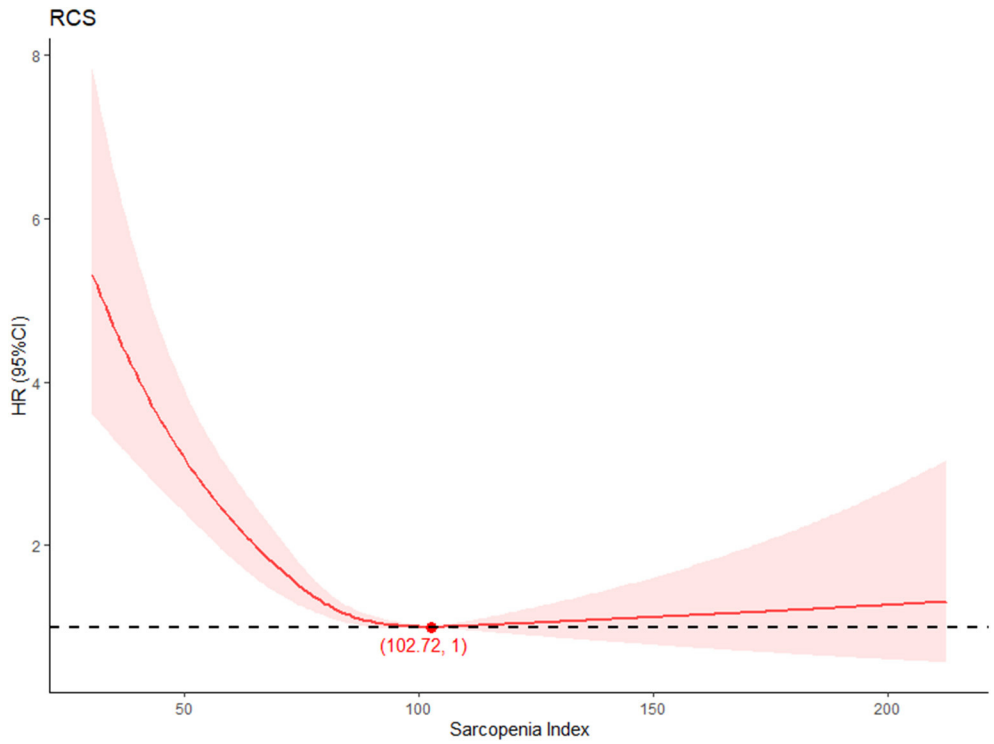

FIGURE 3
Dose-response relationship between SI level and all-cause mortality.

value. However, there were still some limitations that should be noticed. First, due to the details collected by CHARLS, most of the exact death date was ambiguous during the research, which unavoidable brought bias to the survival analysis. Second, all the health information, including the chronic disease, was collected based on the self-report by participants. However, some participants might be unaware of their diseases. Multiple measures, including laboratory tests and treatment messages, were all collected to alleviate this bias. Third, all the data used in this study originated from the CHARLS, which was a

TABLE 4 Subgroup analysis of HRs (95% CIs) of SI for all-cause mortality.

	Q1	Q2	Q3	Q4	*P* for trend	*P* for interaction
	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)		
Gender						0.291
Male	1.00 (Ref)	0.66 (0.51–0.85)	0.50 (0.38–0.66)	0.43 (0.31–0.59)	<0.001	
Female	1.00 (Ref)	0.57 (0.42–0.77)	0.49 (0.33–0.73)	0.44 (0.28–0.71)	<0.001	
Age						0.872
Age < 60	1.00 (Ref)	0.52 (0.30–0.91)	0.55 (0.33–0.93)	0.34 (0.18–0.61)	0.001	
Age ≥ 60	1.00 (Ref)	0.55 (0.45–0.67)	0.36 (0.28–0.45)	0.32 (0.24–0.42)	<0.001	
BMI						0.064
<18.5	1.00 (Ref)	0.61 (0.39–0.97)	0.37 (0.19–0.69)	0.18 (0.06–0.61)	<0.001	
18.5–24	1.00 (Ref)	0.62 (0.48–0.80)	0.55 (0.41–0.75)	0.56 (0.40–0.78)	<0.001	
≥24	1.00 (Ref)	0.68 (0.47–1.00)	0.48 (0.31–0.74)	0.34 (0.21–0.56)	<0.001	
Residence						1
Urban	1.00 (Ref)	0.40 (0.23–0.69)	0.31 (0.17–0.56)	0.24 (0.12–0.46)	<0.001	
Rural	1.00 (Ref)	0.67 (0.55–0.82)	0.54 (0.43–0.69)	0.48 (0.37–0.64)	<0.001	
Hypertension						0.008
With	1.00 (Ref)	0.58 (0.45–0.74)	0.45 (0.33–0.60)	0.48 (0.35–0.66)	<0.001	
Without	1.00 (Ref)	0.72 (0.53–0.97)	0.62 (0.44–0.87)	0.42 (0.27–0.64)	<0.001	
Diabetes						0.103
With	1.00 (Ref)	0.54 (0.34–0.86)	0.48 (0.29–0.80)	0.46 (0.28–0.77)	0.006	
Without	1.00 (Ref)	0.62 (0.50–0.77)	0.50 (0.39–0.64)	0.43 (0.32–0.57)	<0.001	
Dyslipidemia						0.12
With	1.00 (Ref)	0.74 (0.55–0.98)	0.54 (0.39–0.75)	0.51 (0.36–0.73)	<0.001	
Without	1.00 (Ref)	0.54 (0.42–0.70)	0.48 (0.36–0.66)	0.39 (0.27–0.56)	<0.001	
eGFR						0.548
eGFR < 90	1.00 (Ref)	0.64 (0.50–0.82)	0.46 (0.35–0.61)	0.50 (0.37–0.67)	<0.001	
eGFR ≥ 90	1.00 (Ref)	0.67 (0.49–0.91)	0.79 (0.56–1.12)	0.54 (0.35–0.84)	0.008	

BMI, Body mass index; eGFR, estimated glomerular filtration rate.
In the multivariate models, confounding factors such as age, gender, BMI, education level, marriage status, hypertension, diabetes, eGFR, cancer, chronic lung disease, memory related disease, and smoking were included unless the variable was used as a subgroup variable.

representative national middle-aged and older adults database in China. It was unclear whether the conclusion could be applied to other countries.

Conclusion

This study explored the relationship between SI and all-cause mortality among middle-aged and older adults Chinese. As the result shows, low SI was closely related to elevated mortality. More attention should be paid to individuals with low SI. The sensitivity analysis also confirmed the relationship.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Biomedical Ethics Review Committee of Peking University (IRB00001052-11015). The Ethics Committee waived the requirement of written informed consent for participation.

Author contributions

YW, HW, and YT: methodology, writing, and revision. XZ, YL, QL, and JR: data curation and investigation. CL: supervision, reviewing, and editing the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1122922/full#supplementary-material

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The subjective perception of the happiness of older adult residents in Colombia

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Introduction: Happiness is understood as the perception of subjective well-being, it can be a quality, a result, or a state characterized by well-being or satisfaction that every person wants to achieve. In older adults, this satisfaction is a sum of lifelong achievements and triumphs; However, some factors influence this ideal.

Objective: Analyze demographic, family, social, personal, and health factors associated with the subjective perception of happiness in older adults, using data from a study conducted in five cities in Colombia, in order to make a theoretical contribution in the search for improvement of their physical, mental and social health.

Materials and methods: A quantitative, cross-sectional, analytical study was carried out, using primary source information, obtained with 2,506 surveys from voluntary participants aged 60 and over, who had no cognitive impairment, and who reside in urban areas but not in long-term centers. The variable happiness (classified as high or moderate/low) was used for: (1) A univariate explorative characterization of older adult, (2) a bivariate estimation of the relationships with the factors studied, and (3) a multivariate construction of profiles through multiple correspondences.

Results: 67.2% reported high happiness levels, with differences by city: Bucaramanga (81.6%), Pereira (74.7%), Santa Marta (67.4), Medellín (64%), and Pereira (48.7%). Happiness was explained by the absence of risk of depression and little hopelessness, strengthened psychological well-being, a perception of high quality of life, and living in a functional family.

Conclusion: This study provided an overview of possible factors that can be enhanced and strengthened with public policies (structural determinant), community empowerment, family strengthening (intermediate determinant), and educational programs (proximal determinant). These aspects are included in the essential functions of public health, in favor of mental and social health in older adults.

KEYWORDS

older person, happiness, aging, subjective well-being, mental health

Introduction

The term happiness, sometimes interchangeable with life satisfaction, is used for the affective appraisal of life and is synonymous with the hedonic level of effect or subjective well-being in three components: affective well-being, eudemonic well-being, and evaluative well-being (1). Happiness is an essential factor for healthy aging, and there is a growing interest in the role that positive affect plays in improved health, lower mortality, decreased morbidity, and functional independence, in both community and clinical populations (2).

Happiness is understood as a vital experience of the human condition. In general, humans desire and seek happiness. It consists of the sensory, affective, and evaluative experiences of feeling good and how well life goes (3). Higher levels of well-being increase survival in older adults (4).

The importance of the concept of happiness is evident; The General Assembly of the United Nations declared March 20 as the "International Day of Happiness" to recognize it as a universal aspiration to be considered in government policies (5). According to the report on world happiness 2021, Colombia ranked 66/146 (6); it dropped in comparison to the previous years.

Latin Americans have a high subjective perception of happiness, as reported by its citizens (7). This is a paradox due to the region's high poverty rates, inequities, and low access to social and health services, compared to some European countries (8). In different countries, such as Chile, Bhutan, France, and England, the measurement of happiness has been incorporated into their censuses and household surveys (9).

In a study carried out in three Colombian cities (2016), it was found that a better quality of life increases the probability that older persons are happier. The study found that the conditions related to education, health, habits, community, and family support contribute to this perception of happiness, with the coastal city of Barranquilla having the happiest group (10). Likewise, in the city of Manizales, it was found that the experience of well-being is strengthened by access to different material resources (11).

Affective, family and social bonds, and social support, generate positive feelings, this subjective expression of personal well-being also includes an evaluation of one's own emotional state and satisfaction with life (12). The concept of happiness must be observed in its integrality. A study conducted in Bhutan suggests that such perception is holistic, that is, it is obtained when the spiritual, material, and social needs of the human being are achieved. This welfare state generates a vision of balanced progress, related to good health and the World Health Organization (WHO) considers it an indicator of development (13).

Physical, psychological, and social well-being are part of a good aging process, it includes individual, social, cultural, economic, and environmental aspects. High levels of subjective well-being, such as feelings of happiness, enjoyment, personal aspirations, and achievements can increase health, fitness, and longevity, leading to happy older people living longer and better lives (14).

The fundamental properties of happy behavior are personal satisfaction, possession of goods, achievement of goals, and the absence of negative emotional states (15). Despite efforts to quantify the state of happiness, this notion is still under construction and constantly re-evaluated as it has been studied with a multidisciplinary approach.

Happiness is an affective state of satisfaction subjectively experienced by an individual in possession of desired goods (16). It is from this definition that Alarcón (15) proposed that happiness has the following characteristics: (a) Happiness is an emotion of satisfaction experienced by an individual in his or her inner life, with subjective elements that allow for the individualization happiness; (b) Happiness is a state of conduct, which refers to its temporary nature, so it can be enduring or perishable; (c) Happiness implies the possession of goods, that is, the desired objects cause the individual to be happy; (d) The things that produce happiness have diverse traits (material, ethical, esthetic, psychological, religious, social, etc.) to which an individual assigns a certain value; (e) At a given time and in a particular cultural or society, group desires could coincide in the aspiration of a certain asset or specific assets. This definition includes the substantive characteristics of happiness.

In general, the measurement and study of happiness in older adults can be analyzed as proposed by Lyubomirsky (17), who considers that happy people are successful through multiple domains of life, for example, friendship, income, job performance, and health. Those who perceive themselves as happy adapt better to everyday experiences with decision-making, the perception and interpretation of social situations, and the recovery from negative events such as failure. Happiness in old age and its relationship with the improvement of physiological and immune parameters (18) have been shown in the results of medical treatments. These also improve the perception of levels of quality of health care (19).

Materials and methods

Objective

We sought to analyze the demographic, family, social, personal, and health factors associated with the subjective perception of happiness in older adults, in five Colombian cities (Bucaramanga, Medellín, Pereira, Popayan, and Santa Marta), to contribute to the improvement of their physical, mental, and social health.

Design

A quantitative, cross-sectional, analytical, primary source study was carried out based on 2,506 surveys of people over the age of 60, residing in the urban area of the cities of Bucaramanga, Medellín, Pereira, Popayan, and Santa Marta, participation was voluntary, and required written consent. Those with cognitive impairment according to the Mini-Mental State Examination (MMSE) (20) were excluded. Older adults under the influence of psychoactive substances, those with hearing limitations, and those residing in long-term care centers were also excluded.

Population

The reference population included 681,715 people aged 60 or over, residing in the urban areas of Bucaramanga (96,748), Medellín (407,879), Pereira (78,127), Popayan (42,710), and Santa Marta (56,251) according to the population projections of the Administrative

Department of National Statistics (21). The selection of the cities corresponded to two criteria: geographical location, for which the country was divided into five regions, and a city was taken from each of these (north, south, eastern, western, and central). The second criterion was the size of the older adult population, seeking to have cities with different population sizes. In each city, approximately 500 older people were selected, corresponding to the sample size required to achieve the representation of the variables of interest. The selection was carried out by cluster sampling in two stages: (a) random selection of 51 neighborhoods in each city, and (b) random selection of two blocks per neighborhood (102 per city). The final unit of analysis was all older adults residing in houses in the selected blocks. Older adults were surveyed simultaneously in all five cities, by a group of trained surveyors in each city, at different times of day and different days of the week. The final probabilities of selection and expansion factors were calculated for each older adult in each of the cities studied. Finally, the sampling error was 1.7%.

Description of variables

Independent variables were grouped into demographic, family, social, personal, and health factors. These variables were measured with validated scales, prior authorization of their authors, and signing of the written consent by participants. The ethical considerations were approved by an Institutional Ethics Committee and by the entities funding the study (titled *Salud y Bienestar mental de la persona mayor, en cinco ciudades de Colombia, año 2021,* in its original language).

Happiness

The Reynaldo Alarcón Lima scale (15) has the purpose of measuring happiness in the subscales: absence of deep suffering, satisfaction with life, personal fulfillment, and joy of living. The scale is made up of 27 Likert-type items, with five alternatives: totally agree, agree, neither agree nor disagree, disagree, and totally disagree. It allows happiness to be classified into three categories: high, moderate, and low. Previous validations showed that it is a reliable scale, with an acceptable internal consistency, with a Cronbach's alpha of 0.84 (22). The scale was adapted and validated for older adults with 14 items grouped into four dimensions (23) and applied to other population groups in Latin America: Venezuela (24), Argentina (25), and Mexico (26).

Data analysis

To characterize adults according to demographic, family, social, personal, and health factors, qualitative variables were taken, and frequency measures were used. Descriptive measures were calculated for quantitative variables, and the Kolmogorov–Smirnov test was used to determine normality.

To estimate the subjective perception of happiness in older adults, hypothesis tests were used, such as Chi-square, with value of p, and a statistical association was considered with a value of p of < 0.05. The dependent variable was recategorized as high (totally agree + agree) and moderate-low (neither agree nor disagree + disagree + totally disagree), to build comparable groups.

For the purpose of associating happiness with demographic, family, social, personal, and health status factors, the Chi-square test was used. Crude measures of association (prevalence ratios—PRc) were calculated; and subsequently, the association was adjusted with those that were significant ($p < 0.05$), with potentially confounding variables following those described in the literature on the subject and that did not present collinearity, obtaining from this adjusted association measures (RPa) with their respective confidence intervals, through stratified analysis and logistic regression techniques for explanatory or adjustment purposes.

A multiple correspondence model was estimated to look at the conditions of older adults with high and those with a moderate/low perceptions of happiness. For the statistical analysis of the data, the statistical package IBM SPSS Statistics for Windows version 25 (IBM Corp., Armonk, NY, United States) was used.

This article is derived from a study entitled "Mental health and well-being of older adults, in five cities of Colombia, year 2020" (*Salud y Bienestar mental de la persona mayor, en cinco ciudades de Colombia, año 2021,* in its original language). It was approved by the ethics committee of the CES University, classified as having minimal risk (Act 134 of May 23, 2019) and participants were required to sign informed written consent.

Results

Characteristics of older adults according to demographic, family, social, personal, and health factors

Information was obtained from 2,506 older adults, residents of five cities in Colombia: Bucaramanga, Medellin, Pereira, Popayan, and Santa Marta, each representing approximately 20% of the total sample. In relation to sex, Bucaramanga had the highest rate of female participants with 62.6%, men ranged from 37.4 to 54.25% between the cities. It was found that five out of every ten older adults were between 60 and 69 years old. The mean age was approximately 68, with a range of 45 years, from 60 to 105, which was the oldest. The most frequent marital status reported was, no partner, representing more than 57.5% approximately, although it is noteworthy that for the city of Santa Marta three out of five older adults are married or in a free union. It was found that 3 out of 100 older adults were not health system affiliation (health insurance), with greater intensity in Santa Marta. Six out of ten stated that they have no income, and of those who reported income, 50% earn around COP 500.000, and 75% earn around COP 980.000 (Table 1).

It was found that more than half of older adults may have an episode of clinical depression, and three out of five manifested mild hopelessness, although it is noteworthy that in the case of Santa Marta, this increases to approximately four. In relation to the ability to face new challenges or opportunities, they state that they have low resilience (Table 1).

Happiness and its associated factors

When analyzing behavior each of the factors that could be related to happiness, statistical differences were found in income, risk of

TABLE 1 Percentage distribution of older adults, according to demographic, family, social, personal, and health status factors.

Characteristics	City										Total	
	Bucaramanga		Medellín		Pereira		Popayan		Santa Marta			
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Sex												
Male	187	37.4	199	39.8	266	52.7	230	45.9	271	54.2	1,153	46.0
Female	313	62.6	301	60.2	239	47.3	271	54.1	229	45.8	1,353	54.0
Age group												
60–69	278	55.6	328	65.6	285	56.4	223	44.5	295	59.0	1,409	56.2
70–79	173	34.6	137	27.4	156	30.9	191	38.1	166	33.2	823	32.8
80 or over	49	9.8	35	7.0	64	12.7	87	17.4	39	7.8	274	10.9
Marital status												
Single	91	18.2	110	22.0	166	32.9	132	26.3	104	20.8	603	24.1
Married—partners	195	39.0	215	43.0	181	35.8	202	40.3	272	54.4	1,065	42.5
Separated—divorced	69	13.8	80	16.0	79	15.6	50	10.0	34	6.8	312	12.5
Widowed	145	29.0	95	19.0	79	15.6	117	23.4	90	18.0	526	21.0
Healthcare provider affiliation												
Yes	489	97.8	491	98.2	486	96.2	495	98.8	480	96.0	2,441	97.4
No	11	2.2	9	1.8	19	3.8	6	1.2	20	4.0	65	2.6
Income category												
Less than 1 min. Salary	207	41.4	199	39.8	118	23.4	238	47.5	92	18.4	854	34.1
Between 1 and 2 min. Salaries	57	11.4	16	3.2	15	3.0	15	3.0	59	11.8	162	6.5
More than 2 min. Salaries	12	2.4	2	0.4	2	0.4	2	0.04	32	6.4	50	2.0
Without income	224	44.8	283	56.6	370	73.3	246	49.1	317	63.4	1,440	57.5
Risk of depression												
Normal	334	66.8	178	35.6	177	35.0	393	78.4	176	35.2	1,258	50.2
Clinical depression	166	33.2	322	64.4	328	65.0	108	21.6	324	64.8	1,248	49.8
Hopelessness												
Normal or asymptomatic	190	38.0	108	21.6	17	3.4	158	31.5	70	14.0	543	21.7
Light	246	49.2	284	56.8	262	51.9	261	52.1	397	79.4	1,450	57.9
Moderate–severe	64	12.8	108	21.6	226	44.8	82	16.4	33	6.6	513	20.5
Resilience												
Low	454	90.8	498	99.6	502	99.4	470	93.8	493	98.6	2,417	96.4
High	46	9.2	2	0.4	3	0.6	31	6.2	7	1.4	89	3.6
Mistreatment												
Not mistreated	174	34.8	100	20.0	232	45.9	306	61.1	232	46.4	1,044	41.7
Have suffered some kind of mistreatment	326	65.2	400	80.0	273	54.1	195	38.9	268	53.6	1,462	58.3
Psychological wellbeing												
Great strength	256	51.2	56	11.2	166	32.9	233	46.5	238	47.6	949	37.9
Without strength	244	48.8	444	88.8	339	67.1	268	53.5	262	52.4	1,557	62.1
Quality of life												
Low	124	24.8	203	40.6	231	45.7	104	20.8	102	20.4	764	30.5
Moderate	166	33.2	240	48.0	151	29.9	223	44.5	279	55.8	1,059	42.3
High	210	42.0	57	11.4	123	24.4	174	34.7	119	23.8	683	27.3

(Continued)

TABLE 1 (Continued)

Characteristics	City										Total	
	Bucaramanga		Medellín		Pereira		Popayan		Santa Marta			
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Compulsive gambling												
Without problems	51	54.8	20	42.6	20	35.1	10	30.3	5	11.6	106	38.8
Some problems	42	45.2	27	57.4	24	42.1	23	69.7	27	62.8	143	52.4
Probable compulsive gambler	0	0.0	0	0.0	13	22.8	0	0.0	11	25.6	24	8.8
Family functionality												
Normal	432	86.4	344	68.8	370	73.3	421	84.0	343	68.6	1910	76.2
Light dysfunction	37	7.4	90	18.0	98	19.4	52	10.4	106	21.2	383	15.3
Moderate dysfunction	13	2.6	21	4.2	20	4.0	20	4.0	27	5.4	101	4.0
Severe dysfunction	18	3.6	45	9.0	17	3.4	8	1.6	24	4.8	112	4.5
Drug misuse												
No consumption	428	85.6	364	72.8	410	81.2	458	91.4	411	82.2	2071	82.6
1 substance	55	11.0	106	21.2	55	10.9	36	7.2	71	14.2	323	12.9
2 or more substances	17	3.4	30	6.0	40	7.9	7	1.4	18	3.6	112	4.5
Of incapacity												
Without risk	30	6.0	8	1.6	4	0.8	15	3.0	13	2.6	70	2.8
High risk	470	94.0	492	98.4	501	99.2	486	97.0	487	97.4	2,436	97.2
Happiness												
High	408	81.6	320	64.0	246	48.7	374	74.7	337	67.4	1,685	67.2
Low to moderate	92	18.4	180	36.0	259	51.3	127	25.3	163	32.6	821	32.8
Life satisfaction												
High	447	89.4	412	82.4	323	64.0	398	79.4	456	91.2	2036	81.2
Low to moderate	53	10.6	88	17.6	182	36.0	103	20.6	44	8.8	470	18.8
Personal fulfillment												
High	430	86.0	406	81.2	347	68.7	367	73.3	421	84.2	1971	78.7
Low to moderate	70	14.0	94	18.8	158	31.3	134	26.7	79	15.8	535	21.3
Positive attitude to life												
High	235	47.0	140	28.0	160	31.7	280	55.9	108	21.6	923	36.8
Low to moderate	265	53.0	360	72.0	345	68.3	221	44.1	392	78.4	1,583	63.2
Enjoyment of life												
High	287	57.4	251	50.2	264	52.3	341	68.1	149	29.8	1,292	51.6
Low to moderate	213	42.6	249	49.8	241	47.7	160	31.9	351	70.2	1,214	48.4

Five Colombian cities included, 2021.

depression, hopelessness, psychological well-being, quality of life, and family function. These conditions being the ones used to adjust the measure of association (Table 2).

Likewise, it is possible that for every person who is at risk of clinical depression and is happy, 1.51 persons do not have any risk of depression and are happy, but when doing the multivariate analysis, with the other variables, it was found that those who did not present this risk are 1.16 higher than those with clinical depression. It is observed in the crude association measures of the five final variables, that the prevalence ratio is underestimated, and once possible confusion factors were controlled, the strength of the association increased, preserving the statistical association in the relationship. Similarly, there is an increase when there is a better quality of life PR 1.91 (1.76–2.08) and there is no hopelessness 2.52 (2.23–2.85; Table 3).

Profile of older adults according to their subjective perception of happiness

A profile of people who are not happy, present clinical depression, have a low quality of life, present severe or moderate hopelessness, or have a dysfunctional family was identified. It presented with greater intensity in Medellín and Pereira. The profile of happy older adults who have family functionality and normal depression live in

TABLE 2 Demographic, family, social, personal, and health factors are associated with the happiness of older people.

Characteristics	Happiness		X^2	*p*-value	PRc (CI 95%)
	High *n* (%)	Moderate to low *n* (%)			
Sex					
Male	764 (45.3)	389 (47.3)	0.925	0.336	1.00
Female	921 (54.6)	432 (52.6)			1.02 (0.97–1.08)
Age group					
60–69	939 (55.7)	470 (57.2)	0.676	0.713	1.00
70–79	557 (33.0)	266 (32.3)			1.01 (0.95–1.07)
80 or over	189 (11.2)	85 (10–3)			1.03 (0.94–1.12)
Marital status					
Single	401 (23.7)	202 (24.6)	0.613	0.893	1.00
Married—Partners	725 (43.0)	340 (41.4)			1.02 (0.95–1.09)
Separated—divorced	209 (12.4)	103 (12.5)			1.00 (0.91–1.10)
Widowed	350 (20.7)	176 (21.4)			1.00 (0.92–1.08)
Healthcare provider affiliation					
Yes	1,640 (97.3)	801 (97.5)	0.120	0.728	1.00
No	45 (2.67)	20 (2.43)			1.03 (0.87–1.21)
Categorized income					
Less than 1 min. Salary	594 (35.2)	260 (31.6)	23.893	<0.001	1.00
Between 1- and 2-min. Salaries	130 (7.71)	32 (3.89)			1.15 (1.05–1.26)
More than 2 min. Salaries	39 (2.31)	11 (1.33)			1.12 (0.96–1.30)
Without income	922 (54.7)	518 (63.0)			0.92 (0.86–0.97)
Risk of depression					
Clinical depression	668 (39.6)	580 (70.6)	212.226	<0.001	1.00
Normal	1,017 (60.3)	241 (29.3)			1.51 (1.42–1.60)
Hopelessness					
Moderate—severe	179 (10.6)	334 (40.6)	361.949	<0.001	1.00
Light	1,027 (60.9)	423 (51.5)			2.02 (1.79–2.29)
Normal range or asymptomatic	479 (28.4)	64 (7.79)			2.52 (2.23–2.85)
Resilience					
Low	1,624 (96.3)	793 (96.5)	0.071	0.790	1.00
High	61 (3.62)	28 (3.41)			1.02 (0.88–1.17)
Mistreatment					
Not mistreated	687 (40.7)	357 (43.4)	1.671	0.196	1.00
Have suffered some kind of mistreatment	998 (59.2)	464 (56.5)			1.03 (0.98–1.09)
Psychological well-being					
Without strength	919 (54.5)	638 (77.7)	125.957	<0.001	1.00
Great strength	766 (45.4)	183 (22.2)			1.36 (1.29–1.44)
Quality of life					
Low quality of life	346 (20.5)	418 (50.9)	290.970	<0.001	1.00
Moderate quality of life	746 (44.2)	313 (38.1)			1.55 (1.42–1.69)
High quality of life	593 (35.1)	90 (10.9)			1.91 (1.76–2.08)
Compulsive gambling					
No gambling problems	72 (37.3)	34 (42.5)	1.983	0.370	1.00
Some gambling problems	106 (54.9)	37 (46.2)			1.09 (0.92–1.28)
Probable compulsive gambler	15 (7.77)	9 (11.2)			0.92 (0.65–1.28)

(Continued)

TABLE 2 (Continued)

Characteristics	Happiness		X^2	*p*-value	PRc (CI 95%)
	High *n* (%)	Moderate to low *n* (%)			
Family functionality					
Severe dysfunction	37 (2.19)	75 (9.13)	206.655	<0.001	1.00
Moderate dysfunction	36 (2.13)	65 (7.91)			1.07 (0.74–1.56)
Slight dysfunction	189 (11.2)	194 (23.6)			1.49 (1.12–1.98)
Normal	1,423 (84.4)	487 (59.3)			2.25 (1.73–2.93)
Drug misuse					
No consumption	1,400 (83.0)	671 (81.7)	0.0.16	0.699	1.00
1 substance	212 (12.5)	111 (13.5)			0.97 (0.89–1.05)
2 or more substances	73 (4.33)	39 (4.75)			0.96 (0.83–1.10)
Risk of incapacity					
No risk	54 (3.20)	16 (1.94)	3.207	0.073	1.00
High risk	1,631 (96.7)	805 (98.0)			0.86 (0.76–0.98)

PRc: crude prevalence ratio; CI: confidence interval. Five Colombian cities included, 2021.

Bucaramanga, Popayan, and Santa Marta, have a moderate and high quality of life, and are very strong in terms of their psychological well-being, an important aspect to mention in this profile was the grouping that occurred in each of the categories of analysis (Figure 1).

Discussion

Happiness is part of the component of subjective well-being that includes a broad category of phenomena among which are the emotional responses of people, the domains of satisfaction, and global judgment regarding life satisfaction (27). Given accelerated demographic changes and the challenges that they bring, happiness as a focus for the care of older adults should be considered by aging and old age policymakers, public health, social, and environmental science professionals, among others. It is not enough just to maintain health but to provide general well-being (28), and it is known that this is a key objective for society as a whole, since it leads to the happiness of its members (29).

In this study, two out of three older adults reported, according to the Lima Scale, a high happiness perception. A previous study carried out in 2016 found, with this same measurement, that 85.6% of older adults from three Colombian cities were in the happy or totally happy category (10). This shows a reduction in happy older adults, an aspect also seen at the population level that deserves attention because of aging populations. In the latest World Happiness Report (30), recently cited in a press release, Colombia is ranked 66th among the happiest countries in the world. The happiness index score in Finland, recognized as the happiest country in the world, with a score of 7,821, while Colombia scored 5,871 (30). Although the general happiness in the Colombian population has been declining in location (−3.84% variation) after being one of the happiest in the world, it now stands far from some South Americans (Uruguay has the best index of the region and is in position 30), happiness among older adults is higher than other countries. For example, in one part of Asia, it has been documented that the proportion of adults aged 60 years and over who are happy is around 55% (31). A recent population-based study in Iran reported that less than half of older adults reported an acceptable level of happiness (32). Likewise, studies in contexts similar to Colombia, such as Mexico, reported that, adjusting for age, the proportion of happy older adults is very small (33). However, Singapore, for example, has reported proportions of happiness in older adults as high as 96% (34).

Although these differences may have an important effect on the regional context in which people age, factors closer to the individual play a fundamental role. For older adults, happiness is related to subjective well-being, and, in this sense, it is shown as a complex construct, since it is conditioned by a variety of factors and determinants (some closer than others). Subjective well-being, life satisfaction, optimism, and positive emotions, all related to happiness, have been documented to improve health and longevity. Therefore, identifying the factors associated with happiness and the profile of older adults with a high subjective perception of happiness is important to guide strategies that provide a positive sense of life, especially during aging, both individual and collective, that translates into better indicators of happiness.

This study found that the happiness of older adults was explained mainly by the absence of the risk of depression, being asymptomatic to hopelessness, strengthening their psychological well-being, having a perception of high quality of life, and living in a functional family. Previous evidence has shown that several of these factors act jointly to determine the happiness of older adults, contribute to its mediation, and even intervene in it (35). In this sense, authors have proposed the concept of the multidimensionality of happiness, which is divided into four domains of life according to an extensive review of the literature: family, financial well-being, health and quality of life, and social interactions (36).

Among the factors that determine the happiness of older adults and that have been reported with greater consistency in studies are those that are related to social support: community and friends (37), living with a partner (38) and a functioning family (39). The happiness of older adults is more likely when they have a family, participate in social activities, and feel satisfied with their neighborhood environment (38) aspects that, in turn, explain, in part, the differences

TABLE 3 Crude and adjusted measures of the happiness of older adults, according to demographic, family, social, personal, and health factors.

Characteristics	X^2	*p* Value	PRc (IC 95%)	*p*-value	PRa (CI 95%)
Risk of depression					
Clinical depression	212.226	<0.001	1.00		1.00
Normal			1.51 (1.42–1.60)	<0.001	2.16 (1.761–2.65)
Hopelessness					
Moderate to severe	361.949	<0.001	1.00		1.00
Light			2.02 (1.79–2.29)	<0.001	6.075 (4.39–8.58)
Normal range or asymptomatic			2.52 (2.23–2.85)	<0.001	3.25 (2.57–4.10)
Psychological well-being					
Without strength	125.957	<0.001	1.00		1.00
Great strength			1.36 (1.29–1.44)	0.003	1.40 (1.12–1.75)
Quality of life					
Low quality of life	290.970	<0.001	1.00		1.00
Medium quality of life			1.55 (1.42–1.69)	<0.001	1.84 (1.48–2.293)
High quality of life			1.91 (1.76–2.08)	<0.001	3.17 (2.35–4.28)
Family functionality					
Severe dysfunction	206.655	<0.001	1.00		1.00
Moderate dysfunction			1.07 (0.74–1.56)	<0.001	4.14 (2.61–6.55)
Slight dysfunction			1.49 (1.12–1.98)	<0.001	2.015 (1.22–3.312)
Normal			2.25 (1.73–2.93)	0.451	1.27 (0.679–2.38)

PRc: Crude prevalence ratio; PRa: Adjusted prevalence ratio; CI: Confidence interval. Five Colombian cities included, 2021.

between older people with depression, hopelessness, and low perception of quality of life and psychological well-being.

These domains of support (social, friends, and family), manage to predict happiness, and this, in turn, is positively related to life satisfaction. One of the most recent studies reported by (37), managed to reveal significant differences in the happiness index among older adults who live alone (6.22 ± 2.11) compared to those who live with their partner (6.76 ± 1.99) and with their families (6.46 ± 1.94). Additionally, they found that older adults who live with their families showed greater happiness (OR = 0.80, 95% CI = 0.65–0.99) and that those who lived with their spouse increased their happiness when contact with friends was higher (OR = 0.69, 95% CI = 0.56–0.84) (39). For its part, a study by Saber et al. (32) proposed a relationship between happiness and social support, finding that the highest mean of this support was among those older adults who were happier and suggested, therefore, that it is urgent to address the social needs and communication networks of older people, as these can have a direct impact on their state of health and happiness. A study in three Colombian cities found that those with good functional families, even mild or moderate dysfunction, have a chance greater than 27% of being happy compared to those with severely dysfunctional families. It also found that the profile of happy older adults is given in part by having a functional family. Previous similar studies in our context have reported that two out of three older adults people have functional families (40) and, although this study did not find an association with the marital status of older adults, it has been indicated that this is an important characteristic that affects their well-being since greater satisfaction with life is found among married or accompanied older adults (39), which is also part not only of family formation but also, on occasions, an indicator of family functioning and perceived support of the couple.

Under this concept of the multidimensionality of happiness, and of conditions such as health and family, among other determinants, there are also associated factors that are related to each other and that end up defining the happiness and satisfaction of older adults (29, 31). Studies have shown that having close family ties protects against family dysfunction. Those who live in nursing homes far from their families and do not have social support, show more depressive symptoms, and their quality of life is lower (29, 41). The absence of depression, which this study found to be part of the happiness profile, has also been documented to have a mediating role in the relationship between happiness and living with a partner (38). A study that sought to determine the factors that influence the happiness of more than 14,000 older adults who live alone found that depression, as well as the quality of life, had a preponderant role in affecting the happiness of older adults (42). Most of the studies in this age group have specific approaches such as gender, people who live alone, on a low income, the institutionalized, and those with morbid conditions (for example, type 2 diabetes) among others. In general, the role played by depression as a factor influencing the happiness of older adults is consistently found. A recent systematic review (31) reported that the degree of depression had a strong impact on life satisfaction.

Quality of life and happiness largely depend on health status, and aging is a complex process with physical, psychological, and social changes, which can lead to illness and disability, and further reduce levels of happiness. An illness such as depression, for example, or a disability, can affect independence by limiting individual actions, and thus impairing quality of life, reducing the probability of being happy

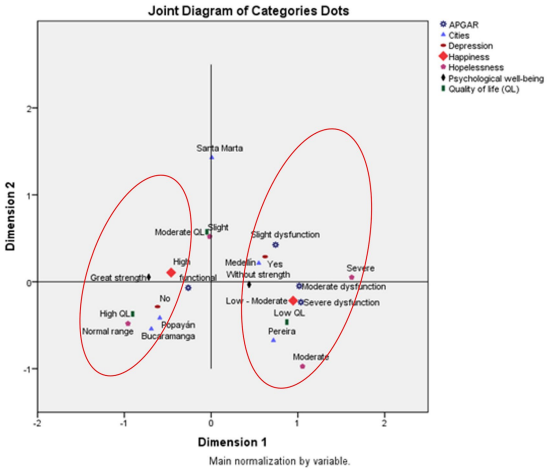

FIGURE 1
Profile of older adults, according to the subjective perception of their happiness. Five Colombian cities included, 2021 (Sans serif -SPSS).

(35, 38). Authors such as Kim have suggested that family income, depression, subjective levels of stress, subjective levels of health, quality of life, and lack of medical services influence the happiness of older adults, mainly those who live alone (41).

In this sense, loneliness is a phenomenon of great concern due to its high incidence and impact. Hopelessness, specifically the loss of motivation and negative expectations about the future, are critical aspects of the development of feelings of loneliness in older adults (43). One of the factors in this study that characterized older adults who are not happy was hopelessness, and only one in five older adults do not suffer from it. This has been considered an important determinant of health and death, and, although it is a predictor of suicide (44) and loneliness (45), among other outcomes, it has become a modifiable risk factor for older adults, so this finding deserves attention and intervention (46). Additionally, evidence has also documented that hopelessness, in combination with depression and dissatisfaction with life, predicts conditions of psychological frailty in at least 68.4% of cases (46) and, although there is no specific evidence of hopelessness and its direct relationship with happiness in older adults, its mediating role in the relationship between psychological vulnerability and happiness in younger population groups has already been alerted (46, 47).

Although our study did not include an analysis of adjusted association measures in the final explanatory model, income was a condition associated with happiness (invariant analysis). More than half of the older adult population does not receive any income, and this reduces the probability of being happy by 8%. Previous evidence has shown that old age is linked to poverty and that the proportion of older people who do not receive any income exceeds 25% (48). Older people lack opportunities in the labor market, and the vast majority work in the informal sector (36). This implies that older people require economic support from relatives (36). Financial capacity is a determining factor for life satisfaction among older adults, as those with a better self-assessed economic capacity than others are generally more satisfied with their lives (31).

Happiness is a broad concept that includes several related elements such as life satisfaction, a good life, a better life, well-being, and quality of life (49). The profile of happy older adults, as well as the factors associated with happiness, are related to each other and, therefore, attending to them should involve an integrative approach that covers several fronts to achieve successful aging processes. Avoiding unhappiness through interventions that address issues related to social isolation, disability, and depression is recommended (34). Given the fact that the factors that explain it are modifiable, it is desirable that older adults be happy through the diverse options that, holistically, include individual conditions from psychological and physical well-being as well as family aspects, and social and community support.

A limitation of this study was the fact that other conditions such as those of a functional type such as physical activity, which is related as one of the determinants of this state among older adults were not explored. Previous evidence has reported that regular physical activity is an essential factor that influences happiness, even slight happiness, as it provides relaxation (50) and, in this sense, its study also allows its implementation as a prevention and care strategy. There might be another limitation in addressing happiness as the same concept during the various stages of aging and some characteristics of older adults. It has been reported, for example, that the perception of happiness changes with age because priorities and what makes people happy change. Blanchflower states that the reasons for relative happiness in old age are many, anchored by lower levels of stress and responsibility, and encouraged by free time (51). They are also conditioned by gender, marital status, economic conditions, social support, and functional families (52) as well as by the happiness motivation that derives from those hedonic or eudemonic motives. Although the association of some of these conditions was explained and how they constitute the profile of the happy older adult, it is recommended that future studies address these differences through stratified analysis, or by estimating the mediating role in the various relationships that lead to happiness.

Conclusion

Happiness has been of interest in various parts of the world to different cultures and populations, and globally with the world report. Specifically, this research provides a theoretical contribution to the factors that can make old age a satisfying, calm, and gratifying part of life, as current evidence has shown that health problems and social situations take on a more important role at older ages. In this way, the first great conclusion is that happiness is not simply the result of depressive states, illness, loneliness, hopelessness, low quality of life, and not having social support, among others, but that it is related to a variety of characteristics, conditions, and processes, which accumulate throughout life.

It has also been identified that happiness has broad ramifications in the course of life and is affected, conditioned, and determined by personal, social, and economic relationships, biological risk factors, health behaviors and healthy habits, leisure, and use of time, as well as the health situation. This calls on institutions and actors to implement spaces in which these aspects are strengthened much more, with the care that happiness is modifiable when it improves the health and well-being of older adults or even with mood swings.

This study provided a systematic overview of the possible factors that can be enhanced and strengthened with public policies (structural

determinant), community empowerment and family strengthening (intermediate determinant), and educational programs (proximal determinant), aspects included in the essential functions of public health, in favor of the mental and social health of older adults.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving human participants were reviewed and approved by Comité Institucional de Ética en Investigación en Humanos, Universidad CES. The patients/participants provided their written informed consent to participate in this study.

Author contributions

AS, DC, CR, and AS: material preparation, data collection and analysis, and writing—original draft preparation. AS and DC: conceptualization. AS: methodology. AS, DC, CR, DM, and AS: formal analysis and investigation. DM: writing—review and editing. DC: funding acquisition. Resources: Minciencias. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Revised Chinese resident health literacy scale for the older adults in China: simplified version and initial validity testing

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Objective: This study aimed to develop a short version of the Chinese Resident Health Literacy Scale focused on older adults in China, and further assess the reliability and validity of this short version.

Methods: The data was from a cross-sectional community-based older adults health survey conducted in 2020. The total of 5,829 older adults were randomly divided into two parts using for the simplification and assessment of the scale, respectively. Item Response Theory (IRT) and Differential Item Functioning (DIF) were used for item analysis and scale simplification. Cronbach's alpha and McDonald's omega were used to assess the reliability and three factors Confirmatory Factor Analysis (CFA) was used to assess the validity, which were compared to the original version. Moreover, Multi-group Confirmatory Factor Analysis (MCFA) was used to test the model invariance of the short version across groups of gender, age groups, level of education, and cognitive status.

Results: The simplified version consisted of 27 items taken from 50 original items, of them 11 items from the dimension of knowledge and attitudes, 9 items from the dimension of behavior and lifestyle, and 7 items from the dimension of health-related skills. The overall Cronbach's alpha and McDonald's omega were both 0.87 (95%CI: 0.86–0.88). The goodness-of-fits of CFA in simplified version were still acceptable in CFI, TLI, GFI, and RMSEA, even improved in CFI, TLI, and GFI compared to those of original version. Also, the model was stable and invariant in MCFA across gender, cognitive status, and educational level groups.

Conclusion: In this study, we formed a simplified instrument for measuring health literacy focused on older adults in China. This short version might be more suitable for the priority recommendation in extended tracking of the dynamic changes on the levels of health literacy in the whole life cycle in public health settings. Further research might be to identify the cut-off values to distinguish the older adults with different levels of health literacy.

KEYWORDS

health literacy, item response theory, differential item functioning, confirmatory factor analysis, older adults

Introduction

Among community-dwelling older adults, inadequate health literacy was independently linked to poorer physical and mental health (1). The previous studies found that lower health literacy was related to less understanding health information, a lack of basic knowledge of diseases, and/or poorer medication adherence (2), which could further increase the hospitalization and mortality rates (3, 4). Especially for those suffering from chronic diseases, over 40% of them took a grave risk to misunderstand, forget, or ignore healthcare advice (5). Therefore, promoting health literacy might be the most effective and affordable strategy for dealing with Non-communicable Chronic Disease (NCD) challenges (6, 7). In order to develop interventions to improve health literacy, it needed to give priority to measure the level of health literacy, especially among older adults, which was fundamental for the evaluation and surveillance.

Until now, over 150 instruments of health literacy have been developed, ranging from traditional tools focused on individual skill and health education to updated instruments from multidimensional perspectives (8–11). In China, health literacy also attracted more and more attention and some instruments were developed and applied in clinical or public health settings (12–17). Of these instruments, the Chinese Resident Health Literacy Scale (CRHLS) was developed on the manual of "Basic Knowledge and Skills of People's Health Literacy" published by the National Health and Family Planning Commission and firstly released in 2008 (16). It was widely used in the National Health Literacy Surveillance among Chinese residents aged 15–69 years old (17, 18). According to data from National Health Literacy Surveillance, the health literacy levels (CRHLS scores of 80% or above) increased to 23.15% in 2020 and social development index, age, and education level were highly associated with health literacy (19). However, rare data of the health literacy for the older adults were released and in previous published study only 5.31–7.74% older adults aged 60–69 were found to reach this level (20).

CRHLS might be unsuitable for older adults in China. Firstly, the time consuming might be a huge challenge for older adults. Most of the young and middle-aged adults might spend about 30 min to complete measurement (16), while older adults might need to spend more time to do it, even longer for those with limited literacy (21). Secondly, some of items in CRHLS might be floor or ceiling effects for older adults. For example, the items of "reading and understanding OTC drug facts label" or "description of the liver function" might be beyond the scope of reading and understanding ability especially for those with lower level of education, or some items (e.g., item of "national unified toll-free hotline number") deviated from the areas of concern for some older adults, which might led to the lower awareness rates. Lastly, CRHLS score 80% or more as the cutoff value with health literacy might be too strict for older adults and lack of evidence (22). Developing a brief version adapted from the original CRHLS for older adults might have several advantages, including brevity, availability of normative data, ease of administration, and lower cost. It would be more suitable for tracking the dynamic changes in the whole life cycle and evaluating the relationship between health literacy and health outcomes or health behaviors in the Chinese society context. Therefore, it was necessary to investigate how to simplify original scale reasonably and maintain the original reliability and validity as much as possible.

Item response theory (IRT) was a complex approach that attempted to explain the relationship between latent traits (unobservable characteristic or attribute) and their manifestations (i.e., observed outcomes, responses or performance) (23–31). Recently, more and more researchers used IRT models to analyze the latent properties of the scales and furtherly revise or simplify the scales (32). The advantage of using IRT was that each item in the scale was paid attention during the simplification of scale. It was assumed that the latent construct (e.g., knowledge, attitudes, *et al*) and items measured were organized in an unobservable continuum (24), which established a link between the properties of items on an instrument, individuals responding to these items and the underlying trait being measured (23).

Because that the level of education and cognitive status were the important factors related to the health literacy in previous studies (33, 34), and the health literacy level of older adults associated positively with the education level or cognitive function. The equivalence in the measurement of health literacy should be considered across groups of cognitive ability or education. The differential item functioning (DIF) to assess the equivalence of items in the scales was more and more applicated in some studies of educational or health assessment (35). The measurement invariance (MI) was defined as statistical property of a measurement that the same underlying construct was measured across groups or across time (36). MI should be considered in the simplification of scale and lack of MI (meaning DIF) indicated that the populations with the same latent ability do not have equal probability of getting an item correct, regardless of group membership (37). DIF also examined the relationship between the item response and another group variable, after controlling for the underly construct (38). When groups had different probabilities of response to a given item in DIF analysis, that indicated DIF occurred and this item was labeled as DIF-item (37).

Therefore, the purpose of this study was to simplified CRHLS based on IRT and DIF methods to form a more suitable instrument of health literacy for the Chinese older adults, and further assess the reliability and validity of simplified version.

Methods

Participants

The data was from a cross-sectional health survey carried out in Beijing among the community-based older adults in 2020, in which 5,829 participants were used for analysis in this study (39).

The simple random sampling method was used to select the 50% of total older adults as the sample for simplification (marked as Sample A) and the other 50% as the sample for validation (marked as Sample B). There were no differences in demographic and original version health literacy scores found between the two samples.

Measures

The survey collected information on sociodemographic characteristics (including age, gender, ethnicity, education level, marital status, and so on), health literacy, and cognition impairment.

Health literacy was measured by the CRHLS for the 2018 edition, which consisted of 50 items to assesses health knowledge, attitudes, behaviors and skills that are necessary to address real-world health problems and three dimensions: (1) knowledge and attitudes: basic knowledge and concepts related to health (22 items); (2) behavior and lifestyle: health-related behaviors and lifestyle (16 items); and (3) health-related skills: basic health-related skills (12 items). There are four types of questions in the scale: true-or-false; single-answer (only one correct answer in multiple-choice questions); multiple-answer (more than one correct answer in multiple-choice questions); and situational questions. With multiple-answer questions, a correct response had to contain all the correct answers and no wrong ones. Situational questions were given following a paragraph of instruction or medical information. Of these items, according to the scoring rules of this scale 2018 edition, total 50 items were included in the scores of health literacy with correct response allocated 1 point (except for the multiple-answer items in which correct response was allocated 2 points). The total score ranged from 0 to 66 points. Cronbach's α coefficient and the McDonald's omega of the Chinese Resident Health Literacy Scale were both 0.90 in our study.

Older adults might experience subtle cognitive changes associated with aging. The Ascertain Dementia 8 (AD8) questionnaire was used for screening cognitive impairment in this study (40). AD8 was a brief informant-based measure with only eight questions and performed well in distinguishing cognitive impairment from normal cognition (41). The person with an AD8 score ≥ 2 was suspected of having a cognitive impairment and needed further testing to be diagnosed. Cronbach's α coefficient of AD8 was 0.87 in our study.

Data analysis

The first phase of simplification in sample A

There were two stages included in this study. The first phase was used for simplification of the CRHLS in Sample A. The two-parameter logistic model (2PLM), one of the IRT models, was used to predict the probability of a successful answer for each item in each dimension (40). Difficulty and discrimination were two important parameters in 2PLM. The formula was as follows (42):

$$P_{(x_j=1|\theta)}=\frac{1}{1+\exp\left[-a_j\left(\theta-b_j\right)\right]}$$

Where x_j was the response to item j in the scale; a_j was the discrimination parameter; b_j was the difficulty parameter, which indicated the point where an individual would have a 50% chance of endorsing item j; and θ is the ability value being measured. The basic assumptions of IRT included unidimensionality, local independence, and monotonicity (25–29), which were assessed, respectively, by the eigenvalue examination in factor analysis (30), Yen's Q3 statistic (29), splines modeling via flexible IRT models and Pearson χ^2 statistics (31) in this study.

The information about individuals was based on their responses to items and the properties of all the items (43). The maximum likelihood method was used for parameter estimations. According to the parameters of discrimination and difficulty, the information function for each item was calculated (44). Item information functions for the 2PLM would have their maximum value at the value of the threshold (difficulty) (16). And slopes (discrimination) control how peaked the item information function was, and the higher the slope value was, the more information that item provided, the smaller the measurement error (45). In our study, the item response probability was chosen as 2/3 to calculated θ value in order to estimate the maximum amount of information for each item labeled as I(θ), which was one of the most popular standard setting methods of response probability in the Bookmark method (46–48).

Furthermore, in order to present how each dimension of scale was functioning as a whole, we also combine the item-level information functions to create a test information function, shown as test information curves (TIC). The standard errors were the square root of the inverse of information at a given level of ability. The item, with a discrimination parameter of 0.5 to 2.0 and a difficulty parameter of −3.0 to 3.0, was considered to provide the most information (16), which was also used in this study. Furthermore, I(θ) was also the criteria of item selection in this study, that was: removed items ($I(\theta)\leq 0.10$), modified items ($0.10<I(\theta)\leq 0.20$), and kept items ($(I(\theta)>0.20$) (49).

Moreover, Differential Item Functioning (DIF) was used to test the equivalence of items. We applied logistic regression for identification of DIF using the ability (θ) derived from IRT analysis as the matching variable. This method has been used in previous published studies (50–52). The group variables were cognitive status (Normal or Impairment) or the levels of education (Illiterate or Primary school, Junior high school, and Senior high school or above). If the determination coefficient (*value of p*) of DIF for a given item was significant (item with DIF), the item was labeled as DIF-item, which was considered to be removed from the scales (53).

In brief, if any of the following criteria was met in this phase, the item would be removed from original CRHLS: (a) discrimination(α) <0.5 or > 2.0 (16); or (b) difficulty(b) < −3.0 or > 3.0 (16); or (c) $I(\theta)\leq 0.20$ (49); or (d) items exhibiting DIF on cognitive status or education level (54).

The second phase of validation in sample B

The second phase was validation of the simplified version as above in Sample B. Compared to the original version, the reliability, the construct validity, as well as Goodness-of-fit was estimated in the simplified version scale. Both Cronbach's alpha and McDonald's omega, as well as their 95%CI, were used to assess the reliability of the simplified version scale. The three factors Confirmatory Factor Analysis (CFA) was used to assess the convergent validity and discriminant validity. The goodness-of-fit was examined via structural equation modeling using the maximum likelihood method (55). The indicators of comparative fit index (CFI), Tucker-Lewis index (TLI), goodness-of-fit index (GFI), and root of the mean square residual (RMSEA) were calculated and compared between models. It was considered to be acceptable for the goodness-of-fit when CFI > 0.90, TLI > 0.90, GFI > 0.90, and RMSEA<0.08 (56).

In addition, Multi-group CFA (MCFA) was used to test the invariance of the simplified version across groups of gender, age, level of education, and cognitive status. The four models were used in MCFA analysis, that was: (1) configural invariance: the basic factor structure was the same across groups; (2) metric invariance: constraining factor loadings to be equal between groups based on the basic factor structure; (3) strong invariance: constraining the intercepts of the items to be the same between groups based on metric invariance; (4) strict invariance: further constraining residuals to be equal between groups (57). Invariance across subgroups is depicted by significant χ^2, chi-square should not

significantly differ between models, along with ΔCFI<0.02, ΔTLI<0.02, and ΔRMSEA<0.015 (58).

IRT analyses were conducted using the R mirt package (59). The calculation of reliability was conducted using the R ltm and coefficientalpha packages (60). CFA and MCFA were performed in AMOS 17.0. Other analyses, including descriptive analysis, t-test, and chi-square test, were conducted using SAS 9.4. The significance level was 0.05 for all statistical tests.

Results

A total of 5,829 older adults were included in this study, 50% of male, mean age of 70.29 ± 7.37 years old, about 23% from rural regions, and 28% of education level of primary school or below. In total, 1888 participants (32.39%) might be cognitive impairment screened by AD8 (scores of AD8 ≥ 2 points). There was no significant difference in the characteristics between Sample A and Sample B ($p > 0.05$; Table 1).

The simplification of Chinese resident health literacy scale

As shown in Table 2, the final 27 items kept in the simplified version of health literacy for older adults based on IRT and DIF consisted of 11 items in the knowledge and attitudes dimension, 9 items in the behavior and lifestyle dimension, and 7 items in the health-related skills dimension. A total of 23 items were removed, of which 21 items based IRT with low information or discrimination, and/or 4 DIF-items on cognitive status or education level (Table 2).

The reliability and validation of simplified version

Due to the 23 items removed, the overall Cronbach's alpha coefficient for simplified version was 0.87 (95%CI: 0.86–0.88), slightly lower than that of original version (0.90, 95%CI: 0.89–0.90), but still considered better reliability (Table 3). The sufficient reliabilities were also found in the dimension of knowledge and attitudes (0.72, 95%CI: 0.70–0.73) and behavior and lifestyle (0.73, 95%CI: 0.72–0.75), while undesirable reliability in dimension of health-related skills (0.65, 95%CI: 0.63–0.67). There was a similar McDonald's omega between simplified version and original version (Table 3). Also, the characteristics of items, the correlation to dimension scores, and factor loading in the simplified version in Sample B were detailed in Supplementary Table 1.

The results in Table 4 indicated the goodness-of-fits of CFA. The indicators of three-factor structures in simplified version were still acceptable in CFI, TLI, GFI, and RMSEA, even improved in CFI, TLI, and GFI compared to those of original version. The test information and measurement error curves were shown in Figure 1.

Testing for measurement invariance of simplified version

After then, Sample B was stratified by gender (male or female), age (60–70 years or ≥ 70 years or over), cognitive status (normal or impairment), or education level (illiterate or primary school, junior school, or high school or above), then fitted into the model of the simplified version separately.

As shown in Table 5, the model of the simplified version is invariant and stable across groups of gender, age, cognitive status, and education level. The indexes of ΔCFI, ΔTLI, and ΔRMSEA indicated the equivalence of the three-factor structure of the simplified version between groups. However, χ^2 might be significant in model fit across groups due to large sample size (61).

Discussion

In this study, we first simplified the CRHLS (2018 edition) based on IRT and DIF methods. Finally, the simplified version of the remaining 27 items for older adults was adapted with a good reliability and even slightly improved in construct validation. The original scale, widely used in the periodic national survey to monitor the level and dynamic changes of health literacy in Chinese adults aged 15–69 years old, was developed on the manual of "Basic Knowledge and Skills of People's Health Literacy" published by the National Health and Family Planning Commission (18), which was still an important material of health education and health communication for the public in China now. Therefore, this simplified version adopted from CRHLS focused on older adults might be more suitable for extended tracking of the dynamic changes in the whole life cycle in the future, evaluating the intervention effect of health education in chronic diseases, and investigating the relationship to health outcomes or health behaviors under the Chinese context. Moreover, it was more convenient for collection and administration of data than the original CRHLS.

Recently, IRT was more and more applied to assess and revise the scales in public health or clinical studies (43). Different from the previous simplified studies just focused on the difficulty and discrimination when using IRT model (31, 62–64), our findings also integrated the equivalence and information of items into the criteria of remaining items in order to obtain a relative accuracy of measurement of health literacy for older adults. The previous study by Shen et al. reported the overall reliability of original version was 0.95 among the population aged 15–69 years old in China (16). In contrast, the reliability of original version in our study was found to be 0.90 for the older adults, but still a good reliability. It also showed that original CRHLS, although with some shortcomings, could be used to measure the level of health literacy for the old population. Compared to the original version, simplified version still had good overall reliability ($\alpha = 0.87$) and acceptable reliability in each dimension, which was slightly lower due to the great reduction of items. Moreover, according to the Goodness-of-fits in three factors models of CFA in our study, the simplified version seemed to be better construct validation and construct invariance across groups. All of these supported that the simplified version scale might be suitable for the priority recommendation as an instrument of health literacy for older adults in Chinese social context.

We simplified the Chinese instrument for measuring health literacy by removing some redundant or DIF items to finally form the simplified version with 27 items focused on older adults in China. However, there were some limitations. Firstly, IRT model needed to meet basic assumptions of unidimensionality, monotonicity and local independence. In this study, the data was verified to satisfy these basic assumptions only except for the

TABLE 1 Characteristics of study participants.

Demographic variables	Total (*N*=5,829)	Simplification (Sample A, *N*=2,915)	Validation (Sample B, *N*=2,914)	*p*-value
Gender				
Male	2,891 (49.6%)	1,448 (49.67%)	1,443 (49.52%)	0.91
Female	2,938 (50.4%)	1,467 (50.33%)	1,471 (50.48%)	
Subgroups of age				
60–69	2,925 (50.18%)	1,473 (50.53%)	1,452 (49.83%)	
70–79	2,166 (37.16%)	1,077 (36.95%)	1,089(37.37%)	0.65
≥80 or over	738 (12.66%)	365 (12.52%)	373(12.80%)	
Ethnicity				
Han	5,614 (96.3%)	2,811 (96.43%)	2,803(96.19%)	0.63
Other	215 (3.7%)	104 (3.57%)	111(3.81%)	
Type of residence				
Urban	4,505 (77.29%)	2,252 (77.26%)	2,253(77.32%)	0.96
Rural	1,324 (22.71%)	663 (22.74%)	661(22.68%)	
Education				
Illiterate or Primary school	1,625 (27.88%)	794 (27.24%)	831(28.52%)	
Junior high school	2,129 (36.52%)	1,056 (36.23%)	1,073(36.82%)	0.65
Senior high school or above	2075 (35.60%)	1,065 (36.54%)	1,010(34.66%)	
Marital status				
Married	4,856 (83.30%)	2,441 (83.74%)	2,415(82.88%)	0.38
Unmarried, Divorced, or Widow	973 (16.69%)	474 (16.26%)	499(17.12%)	
Smoking condition				
Never Smoking	3,855 (66.13%)	1,951 (66.93%)	1904 (65.34%)	
Smoking	1,155 (19.81%)	562 (19.28%)	593(20.35%)	0.25
Smoked, but quit now	819 (14.05%)	402 (13.79%)	417(14.31%)	
Medical insurance				
Yes	5,721 (98.15%)	2,852 (97.84%)	2,869(98.46%)	0.09
No	108 (18.34%)	63 (2.16%)	45(1.54%)	
Cognitive ability				
Cognitive normal	3,941 (67.60%)	1978 (67.86%)	1963(67.36%)	0.69
Cognitive impairment	1,888 (32.40%)	937 (32.14%)	951(32.64%)	
Total scores of health literacy (Mean ± SD)	39.20 ± 12.80	39.31 ± 12.69	39.08 ± 12.91	0.49
Scores of three dimensions (Mean ± SD)				
Knowledge and attitudes	17.24 ± 5.57	17.27 ± 5.53	17.20 ± 5.61	0.63
Behavior and lifestyle	12.79 ± 4.90	12.83 ± 4.89	12.74 ± 4.91	0.51
Health-related skills	9.17 ± 3.61	9.22 ± 3.57	9.13 ± 3.64	0.34
Health literacy*				
Less than 80% of total scores	4,921 (84.4%)	2,460(84.4%)	2,461(84.50%)	0.97
80% of total scores or above	908 (15.6%)	455(15.6%)	453(15.50%)	

*The scores of 80% or more was the cutoff value with health literacy in CRHLS.

eigenvalue examination in the dimension of health-related skills (the ratio of the first to second eigenvalue was 2.52, which slightly less than 3 of threshold value). Secondly, because the original version was initially developed by an expert panel from the Ministry of Health and now was widely used for community-based adults aged 15–69 years old in China, we did not further assess the content validity in this study. Moreover, the items kept in short version were selected based on IRT and DIF. The additional items recommended by researchers might be subjective, so did not be considered in this study. Thirdly, we used the data of the representative sample of older

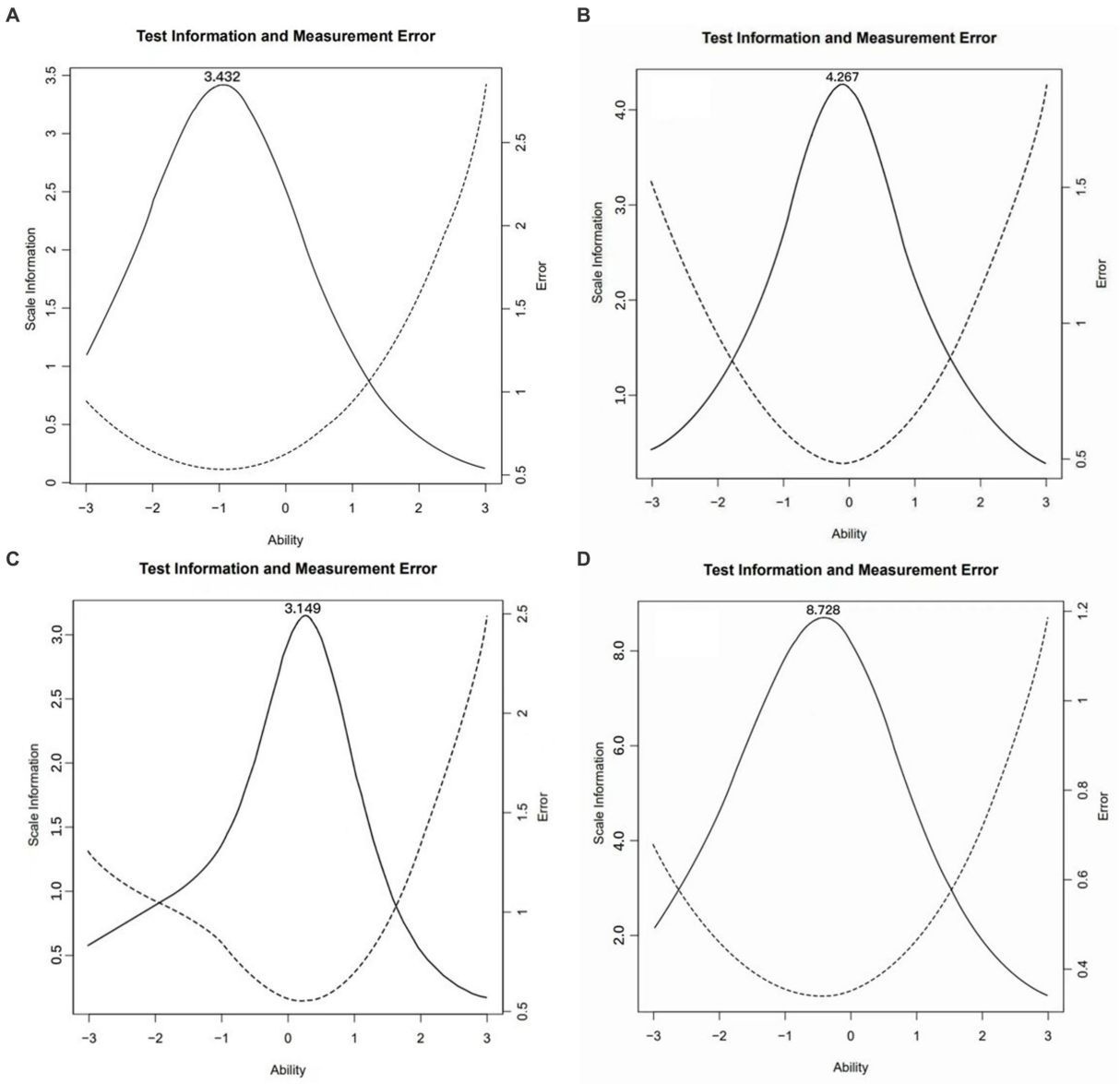

FIGURE 1
The test information and measurement error curves in simplified version. **(A)** Dimension of knowledge and attitudes; **(B)** Dimension of behavior and lifestyle; **(C)** Dimension of health-related skills; and **(D)** the total of simplified version.

adults from a cross-sectional study conducted in Beijing. There might be differences in characteristics among older adults living in different regions, which might have an impact on the reliability and validity of the scale when it was extended used in general Chinese older adults. So, this simplified version needs to the further assess in the general populations.

Conclusion

In this study, we form a simplified version instrument for measuring health literacy focused on older adults in China. It might be more suitable for the priority recommendation in extended tracking of the dynamic changes in the whole life cycle and assessing the level of health literacy among older adults in public health settings.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation. Requests to access these datasets should be directed to YHW, wyhong826@pumc.edu.cn.

Ethics statement

The studies involving human participants were reviewed and approved by the institutional review board of the institute of Basic Medical Sciences, Chinese Academy of Medical Sciences (Project No. 064–2020). The patients/participants provided their written informed consent to participate in this study.

TABLE 2 Evaluation of items based on IRT and results of DIF analysis of the original version of the Chinese Resident Health Literacy Scale in Sample A.

Item abbreviation		Correct (%)	Correlation to dimension score	IRT parameters			DIF						Kept
							Cognitive Status			Education Level			
				Difficulty	Discrimination	Information level	Statistic	*p*	R^2	Statistic	*p*	R^2	
Dimension1: Knowledge and attitudes													
A01	Prevention of the flu	79.35	0.43	−1.44	1.13	0.32	0.52	0.74	0.0001	0.65	0.52	0.0002	Yes
A02	Health care products	79.20	0.26	0.58	1.42	0.08	<0.001	0.99	<0.0001	5.20	0.07	0.0017	No
A03	Infusion	79.86	0.42	−1.43	1.08	0.29	0.22	0.76	0.0001	0.64	0.52	0.0002	Yes
A05	Health products	79.11	0.31	−2.26	0.63	0.10	<0.001	0.99	<0.0001	5.20	0.07	0.0017	No
A10	Body temperature	78.03	0.23	−3.57	0.37	0.03	7.90	0.04	0.0026	7.16	0.78	0.0002	No
B01	The definition of health	71.90	0.52	−0.92	1.43	0.51	0.20	0.76	<0.0001	4.63	0.08	0.0011	Yes
B03	Hepatitis B	56.30	0.38	−0.96	0.75	0.14	0.99	0.63	0.0003	3.87	0.05	0.0024	No
B04	Blood pressure measurement	48.75	0.38	−0.40	0.69	0.12	0.79	0.63	0.0002	0.03	0.78	0.0003	No
B06	Early symptoms of cancer	51.32	0.41	0.11	0.82	0.17	2.27	0.32	0.0006	5.71	0.90	<0.0001	No
B07	Management of gas poisoning	77.12	0.40	−1.55	0.93	0.21	4.91	0.08	0.0014	2.51	0.19	0.0007	Yes
B08	Tuberculosis treatment	61.68	0.57	−0.05	1.55	0.59	8.59	0.04	0.0019	4.38	0.10	0.0011	No
B09	Toxic and hazardous work	70.60	0.47	−0.96	1.16	0.34	6.48	0.05	0.0017	4.72	0.08	0.0013	Yes
B10	Harm of iodine deficiency	64.01	0.36	−0.79	0.63	0.10	0.09	0.80	<0.0001	0.27	0.87	<0.0001	No
B13	Vaccines for children	63.29	0.45	−0.69	0.93	0.19	0.37	0.76	0.0001	0.44	0.07	0.0016	No
B17	Meaning of warning diagram	69.47	0.51	−0.79	1.35	0.45	3.98	0.13	0.0010	5.25	0.07	0.0013	Yes
C02	Medical visits	70.31	0.45	−0.98	1.08	0.29	0.27	0.76	0.0001	6.20	0.07	0.0017	Yes
C03	Liver	14.30	0.45	−1.49	1.35	0.46	14.06	0.00	0.0039	7.69	0.08	0.0010	No
C06	Packaged food	37.29	0.28	2.75	0.73	0.13	0.89	0.63	0.0003	0.93	0.66	0.0001	No

(Continued)

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TABLE 2 (Continued)

Item abbreviation		Correct (%)	Correlation to dimension score	IRT parameters			DIF						Kept
							Cognitive Status			Education Level			
				Difficulty	Discrimination	Information level	Statistic	*p*	R^2	Statistic	*p*	R^2	
C07	Treatment of sick and dead livestock	68.27	0.50	−0.70	1.22	0.37	1.04	0.64	0.0003	0.04	0.87	<0.0001	Yes
C15	Pesticide storage	58.44	0.49	−0.38	1.13	0.32	5.13	0.08	0.0013	8.44	0.06	0.0021	Yes
D03	Control weight	61.64	0.48	−0.55	1.07	0.28	0.14	0.78	<0.0001	0.77	0.52	0.0002	Yes
D04	Obesity-related disease	67.79	0.46	−0.86	1.07	0.27	6.27	0.05	0.0017	2.22	0.21	0.0006	Yes
Dimension2: Behavior and lifestyles													
A04	Fruits and vegetables	80.75	0.37	−2.17	0.70	0.12	0.35	0.74	0.0001	0.75	0.78	0.0001	No
A06	Depression	86.24	0.36	−2.33	0.88	0.19	4.80	0.23	0.0015	1.07	0.05	0.0022	No
A09	Chronic disease treatment	62.95	0.33	−1.37	0.41	0.04	1.42	0.64	0.0005	0.04	0.78	0.0001	No
B05	Dangers of smoking	52.66	0.50	−0.05	0.99	0.24	2.38	0.49	0.0006	1.46	0.73	0.0004	Yes
B11	Hydration	62.57	0.46	−0.63	0.84	0.17	0.08	0.89	<0.0001	0.49	0.78	0.0002	No
B12	National basic public health service	40.07	0.49	0.51	1.05	0.27	0.28	0.74	0.0001	2.93	0.67	0.0008	Yes
B14	Fever	77.43	0.4	−1.80	0.80	0.15	1.11	0.64	0.0003	0.23	0.90	<0.0001	No
B15	Adverse reactions	79.52	0.33	−2.30	0.62	0.09	0.03	0.89	<0.0001	0.49	0.26	0.0008	No
B19	Medical visits	71.18	0.62	−0.91	1.29	0.41	0.84	0.64	0.0002	0.15	0.80	<0.0001	Yes
B21	Opening windows for ventilation during flu season	70.05	0.45	−0.98	0.99	0.24	0.88	0.64	0.0002	0.53	0.78	0.0001	Yes
C01	Promoting mental health	52.25	0.58	0.03	1.92	0.90	1.34	0.64	<0.0001	1.86	0.69	<0.0001	Yes
C04	Fever and rash in children	56.09	0.6	−0.17	2.00	0.97	0.47	0.74	<0.0001	2.34	0.67	<0.0001	Yes
C09	Benefits of eating soy products	31.60	0.43	0.95	1.05	0.27	2.63	0.49	0.0007	0.24	0.78	0.0001	Yes

(Continued)

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TABLE 2 (Continued)

Item abbreviation		Correct (%)	Correlation to dimension score	IRT parameters			DIF						Kept
							Cognitive Status			Education Level			
				Difficulty	Discrimination	Information level	Statistic	*p*	R^2	Statistic	*p*	R^2	
C10	Health benefits of exercise	45.11	0.54	0.23	1.62	0.63	0.02	0.89	<0.0001	0.01	0.96	<0.0001	Yes
C12	Coughing and sneezing	46.90	0.38	0.29	0.53	0.07	5.75	0.23	0.0018	5.89	0.26	0.0005	No
C13	Medical visits	67.75	0.52	−0.72	1.21	0.36	0.41	0.74	0.0001	0.25	0.78	0.0001	Yes
Dimension3: Health-related skills													
B16	Treatment of virulent infectious diseases	83.81	0.44	−1.63	1.24	0.36	0.03	0.93	<0.0001	0.14	0.26	0.0007	Yes
B18	Toll-free health hotline number	34.90	0.41	1.00	−0.75	0.24	2.63	0.27	0.0007	0.07	0.01	0.0033	No
B20	OTC	28.37	0.42	1.38	0.79	0.15	2.54	0.27	0.0007	0.24	0.42	0.0002	No
B22	Glass thermometer	62.74	0.44	−0.79	0.7	0.12	0.20	0.85	0.0001	0.28	0.49	0.0003	No
B25	Mild burns	73.21	0.45	−1.31	0.92	0.19	2.10	0.29	0.0006	0.05	0.10	0.0010	No
B26	Fire handling	46.14	0.4	0.41	0.55	0.07	0.01	0.93	<0.0001	0.37	0.24	0.0018	No
C08	Cardiac arrest	59.07	0.52	−0.31	1.09	0.28	4.24	0.16	0.0011	0.10	0.36	0.0004	Yes
C11	Hypoglycemic products	70.94	0.47	−1.03	0.99	0.23	7.51	0.07	0.0020	0.41	0.26	0.0006	Yes
C14	Benefits of breastfeeding for babies	44.94	0.52	0.24	1.13	0.30	0.34	0.84	0.0001	2.64	0.26	0.0006	Yes
C16	Lightning weather outdoors	82.40	0.42	−1.80	0.99	0.23	0.61	0.75	0.0002	0.04	0.42	0.0002	Yes
D01	Calculation of BMI	35.13	0.54	0.61	1.62	0.63	6.43	0.07	0.0013	0.05	0.14	0.0011	Yes
D02	Classification of BMI	42.50	0.56	0.28	1.69	0.69	0.14	0.85	<0.0001	1.22	0.26	<0.0001	Yes

R^2: DIF magnitude, applying the cut-offs of: <0.13 = negligible; 0.13–0.26 = moderate; >0.26 = not negligible (53).

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TABLE 3 Reliability of the original version and the simplified version of the Chinese Resident Health Literacy Scale in Sample B.

Dimension	Cronbach's alpha	95%CI	McDonald's omega	95%CI
Original version				
Overall	0.90	0.89–0.90	0.90	0.89–0.90
Three dimensions				
Knowledge and attitudes	0.78	0.77–0.80	0.79	0.78–0.80
Behavior and Lifestyle	0.74	0.73–0.75	0.74	0.73–0.76
Health-related Skills	0.70	0.68–0.71	0.70	0.68–0.72
Simplified version				
Overall	0.87	0.86–0.88	0.87	0.86–0.88
Three dimensions				
Knowledge and attitudes	0.72	0.70–0.73	0.72	0.70–0.73
Behavior and Lifestyle	0.73	0.72–0.75	0.74	0.72–0.75
Health-related Skills	0.65	0.63–0.67	0.65	0.62–0.67

TABLE 4 Goodness-of-fit of the CFA models of the original version and the simplified version of the Chinese resident health literacy scale in Sample B.

	χ^2	df	p (χ^2)	CFI	TLI	GFI	RMSEA	RMSEA 95%CI
Original version	9420.34	1,171	<0.001	0.693	0.679	0.852	0.049	0.048–0.050
Original version (modified)*	8625.16	1,166	<0.001	0.742	0.728	0.866	0.041	0.040–0.043
Simplified version (modified)**	3099.31	319	<0.001	0.825	0.808	0.910	0.055	0.054–0.056

CFI, Comparative fit index; TLI, Tucker-Lewis index; GFI, Goodness of Fit Index; RMSEA, root mean square error of approximation.
*modified original version with five specified error covariances: A01 with A03; A09 with A10; B18 with B20; C06 with C10; D01 with D02.
**modified simplified version with two specified error covariances: A01 with A03; D01 with D02.

Author contributions

YHW and LW participated in the design of the study and organized the training of investigators. QJ, HW, YLW, and KZ participated in data collection and quality control. BY and LL participated in the literature research and collation. YLW and YHW drafted the manuscript, performed the statistical analysis, and revision of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1147862/full#supplementary-material

TABLE 5 Invariance of the simplified version of the Chinese resident health literacy scale across groups of gender, age, cognitive status, and educational levels in Sample B.

Groups	Invariance levels	χ^2	df	*p*-value	$\Delta\chi^2$	Δdf	*p* ($\Delta\chi^2$)	CFI	ΔCFI	TLI	ΔTLI	GFI	ΔGFI	RMSEA	ΔRMSEA
Gender															
	Male	1759.06	319	<0.001				0.813		0.794		0.902		0.056	
	Female	1719.63	319	<0.001				0.831		0.814		0.903		0.055	
	Configural	3478.70	638	<0.001				0.822		0.805		0.902		0.039	
	Metric	3505.46	662	<0.001	26.76	24	0.316	0.822	0.000	0.811	0.006	0.902	0.000	0.038	0.001
	Strong	3508.39	668	<0.001	2.93	6	0.818	0.822	0.000	0.813	0.002	0.902	0.000	0.038	0.000
	Strict	3539.81	697	<0.001	31.42	29	0.346	0.822	0.000	0.821	0.008	0.901	0.001	0.037	0.001
Age															
	60–69	1709.95	319	<0.001				0.824		0.806		0.902		0.055	
	≥70 or over	1719.84	319	<0.001				0.827		0.809		0.904		0.055	
	Configural	3429.78	638	<0.001				0.825		0.808		0.903		0.039	
	Metric	3452.84	662	<0.001	23.06	24	0.516	0.825	0.000	0.815	0.007	0.903	0.000	0.038	0.001
	Strong	3464.03	668	<0.001	11.19	6	0.083	0.825	0.000	0.816	0.001	0.903	0.000	0.038	0.000
	Strict	3508.25	697	<0.001	44.22	29	0.035	0.824	0.001	0.823	0.007	0.902	0.001	0.037	0.001
Cognitive status															
	Normal	2292.98	319	<0.001				0.810		0.791		0.905		0.056	
	Impairment	1285.07	319	<0.001				0.816		0.798		0.892		0.056	
	Configural	3578.11	638	<0.001				0.812		0.793		0.901		0.040	
	Metric	3631.58	662	<0.001	53.47	24	0.001	0.810	0.002	0.799	0.006	0.900	0.001	0.039	0.001
	Strong	3647.84	668	<0.001	16.26	6	0.012	0.810	0.000	0.800	0.001	0.899	0.001	0.039	0.000
	Strict	3884.22	697	<0.001	236.38	29	0.000	0.796	0.004	0.795	0.005	0.893	0.006	0.040	0.001
Education level															
	Education 1	1262.39	319	<0.001				0.820		0.802		0.882		0.060	
	Education 2	1379.87	319	<0.001				0.794		0.773		0.897		0.056	
	Education 3	1313.93	319	<0.001				0.809		0.789		0.900		0.056	
	Configural	4394.94	1,016	<0.001				0.783		0.775		0.883		0.034	
	Metric	4425.02	1,040	<0.001	30.08	24	0.182	0.783	0.000	0.780	0.005	0.882	0.001	0.033	0.001
	Strong	4430.57	1,046	<0.001	5.55	6	0.475	0.783	0.000	0.781	0.001	0.882	0.000	0.033	0.000
	Strict	4471.92	1,075	<0.001	41.35	29	0.064	0.782	0.001	0.787	0.006	0.881	0.001	0.033	0.000

χ^2: chi-square; df: degrees of freedom; CFI, Comparative fit index; TLI: Tucker–Lewis index; GFI, Goodness of Fit Index; RMSEA, root mean square error of approximation.
Education 1: Illiterate or Primary school; Education 2: Junior school; Education 3: High school, College, or Graduate school.

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Experience and local memory of older people in the face of disasters: a systematic review

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Introduction: The increase in population aging establishes new risk scenarios in the face of the intensification of disasters due to climate change; however, previous experiences and collective memory would generate opportunities for older people to acquire adaptive and coping capacities in the face of these events.

Objective: To analyze the theoretical-methodological characteristics presented by the studies carried out between the years 2012 and 2022 about the experience and collective memory of the older adult in the face of climate change.

Method: A systematic literature review (SLR) was carried out following the guidelines of the PRISMA statement. The databases consulted were Web of Science, Scopus, EBSCO host, and Redalyc, selecting 40 articles in Spanish, English, and Portuguese.

Results: The importance of experience and collective memory in the face of disasters as an adaptive factor in older people was identified. In addition, sharing experiences allows them to give new meaning to what happened, emphasizing confidence in their personal resources and self-management capacity and fostering perceived empowerment.

Discussion: It is essential that in future studies the knowledge provided by the older adult can be privileged, recognizing the importance of their life histories and favoring the active role in their development and wellbeing.

KEYWORDS

older people, climate change, disasters, vital experience, collective memory

Introduction

Climate change has become one of the main risks that increase vulnerability to natural disasters, so it is essential to provide opportunities for the most exposed groups to acquire adaptation and coping capacities to face this problem on a global and local scale (1).

In this context, it is necessary to strengthen those societal and community measures that foster adaptive capacity and reduce vulnerability to disaster risk processes intensified by climate change, especially in the most susceptible groups, such as the older adult population (2, 3).

In addition to this scenario of global environmental crisis, there are statistical projections on the accelerated population aging (4), under which one out of every 11 older adult people living in underdeveloped countries is exposed to climate risks (5, 6).

In terms of the susceptibility of the older adult population to climate change, it is important to consider various aspects, such as mobility difficulties in evacuation and emergency processes, as well as the morbidities inherent to the evolutionary stage in which they find themselves (7–9).

On the other hand, the literature highlights that a population that manages to adapt to climatological stressors is considered less vulnerable to the impacts of climate change, due to the deployment of coping strategies that can absorb, recover, and/or resignify the potentially traumatic event in a resilient manner (10–13).

Among the studies that address the coping strategies used by the older adult population in the face of disaster risk processes, the importance of access to communication and dissemination technologies (14), recognition of safe zones within the home (15), and early warning systems (16) are noted. Likewise, in collective terms, collective memory has been recognized as a central community strategy because of the possibilities of resignification that it gives to the lived experience, as well as the intersubjective understanding of the stages of the disaster that occurred (17, 18), enabling the maintenance of a high collective awareness of the risks (19).

Another relevant individual capacity is life experiences in risk situations, which determine to a large extent the presence of those affected by disasters, which is conditioned by multiple factors such as identity, personality type, lifestyle, and living conditions, to mention just a few (20, 21). Within this field, there is research that indicates that sharing a strongly shocking collective experience tends to increase cohesion, operating as an instance of support, containment, and post-disaster repair (22, 23).

Therefore, and in line with the importance of both capacities to adapt to climate change in the older population, we argue the need to deepen the existing scientific evidence, on the experience and collective memory in the face of climate change (11, 24). To accomplish the above, we conducted a systematic literature review (SLR) of empirical research published between the years 2012 and 2022, that addressed the relationship between previous disaster experiences and/or collective memory of older people in the face of climate change risks. For this, we set the following objectives: (i) to identify authors, countries of the studies, types of memory and/or experiences, types of risk and/or disaster of natural origin associated, and sources of information and methodology used; (ii) to analyze the relationship of previous experiences of disaster and/or collective memory of the older adult to the risks of climate change; and (iii) to identify the lessons learned from the experiences and/or collective memory of the older adult population in the face of the risks of climate change.

Methods

A systematic review of the literature (SLR) was carried out following the guidelines and recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, complying with points 1–10, 13, 16–17, 20, and 23–27, from their checklist (25). In turn, following the PICo format of qualitative research, we pose the following research question: What role do previous disaster experiences and the collective memory of older people play in the face of climate change risks?

Search strategies

The search for articles was limited to studies with empirical data conducted in Spanish, English, and Portuguese with their respective keywords (see Table 1), using the Boolean operators AND, OR, and quotation marks AND and OR with the symbol + and quotation marks for the search, as indicated in Table 2. In addition, the exploration of articles published between 2012 and 2022 was configured during April and August 2022 from the search in four databases, from which a total of 50,849 documents were obtained Web of Science ($n = 566$), Scopus ($n = 102$), EBSCO host ($n = 33$), and Redalyc ($n = 31{,}733$). To complement the selection process, a second search for articles updated until the end of 2022 was carried out in the Web of Science (4 articles), Scopus (1 article) and Redalyc (9 articles) databases. In total, 15 additional articles were identified that met the eligibility criteria.

Article selection procedure

A selection was made in stages (see Figure 1). First, all the articles collected ($n = 508$) were compiled; second, the titles were read and duplicates were eliminated ($n = 108$); third, the titles, abstracts, keywords, and instruments used were read, eliminating those that did not meet the inclusion criteria ($n = 300$); fourth, a full-text reading was carried out, eliminating theoretical instrumental studies or those that did not focus their results on the collective experience and/or memory, climate change, and the older people ($n = 67$); fifth, a second search to obtain studies updated to 2022 from the databases and the search for citations ($n = 29$); and sixth, the last elimination was made of articles that did not meet the inclusion criteria ($n = 12$).

After the analysis and review of the selected articles ($n = 40$), an integrative synthesis of the selected works was carried out to compare the different studies, extracting: author/s and year of publication, country of the study, type of report or experience addressed, type of risk and/or disaster, methodology, sample, source of information, and whether it is primary or secondary.

Results

Table 3 presents the synthesis of empirical studies, which are concentrated in Australia (13.2%), China (10.5%), the United States (7.9%), Mexico (7.9%), India (5.3%), and the United Kingdom (5.3%). In this context, Latin America and the Caribbean have gathered 18.9% of the studies, focusing their research on Mexico (7.9%), Chile (2.6%),

TABLE 1 Keywords searched in the databases.

Spanish	English	Portuguese
Memoria colectiva	Collective memory	Memória coletiva
-	Memories/memory	Memória
Experiencia	Experience	Experiência
Cambio climático	Climate change	Alterações climáticas
Personas mayores	Elderly	Idoso

Made by the authors.

TABLE 2 Database search equations.

Search Equation	Search Articles 1	Search Articles 2
"memoria colectiva" AND "personas mayores" AND "cambio climático"	4	0
"memory" or "experience" AND "elderly" AND "climate change"	165	6
"memories" or "experience" AND "elderly" AND "climate change"	165	6
"memoria" OR "experiencia" AND "personas mayores" AND "cambio climático"	135	2
"memória" OR "experiência" AND "idoso" AND "alterações climáticas"	28	0
"collective memory" AND "elderly" AND "climate change"	10	0
"memória coletiva" AND "idoso" AND "alterações climáticas"	1	0
Total de artículos encontrados	508	14

Made by the authors.

and Ecuador (2.6%) while 10.5% of the remaining studies do not report the country of study.

There was a greater development of research around the general experience of the older adult (34.3%), oriented to the knowledge acquired from a lifetime; the lived experience (14.9%), referring to what was lived around daily life at the time of the disaster; personal experience (6%), which is not influenced by third parties, but only the subjective attribution of the subject is conceived; previous experience (4.5%), understood as the information that was obtained before the event, either directly or indirectly; life experience (4.5%), understood as the knowledge generated from what has been learned, directly or through the story provided by other people; local experience (3%), alluding to the learning generated from the environment and from what was lived in the community of origin; collective memory (3%); daily experience (3%), referring to what was lived around the daily chores within the home during the disaster; spatial experience (3%), understood as knowledge based on the area inhabited and beyond the home of origin, for example, knowledge based on what has been experienced as an immigrant.

Although there are several disasters of natural origin associated with climate change, studies on the experience of the older adult have mainly addressed floods (18.8%), heat waves (10.4%), storms (6.3%), droughts (6.3%), and climate change, in general (6.3%).

In terms of methodology, there was a predominance of qualitative studies (67.5%) that used interviews (52.5%) as the main technique. In relation to the role of older persons in the research analyzed, three subgroups were identified: i) older persons as a primary source (41%), ii) older persons as a mixed source, in which other key agents who live or work with the older adult population were incorporated (30.8%), and iii) older persons as an indirect source, that is, only through key agents (25.6%).

In another area, research has reported various lessons learned from the experience and/or collective memory of older people after a disaster (see Table 4). Through experience and from the cognitive point of view, this age group has been valued as a historical source due to all the knowledge they have obtained from their experience of a disaster (15%) and a greater risk perception after experiencing a disaster (12.5%). However, the valence effect (12.5%) has also been highlighted, which causes a greater risk in the population, making them believe that they have a lower risk of experiencing a negative event compared to other people (36). At *an emotional level*, emotional resilience stands out (15%), understood as the ability to not be affected or to overcome more quickly the worry, uncertainty, and anxiety caused by a disaster (41) and the one that can recognize the traumatic event (12.5%). At the *social level*, it stands out that after a disaster, the older adult tend to form a group identity (10%), favoring the social support obtained (7.5%) and the manifest need for support (7.5%). In other words, social cohesion increases and, consequently, it would favor the generation of new support networks, whether intra- or extra-familial (28). At the *behavioral level*, behavioral adaptation is revealed through generalized coping strategies (25%), the change in gender roles (20%), and a greater general adaptation to climate change (20%). At the *spatial level*, a greater attachment to the place where the older adult live (15%) and an active role in planning (10%) were observed.

Regarding collective memory, it was identified that, after a disaster, older people gained greater hope for the future, seeing it as a better future, and from this, they began to promote actions together with their peers to overcome the circumstances of risk of natural origin. However, this learning involved only 2.5% of recent research. Finally, regarding the characteristics of the other learning obtained, see Supplementary material S1 for their definitions.

Discussion

Systematized scientific evidence shows that it has recently begun to be understood that the physical and emotional wellbeing of the older adult can be influenced by controlling the environment (34). However, it is paradoxical that this manifestation, on many occasions, does not come directly from this age group, but from key agents who interact with the older adult; it would therefore be interesting to know the perspective of the protagonists themselves. Therefore, it is essential that in future studies, the knowledge provided by the older adult can be privileged, recognizing the importance of their life histories and favoring the active role in their development and wellbeing (28).

It has been observed that when people can tell their stories of trauma, they can recover and resignify what happened more easily, emphasizing the confidence they have achieved in their strength and in the ability to manage the resources they were able to deploy in the face of a certain disaster, thus adapting to the post-event physical and social environment, enhancing perceived empowerment (28). In connection with the above, after experiencing a disaster, it would

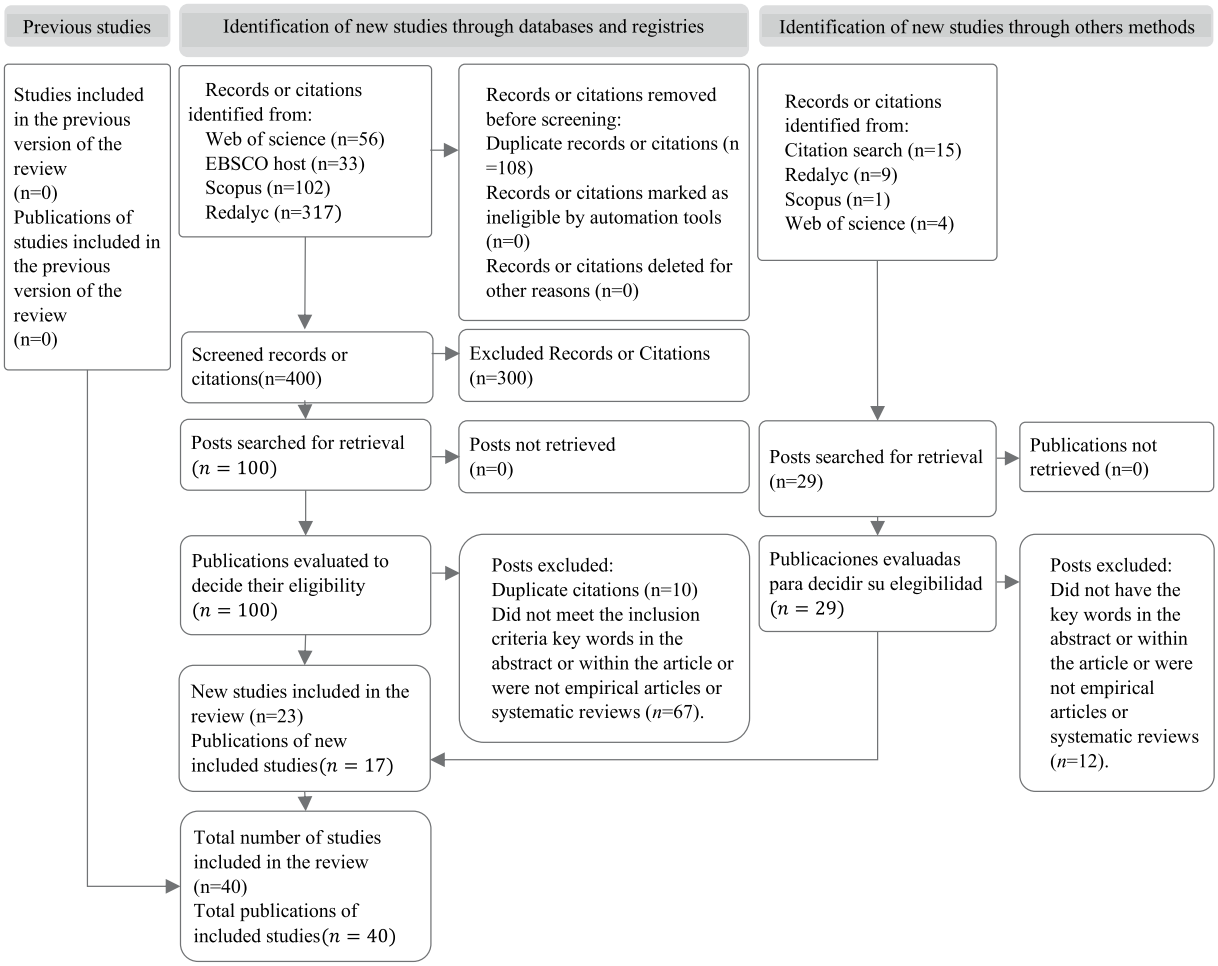

FIGURE 1
PRISMA flow diagram: literature identification and selection process. Prepared from Page et al. (25).

be beneficial for this group to have listening spaces, even more so given the perception of loneliness that has been manifested in various studies (11, 41, 55).

On the other hand, there is a gap in the literature regarding the study of the previous experiences and collective memory of the older adult in the face of risks and/or disasters of natural origin, mainly those caused by climate change, reflected in the low number of empirical studies found. In this way, it is important to delve into this issue, and, through it, enhance the agency capacity of the older adult, especially in those places where they are at greater risk of disaster (45).

When making a comparison between the number of studies that address experience and collective memory, the difference observed is significant, since when looking for an explanation, some studies express their preference for investigating collective memory only when it refers to phenomena that have greater social and psychological significance for the community (56, 57), prioritizing those events that are considered more "collectively representative" among the population. Therefore, some of the "silent risks" of climate change (such as heat waves and frosts) do not have great research relevance so far (58), increasing the scientific debt toward the older adult population. However, it is important to highlight that environmental gerontology, a relatively new discipline (especially in Latin America), has been focusing on carrying out multidisciplinary work that addresses this debt through the understanding, analysis, and optimization of the relationship between the physical-social environment and the aging person (59, 60). In this way, it is intended to raise awareness about the phenomenon of aging and the importance of building friendly environments that reinforce support networks within the community (29, 61).

In another area, it is possible to point out that much of the literature reviewed in the field of environmental gerontology and older people have been built in developed countries, evidencing a scarcity of research focused on the population of Latin America and the Caribbean (58, 62). In the same way, these studies are developed under qualitative methodologies, leaving aside other research perspectives (quantitative or mixed designs, for example), so it is necessary to expand the research development from this perspective (6), generating new knowledge based on the permanent change of the physical and social environments, even more so when they are in danger of experiencing a disaster in the short, medium or long term (59).

In short, it is essential to obtain adequate knowledge so that this same age group can generate the necessary strategies to adapt and protect itself from climate risks (13), minimizing susceptibilities by strengthening its capacity for the agency (28).

TABLE 3 Synthesis of empirical studies.

Author/s	Study country	Type of memory or experience	Disasters or associated risks	Methodology	Sample	Source of information	Primary, secondary or mixed source?
Baldwin et al. (22)	Australia	Experience	Heat waves (urban heat islands)	Qualitative	Representatives of care centers for the elderly	Workshop/discussion group	Secondary
Iglesias Da Cunha et al. (17)	Spain	Lived experience, collective memory	High carbon emissions	Qualitative	Old people	Group interview	Primary
McNamara and Clissold (26)	Maldives	General and lived experience	droughts, tsunamis, earthquakes, floods, Tropical storms, saltwater Intrusion, changes in seasons, coastal erosion	Qualitative	Snowball sampling: 24 participants from Laamu Atoll and Malé	Semi-structured interview	Secondary
Chávez Alvarado and Sánchez González (27)	Mexico	Traumatic experience	Floods	Qualitative	Not probabilistic. 68 people aged 60 and over with disabilities who had suffered at least one flood, and residents of private homes in areas at risk of flooding	Interwiew	Primary
García-Valdez et al. (28)	Latin America and the Caribbean	Spatial and everyday experience	Climate change, heat waves and migration	Qualitative	Articles from journals indexed in Web of Science and Scopus	Articles from journals indexed in Web of Science and Scopus	Secondary
Sánchez González (29)	Latin America	Space experience	Environmental migration	Qualitative	-	-	Secondary
Gilchrist and Gearey (30)	United Kingdom	Lived and historical experience	Lack of water resources: Drought	Qualitative	22 people age 55 or older who are of retirement age or have chosen to retire	Semi-structured interview	Mixed
Huang et al. (31)	China	Experience	Floods	-	-	Survey	Primary
Astill and Miller (10)	Australia	General, lived and past traumatic experience	Cyclones	Qualitative	Older people who have lived in the region for at least 10 years	Semi-structured interview, focus group	Primary
Haq and Gutman (32)	Nordic arctic	Overall experience	-	Qualitative	Seniors, researchers, and a number of local individuals and professionals who provide services to promote northern culture and the well-being of seniors	Interwiew	Mixed
Begum (7)	-	Overall experience	Extreme phenomena	-	-	-	-

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TABLE 3 (Continued)

Author/s	Study country	Type of memory or experience	Disasters or associated risks	Methodology	Sample	Source of information	Primary, secondary or mixed source?
Sampson et al. (9)	United States	General and evacuation experience	Hot spells	Qualitative	Detroit (22 community members and 22 government or nonprofit leaders); New York (25 community members and 21 nonprofit or government leaders); Philadelphia (27 community members and 9 non-profit or government leaders); and Phoenix (22 community members and 25 government or nonprofit leaders).	Semi-structured interview, workshop	Mixed
Sampson et al. (33)	United States	General, traumatic and lived experience	Flood	Qualitative	Snowball sampling: Heads of household over 18 years of age	Entrevista semiestructurada	Primary
Seebauer and Winkler (15)	Austria	Overall experience	Flood	Qualitative	79 households living in the relocation zone	Semi-structured interview	Primary
Vasseur et al. (16)	Canada	General and storm experience	Flood	Qualitative	74 participants	Semi-structured interview	Mixed
Gutsa (34)	Zimbabwe	Overall experience	Dry weather	Qualitative	10 elderly women heads of household	Focus group, interview	Secondary
Malak (8)	Bangladesh	Overall experience	Cyclone	Qualitative	Older people and key stakeholders (local elected representatives, school teacher, NGO officials, local state executive, community health provider and social worker)	Semi-structured interview, focus group discussion and oral histories in three villages (Lebubunia, Gabura and Dumuria)	Mixed
Nobert and Pelling (35)	England	Everyday and temporary experience	Heat waves	Qualitative	30 independent older people (68–95 years) and carers in the Boroughs of Islington, Waltham Forest and London during and after the 2013 heatwave	Semi-structured interview, first hand observation and document analysis	Mixed
Reckien and Petkova (36)	United States	Previous, local and drought experience	Previous, local and drought experience	Qualitative	Randomly selected, representative of the adult population of New York City in terms of gender and age	Online Questionnaire Survey	Mixed
Rich et al. (37)	Australia	General, lived and aging experience	Drought	Qualitative	15 Australian women over the age of 70	Mail survey	Primary
Zhu and Sun (24)	China y Japan	General, previous and life experience	Earthquake	Qualitative	Elderly people over 75 years	Earthquake databases, earthquake shaking map and census	Primary
Stafford and Baldwin (38)	-	General and lived experience	-	Qualitative	96 peer-reviewed articles in English published between 2000 and 2016	Articles	-

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TABLE 3 (Continued)

Author/s	Study country	Type of memory or experience	Disasters or associated risks	Methodology	Sample	Source of information	Primary, secondary or mixed source?
Ogunbode et al. (39)	United Kingdom	Extreme weather experiences and staff	Extreme weather	Mixed	Specific oversampling of people in 5 flood-affected parts of the UK	Survey	Mixed
Yang et al. (14)	China	Personal experience	Air pollution	Qualitative	1,181 respondents from 3 cities in China	Survey	Primary
Loughnan et al. (40)	Australia	Personal experience	Heat waves	Mixed	Snowball sampling: Individuals 55 years or older, living independently, and able to speak and read English	Grupo focal, entrevista y registro de actividades diarias	Primary
Gray et al. (41)		Experience	-	Mixed	Silent generation1, baby boomers2, generation x3 and millennials4	Survey	Mixed
Brockie and Miller (11)	Australia	Life experience and previous	Flood	Qualitative	10 Brisbane seniors who were evacuated in the 2011 and 2013 floods	Interview	Primary
Rubio Aguilar (42)	Chile	General and life experience	Fire	Qualitative	Inclusion criteria: 1 affected elderly male living alone and 1 accompanied, 1 affected elderly female living alone and 1 accompanied	Interview	Primary
Gifford and Nilsson (43)	-	Childhood experience	Environmental damage	Qualitative	Research	Empirical articles	Primary
Yang et al. (44)	China	Emotional experience	Air pollution	-	University students who were with their grandparents	Affective Imaging, Self-Assessment Manikin (SAM), Beck Depression Inventory (DBI), State–Trait Anxiety Inventory (STAI), and Physiological Measurement	Secondary
Rojas Baltazar et al. (45)	México	Overall experience	Insuficiencia de suministros urbanos	Qualitative	-	Aplicación de escala	Primary
Torres Carral and Castillo López (46)	México	General and personal experience	Migration	Qualitative	16 people over 40 years of age	Semi-structured interview	Primary
Weitz et al. (47)	India	Overall experience	Heat waves	-	Elderly residents of an urban slum and elderly residents of rural villages in India (n = 130)	Interview and questionnaire	Primary
Chanza and Musakwa (48)	Zimbabwe	Lived and local experience	Storm, flood and drought	Qualitative	23 women and 14 men with an average age of 63 years	Semi-structured interview	Primary
Yang et al. (49)	China	Overall experience	Heat waves	-	Labor force with ages between 15 and 64 years	China Labor Force Dynamic Survey (CLDS)	Mixed

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TABLE 3 (Continued)

Author/s	Study country	Type of memory or experience	Disasters or associated risks	Methodology	Sample	Source of information	Primary, secondary or mixed source?
Sawangnate et al. (50)	Thailand	Past flood experiences	Flood	Mixed	Expert interview and community survey	Expert interview and community survey	Mixed
Crona et al. (51)	Fiji, Ecuador, New Zealand, Australia, United Kingdom and United States	Individual personal and historical experiences	Climate change	Mixed	Non-probability purposive sampling designed to capture only local residents (n = 29)	Location-Based Open Interview	Secondary
Ford et al. (52)	-	General and lived experience	Climate change	Qualitative	IPCC Articles	IPCC Articles	Secondary
Smith et al. (53)	India	General and crop experience	Decline in pollinators	Mixed	80 farmers who were trained and 50 farmers who were not trained	Group discussion	Mixed

"-": Not reported in studies. 1: People born between 1925 and 1945 (41). 2: People born between 1946 and 1964 (41). 3: People born between 1965 and 1981 (41). 4: People born between 1982 and 1999 (41). Made by the authors.

Conclusion

Previous disaster experiences and collective memory have been identified as adaptive capacities in older people (63), which has been expressed through the learnings obtained after some potentially traumatic event of natural origin. Specifically, negatively valenced emotions, be it fear and anger, and perceived self-efficacy would drive precautionary attitudes and behaviors (8, 53). In this case, the deployment of coping skills would be motivated by the level of involvement of the person in the face of the event experienced, which would amplify the perception of risk and the organization of their resources to deal functionally with climate change (43). Similarly, Sandoval-Obando (64) describes generative coping as that set of actions and tasks deployed by the older adult in the face of potentially traumatic events (pandemic for example), in which solidarity, trust, social participation, reciprocity, and mutual support give them a greater degree of self-efficacy and social support in the face of these events (65).

The agency capacity of the older adult in the face of disasters of natural origin, either individually or collectively, favors adaptation processes through experience and the respective personal meaning of what they have experienced (24, 31), actively empowering itself during the aging process. In other words, on a personal level, the older adult can value and make decisions about their lives and know how to act in the face of danger, beyond their family, and, on a social level, allows them to be part of the community, integrating and actively participating in their environment (66–68). In short, the empowerment of the older adult makes it possible to overcome ageism conceptions of old age, reducing vulnerability indices to the risks generated by climate change, and at the same time, allows them to be recognized as an age group of enormous historical-cultural value for future generations (30, 48).

By way of reflection, it is possible to point out that the experience and collective memory of this age group in the face of potentially traumatic events of natural origin, emerges as a resilient post-disaster attitude, thanks to the positive assessment they establish with themselves, in addition to the recognition and appreciation of their knowledge and personal resources (12, 42), becoming a determinant of individual/social resilience (69). At the same time, it would favor a better psychological adjustment and less emotional distress after a disaster (11). Finally, the experience of aging in changing environments as a consequence of climate change can stimulate the emergence of functional behaviors and challenging tasks for the older adult, contributing to their adaptive process (59).

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

CN-V and JS-D contributed to conception and design of the study. CN-V organized the database. CN-V, JS-D, and ES-O wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

TABLE 4 Learning obtained through experience or collective memory after a disaster according to studies.

The way of knowledge	Category	Learning obtained	Frequency	Authors
Experience	Cognitive	Determinant of psychological well-being	4	García-Valdez et al. (28), Haq and Gutman (7), Malak et al. (8), Sánchez González (29)
		Spirituality Connection	4	Gifford and Nilsson (43), Malak et al. (8), Rubio Aguilar (42), Sánchez González (29)
		Use of common sense	1	Nobert and Pelling (35)
		Gambler fallacy1	4	Brockie and Miller (11), Reckien and Petkova (36), Rich et al. (37), Viglione et al. (19)
		Valence effect2	5	Brockie and Miller (11), Loughnan et al. (40), Petkova et al. (54), Reckien and Petkova (36), Sawangnate et al. (50), Yang et al. (49)
		Indigenous knowledge (mitigation/adaptation)	2	Ford et al. (52), Smith et al. (53)
		Global cultural competence	1	Crona et al. (51)
		Risk perception	5	Brockie and Miller (11), Crona et al. (51), Gifford and Nilsson (43), Huang et al. (31), Ogunbode et al. (39), Sampson et al. (33)
		Positive assessment of the past	1	Rubio Aguilar (42)
		Common sense of history	4	Brockie and Miller (11), Gray et al. (41), Sánchez González (29), Zhu and Sun (24)
		Older person as a historical source	6	Chanza and Musakwa (48), Gutsa (34), Sampson et al. (33), Sawangnate et al. (50), Smith et al. (53), Torres Carral and Castillo López (46)
		Resignify what has been lived	1	McNamara and Clissold (26)
	Emotional	Home meaning and satisfaction	1	García-Valdez et al. (28)
		Emotional resilience	6	Brockie and Miller (11), Rich et al. (37), Rubio Aguilar (42), Sampson et al. (33), Seebauer and Winkler (15), Zhu and Sun (24)
		Feeling of loss and instability	1	Rich et al. (37)
		Recognition of traumatic event	5	Brockie and Miller (11), Gray et al. (41), Huang et al. (31), Rich et al. (37), Seebauer and Winkler (15)
	Social	Determinant of social support obtained	3	García-Valdez et al. (28), Haq and Gutman (7), Malak et al. (8)
		Manifest need for support	3	Brockie and Miller (11), Sampson et al. (33), Sawangnate et al. (50)
		Loss of community networks	1	Rich et al. (37)
		Deterioration of family cohesion	1	Rich et al. (37)
		Social change due to environmental migration	1	Begum (32)
		Climate change communication	2	Sawangnate et al. (50), Yang et al. (14),
		Group identity	4	Iglesias Da Cunha et al. (17), McNamara and Clissold (26), Ogunbode et al. (39), Seebauer and Winkler (15)
		Greater group connection	2	Baldwin et al. (22), Brockie and Miller (11)
	Behavioral	Determinant of physical well-being	4	García-Valdez et al. (28), Haq and Gutman (7), Malak et al. (8), Sánchez González (29)
		Service provision	1	McNamara and Clissold (26)
		Pro-environmental behavior (mitigation)	5	Chanza and Musakwa (48), Crona et al. (51), Gifford and Nilsson (43), Gray et al. (41), Smith et al. (53)

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TABLE 4 (Continued)

The way of knowledge	Category	Learning obtained	Frequency	Authors
		Follow recommendations from authorities	3	Chávez Alvarado and Sánchez González (27), Nobert and Pelling (35), Sawangnate et al. (50)
		Digital literacy	1	Sawangnate et al. (50)
		Conscious volunteering	1	Gilchrist and Gearey (30)
		Generation of changes according to assets	1	Malak et al. (8)
		Coping strategies (adaptation in general)	10	Brockie and Miller (11), García-Valdez et al. (28), Huang et al. (31), Malak et al. (8), Rubio Aguilar (42), Sampson et al. (9), Sampson et al. (33), Sawangnate et al. (50), Stafford & Baldwin (38), Zhu and Sun (24)
		Double presence of women	8	Begum (32), Chanza and Musakwa (48), Crona et al. (51), Gutsa (34), Malak et al. (8), Rich et al. (37), Sánchez González (29), Vasseur et al. (16), Weitz et al. (47)
		Promote necessary changes at a general level (psychological adaptation)	8	Begum (32), García-Valdez et al. (28), Huang et al. (31), Iglesias Da Cunha et al. (17), Nobert and Pelling (35), Smith et al. (53), Stafford and Baldwin (38), Sánchez González (29)
	Space	Environment optimization	2	Haq and Gutman (7), Sánchez González (29)
		Attachment to place	6	Brockie and Miller (11), García-Valdez et al. (28), Gifford and Nilsson (43), Rubio Aguilar (42), Seebauer and Winkler (15), Sánchez González (29)
		Active role in planning	4	Rojas Baltazar et al. (45), Smith et al. (53), Sánchez González (29), Zhu and Sun (24)
		Aging in place	3	Ford et al. (52), García-Valdez et al. (28), Huang et al. (31)
		Belonging to a symbolic space that no longer exists	3	Brockie and Miller (11), Ford et al. (52), Sánchez González (29)
		Green infrastructure as a mitigator	1	Baldwin et al. (22)
Collective memory	General	Hope for a better future	1	Iglesias Da Cunha et al. (17)
		Promote joint actions	1	Iglesias Da Cunha et al. (17)

*The definition of apprenticeships can be reviewed in depth in the attached section. 1: Cognitive bias that causes a person to consider that they are at less risk of experiencing a negative event compared to other groups (36). 2: Belief that if an event occurs more frequently over time, it will happen less frequently in the future (36). Made by the authors.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1163561/full#supplementary-material

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Is sleep apnea truly associated with hearing loss? A nationwide, population-based study with STOP-BANG questionnaire

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Objectives: We aimed to investigate the effect of obstructive sleep apnea (OSA) on hearing ability.

Methods: We retrospectively reviewed the population-based survey data collected by the Korean National Health and Nutrition Examination Survey between January 1, 2019 and December 31, 2020. The data included 3,575 participants who completed the STOP-BANG questionnaire (SBQ) and pure-tone audiometry. OSA risk was assessed using the SBQ, and the hearing level was compared between the risk groups.

Results: Among the 3,575 participants, 2,152 (60.2%), 891 (24.9%), and 532 (14.9%) were classified as being low, intermediate, and high risk, respectively. The intermediate- and high-risk groups showed significantly worse hearing levels than the low-risk group. When age and sex were adjusted, the hearing level did not differ between the risk groups.

Conclusion: The study found that the presence of OSA minimally affected hearing level. Because hearing loss due to hypoxic damage develops over a long period of time, further research on the association between the duration of OSA, rather than the presence or severity of OSA, and hearing loss is needed.

KEYWORDS

sleep apnea, hearing loss, STOP-Bang questionnaire, age, KNHANES

Introduction

Obstructive sleep apnea (OSA) is a disorder that causes frequent pauses in breathing during sleep due to the repetitive collapse of the upper airway. OSA causes a reduction in oxygen in the blood (hypoxia) and repeated awakenings during sleep. This can injure the delicate hair cells responsible for hearing in the inner ear, resulting in hearing loss. Hypoxia-induced oxidative stress, inflammation, and alterations in blood flow to the inner ear are believed to contribute to the pathophysiological basis of hearing loss in OSA (1, 2). Additionally, the recurrent arousals and sleep fragmentation associated with OSA can disrupt the normal physiological processes involved in hearing, leading to further damage over time (3).

The prevalence of OSA varies greatly from 0.26 to 49.7% (4, 5), and approximately 80 to 90% of patients with OSA remain undiagnosed (6, 7). The difference in the prevalence among these studies is likely due to the difficulty in diagnosing OSA. The gold standard for diagnosing OSA

is an overnight polysomnogram (PSG), which measures sleep apnea parameters, such as the respiratory disruption index or the apnea-hypopnea index (AHI) during sleep, providing comprehensive data. However, PSG requires specialists with sufficient time and space, resulting in a high cost. Although delayed detection of OSA can lead to life-threatening conditions, patients with OSA have to wait an average of 11.6 months before beginning medical therapy in Canada (8). Therefore, simple and practical methods are emerging to identify and classify patients at high-risk of OSA.

The need for a quick, user-friendly screening tool in clinics led to the development of the STOP-BANG questionnaire (SBQ), which includes eight dichotomous questions (9). This questionnaire provides superior reliability and accuracy in detecting OSA compared with the existing Berlin questionnaire or Epworth sleepiness scale (10). Because of the usefulness and convenience of the SBQ as well as the need for early detection of OSA, the SBQ has been implemented in the Korean National Health and Nutrition Examination Survey (KNHANES) since 2019.

Various studies have been conducted under the hypothesis that OSA affects auditory function. Numerous studies have evaluated the correlation between OSA and auditory dysfunction, but the results are inconsistent. Some studies have claimed a significant relationship between OSA and hearing, such as meaningful hearing loss at high frequencies or quantitative association with the severity of OSA (11–13). In contrast, other studies have found no relationship between OSA and hearing at all (14, 15). While some studies argued that the effect of OSA on hearing was due to recurrent hypoxemia affecting the cochlea (1), other studies have argued that the OSA affects the central auditory pathway, not the cochlea (14, 15). These diverse results are likely due to the small sample size of the studies, the different methods of defining OSA and hearing level, and the extent to which factors affecting hearing are adjusted. Therefore, this study aimed to predict the association between OSA assessed by the SBQ and hearing loss in a large cohort from the KNHANES.

Materials and methods

Study design and participants

This study was based on data from the KNHANES conducted by the Disease Control Headquarters to produce nationwide statistics to identify the health and nutritional statuses of Koreans. A cohort was surveyed between 2019 and 2020. The target population was Koreans aged 1 year or older, and samples were extracted using a two-stage stratified cluster sample extraction method, with survey locations and households serving as the first and second extraction units, respectively. This study included participants who had completed the SBQ, which was administered to those older than 40 years, and had undergone hearing assessment using pure-tone audiogram. This study was approved by the authors' institutional review board (approval number: 2022-12-023).

Clinical and laboratory measurements

Anthropometric, health-related variables, and biochemical measurements were included in the analysis. Body mass index (BMI) was calculated as weight in kilograms divided by height squared in meters. Neck circumference (NC) was assessed by measuring at the horizontal level of the seventh cervical vertebra. Waist circumference (WC) was assessed by measuring at the midpoint between the lowest rib and the anterior iliac crest in the standing position. Blood pressure (BP) was measured three times at the sitting position after resting for 5 min, and the average of the second and third results was used for analysis. High BP was defined as systolic BP $\geq$ 140 mmHg, diastolic BP $\geq$ 90 mmHg, or taking antihypertensive medication. The fasting blood glucose (FBG), glycosylated hemoglobin (HbA1c) level, triglyceride (TG), total cholesterol (TC), high-density lipoprotein cholesterol, and low-density lipoprotein cholesterol (LDL) were measured after overnight fasting. Diabetes was defined as FBG $\geq$ 126 mg/dL, diagnosis by a doctor, use of hypoglycemic agents or insulin injections, or HbA1c $\geq$ 6.5%. Hyperlipidemia was defined as TC $\geq$ 240 mg/dL or taking cholesterol-lowering drugs. Hypertriglyceridemia was defined as TG $\geq$ 200 mg/dL. Smoking status was classified into two groups: never smoker and former/current smoker. Participants who had ceased smoking at the time of the survey were considered former smokers, regardless of the duration of smoking cessation.

OSA risk assessment

OSA risk was assessed by the SBQ (9), which contains eight dichotomous questions: loud snoring (S), day-time tiredness (T), observed apnea (O), high BP (P), BMI > 30 kg/m^2 (B), age > 50 years (A), NC > 40 cm (N), and male sex (G). The low-risk group was defined as those who answered "yes" to 0–2 questions; the intermediate-risk group was defined as those who answered "yes" to 3–4 questions; the high-risk group was defined as those who answered "yes" to 5–8 questions or those who answered "yes" to 2 or more STOP questions with a BMI > 30 kg/m^2, a NC > 40 cm, or male sex.

Audiometric evaluation

The hearing threshold was evaluated by trained audiologists using an automatic audiometer (GSI SA-203; Entomed Diagnostics AB, Lena Nodin, Sweden) in a soundproof booth. The thresholds for 0.5, 1, 2, 4, and 8 kHz from both ears were available. Hearing thresholds were measured in each ear by pure-tone audiometry using an ascending/descending technique in 5 dB steps at frequencies of 0.5, 1, 2, 3, 4, and 8 kHz. The order of sound frequency was assigned randomly (16, 17). The pure-tone average (PTA) was defined as the mean values of the pure-tone thresholds at 0.5, 1, 2, and 4 kHz, whereas the high-frequency average was defined as the mean values at 4 and 8 kHz. We compared the PTA from each ear and selected the better hearing level in order to exclude those with pathologically damaged hearing, such as those with chronic otitis media, sudden hearing loss, etc.

Statistical analysis

All statistical analyses were conducted using SPSS version 21 for Windows (IBM Corp., Armonk, NY, United States). The mean and standard deviation were used for descriptive statistics. The variables were compared among the low-, intermediate-, and high-risk groups using analysis of variance with Bonferroni post-hoc analysis and

Pearson's chi-squared test. When the variables were compared between two risk groups (e.g., low- vs. intermediate/high-risk groups), *t*-test and chi-squared test were used. Multiple linear regression predicted the association between hearing level and OSA-associated factors. A value of $p < 0.05$ was considered statistically significant.

Results

Study population

A total of 7,359 participants, aged 1 year to 80 years, were included in the survey. A total of 4,188 participants were older than 40 years and were administered SBQ. Meanwhile, 395 and 218 participants were excluded due to missing SBQ and hearing assessment data, respectively. Finally, 3,575 participants were included in this study. The participants were grouped according to their STOP-BANG scores as follows: 2,152 participants (60.2%) were classified as having low risk, 891 (24.9%) were classified as having intermediate risk, and 532 (14.9%) were classified as having high risk (Figure 1). The results of the SBQ according to risk group are shown in Table 1. The higher the risk, the higher the proportion of most variables, except for age. The intermediate-risk group had a higher proportion of participants aged >50 years than the high-risk group.

Concordance between the SBQ and OSA diagnoses

The KNHANES included a question about whether the participants had been diagnosed with OSA by a doctor using PSG. The answers were analyzed as "yes," "no," and "do not know/no response." A total of 22 participants answered "yes," whereas 3,553 answered "no." Of the 22 participants who had been diagnosed with OSA, 5 were low risk, 1 was intermediate risk, and 16 were high risk according to the SBQ.

Comparison of OSA-associated factors according to the risk of OSA

The factors previously known to affect OSA were compared according to the risk of OSA (Table 2). The missing data for each factor was ≤2%, except for LDL ($n = 506$). When the variables were compared among the three groups, most showed significant differences. Systolic BP, FBG, HbA1c, presence of diabetes, TC, and presence of hyperlipidemia showed no differences between the intermediate- and high-risk groups, whereas these values in the intermediate/high-risk groups were significantly different from those in the low-risk group. Age was highest in the intermediate-risk group, and it was significantly different from that in the low- and high-risk groups; however, age did not differ between the low- and high-risk groups. LDL was highest in the low-risk group, and the difference was only significant between the low- and intermediate-risk groups. All variables showed significant differences between the low- and intermediate/high-risk groups.

Hearing level according to the risk of OSA

Hearing level was analyzed according to the risk of OSA (Figure 2). The hearing level was worse in the intermediate-,

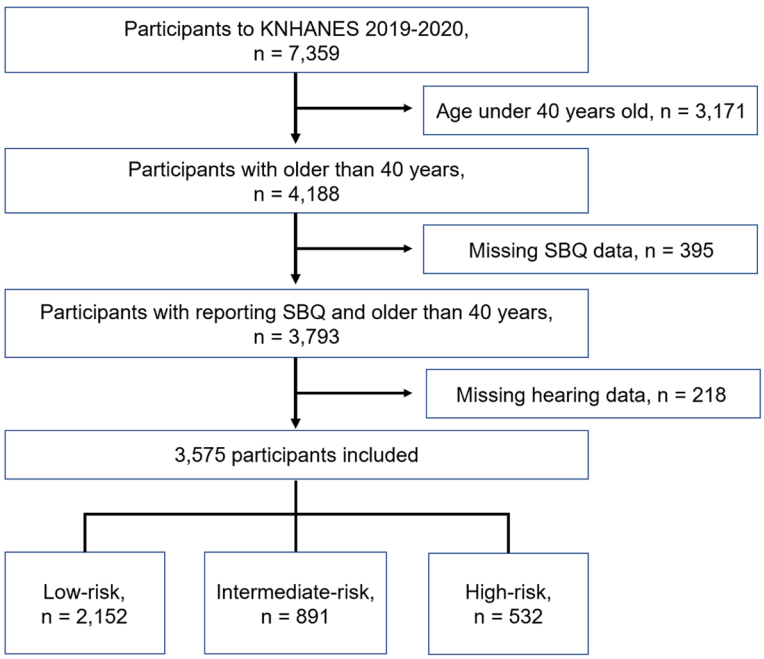

FIGURE 1
Schematic illustration of participant selection in the present study. KNHANES, Korean National Health and Nutrition Examination Survey; SBQ, STOP-BANG questionnaire.

TABLE 1 Variables of STOP-BANG questionnaire in each risk group.

	Total (n=3,575)	Low risk (n=2,152)	Intermediate risk (n=891)	High risk (n=532)	*p*-Value*	Intermediate/ high risk (n=1,423)	*p*-Value#
STOP-BANG score	2.3 ± 1.4	1.4 ± 0.7	3.1 ± 0.3	4.5 ± 1.0	<0.001	3.6 ± 0.9	<0.001
Loud snoring	710 (19.1%)	98 (4.6%)	248 (27.8%)	364 (68.3%)	<0.001	612 (43.0%)	<0.001
Day-time tiredness	1,052 (29.4%)	384 (17.8%)	352 (39.5%)	316 (59.3%)	<0.001	668 (46.9%)	<0.001
Observed apnea	319 (8.9%)	27 (1.3%)	70 (7.8%)	222 (41.7%)	<0.001	292 (20.5%)	<0.001
High blood pressure	1,469 (41.1%)	462 (21.5%)	617 (69.2%)	390 (73.2%)	Low vs. intermediate: <0.001 Low vs. high: <0.001 Intermediate vs. high: 0.252	1,007 (70.7%)	<0.001
Body mass index >30 kg/m^2	152 (4.3%)	25 (1.2%)	44 (4.9%)	83 (15.6%)	<0.001	127 (8.9%)	<0.001
Age > 50 years	2,657 (74.3%)	1,406 (65.3%)	848 (95.1%)	403 (75.6%)	<0.001	1,251 (87.9%)	<0.001
Neck circumference > 40 cm	228 (6.4%)	11 (0.5%)	91 (10.2%)	126 (23.6%)	<0.001	217 (15.2%)	<0.001
Male sex	1,550 (43.4%)	541 (25.1%)	521 (58.4%)	488 (91.6%)	<0.001	1,009 (70.9%)	<0.001

*p-value: comparing three groups by one-way ANOVA with Bonferroni post-hoc analysis for a continuous variable and by chi-squared test for nominal variables. #p-value: comparing two groups (low- vs. intermediate/high-risk groups) by an independent t-test for a continuous variable and by the chi-squared test for nominal variables. Continuous variable: STOP-BANG score. Nominal variables: Loud snoring, day-time tiredness, observed apnea, high blood pressure, body mass index, age, neck circumference and male sex. ANOVA, analysis of variance; STOP-BANG: S, loud snoring; T, day-time tiredness; O, observed apnea; P, high blood pressure; B, body mass index > 30 kg/m^2; A, age > 50 years; N, neck circumference > 40 cm; G, male sex.

high-, and intermediate/high-risk groups than that in the low-risk group. The differences in the hearing level were all significant, except for that in the low-risk group and that in the high-risk group at 500 Hz ($p = 0.178$). For all frequencies, the hearing level in the intermediate-risk group was worse than that in the high-risk group.

Multiple regression analysis was performed to identify whether any factor in the SBQ or any OSA-associated factor affected the hearing level. Among the 17 variables, age and sex significantly affected the hearing level. For PTA, the regression coefficient was 0.597 for age and 0.156 for sex. For high-frequency PTA, the regression coefficient was 0.648 for age and 0.268 for sex (Supplement 1). Because we aimed to determine the effect of OSA on hearing level, data adjusted for age and sex further analyzed. The data were adjusted by diving the total population into eight groups by age (40–50, 51–60, 61–70, and 71–80 years) and by sex. In all eight subgroups, no significant difference between age and sex was observed between the low- and intermediate/high-risk groups. Within the subgroups, the hearing levels according to the frequencies were compared between the low- and intermediate/high-risk group. Hearing level differences were found in a small proportion of participants (Supplement 2): at 8 kHz in 71–80 year-old males (low-risk group, 74.5 ± 18.3 dB, vs. intermediate/high-risk group, 68.5 ± 20.7 dB, $p = 0.017$), at 0.5 kHz in 51–60 year-old females (low-risk group, 11.4 ± 8.0 dB, vs. intermediate/high-risk group, 13.3 ± 9.3 dB, $p = 0.027$), and at 4 and 8 kHz in 71–80 year-old females (low-risk group, 37.7 ± 16.9 dB, vs. intermediate/high-risk group, 42.9 ± 17.2 dB, $p = 0.005$, and low-risk group, 60.8 ± 18.8 dB, vs. intermediate/high-risk group, 64.9 ± 17.7 dB, $p = 0.034$, respectively).

Discussion

The present study investigated the relationship between OSA and hearing loss in a large cohort from the KNHANES. It included 3,575 participants and used the actual hearing level measured by frequency, rather than the pass/non-pass results of general health checkups.

In the present study, the risk of OSA was screened using the SBQ, which is a validated and easy-to-apply tool for screening OSA that requires careful interpretation. As the severity of OSA increases, the sensitivity of the SBQ increases. The probability of obtaining an SBQ score ≥ 3 has been reported to be 84% in patients with OSA (AHI > 5) and 100% in patients with severe OSA (AHI > 30) (9). However, among those with an SBQ score of 3, the probability of having OSA is 72%, whereas the probability of having severe OSA decreased to 13%. Even with an SBQ score of 8, the probability of having OSA is 86%, whereas that of having severe OSA is as low as 38% (18). In other words, among the general population whose OSA status is unknown, the SBQ can only predict the presence of OSA, but not the severity. Therefore, the results indicating low, intermediate, and high risks should not be misinterpreted as indications of the severity of OSA. In addition, the present study found that the known OSA-related factors showed significant quantitative differences in each group; however, these differences should not be interpreted as representing the severity of OSA.

We aimed to determine the concordance between the SBQ and OSA diagnoses; however, this analysis was not possible due to the small number of patients and lack of reliability in the test results. Among 3,575 participants, only 22 answered "yes" to whether they had been diagnosed with OSA by a doctor using a PSG. The calculated probability of obtaining an SBQ score ≥ 3 in patients with OSA is 77%, which is slightly lower than that suggested by its developers.

TABLE 2 Comparison of OSA-associated factors according to the risk of OSA.

	Total (*n*=3,575)	Low risk (*n*=2,152)	Intermediate risk (*n*=891)	High risk (*n*=532)	*p*-value*	Intermediate/ high risk (*n*=1,423)	*p*-value#
Age (years)	59.5 ± 11.4	57.5 ± 11.5	64.8 ± 9.4	59.1 ± 10.8	<0.01	62.6 ± 10.3	<0.001
Neck circumference (cm)	35.8 ± 3.4	33.9 ± 2.8	36.3 ± 3.1	38.7 ± 2.5	<0.001	37.2 ± 3.1	<0.001
BMI (kg/m^2)	24.3 ± 3.3	23.5 ± 3.0	25.0 ± 3.2	26.4 ± 3.7	<0.001	25.5 ± 3.4	<0.001
WC (cm)	85.8 ± 9.6	82.7 ± 8.8	88.9 ± 8.6	93.1 ± 8.9	<0.001	90.5 ± 9.0	<0.001
Smoking	19.8%	14.6%	50.2%	76.7%	<0.001	27.8%	<0.001
SBP (mmHg)	122.1 ± 16.4	118.2 ± 15.3	128.5 ± 16.7	127.5 ± 15.3	Low vs. intermediate: <0.001 Low vs. high: <0.001 Intermediate vs. high: 0.760	128.1 ± 16.2	<0.001
DBP (mmHg)	76.3 ± 9.8	74.9 ± 8.9	77.1 ± 10.1	80.9 ± 10.9	<0.001	78.5 ± 10.6	<0.001
FBG (mg/dL)	104.4 ± 23.5	101.3 ± 20.9	108.1 ± 24.4	111.0 ± 29.3	Low vs. intermediate: <0.001 Low vs. high: <0.001 Intermediate vs. high: 0.065	109.2 ± 26.3	<0.001
HbA1c (%)	6.0 ± 0.9	5.9 ± 0.9	6.2 ± 0.9	6.2 ± 1.03	Low vs. intermediate: <0.001 Low vs. high: <0.001 Intermediate vs. high: 0.250	6.2 ± 1.0	<0.001
DM	33.1%	29.1%	26.8%	29.3%	Low vs. intermediate: <0.001 Low vs. high: <0.001 Intermediate vs. high: 0.309	39.1%	<0.001
TC (mg/dL)	190.4 ± 40.4	195.3 ± 38.9	182.7 ± 41.5	183.3 ± 41.5	Low vs. intermediate: <0.001 Low vs. high: <0.001 Intermediate vs. high: 1.000	182.9 ± 41.5	<0.001
HDL (mg/dL)	50.8 ± 12.3	53.0 ± 12.5	48.7 ± 11.8	45.5 ± 10.0	<0.001	47.5 ± 11.3	<0.001
TG (mg/dL)	135.5 ± 111.5	123.5 ± 86.0	140.4 ± 123.7	176.0 ± 160.4	<0.001	153.7 ± 139.6	<0.001
LDL (n = 508)	111.9 ± 36.9	117.0 ± 38.4 (n = 240)	107.2 ± 34.4 (n = 142)	107.5 ± 35.5 (n = 126)	Low vs. intermediate: <0.05 Low vs. high: 0.059 Intermediate vs. high: 1.000	107.4 ± 34.9 (n = 268)	0.03
Hyperlipidermia	13.8%	11.0%	40.5%	36.6%	Low vs. intermediate: <0.001 Low vs. high: <0.001 Intermediate vs. high: 0.153	17.9%	<0.001
Hypertriglycemia	39.%	25.9%	14.9%	23.2%	<0.001	60.1%	<0.001

*p-value: comparing three groups by one-way ANOVA with Bonferroni post-hoc analysis for continuous variables and by chi-squared test for nominal variables. #p-value: comparing two groups (low- vs. intermediate/high-risk groups) by an independent t-test for continuous variables and by chi-squared test for nominal variables. Continuous variables: age, neck circumference, BMI, WC, SBP, DBP, FBG, HbA1c, TC, HDL, TG and LDL. Nominal variables: smoking, DM, hyperlipidermina, and hypertriglycemia. ANOVA, analysis of variance; BMI, body mass index; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; HbA1c, glycosylated hemoglobin; DM, diabetes mellitus; HDL, high-density lipoprotein cholesterol; OSA, obstructive sleep apnea; TC, total cholesterol; TG, triglyceride; LDL, low-density lipoprotein cholesterol.

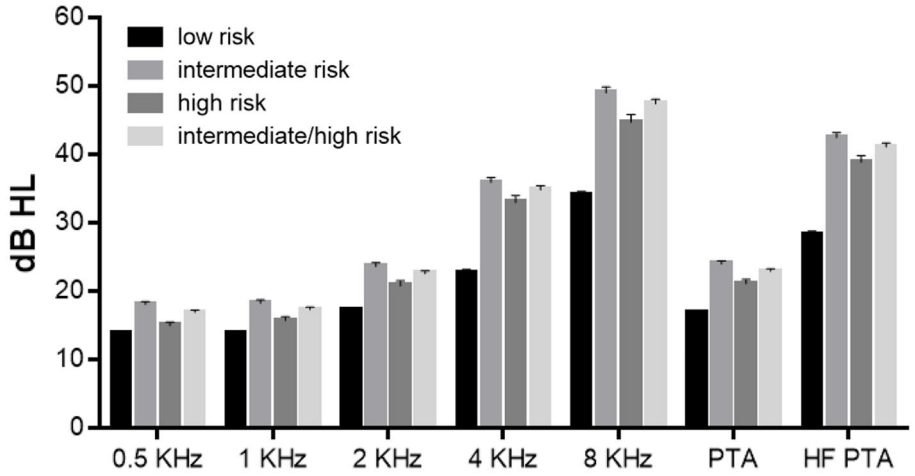

FIGURE 2
Hearing level according to the risk of obstructive sleep apnea (OSA). The hearing level differed significantly between the low- and intermediate-risk groups, the low- and high-risk groups, the low- and intermediate/high-risk groups, and the intermediate- and high-risk groups, except for the hearing level in the low- and high-risk groups at 500Hz (p=0.178).

Interestingly, the remaining 3,553 participants answered "no" to this question, although the answer options were "yes," "no," and "do not know/no response." It is highly likely that the answers "no" and "do not know/no response" are interpreted interchangeably by the participants. However, the fact that only 22 participants answered "yes" to this question underscores the difficulty in accurately diagnosing OSA because either the participants did not suspect OSA themselves or the process leading to a PSG is difficult. These results once again highlight the importance of an easily accessible OSA questionnaire.

The present study found that the hearing level of the intermediate/high-risk group was worse than that of the low-risk group. However, when the factors that affect hearing, such as age and sex, were adjusted, no significant difference was observed in hearing level between the two groups. This result differs greatly from previous studies. Similar to this study, a study that evaluated the relationship between SBQ scores and hearing level in 794 Chinese males aged 40–65 years reported that the hearing level of the intermediate/high-risk group was worse, even after adjusting for age, BMI, and cardiovascular risk (19). However, the study used pass/fail results of hearing screening centered at 25 dB, which could be seen as relatively less accurate in evaluating the hearing level than the present study. A systematic meta-analysis published in 2022 also concluded that OSA and hearing loss were significantly correlated and that hearing loss was affected by the severity of OSA (13). They argued that age was adjusted because most of the papers they included were age-matching studies; however, only 11 of the 20 papers they included were age-matched. Therefore, we believe that the meta-analysis cannot claim that its data are age-matched, as only a subset of its data are age-matched and subgroup analyses may be misleading. Meanwhile, Hwang et al. and İriz et al. did not find any differences in PTA between patients with and without OSA after adjusting for age, sex, and other variables (14, 15).

The effect of OSA on hearing has not been clearly defined, but most studies have agreed that the main pathology of hearing loss in patients with OSA is cochlear ischemia due to chronic intermittent hypoxemia (20, 21). Because this pathophysiology does not occur suddenly like noise exposure or infection, damage to the cochlea likely occurs gradually over a long period of time and does not recover. A previous study investigated whether hearing was restored when OSA was treated using CPAP and found that hearing was unchanged (13), confirming that damage to the cochlea occurs over a long period of time and the damage is irreversible. Considering that hearing loss in OSA is a long-term phenomenon, it would be difficult to predict the effect of OSA on hearing using the current PSG parameters. The parameters are a result of measurements taken at a given time in a patient with OSA. In other words, to determine the actual effect of OSA on hearing, we should not only examine the frequency of apnea or hypopnea (AHI) or the lowest oxygen saturation level (lowest SaO_2) at a given time but also investigate the duration of exposure to hypoxemia. This will also explain the paradoxical relationship between PSG results and hearing in the older adult. As age increases, the frequency of desaturation events (O_2 nadir) becomes lower, and the lowest saturation level increases, which means that the hypoxic state is less induced in the older adult with OSA than in middle-aged adults, suggesting that the older adult will have less damage from hypoxia (22). Nevertheless, that hearing level deteriorated with increasing age supports the fact that long-term hypoxia has a greater effect on hearing than fragmentary hypoxia. Therefore, the fact that the previous studies have shown so many different results and that age has a great effect on hearing in most studies, including the present study, could be accepted to some extent. Moreover, determining the duration of OSA is even more difficult to determine than the diagnosis of OSA. Thus, no study has investigated the relationship between the duration of OSA and hearing. Hence, a long-term comparison of the hearing level of patients with and without treatment after diagnosis of OSA is warranted.

The present study found no significant correlation between the presence of OSA and hearing level in a large cohort after adjusting for other factors that affect hearing. However, these results should be interpreted carefully. First, because hearing loss due to OSA is a long-term event, the relationship between OSA and hearing

cannot be simply evaluated by the presence or absence of OSA using the current cross-sectional data. Moreover, evaluating the effect of OSA on hearing only with the results of pure-tone audiometry, which only measures the audible range, has limitations. For example, there could be differences in frequencies above 8 kHz that are more vulnerable to damage, in otoacoustic emission test that measures cochlear function, or in central auditory functions. Nevertheless, the present study confirmed the need to evaluate the effects of OSA on hearing loss in greater detail and with a longer duration.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the authors' institutional review board (Inje University College of Medicine, approval number: 2022-12-023). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

JML and HJL: conceptualization, methodology, project administration, visualization, and writing—review and editing. JML: data curation and writing—original draft. HJL: formal analysis. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1170470/full#supplementary-material

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Association of handgrip strength with new-onset CKD in Korean adults according to gender

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Introduction: Handgrip strength (HGS) is an indicator of many diseases such as pneumonia, cardiovascular disease and cancer. HGS can also predict renal function in chronic kidney disease (CKD) patients, but the value of HGS as a predictor of new-onset CKD is unknown.

Methods: 173,195 subjects were recruited from a nationwide cohort and were followed for 4.1 years. After exclusions, 35,757 participants remained in the final study, and CKD developed in 1063 individuals during the follow-up period. Lifestyle, anthropometric and laboratory data were evaluated in relation to the risk of CKD.

Results: The participants were subdivided into quartiles according to relative handgrip strength (RGS). Multivariate Cox regression demonstrated that RGS was inversely associated with incident CKD. Compared with the lowest quartile, the hazard ratios (HRs) [95% confidence intervals (CIs)] for incident CKD for the highest quartile (Q4) was 0.55 (0.34–0.88) after adjusting for covariates in men and 0.51 (0.31–0.85) in women. The incidence of CKD decreased as RGS increased. These negative associations were more significant in men than in women. The receiver operating characteristic (ROC) curve showed that baseline RGS had predictive power for new-onset CKD. Area under the curve (AUC) (95% CIs) was 0.739 (0.707–0.770) in men and 0.765 (0.729–0.801) in women.

Conclusion: This is the novel study demonstrating that RGS is associated with incident CKD in both men and women. The relationship between RGS and incident CKD is more significant in women than in men. RGS can be used in clinical practice to evaluate renal prognosis. Regular measurement of handgrip strength is essential to CKD detection.

KEYWORDS

handgrip strength, sarcopenia, chronic kidney disease, renal function, gender difference

Introduction

CKD has been increasing over the past few decades. The all-stage mean global prevalence of CKD is 13.4% (1). Furthermore, CKD can aggravate hypertension, metabolic syndrome, and diabetes, all of which are risk factors for cardiovascular diseases (CVDs) (2, 3); and many studies

have found associations of these comorbidities with CKD, including end-stage renal disease (ESRD) (4).

Prediction and early detection of CKD is an essential issue to prevent progression to ESRD, which can result in a range of complications, including malnutrition, anaemia, acidosis, and bone metabolism disorder (5). Nevertheless, individual willingness to prevent CKD acquisition and progression is often absent. Also, early CKD is often not diagnosed at an early stage due to the absence of clinical signs and symptoms. In the Third National Health and Nutrition Survey (NHANES III), only 8% of CKD patients understood the implications of their CKD diagnosis (6).

Sarcopenia, a comprehensive condition characterized by declining muscle strength and mass, is an essential public health concern worldwide. The global prevalence of sarcopenia was estimated at 10% (7). Sarcopenia is associated with several comorbidities such as pneumonia, falling, cardiovascular disease and cancer (8–10). For this reason, timely detection of sarcopenia is important. Handgrip strength is an inexpensive and convenient tool to evaluate muscle strength and is an effective method for diagnosing sarcopenia (11). Handgrip strength has been previously used to be a predictor of non-alcoholic fatty liver disease and healthy aging (12, 13). Recent studies have suggested that body mass index (BMI)-adjusted RGS is a more useful indicator than absolute handgrip strength (14). We, therefore, used RGS, absolute HGS divided by BMI, as the definitive measure in this study (14).

Several studies have already found a relationship between handgrip strength and CKD; however, these studies are cross-sectional studies (15, 16). In addition to investigating the association of RGS with CKD in Korean adults using nationwide cohort data, we assessed the utility of RGS as a predictor of new-onset CKD by using the data with the exclusion of baseline CKD.

Materials and methods

Study population

In the cohort study, data were collected from the Korean Genome and Epidemiology Study (KoGES) of the Korean general population. The KoGES data includes the KoGES_health examinee (HEXA) study, the KoGES_Ansan-Ansung study and the KoGES_cardiovascular disease association study (CAVAS). Our study used the KoGES HEXA study consisting of participants recruited from multiple clinics and aged ≥40 years at baseline. The population-based prospective cohort study was conducted to evaluate environmental and lifestyle determinants for the prevalence and incidence of chronic diseases (i.e., metabolic syndrome, obesity, hypertension, diabetes mellitus, osteoporosis, and CKD). Study design and information for KoGES have been previously described in detail (17).

A total of 173,343 men and women aged 40–80 years participated in the baseline HEXA study conducted at 38 health centres nationwide from 2004 to 2013. A follow-up study was conducted from 2007 to 2016. Among the participants of the baseline study, we excluded those who: (1) were lost to follow-up, (2) were missing HGS data, (3) were missing laboratory data, or (4) were diagnosed with having CKD at the time of the baseline study (Figure 1).

The study protocol was approved by the Institutional Review Board (IRB) of the Yonsei University Wonju College of Medicine (IRB no. CR322322). This study was performed in compliance with the Declaration of Helsinki. Informed consent was acquired from all subjects, and all data were subsequently anonymized.

Measurement of handgrip strength

Handgrip strength was measured twice with a 1 minute intervening rest interval using a digital grip strength dynamometer (T.K.K.5401, TAKEI Scientific Instruments Co., Ltd., Nigata, Japan) (18). The participants were trained to squeeze the dynamometer with as much force as possible. Each HGS was assessed after the grip was maintained at 15° from hip flexion. Absolute HGS was defined as the maximum value from both hands and was presented in kilograms (14). In order to normalize the impact of body size on HGS, relative handgrip strength (RGS) was used. RGS was defined as the absolute HGS divided by BMI, which had been previously used as indicator for muscle strength (14). The RGS data were subdivided into gender-specific quartiles.

Anthropometric and laboratory measurements and general data

Anthropometric, demographic, lifestyle, and laboratory data were collected from all the participants. The anthropometric data included gender, age, waist circumference (WC), BMI, systolic blood pressure (SBP), and diastolic blood pressure (DBP). WC was measured using flexible tape (Seca 220; Seca) at the midpoint between the lowest margin of the rib and the uppermost border of the iliac crest during expiration (19). The BMI was calculated as weight divided by height squared (kg/m^2). Blood pressure (BP) was measured using a mercury sphygmomanometer after the subjects rested for five min in a sitting position (Baumanometer Wall Unit 33(0850)). All BP examinations were performed on the right arm twice using the same tool at 30 s intervals (20). Hypertension was diagnosed as SBP ≥ 140 mmHg, DBP ≥ 90 mmHg or being administered antihypertensive drugs (21). Diabetes mellitus was defined as when one of the following criteria based on the American Diabetes Association (ADA) criteria was met: fasting plasma glucose ≥126 mg/dL, HbA1c ≥ 6.5%, or plasma glucose level 2 h after 75 g OGTT ≥ 200 mg/dL (22). Participants who answered "yes" to taking diabetes medication were also regarded as diabetes. The medication history was collected using questionnaires. In addition to the medication history, the participants answered the questionnaires including information on demographics, lifestyle, and medical conditions: gender, age, alcohol intake, smoking history, regular exercise, and current and past medical history of diseases. Alcohol history data were collected using questionnaires including the type (beer, hard liquor, and soju), amount, and frequency of drinks. Alcohol intake was defined as drinking at least once a week; the cut-off for amount of alcohol intake per week was >140 g for men and >70 g for women (23). Smoking history was categorized as current smokers, ex-smokers, and never smokers. Current smokers were regarded as those who responded "yes" to the statement "I have smoked more than 5 packs of cigarettes in a lifetime and still smoke." Ex-smokers were regarded as those who answered "yes" to the statement "I have smoked more than 5 packs

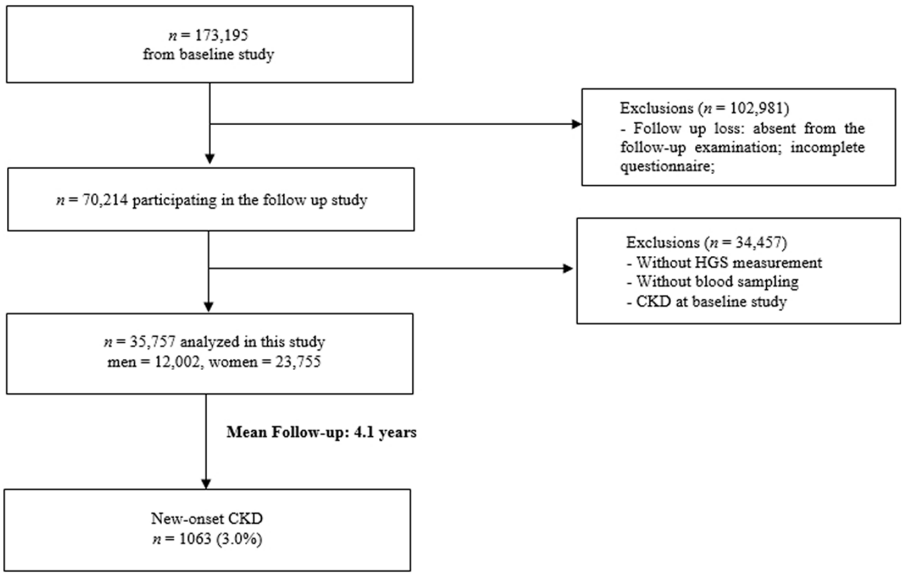

FIGURE 1
Flow diagram of studies meeting inclusion/exclusion criteria.

of cigarettes but do not smoke anymore." Never smokers were regarded as those who answered "yes" to the statement "I have smoked less than 5 packs of cigarettes in a lifetime" (24). Regular exercise was defined as engaging in vigorous physical activity more than 3 times per week. Patients with cardiovascular disease were considered as those who responded "yes" to the statement "I have been diagnosed with cardiovascular disease by a physician." The global physical activity questionnaire (GPAQ) was applied to assess the level of physical activity (25). Aspartate aminotransferase (AST), alanine aminotransferase (ALT), total cholesterol (TC), low-density lipoprotein (LDL) cholesterol and c-reactive protein (CRP) levels were measured by high-performance liquid chromatography with an automated HGLC-723G7 analyser (Tosoh Corporation, Tokyo, Japan).

Definition of chronic kidney disease

CKD was defined as an estimated glomerular filtration rate (eGFR) less than 60 mL/min/1.73 m^2 or proteinuria ≥1+ according to the Kidney Disease Outcomes Quality Initiative (KDOQI) CKD classification (26). eGFR was calculated using the equation from the chronic kidney disease epidemiology collaboration, CKD-EPI 2021. This equation is (27):

$$\text{eGFR} = 142 \times \min\left(\frac{S_{\text{cr}}}{K}, 1\right)^{\alpha} \times \max\left(\frac{S_{\text{Cr}}}{K}, 1\right)^{-1.200} \times 0.9938^{\text{Age}} \times 1.012\left[\text{if female}\right]$$

S_{cr} (Serum creatinine) = mg/dL; K = 0.7 (females) or 0.9 (males); α = −0.241 (females) or −0.302 (males); Min = indicates the minimum of S_{cr} or 1; Max = indicates the minimum of S_{cr} or 1.

Participants who reported being diagnosed with CKD by physicians were also regarded as having CKD.

Statistical analysis

All covariates were analysed by chi-square test for categorical variables and independent *t*-test and analysis of variance (ANOVA) tests for continuous variables. The categorical and continuous variables were expressed as *n* (%) and mean ± standard deviation, respectively (Table 1). Cox regression analysis was conducted to evaluate the association of RGS (per 0.01 kg) with incidence of CKD after adjusting for age; alcohol consumption; smoking status; regular exercise; and SBP, DBP, AST, ALT, TC, LDL-cholesterol, and CRP levels (Table 2). RGS data were subdivided into quartiles: Q1, ≤1.36; Q2, 1.36–1.57; Q3, 1.57–1.79; and Q4, >1.79 in men. For women, these values were Q1 ≤ 0.84; Q2, 0.84–1.00; Q3, 1.00–1.16; and Q4, >1.16. The weakest RGS group (Q1) was defined as the reference group. Cox regression was performed to calculate the HRs and 95% CIs of incident CKD for RGS quartiles after adjusting for the confounding factors (Table 3). ROC curves were illustrated to analyse the predictive power for new-onset CKD according to baseline RGS, and AUC was calculated. Kaplan–Meier curves were constructed to assess survival probability for incident CKD according to baseline RGS quartiles. Value of p <0.05 was considered statistically significant. Statistical analyses were conducted using SPSS version 27.0 (IBM Corp., Armonk, NY, United States).

Results

Baseline characteristics of the study population according to baseline RGS quartile are described in Table 1. A total of 35,757 participants (12,002 men, 23,755 women) were included in our study. The mean

TABLE 1 Baseline characteristics of study population according to baseline RGS quartile.

	Men	Q_1	Q_2	Q_3	Q_4	value of *p*
		≤1.38	1.38–1.59	1.59–1.82	>1.82	
N	12,002	2,983	2,962	3,074	2,983	
HGS (kg)	38.9 ± 8.4	29.9 ± 6.0	37.0 ± 3.7	41.1 ± 4.3	47.3 ± 7.6	<0.001
RGS (m^2)	1.61 ± 0.37	1.16 ± 0.20	1.49 ± 0.06	1.70 ± 0.07	2.06 ± 0.26	<0.001
Age (years)	55.2 ± 8.4	58.3 ± 8.0	56.4 ± 8.0	54.7 ± 7.9	51.3 ± 7.9	<0.001
Waist circumference (cm)	85.4 ± 7.5	88.5 ± 7.5	86.5 ± 6.8	84.9 ± 7.0	81.7 ± 7.0	<0.001
BMI (kg/m^2)	24.4 ± 2.7	25.7 ± 2.8	24.9 ± 2.4	24.2 ± 2.4	22.9 ± 2.4	<0.001
eGFR (mL/min/1.73 m^2)	94.5 ± 11.8	92.7 ± 11.7	93.6 ± 11.7	94.8 ± 11.8	96.9 ± 11.7	<0.001
Total cholesterol (mg/dl) (mg/dl)	191.9 ± 34.8	191.3 ± 36.2	192.6 ± 35.5	192.8 ± 34.4	191.0 ± 33.0	0.110
LDL-cholesterol (mg/dl)	113.8 ± 31.3	113.6 ± 32.4	114.4 ± 32.2	114.0 ± 30.9	113.3 ± 29.5	0.494
HDL-cholesterol (mg/dl)	49.7 ± 11.9	48.1 ± 11.2	48.9 ± 11.8	50.0 ± 11.8	51.7 ± 12.5	<0.001
Triglyceride (mg/dl)	148.6 ± 102.7	154.4 ± 101.3	152.8 ± 102.0	150.8 ± 106.4	136.2 ± 100.0	<0.001
Albumin (mg/dl)	4.69 ± 0.25	4.67 ± 0.26	4.69 ± 0.26	4.70 ± 0.25	4.72 ± 0.25	<0.001
AST (IU/L)	25.0 ± 13.0	25.5 ± 11.8	25.5 ± 14.5 25.5 ± 14.4	25.1 ± 13.7	24.0 ± 11.6	<0.001
ALT (IU/L)	25.9 ± 16.9	27.5 ± 17.0	26.8 ± 17.1	25.9 ± 17.4	23.4 ± 15.5	<0.001
CRP (mg/dL)	0.159 ± 0.389	0.185 ± 0.430	0.163 ± 0.361	0.144 ± 0.308	0.140 ± 0.443	<0.001
Systolic BP (mmHg)	125.5 ± 13.9	127.2 ± 14.2	125.9 ± 13.6	125.4 ± 13.7	123.7 ± 13.7	<0.001
Diastolic BP (mmHg)	78.1 ± 9.4	78.9 ± 9.4	78.2 ± 9.2	77.8 ± 9.3	77.2 ± 9.5	<0.001
Alcohol intake, *n* (%)	4,109 (34.3)	905 (30.4)	966 (32.6)	1,125 (36.6)	1,113 (37.3)	<0.001
Smoking status, *n* (%)						<0.001
Never smoker	3,190 (26.7)	863 (29.1)	770 (26.1)	806 (26.3)	751 (25.3)	
Ex-smoker	5,452 (45.6)	1,429 (48.1)	1,374 (46.5)	1,407 (46.0)	1,242 (41.8)	
Current smoker	3,316 (27.7)	678 (22.8)	811 (27.4)	846 (27.7)	981 (33.0)	
Regular exercise, *n* (%)	5,083 (42.6)	1,284 (43.3)	1,301 (44.1)	1,325 (43.4)	1,173 (39.5)	0.001
Hypertension, *n* (%)	2,952 (24.6)	1,027 (34.5)	824 (27.8)	690 (22.5)	411 (13.8)	<0.001
Diabetes, *n* (%)	1,138 (9.5)	404 (13.6)	329 (11.1)	262 (8.5)	143 (4.8)	<0.001
CVD, *n* (%)	522 (4.3)	176 (5.9)	151 (5.1)	123 (4.0)	72 (2.4)	<0.001

	Women	Q_1	Q_2	Q_3	Q_4	value of *p*
		≤0.84	0.84–1.00	1.00–1.16	>1.16	
N	23,755	5,828	6,059	5,927	5,941	
HGS (kg)	23.4 ± 5.3	17.8 ± 3.7	22.3 ± 2.5	24.9 ± 2.6	28.6 ± 4.6	<0.001
RGS (m^2)	1.01 ± 0.25	0.70 ± 0.13	0.92 ± 0.05	1.08 ± 0.05	1.32 ± 0.18	<0.001
Age (years)	53.3 ± 7.8	56.9 ± 7.5	54.4 ± 7.4	52.3 ± 7.2	49.5 ± 6.9	<0.001
Waist circumference (cm)	77.9 ± 8.1	82.2 ± 8.4	79.3 ± 7.6	76.8 ± 7.1	73.4 ± 6.7	<0.001
BMI (kg/m^2)	23.5 ± 2.9	25.4 ± 3.2	24.2 ± 2.6	23.1 ± 2.3	21.7 ± 2.2	<0.001
eGFR (mL/min/1.73 m^2)	99.2 ± 11.2	97.4 ± 11.1	99.0 ± 11.0	99.8 ± 11.1	100.7 ± 11.2	<0.001
Total cholesterol (mg/dl) (mg/dl)	199.8 ± 35.5	202.4 ± 36.9	202.0 ± 35.9	199.9 ± 35.2	195.0 ± 33.7	<0.001

(Continued)

TABLE 1 (Continued)

	Women	Q_1	Q_2	Q_3	Q_4	value of *p*
		≤0.84	0.84–1.00	1.00–1.16	>1.16	
LDL-cholesterol (mg/dl)	121.2 ± 32.0	123.7 ± 33.3	123.2 ± 32.4	121.3 ± 31.5	116.4 ± 30.0	<0.001
HDL-cholesterol (mg/dl)	56.3 ± 13.0	53.8 ± 12.2	55.2 ± 12.6	56.8 ± 12.9	59.5 ± 13.5	<0.001
Triglyceride (mg/dl)	113.6 ± 72.6	127.0 ± 76.1	120.6 ± 79.5	110.4 ± 68.7	96.5 ± 60.7	<0.001
Albumin (mg/dl)	4.61 ± 0.24	4.58 ± 0.25	4.61 ± 0.25	4.62 ± 0.24	4.64 ± 0.24	<0.001
AST (IU/L)	22.2 ± 10.3	23.4 ± 11.2	22.7 ± 12.8	21.8 ± 9.0	20.9 ± 7.2	<0.001
ALT (IU/L)	19.6 ± 15.1	22.0 ± 18.2	20.4 ± 17.7	18.8 ± 11.7	17.1 ± 10.8	<0.001
CRP (mg/dL)	0.131 ± 0.396	0.165 ± 0.410	0.146 ± 0.516	0.121 ± 0.333	0.091 ± 0.270	<0.001
SBP (mmHg)	120.9 ± 14.7	123.2 ± 14.7	121.9 ± 14.8	120.6 ± 14.8	118.0 ± 14.1	<0.001
DBP (mmHg)	74.2 ± 9.4	75.4 ± 9.3	74.7 ± 9.3	74.1 ± 9.4	72.7 ± 9.3	<0.001
Alcohol intake, *n* (%)	1,114 (4.7)	202 (3.5)	265 (4.4)	303 (5.1)	344 (5.8)	<0.001
Smoking status, *n* (%)						0.017
Never smoker	22,890 (96.9)	5,630 (97.1)	5,840 (97.0)	5,726 (97.2)	5,694 (96.2)	
Ex-smoker	295 (1.2)	73 (1.3)	65 (1.1)	74 (1.3)	83 (1.4)	
Current smoker	439 (1.9)	94 (1.6)	115 (1.9)	91 (1.5)	139 (2.3)	
Regular exercise, *n* (%)	9,955 (42.1)	2,255 (38.9)	2,524 (41.9)	2,615 (44.4)	256 (43.3)	<0.001
Hypertension, *n* (%)	4,215 (17.8)	1,553 (26.7)	1,204 (19.9)	903 (15.3)	555 (9.3)	<0.001
Diabetes, *n* (%)	1,226 (5.2)	521 (8.9)	341 (5.6)	227 (3.8)	137 (2.3)	<0.001
CVD, *n* (%)	518 (2.2)	237 (4.1)	143 (2.4)	96 (1.6)	42 (0.7)	<0.001

HGS, handgrip strength; RGS, relative handgrip strength; BMI, body mass index; eGFR, estimated glomerular filtration rate; LDL, low density lipoprotein; HDL, high density lipoprotein; AST, aspartate aminotransferase; ALT, alanine aminotransferase; CRP, c-reactive protein; SBP, systolic blood pressure; DBP, diastolic blood pressure; CVD, cardiovascular disease.

TABLE 2 Association between baseline RGS (per 0.01kg) and incidence of CKD in Koreans using cox-regression.

Men			Women		
	HR	value of *p*		HR	value of *p*
Unadjusted	0.46 (0.35–0.60)	<0.001	Unadjusted	0.68 (0.49–0.94)	0.018
Model 1	0.60 (0.45–0.80)	0.001	Model 1	0.67 (0.48–0.94)	0.022
Model 2	0.60 (0.45–0.80)	0.001	Model 2	0.66 (0.48–0.92)	0.012
Model 3	0.68 (0.48–0.98)	0.037	Model 3	0.80 (0.51–1.26)	0.331

CKD, chronic kidney disease; HR, hazard ratio; Model 1: adjusted for age; Model 2: adjusted for age, regular exercise, alcohol intake, and smoking status; Model 3: adjusted for age, hypertension, diabetes, cardiovascular disease, regular exercise, alcohol intake, smoking status, BMI, SBP, DBP, AST, ALT, albumin, proteinuria, eGFR, total cholesterol, HDL-cholesterol, triglyceride, and CRP.

values of some covariates were significantly decreased with increasing RGS quartile. These variables were age, WC, BMI, AST, ALT, CRP, SBP, DBP, presence of hypertension, and presence of diabetes in men. In women, these variables were age, WC, BMI, TC, LDL-cholesterol, AST, ALT, CRP, SBP, DBP, presence of hypertension, and presence of diabetes.

The incidence of CKD decreased with increasing baseline RGS quartile in both men and women (Figure 2). These results suggest that dose–response relationship was present between RGS and CKD. The results of the relationship between baseline RGS (per 0.01 kg) and incidence of CKD in Koreans are tabulated in Table 2. RGS was inversely related to incidence of CKD in all models for both men and women.

Table 3 shows the HRs and 95% CIs for the incidence of CKD according to baseline RGS quartile. The weakest quartile (Q1) of RGS was defined as the reference group (14). Compared with the reference group and after adjusting model 3, the statistically significant HRs (95% CI) for CKD of the participants were 0.55 (0.34–0.88) for the Q4 group of men, 0.43 (0.27–0.69) for the Q3 group of women, and 0.51 (0.31–0.85) for the Q4 group of women.

ROC curves were generated to test RGS as a predictor of CKD (Figure 3). The AUC of Figure 3A is 0.739 (0.707–0.770), and the AUC of Figure 3B is 0.765 (0.729–0.801). During the 90 months of follow-up, new-onset CKD developed in 1063 individuals (3.0%, 1063/35,757). The survival rates without incident CKD were lowest in the Q2 group up to 90 months but increased gradually from Q2 to Q4 in both men and women after the baseline survey (log-rank test, $p < 0.001$) (Figure 4).

TABLE 3 Hazard ratio and 95% confidence intervals for new-onset CKD according to baseline RGS quartile.

	Men				Women			
	Q_1	Q_2	Q_3	Q_4	Q_1	Q_2	Q_3	Q_4
	≤1.36	1.36–1.57	1.57–1.79	>1.79	≤0.84	0.84–1.00	1.00–1.16	>1.16
n	2,961	2,947	3,050	2,970	5,828	6,059	5,927	5,941
Unadjusted	1.00	0.68 (0.53–0.87)	0.67 (0.53–0.86)	0.39 (0.29–0.53)	1.00	0.93 (0.75–1.14)	0.85 (0.68–1.06)	0.78 (0.62–0.97)
Model 1	1.00	0.73 (0.57–0.94)	0.78 (0.61–1.00)	0.51 (0.37–0.70)	1.00	0.92 (0.75–1.14)	0.85 (0.68–1.06)	0.77 (0.61–0.98)
Model 2	1.00	0.76 (0.59–0.97)	0.83 (0.64–1.06)	0.57 (0.42–0.78)	1.00	0.95 (0.77–1.18)	0.89 (0.71–1.12)	0.86 (0.68–1.10)
Model 3	1.00	0.62 (0.46–0.85)	0.83 (0.62–1.13)	0.55 (0.37–0.82)	1.00	1.06 (0.82–1.38)	0.99 (0.75–1.32)	0.84 (0.60–1.16)

Model 1: adjusted for age; Model 2: adjusted for age, regular exercise, alcohol intake, and smoking status; Model 3: adjusted for age, hypertension, diabetes, cardiovascular disease, regular exercise, alcohol intake, smoking status, BMI, SBP, DBP, AST, ALT, albumin, proteinuria, eGFR, total cholesterol, HDL-cholesterol, triglyceride, and CRP.

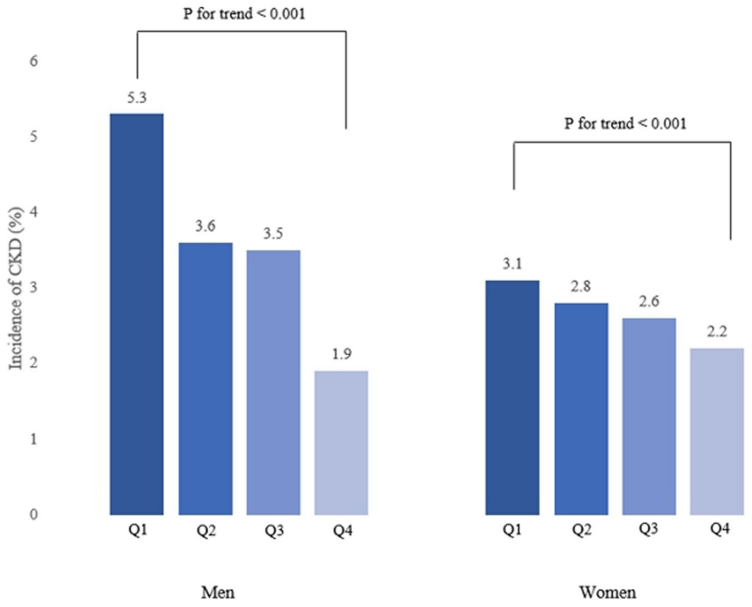

FIGURE 2
Incidence of CKD according to baseline RGS quartiles.

Discussion

In the nationwide cohort study conducted over 12 years, RGS was inversely associated with the incidence of CKD. Furthermore, relative handgrip strength was an independent predictor of CKD, irrespective of age; regular exercise; alcohol intake; smoking history; and SBP, DBP, AST, ALT, TC, LDL-cholesterol, and CRP levels.

Handgrip strength is a prognostic indicator for metabolic syndrome, hypertension and diabetes (28–30). However, these studies commonly suggested that HGS be a practical tool to evaluate these comorbidities in high-risk groups rather than healthy groups. Moreover, several studies have found an association between handgrip strength and CKD (31, 32). However, these studies only demonstrated that HGS is an independent predictor of renal function in CKD patients. The findings of our study are the novel to identify that RGS is a useful tool to predict new-onset CKD. We demonstrated this by excluding subjects with CKD at baseline and by having a large subject sample size. The association remained significant after adjusting for age; blood pressure; and TC, LDL-cholesterol and CRP levels, all of which are risk factors for CKD.

Measurement of handgrip strength is a practical tool to evaluate muscle strength because of its low cost and ease of implementation (33). Low muscle strength, not low muscle mass, is a primary determinant of sarcopenia; muscle strength is a more reliable predictive indicator of falling, fracture, and all-cause mortality than muscle mass (9, 34). Accordingly, handgrip strength is commonly used as a diagnostic approach for sarcopenia.

Even though there are many mechanisms of sarcopenia in CKD patients (35), a mechanical link between sarcopenia and incident CKD has not been fully elucidated. Therefore, we propose putative mechanisms involving mediators of sarcopenia and CKD, e.g., oxidative stress, inflammation, and insulin resistance (IR) (36, 37). Skeletal muscles have an important role in glucose homeostasis; skeletal muscle accounts for 40–50% of lean body mass in an adult

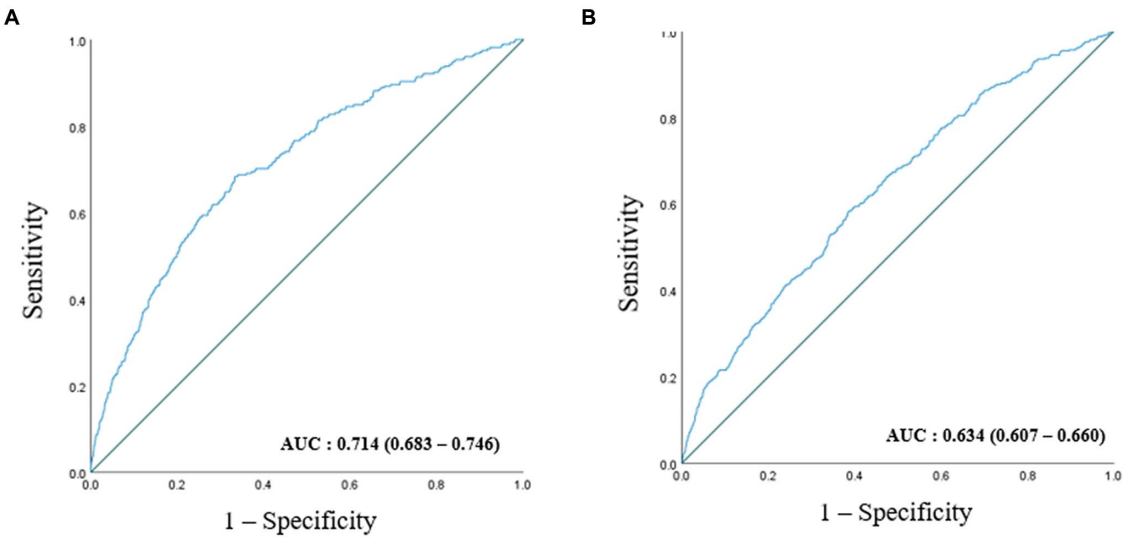

FIGURE 3
ROC curve presenting the predictive power for incident CKD according to baseline RGS in men **(A)** and in women **(B)**.

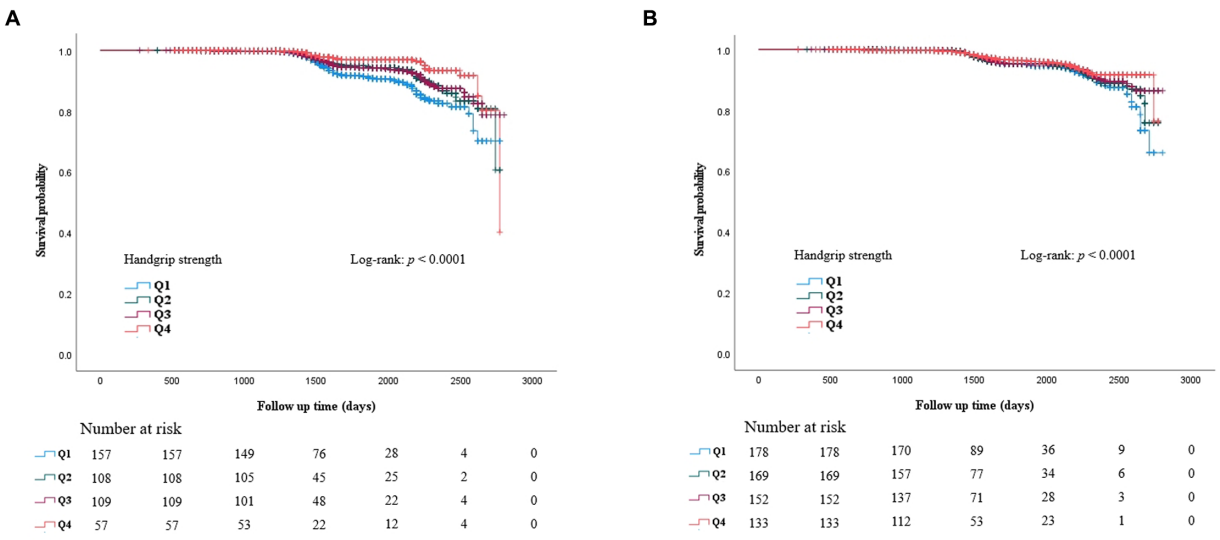

FIGURE 4
Kaplan Meier curve for incident CKD according to baseline RGS quartile in men **(A)** and in women **(B)**.

and, therefore, is the source of most of the body's insulin-stimulated glucose disposal (38). Sarcopenia can lead to the inevitable deterioration of skeletal muscle cell structure and biological function (39) and can impair insulin-stimulated glucose disposal into muscle thereby impacting glucose homeostasis (38). Several sarcopenia-associated features such as mitochondrial dysfunction, increased inflammation, and increased oxidative stress arise; these factors cause IR (40). Decreased muscle strength can involve changes in released inflammatory markers. Several studies have shown that lower HGS is associated with higher levels of inflammatory markers such as interleukin (IL)-6 and tumour necrosis factor (TNF)-alpha. The inflammatory markers affect the maintenance of metabolic homeostasis (41, 42). Through the proposed mechanisms, several studies have previously reported that handgrip strength can be a predictor for the incidence of metabolic syndrome and diabetes (18, 43).

Insulin plays an essential role in glucose metabolism, and the kidney is an insulin target organ because the kidney plays an important role in the clearance and degradation of insulin (44). If cells, particularly kidney cells, fail to respond to insulin, the resulting IR can lead to CKD. Moreover, IR can promote the development of atherosclerosis, hypertension, dyslipidaemia, fatty liver, and obesity, all of which are important risk factors for CKD (13, 45–48).

In spite of many advantages, there are several limitations to our study. First, decreased eGFR should be maintained for at

least 3 months according to the KDOQI definition of CKD (49). However, eGFR less than 60 at the first follow-up was the diagnostic criterion in our study. Because the KoGES HEXA study was conducted in multiple clinics with the recruitment of large number of participants, the maintenance of decreased eGFR was difficult to assess through short term follow-up. Several previous studies also defined CKD as eGFR less than 60. In one study this was true regardless of the maintenance of decreased eGFR (50, 51). Second, although RGS adjusted for BMI was used, our study could not reflect muscle mass because there are no muscle mass data in the KoGES. Therefore, we could not ascertain that the relationship between handgrip strength and CKD was independent of muscle mass. Nonetheless, handgrip strength was used in our study because previous studies determined this to be a more useful tool than muscle mass (34). Sarcopenia is regarded as muscle failure with low muscle strength being a superior measure to a lack of muscle mass (52, 53). Third, the event date of CKD may have been different from the follow-up date. Because the follow-up cohort study had been conducted regardless of the occurrence of CKD, the occurrence date was not always the same date as the follow-up date. Furthermore, participants who might die during follow-up could not be included in our study because they were excluded due to follow-up loss. KoGES did not have mortality data. Fourth, dipstick test is not a quantitative test such as 24 h urine collection. Therefore, it can miss albuminuria. Finally, a proper index to eliminate the effect of body size (weight, height, and BMI) on handgrip strength has not yet been established. Even though RGS can minimize the impact of body size, dividing HGS by BMI cannot completely correct for this effect (54). Nevertheless, RGS has been widely used for lessening body size effects (14). Further studies are needed for muscle strength-associated indices independent of body size.

Conclusion

We found that RGS was independently negatively associated with new-onset CKD in men and women. The association of handgrip strength with incident CKD is more significant in men than in women. RGS can be a useful tool to predict the incidence of CKD. The appropriate measurement of handgrip strength is important to detect CKD.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Institutional Review Board (IRB) of the Yonsei University Wonju College of Medicine. The patients/participants provided their written informed consent to participate in this study.

Author contributions

J-KK: conceptualization and writing-editing. H-JL and S-BL: methodology. S-BL: formal analysis. S-BL and J-KK: investigation. MK and S-BL: writing-original draft preparation. H-JL and J-KK: supervision. All authors have read and agreed to the published version of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Cut-off points of the Ishii test to diagnosing severe sarcopenia among multi-ethnic middle-aged to older adults: results from the West China Health and Aging Trend study

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Objective: This study was designed to establish the cut-off value and diagnostic utility of the Ishii test, which gauges the odds of severe sarcopenia based on the results of an equation based upon age, grip strength, and calf circumference among middle-aged and older adults in Western China.

Methods: This study incorporated adults ≥ 50 years of age from the West China Health and Aging Trend (WCHAT) study. Severe sarcopenia was defined as per the Asian Working Group for Sarcopenia: 2019 Consensus (AWGS2019) recommendations, with the odds of severe sarcopenia being estimated with the Ishii test score chart. The diagnostic utility of the Ishii test in this patient cohort was assessed by analyzing its sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and the area under the ROC curve (AUC).

Results: In total, 4,177 individuals ≥ 50 years of age were included in this study including 2668 females (63.9%) and 1,509 males (36.1%). These included 568 (13.6%) participants affected by severe sarcopenia, of whom 237 were male (15.7%) and 331 were female (12.4%). Optimal Ishii test cut-off values established based on Youden's index were ≥ 114 for males and ≥ 120 for females when using the AWGS2019 reference standard. The sensitivity/specificity/PPV/NPV of the Ishii test when screening for severe sarcopenia were 89.45%/77.15%/0.42/0.98 in males and 90.03%/77.05%/0.36/0.98 in females. The AUC values for the Ishii test in males and females were 0.899 (95% CI, 0.883–0.916) and 0.905 (95% CI, 0.892–0.917), respectively.

Conclusion: These data indicate that the Ishii test offers value as a candidate diagnostic test that can be used to screen for severe sarcopenia, with recommended diagnostic cut-off values of ≥ 114 for males and ≥ 120 for females.

KEYWORDS

severe sarcopenia, Western China, Ishii test, AWGS2019, WCHAT study

Introduction

Severe sarcopenia is a condition associated with a loss of muscle strength and low muscle mass together with altered physical performance as per the Asian Working Group for Sarcopenia: 2019 Consensus (AWGS2019) consensus criteria (1). In one recent meta-analysis of 34 studies, severe sarcopenia prevalence was estimated to range anywhere from 2% to 9% (2). Moreover, severe sarcopenia represents an independent predictor of overall survival, quality of life, and depression. Given its adverse association with multiple different outcomes (3–11), sarcopenia has been a geriatric syndrome of growing focus in recent years. It is thus critical that severe sarcopenia be recognized as quickly as possible in order to guide efforts to mitigate its potentially severe effects.

Several sarcopenia-focused international groups have agreed that a diagnosis of severe sarcopenia necessitates evidence of low muscle strength, low muscle mass, and/or poor physical performance (1, 12–16). Specialized techniques including computed tomography (CT), magnetic resonance imaging (MRI), dual-energy X-ray analysis (DXA), and bio-impedance analysis (BIA) are necessary to definitively diagnose severe sarcopenia. These instruments, however, are costly and require specialized personnel to operate them, restricting their utilization in many medical institutions. Given the lack of access to these diagnostic instruments in some clinical settings, this may lead to the pronounced underdiagnosis of sarcopenia. There is thus a vital need for the design of straightforward, inexpensive, and easy-to-operate tools that can be used to screen for severe sarcopenia in a community setting. Accordingly, the Ishii test was recommended as one such rapid, easy-to-use screening tool by updated version of the European Working Group on Sarcopenia in Older People (EWGSOP2) (17).

The Ishii test was designed by Ishii et al. as a tool that can assess the odds of sarcopenia based on calculations that take patient age, grip strength, and calf circumference into consideration (18). Prior work has demonstrated that Ishii test with the recommended cut-off of 105 for male and 120 for female offers high levels of both sensitivity and specificity when diagnosing sarcopenia among community-dwelling adults and inpatients (18–20). Notably, the Ishii test scores are also significantly related to poorer overall functional status (21), and can predict long-term all-cause mortality among hospitalized older adults (8). A previous study in nursing homes in China showed that the Ishii test be able to differentiate between non-severe and severe sarcopenia with a cut-off of 130 for both male and female (22). No studies to date, however, have examined the cut-off points and accuracy of the Ishii test for male and female separately when used to detect severe sarcopenia in community-dwelling individuals in western China, nor in middle-aged to older adults of various ethnicities in other Asian countries. As such, this study was designed to gauge the cut-off points and accuracy of the Ishii test in both male and female so as to establish whether it can effectively be used to screen for severe sarcopenia among middle-aged and older adults in a community setting so as to provide a foundation for the updating of Asian guidelines as appropriate.

Abbreviations: AWGS, Asia Working Group of Sarcopenia; WCHAT, West China Health and Aging Trend; PPV, Positive predictive value; NPV, Negative predictive value; AUC, Area under the ROC curve; CT, Computed tomography; MRI, Magnetic-resonance imaging; DXA, Dual-energy X-ray analysis; BIA, bio-Impedance analysis; EWGSOP, European Working Group on Sarcopenia in Older People updated version; ASM, Appendicular skeletal muscle mass; ASMI, The ASM index; IQR, Inter-quartile range; BMI, Body mass index; CC, Calf circumference; CI, Confidence interval; SD, Standard deviation.

Materials and methods

Study design and patient recruitment

All data used herein are from the prospective observational West China Health and Aging Trend (WCHAT) study, which was designed to assess healthy aging among community-dwelling adults in Western China ≥ 50 years of age (23). This study was conducted in accordance with the Declaration of Helsinki, and was reviewed and approved by the Medical Ethics Review Committee of West China Hospital in Sichuan University, Chengdu, Sichuan Province, China (reference: 2017-445). All participants or their appropriate proxy respondents provided written informed consent before study participation. The WCHAT study consisted of three primary components: (1) a questionnaire survey; (2) physical examinations; and (3) laboratory analyses. This study employed a multi-stage random cluster sampling approach covering the Yunnan, Xinjiang, Guizhou, and Sichuan provinces in Western China, and had a 50.2% overall response rate (23). Baseline cross-sectional data were collected from July–December 2018 through questionnaires administered by trained personnel in face-to-face interviews. Anthropometric and BIA measurements were made by qualified personnel. For further details regarding the WCHAT study, see previously published cohort profile information (23). Overall, the WCHAT study incorporated 7,536 individuals who were ≥50 years old in 2018 hailing from 4 provinces and 18 ethnic groups. Participants that did not participate in muscle mass ($n = 3,036$) or for whom data were missing ($n = 323$) were excluded from the present study, with 4,177 participants being retained for analysis.

Muscle mass measurements

Muscle mass was assessed using a BIA instrument (InBody 770 Body, Seoul, Korea). Both the appendicular skeletal muscle mass (ASM) and the amount of leg and arm muscle were utilized in conjunction with height as a means to determine the ASM index (ASMI; kg/m^2) (24). Trained personnel completed all measurements within 2 min using the following approach: (1) participants were directed to remove their shoes and to step onto the pedals of the instrument, followed by the input of their personal details; (2) participants remained still in a standing position on the instrument for 5 s such that their weight could be measured; (3) participants gripped the hand electrodes such that four of their fingers were wrapped around the bottom surface of the electrodes while their thumbs were positioned on ovoid electrodes; (4) the participants' thighs were not allowed to touch, and their heels were aligned with the rear foot electrode; and (5) measurements were initiated when participants gripped the handgrips while maintaining their arms in a straight position opened at a 15° angle. Several precautions were observed when conducting this test, including the following: (1) all testing was performed a minimum of 2 h after eating, and participants

were directed to empty their bladder and bowels and to wear light clothing to minimize measurement errors; (2) participants were directed to stand still for 10 min prior to testing to decrease water accumulation in the lower limbs as a result of sudden standing; (3) participants were not permitted to carry any heavy objects or metal items during measurements, including keys, bracelets, watched, and mobile phones; (4) testing was not performed for any individuals with electronic medical devices such as pacemakers; and (5) participants were directed to refrain from talking or moving during the test other than as directed by the personnel administering the testing.

Muscle strength measurements

A digital grip-strength dynamometer (EH101; Camry, Xiangshan Inc. China) was used to assess participant muscle strength. Subjects were initially questioned regarding which hand was their dominant hand. During testing, they were then directed to grip the dynamometer using their dominant hand while standing upright with their feet shoulder-width apart, allowing their arms to droop naturally. At the start of testing, participants were directed to grip the handle using their full capacity. Participants were not permitted to swing their arms, grip the handle intermittently, squat, or contact the dynamometer using other parts of the body. Grip strength was measured two times, and the maximum value was recorded for downstream analyses.

Physical performance measurements

A stride meter (TF-NZ1033, Tsinghua Tongfang, China) was used to measure the walking speed of each participant over a 4 m distance to the nearest 0.01 s as a metric for physical performance. The average of two measurements was used for subsequent analyses. For this test, a linear 6 m area was established, with yellow markings being used to mark the 1, 5, and 6 m distances. Adults were then requested to walk at a normal speed from the 0 m starting point to the 6 m mark, with experimental timing beginning when they crossed the 1 m mark and ending when they crossed the 5 m mark. Subjects wore typical shoes during testing and were allowed to use mobility aids, but could not receive assistance from others. There were no time limits, and participants were allowed to pause and rest if desired, although sitting was not permitted.

Additional measurements

The height and weight of study participants were measured by trained personnel using a standardized approach with a CSTF—5,000 style apparatus (Tongfang Health Technology Co., Ltd.).

Definition of severe sarcopenia

Severe sarcopenia was defined as per the AWGS2019 diagnostic criteria based on low muscle mass (ASMI, males: < 7.0 kg/m^2; females: < 5.7 kg/m^2), low muscle strength (handgrip strength, males: < 28 kg, females: < 18 kg), and poor physical performance (4 m walking test < 1 m/s) (1).

Ishii test analyses

The odds of sarcopenia were approximated using the Ishii test. In males, Ishii test scores were calculated as follows: 0.62 × (age − 64) − 3.09 × (grip strength − 50) − 4.64 × (calf circumference − 42). In females, Ishii scores were calculated as follows: 0.80 × (age − 64) − 5.09 × (grip strength − 34) − 3.28 × (calf circumference − 42) (18). As the Ishii test has no recommended cut-off values for the diagnosis of severe sarcopenia, the maximum Youden's index values were used as cut-off values in the present study.

Statistical analyses

Data were analyzed using SPSS 23.0 (IBM Corp, NY, United States). We used the Paired-Sample Sensitivity Power Analysis from the Diagnostic Tests (ROC) of PASS 11.0 software to calculate the sample size needed for this study. Results suggested that 2,390 samples were enough. Categorical data are given as numbers (percentages), while normally and non-normally distributed continuous data are given as means ± SD and the median and inter-quartile range (IQR), respectively. Data were compared between groups using Student's *t*-tests, rank-sum tests, and Pearson's Chi-square test as appropriate. An exclusion test focused on sensitivity and negative predictive value (NPV) together with the area under the ROC curve (AUC) was used in this study to gauge the accuracy of the Ishii test. The Youden index is the sum of sensitivity and specificity minus 1, that is, Youden index = sensitivity + specificity − 1. The calculated Youden index values were then sorted and the point corresponding to the highest value was selected as the optimal cut-off point. The AUC was used to measure the precision of this screening tool, while differences among ROC curves were assessed via the DeLong method (25). The receiver operating characteristic (ROC) curve was then constructed by plotting the sensitivity (y-axis) against the 1-specificity (x-axis) to derive the AUROC. Corresponding specificity, sensitivity, positive predictive value (PPV), and NPV values were then assessed using these cut-off thresholds, with a two-sides $p < 0.05$ as the significance threshold.

Results

Study population

In total, this study included 4,177 individuals ≥ 50 years old including 2,668 females (63.9%) and 1,509 males (36.1%). These included 568 (13.6%) participants affected by severe sarcopenia, of whom 237 were male (15.7%) and 331 were female (12.4%). The prevalence of severe sarcopenia among males < 60, 60–69, and ≥ 70 years of age were 3.55%, 13%, and 35.42%, respectively, while among females these respective prevalence rates were 4.43%, 10.69%, and 36.34% (Table 1).

Overall, severe sarcopenia prevalence was significantly higher among males relative to females. There were significant differences in age, ethnicity, body mass index (BMI), gait speed, ASMI, CC, handgrip strength, and Ishii test scores when comparing individuals with and without severe sarcopenia in both the male and female subgroups (Table 1).

TABLE 1 Study participant characteristics in the severe sarcopenia and non-severe sarcopenia groups.

Characteristics	Male			Female		
	Non-severe sarcopenia	Severe sarcopenia	*P*	Non-severe sarcopenia	Severe sarcopenia	*P*
	(*n* =1,272)	(*n* =237)		(*n* =2,337)	(*n* =331)	
Age, years, median (iqr)	62(55,68)	68(63,74)	<0.01	60(54,65)	70(62,75)	<0.01
<60, *n* (%)	462(96.45)	17(3.55)		1,122(95.57)	52(4.43)	
60–69, *n* (%)	562(87)	84(13)		919(89.31)	110(10.69)	
≥70, *n* (%)	248(64.58)	136(35.42)		296(63.66)	169(36.34)	
Ethnic			0.001			<0.01
Han, n (%)	474(37.26)	120(50.63)		1,057(45.23)	168(50.76)	
Tibetan, *n* (%)	410(32.23)	51(21.52)		532(22.78)	83(25.08)	
Qiang, *n* (%)	308(24.21)	48(20.25)		620(26.53)	40(12.08)	
Yi, *n* (%)	59(4.64)	13(5.49)		94(4.02)	35(10.57)	
The other, *n* (%)	21(1.66)	5(2.11)		34(1.44)	5(1.51)	
BMI, kg/m^2, mean (SD)	26.1(3.42)	22.3(3.08)	<0.01	25.93(3.76)	22.11(3.83)	<0.01
Gait speed, m/s, median (iqr)	0.89(0.76,1.01)	0.78(0.66,0.91)	<0.01	0.85(0.71,0.98)	0.7(0.53,0.82)	<0.01
Handgrip strength, kg, mean (SD)	30.33(9.14)	23.72(8.12)	<0.01	19.14(5.46)	13.17(2.97)	<0.01
ASMI, kg/m^2, median (iqr)	7.6(7.3,8.1)	6.5(6.2,6.8)	<0.01	6.3(5.9,6.8)	5.3(5,5.5)	<0.01
CC, cm, median (iqr)	36.15(34.5,38)	32.7(31.01,34)	<0.01	35(33.05,36.85)	30.55(29.55,32.25)	<0.01
Ishii test score, mean (SD)	85.94(35)	127.19(32.51)	<0.01	95.96(32.97)	146.27(20.8)	<0.01

BMI, body mass index; ASMI, appendicular skeletal muscle index; CC, calf circumference. Non-severe sarcopenia included both subjects with sarcopenia and normal subjects.

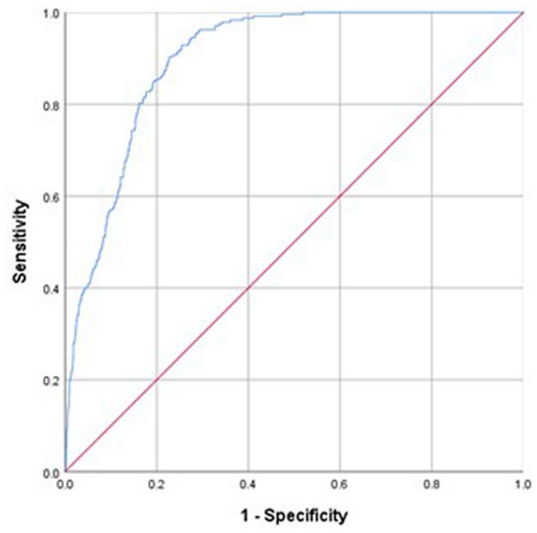

FIGURE 1
Sensitivity and specificity analyses and ROC models used for Ishii test screening for severe sarcopenia diagnosed as per the AWGS2019 criteria in males.

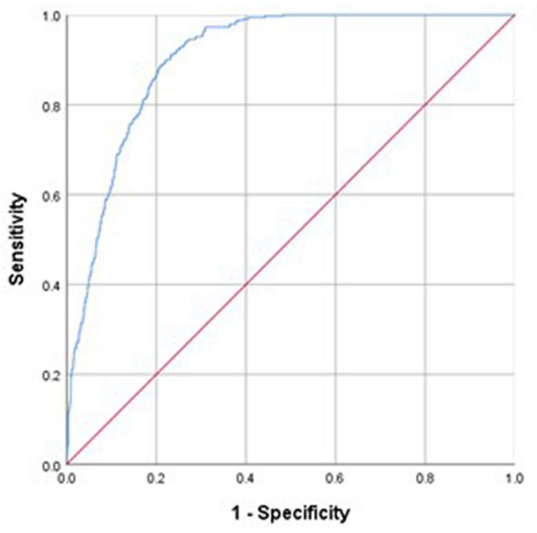

FIGURE 2
Sensitivity and specificity analyses and ROC models used for Ishii test screening for severe sarcopenia diagnosed as per the AWGS2019 criteria in females.

Cut-off points for sarcopenia from Ishii test

Overall, the Ishii test was able to effectively predict severe sarcopenia in both females (AUC: 0.905, 95% CI: 0.892–0.917) and males (AUC: 0.899, 95% CI: 0.883–0.916; Figures 1, 2). As no recommended Ishii test cut-off values have been established for use when screening for severe sarcopenia, the maximum Youden's index values were selected as cut-off thresholds for use in the present study. Import the Ishii score and whether you have sarcopenia into SPSS software, choose to analyze the ROC curve, and then the area under

TABLE 2 Sensitivity and specificity analyses and ROC models used for Ishii test screening for severe sarcopenia diagnosed as per the AWGS2019 criteria.

	Sensitivity, %	Specificity, %	PPV	NPV	AUC
Male					
Ishii test ≥ 114	89.45	77.15	0.42	0.98	0.899(0.883–0.916)
Female					
Ishii test ≥ 120	90.03	77.05	0.36	0.98	0.905(0.892–0.917)

the ROC curve and the "coordinates of the curve" containing a series of sensitivity and 1-specificity values can be obtained. Then calculate the Youden index by the formula Youden index = sensitivity + specificity − 1 in the EXCEL table. Then sort all the Youden indices, and the critical value corresponding to the largest Youden index is the optimal critical value, sensitivity and specificity. The largest Youden index obtained in this study was ≥114 for males and ≥120 for females. Using these cut-offs, the Ishii test yielded respective sensitivity, specificity, PPV, and NPV values of 90.03, 77.05%, 0.36, and 0.98 in females and 89.45%, 77.15%, 0.42, and 0.98 in males (Table 2).

Discussion

This study is the first to have analyzed the performance of the Ishii test when used to screen for severe sarcopenia among community-dwelling adults in Asia based upon the AWGS2019 consensus criteria. These results offer important evidence in support of the accuracy of the Ishii test as a tool for identifying patients with severe sarcopenia. Overall, 13.6% of community-dwelling participants in this study exhibited severe sarcopenia, with this value being in line with previously reported prevalence rates (2). However, severe sarcopenia prevalence was herein found to be higher among males relative to females, in contrast to previous reports suggesting similar prevalence rates irrespective of gender when measured as per the AWGS2019 criteria (2). This may be attributable to differences in inclusion criteria for this study population or in the criteria used to define severe sarcopenia.

The accuracy of the test depends on how well the test separates the group being tested into those with and without the disease in question. Accuracy is measured by the area under the ROC curve (26). In general, an AUC value > 0.8 is indicative of a high degree of accuracy. The results of the present study revealed the Ishii test to exhibit a high degree of accuracy as a tool for severe sarcopenia screening among community-dwelling Chinese middle-aged and older adults. The AUC value for the Ishii test in this cohort was >0.8 in both males and females, and it exhibited high sensitivity and moderate specificity. Importantly, this high sensitivity rate suggests that the Ishii test can be readily used to identify members of the community at risk of severe sarcopenia.

Optimal Ishii test cut-off values used to identify severe sarcopenia in the present. Study were selected based on maximum Youden's index value (≥114 for males, ≥120 for females) based on the AWGS2019 reference standard (2). When using these cut-off values as a diagnostic threshold, the Ishii test yielded NPVs of 98% in both males and females in the present study cohort, in line with prior reports indicating the negative predictive utility of this test. In another report, the Ishii test exhibited sensitivity and NPV values of up to 100% when diagnosing severe sarcopenia among adults ≥ 60 years of age in a geriatric outpatient clinic of a university hospital in Turkey using the EWGSOP criteria as a reference gold standard, when using cut-off values recommended by the founder of the Ishii test, namely, >105 for men and >120 for women (19).

In a separate study of the utility of the Ishii test in evaluating 199 nursing home residents in Western China, the respective sensitivity, specificity, PPV, NPV, and AUC values were 89.6%, 83.3%, 0.73, 0.94, 0.891 when utilizing AWGS2019 criteria as a reference gold standard (22). When using the SARC-F and SARC-Calf criteria, a 130-point cut-off threshold has been recommended to screen for severe sarcopenia, with the Ishii test AUC outperforming that of other screening tools under these conditions (22). However, the Ishii test was not compared to other screening or diagnostic tests in the present study, so similar conclusions cannot be drawn for the present patient cohort. Overall, the Ishii test exhibited high sensitivity and accuracy, which may be attributable to the fact that it takes grip strength, which is itself a diagnostic criterion for sarcopenia, into consideration. While grip strength is just one component of the overall diagnosis of sarcopenia, it can be assessed in an inexpensive, convenient, and portable manner in contrast to DXA and BIA, highlighting its potential value as a screening tool. Overall, the results of this study thus suggest that the Ishii test offers value as a means of screening for severe sarcopenia among community-dwelling adults, although additional research will be essential to validate and expand upon these conclusions.

One strength of the present study is the inclusion of a large cohort of middle aged and older adults from western China. There are certain limitations to this study. For one, a BIA approach was used to approximate skeletal muscle mass, rather than gold-standard approaches such as CT, MRI, or DXA. While less accurate than DXA, BIA is inexpensive, does not entail the need for X-ray exposure, and can be more readily utilized to evaluate community-dwelling individuals. Importantly, BIA has been validated (27, 28), and it has been recommended as an alternative approach to establishing muscle mass under the AWGS2019 criteria (1). Secondly, this study only included community-dwelling middle-aged and older adults from Western China. These results may thus not be representative of findings for patients residing in nursing homes or hospitals. Third, this WCHAT study is an ongoing cohort analysis, and only the associated 2018 cross-sectional data were used for the present analysis, precluding any assessment of the predictive validity of the Ishii test. Moreover, we did not assess the associations between Ishii test findings and adverse outcomes. Fourth, we excluded individuals who had not participated in sarcopenia screening or had missing values, which may have influenced the results. Despite these limitations, this was a large-scale multi-center study that was able to adjust properly for confounders in regression analyses, enhancing the reliability of our overall results.

Conclusion

These findings suggest that the Ishii test represents a promising screening tool and a candidate diagnostic test for severe sarcopenia among community-dwelling older adults in China, with recommended Ishii-test cut-off values of ≥114 for males and ≥120 for females when screening for severe sarcopenia.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

The current research was approved by the Ethical Review Committee of West China Hospital of Sichuan University with the committee's reference number 2017(445). The patients/participants provided their written informed consent to participate in this study.

Author contributions

SL and XC contributed to conceptualization, data collection, data curation, formal analysis, writing the original draft, and review and editing of the paper. LH and JY contributed to data collection, data curation, and review and editing of the paper. XX contributed to data collection and data curation. JY, BD, and LC contributed to study conceptualization, funding acquisition, investigation, methodology, project administration, supervision, and review and editing of the paper. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Cognition in older adults with healthy aging: analysis of the Mexican Health and Aging Study 2012–2015

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Introduction: Maintaining older adults' health and well-being can be achieved through the optimization of physical and mental health, while preserving independence, social participation, and quality of life. Cognitive change has been described as a normal process of aging and it involves domains such as processing speed, attention, memory, language, visuospatial abilities, and executive functioning, among others.

Objective: To describe cognitive changes in older adults with healthy aging.

Methods: This is a study that involved data from 14,893 and 14,154 individuals aged >60years or older from the 2012 and 2015 waves, respectively, who participated in the Mexican Health and Aging Study (MHAS). Participants with healthy aging were identified and described in the MHAS-2012 wave and followed to 2015. Eight cognitive domains evaluated in the Cross-Cultural Cognitive Evaluation (CCCE,) as well as sociodemographic and health characteristics, were described. Criteria for healthy aging involved the following: CCCE≥−1.5 standard deviations above the mean on reference norms, independence on basic and instrumental activities of daily living, self-reported "life close to ideal," and preserved functional and social performance.

Results: From a total of *n*=9,160 older adults from the MHAS-2012 wave, *n*=1,080 (11.8%) had healthy aging. In the healthy aging group, the median age was 67years (IQR: 63–73), 58.1% were female and the median for education was 6 (IQR: 3–8) years. The mean CCCE score was 57 (SD: 16.9) points. In the MHAS-2012 cross-sectional analysis, except for orientation, visuospatial abilities, and verbal fluency, all cognitive domain scores were lower with passing age. When comparing cognitive domain scores in the 225 older adults identified with healthy aging between the 2012 and 2015 MHAS waves, there were almost no observable differences.

Conclusion: In the cross-sectional analysis, Mexican adults with healthy aging had lower scores in the verbal learning memory, visual scanning, numeracy, visual memory, and verbal recall domains', as well as lower global cognitive scores in the higher age groups. There were no cognitive changes in the 3year follow-up, except for a lower gradient of scores in the verbal recall memory domain. Longer prospective studies are needed to characterize greater cognitive changes.

KEYWORDS

healthy aging, cognition, older adults, MHAS, CCCE

Introduction

Due to medical and technological advances along with better social and economic conditions, life expectancy has increased steadily around the world (1, 2). In 2015, it was estimated that the number of Mexican older adults will reach 150 million (3). Moreover, in 2020, life expectancy at birth in Mexico was estimated at 75.2 years (4, 5). However, healthy life expectancy was calculated at 65.4 years, evidencing a 10 year disparity between these two indicators (6, 7). The impact of the aging population, particularly in low- to middle-income countries, translates to an increase in multimorbidity, disability, and dependence, which represent a challenge for health systems (8, 9). Maintaining older adults' health and well-being through the optimization of physical and mental health, while preserving independence, social participation, and quality of life, is essential (10).

Depending on the author, the concept of healthy aging has been approached in several ways. Authors have defined it as "active," "successful," "productive," or "healthy" aging (11). Rowe and Kahn made an important contribution proposing a theoretical model of "successful aging," at the individual level, that encompasses three different areas: disease and disability prevention, maintenance of high physical and cognitive function, and having a sustained commitment to social and productive activities (12–14). However, the World Health Organization (WHO) favors the term "healthy aging," which focuses on functional abilities that result from the individuals´ interaction between their own intrinsic capacities and the environment (15).

Cognitive deterioration has been described as a normal process of aging, but also as part of other clinical conditions such as dementia (16). Normal cognitive changes have been well documented in several studies that describe domains such as processing speed, attention, memory, language, visuospatial abilities, and executive functioning, among others (16, 17). In Mexico, a pair of studies have described cognition as a part of the intrinsic capacity component of the WHO healthy aging definition. A study, based on data from the Mexican Health and Aging Study (MHAS)-2012 wave and a Mex-Cog 2016 study subsample, focused on describing the predictive value of the psychological and cognitive domains of the intrinsic capacity construct over successful memory aging (18). Similarly, Gutierrez-Robledo et al. evaluated intrinsic capacity in the MHAS-2015 wave and found that 88% of individuals had at least one of five domains affected (cognition, psychological, hearing, vision, vitality, and mobility) (19).

To gain a comprehensive understanding of cognitive function in non-demented community-dwelling older adults with healthy aging, it is necessary to describe a wide range of cognitive domains, given that their description in Mexican literature is warranted. The aim of our study is to describe cognition in older adults with healthy aging who participated in the Mexican Health and Aging Study (MHAS) 2012-wave and as secondary objectives, to determine healthy aging prevalence and to analyze cognitive changes between the 2012 and 2015 MHAS waves.

Materials and methods

Study participants and design

The MHAS is a national representative cohort study of Mexican adults aged 50 years or older (20). The baseline survey was conducted in 2001 with 5 follow-up waves in 2003, 2012, 2015, 2018, and 2021. We analyzed cross-sectional data from the MHAS-2012 wave and a 2015-wave subsample was used to fulfill one of the secondary objectives.

The MHAS description and ethical approval data are available at https://www.mhasweb.org/Home/StudyDescription.aspx and the aim and its methodological design is published elsewhere (21).

Sample selection at baseline and follow-up

Figure 1 shows the flowchart of the baseline sample selection. The 2012-MHAS wave included $n = 15{,}723$ participants that provided either direct or proxy interviews. From a total of $n = 10{,}170$ individuals aged 60 years or older, $n = 9{,}160$ with direct interviews were included. Individuals were further classified with ($n = 1{,}080$) or without healthy aging ($n = 8{,}080$). Individuals with healthy aging met all criteria; self-reported life "close to ideal," unimpaired instrumental activities of daily living (IADLs) and activities of daily living (ADLs), a score ≥ -1.5 standard deviations (SD) in the Cross-Cultural Cognitive Examination (CCCE), absence of specific functional limitations, and presence of social skill.

To describe longitudinal cognitive changes, individuals with healthy aging ($n = 1{,}080$) were identified in 2012 and followed-up to 2015 (Figure 2). During follow-up, $n = 23$ individuals died ("decedents") and $n = 103$ had unknown information. A total of $n = 954$ individuals comprised the followed-up sub-sample, which were further classified as with ($n = 225$) or without healthy aging ($n = 729$). Figure 2 shows the characteristics among those without healthy aging at follow-up, of which 90.3% had a score ≥ 1.5 SD in the CCCE, 87.8% had self-reported life "close to ideal," 84.6% had unimpaired instrumental activities of daily living (IADLs), 54.5% had unimpaired activities of daily living (ADLs), and 49.2% remained with no specific functional limitations.

Healthy aging

The WHO healthy aging definition comprises three fundamental principles: (a) functional capacity, which includes preserving the abilities that allow a person to fulfill basic needs, to learn and thrive, make decisions, establish relationships, contribute to society, and maintain mobility, (b) intrinsic capacity, which refers to a combination of a person's physical and mental capacities, including the ability to walk, think, see, and remember, and (c) the environment factor, which involves people's homes and their involvement in their communities (22).

In line with the mentioned criteria, individuals that fulfilled all of the following were classified with healthy aging: unimpaired IADLs (ability to prepare a meal, go shopping, manage money, or take medications), and ADLs (transferring or getting out of bed, dressing, toileting, grooming, or eating), scores in the CCCE ≥ -1.5 standard deviations (SD) above the mean based on previously published norms by age and education, absence of specific functional limitations (carrying objects, pushing or pulling, picking up a coin, or lifting arms), and presence of a social skill, defined by a positive response to the question: "*Does respondent communicate with relatives/friends via phone/internet?*" (23–26). In our study, self-reported life "close to ideal" based on the answer "agreed" to the question: "*Respondent believes his/her life is close to ideal?*," was also considered.

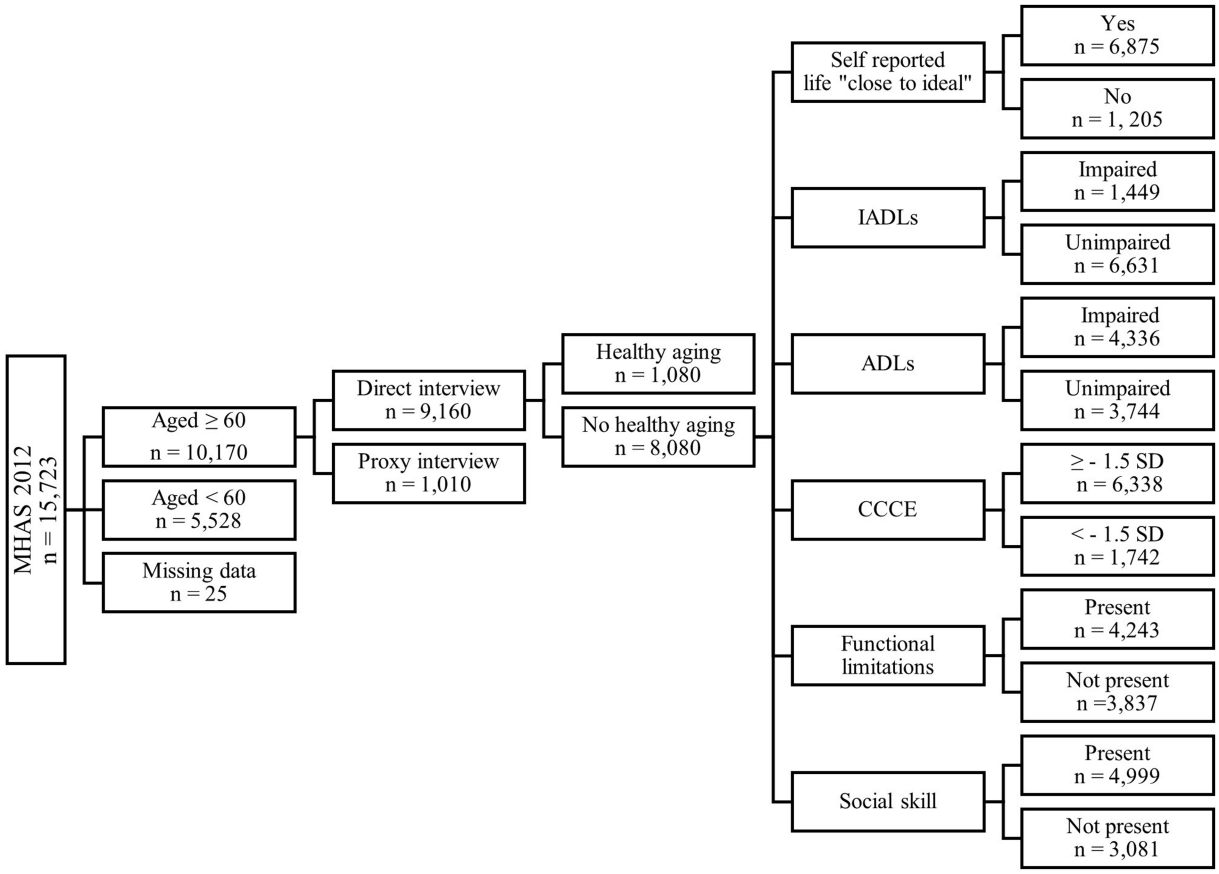

FIGURE 1
Flowchart of sample selection at baseline (MHAS-2012 wave). MHAS, Mexican Health and Aging Study; IADLs, instrumental activities of daily living; ADLs, activities of daily living; CCCE, Cross Cultural Cognitive Examination; SD, standard deviation.

Supplementary Table S1 shows the healthy aging criteria used in this study in contrast to those proposed by the WHO (15).

Cognition and cognitive domain evaluation

In an effort to identify non-demented individuals, as part of a healthy aging definition, individuals with CCCE scores ≥−1.5 SD above the mean based on reference norms by age and education were first identified (26). Individuals had unimpaired IADLs, which is essential when evaluating cognitive impairment (27).

Because other MHAS waves used a modified version of the CCCE, we used data from the 2012 and 2015 MHAS waves, in which a total CCCE score consists of a sum of maximum 99 points. As described by Mejía-Arango et al., the minimum and maximum scores for each cognitive domain are as follows: orientation 0–3, verbal learning memory 0–8, verbal recall memory 0–8, visual scanning 0–60, visuospatial abilities 0–6, visual memory 0–6, verbal fluency 1–4, and numeracy 1–4. Subsequently, each cognitive domain score was described.

Covariables

Sociodemographic characteristics included age, sex, education, civil status, and religious service attendance. The latter was characterized by individuals who answered yes to the question: "*Respondent attends religious services?*." Health characteristics included smoking history and current alcoholism, defined by a positive answer to the questions: "*Last 2 years: Respondent smoked cigarettes?*" and "*Respondent currently drinks alcohol?*," respectively. Individual's affirmative responses to the questions: "*Has a physician ever diagnosed you with [*i.e., *hypertension, type 2 diabetes mellitus, cancer, heart attack, and rheumatoid arthritis]?*," were also considered as comorbidities. Obesity was defined as a body mass index (BMI) ≥ 30 kg/m^2 (28). We defined depressive symptoms according to a 9-item (yes/no) previously validated version of the Center for Epidemiological Studies-Depression (CES-D) included in the MHAS. A score ≥5 was considered as clinically significant depressive symptoms (29).

In this study, we included common geriatric syndromes such as the presence of falls, pain, stress and urge urinary incontinence, loss of appetite, hearing aid use, and visual impairment positive answers to the questions: "*Last 2 years: Has respondent fallen down?*," "*Respondent suffers from pain?*," "*Last 2 years: frequent incontinence while performing task(s)*?, "*Last 2 years: Frequent incontinence with urge to urinate*" "*Respondent uses hearing/auditory device?*," respectively. Visual impairment refers to individuals who responded that they used glasses and had an "excellent-regular" vision with them.

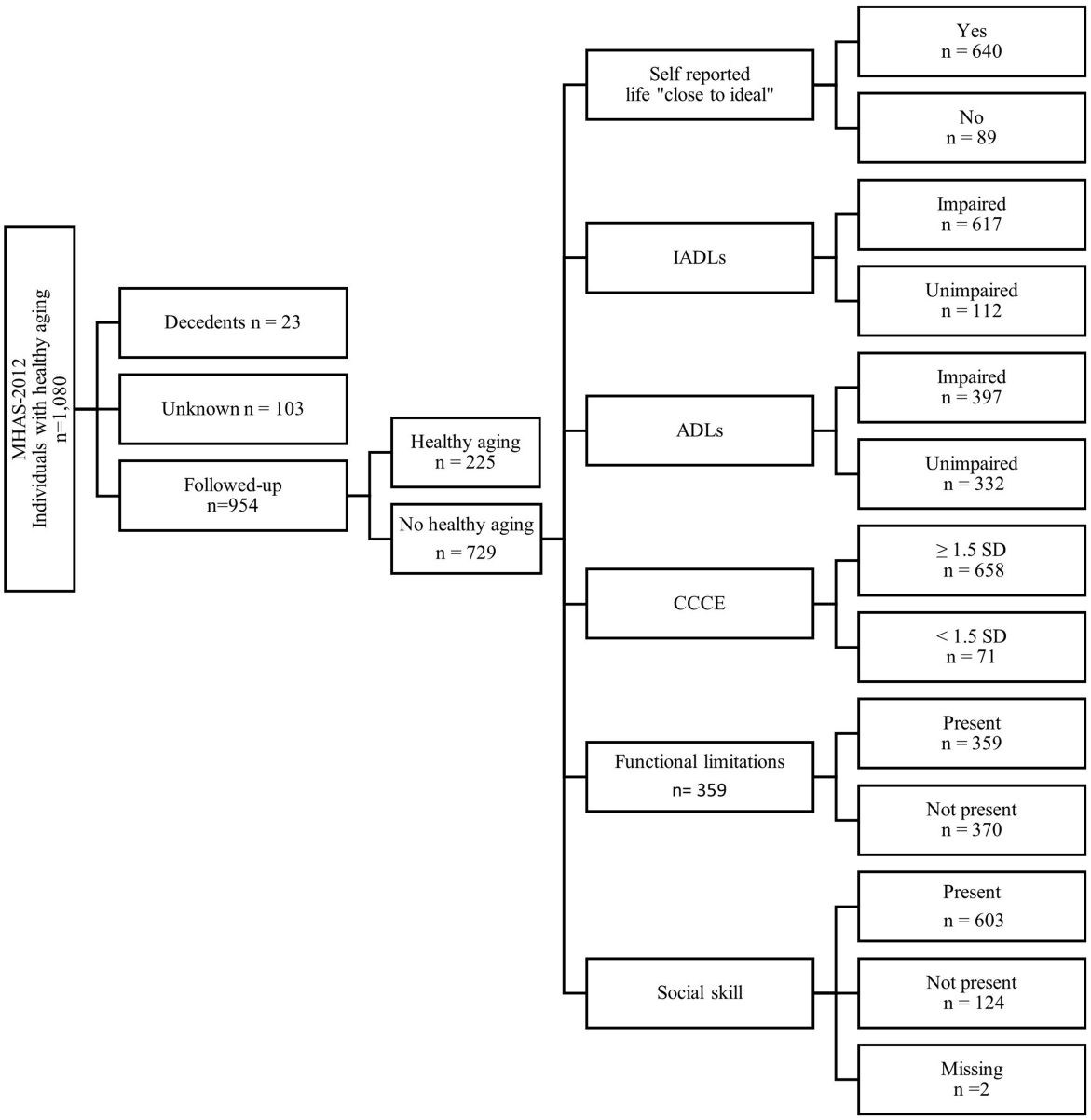

FIGURE 2
Flowchart of the followed-up sub-sample from the MHAS-2015 wave with and without healthy aging. MHAS, Mexican Health and Aging Study; IADLs, instrumental activities of daily living; ADLs, activities of daily living; CCCE, Cross-Cultural Cognitive Examination; SD, standard deviation.

Statistical analysis

A Kolmorogov–Smirnoff test was conducted to determine the sample's data distribution. In the cross-sectional analysis, median, interquartile ranges, and Mann–Whitney U tests were used to describe numerical variables and a Chi-square test was used for categorical variables. The total CCCE score was the only normally distributed variable and was described with means and *t*-student tests. Using information from the MHAS-2012 wave, box plots were constructed to show differences, by age group, between the median values of each cognitive domain and total CCCE scores. Domains with no visible cognitive change (orientation, visuospatial abilities, and verbal fluency) were not included. A prevalence rate was calculated in the MHAS-2012 wave. For the longitudinal analysis, information from individuals who fulfilled healthy aging criteria in both 2012 and 2015 ($n = 225$), were analyzed with the Wilcoxon signed-rank test and *t*-student paired test. Statistical significance was considered at a value of $p \leq 0.05$ and analyses were performed using SPSS software for Windows® (SPSS Inc., Chicago, IL version 23.0).

Results

Sociodemographic, health characteristics, and presence of geriatric syndromes of the MHAS-2012 sample are shown on Table 1. From a total of 9,160 participants aged 60 years or older, 1,080 (11.8%) had healthy aging, median age was 68 years, most were women, and the median for education was 4 years. More than half of individuals

were married and almost 80% of the sample said they attended a religious service. Thirty-one percent of participants had a history of smoking and 21.3% had current alcoholism. Almost half of the sample had hypertension, a quarter had diabetes mellitus, and 16.4% had rheumatoid arthritis. A history of previous heart attack and cancer diagnosis were present to a lesser extent. The most prevalent geriatric syndromes were the presence of falls, pain, and depressive symptoms, followed by visual impairment, both stress and urge urinary incontinence, loss of appetite, and hearing aid use.

When compared to the medians from the group without this characteristic, the healthy aging group was slightly younger and had a higher education (Table 1). Moreover, in the healthy aging group there was a statistically significant greater frequency of women, current alcoholism, and obesity, when compared to the group without it. The only comorbidities that were more prevalent in the group without healthy aging were depressive symptoms and rheumatoid arthritis. Loss of appetite and visual impairment were the less prevalent geriatric syndromes in the group with healthy aging. There were no significant differences between groups regarding other health characteristics.

Regarding the cognitive domain description between groups from the MHAS-2012 wave presented in Table 2, individuals with healthy aging had a higher global CCCE score and visibly greater individual cognitive domain scores in the verbal learning memory, visual scanning, numeracy, and verbal recall memory domains. When compared to the group without it.

The box plots showing cognitive domain changes by age group in the MHAS-2012 wave are presented in Figure 3. The median cross-sectional scores for all cognitive domains were visibly lower at older age, except for orientation, visuospatial abilities, and verbal fluency, thus, not included in the figure. The mean total CCCE score also had a significant decline. A detailed description of these variables is shown in Supplementary Table S2.

On Table 3, the cognitive domain changes observed between the 2012 and 2015 MHAS waves are shown. A total of 225 older adults survived and fulfilled healthy aging criteria in 2015. In this analysis, there were no observable differences among the assessed cognitive domain, except for the verbal recall memory domain interquartile range scores, which were lower in 2015 [5 (IQR: 3–6) points], when compared to 2012 [5 (IQR: 4–6) points] ($p = 0.044$), suggesting a gradient of changes in this domain in the 3 year follow-up. Supplementary Table S3 shows cognitive performance scores among the 954 individuals with healthy aging in 2012 that survived follow-up but did not fulfill healthy aging criteria. In this analysis the visual

TABLE 1 Sociodemographic, health characteristics, and presence of geriatric syndromes in the MHAS-2012 sample.

	Total n=9,160	Healthy aging n=1,080	With no healthy aging n=8,080	p value*
Age median (IQR)	68 (64–75)	67 (63–73)	68 (64–75)	<0.001
Sex (female) (%)	54.5	58.1	54.0	0.013
Education median (IQR)	4 (1–6)	6 (3–8)	4 (1–6)	<0.001
Civil status (%)				0.190
Married	58.2	61.3	57.8	
Attends religious service (%)**	77.8	78.2	77.7	0.913
Smoking history (%)	31.0	32.0	30.9	0.614
Current alcoholism (%)	21.3	24.6	20.8	0.038
Obesity (%)	26.2	33.8	25.1	<0.001
Hypertension (%)	48.8	48.9	48.8	0.916
DM (%)	24.8	23.8	25.0	0.657
Cancer (%)	2.4	1.9	2.4	0.657
Heart attack (%)	4.3	4.0	4.3	0.875
RA (%)	16.4	13.1	16.8	0.013
Depressive symptoms (%)	33.4	25.6	34.5	<0.001
Geriatric syndromes				
Falls (%)	42.9	42.1	43.0	0.842
Pain (%)	39.4	37.2	39.7	0.245
Stress urinary incontinence (%)	15.7	15.6	15.7	0.784
Urge urinary incontinence (%)	16.2	16.2	16.2	0.960
Loss of appetite (%)***	6.2	3.6	6.5	<0.001
Hearing aid use (%)	1.5	1.5	1.4	0.931
Visual impairment**** (%)	10.8	6.7	11.4	<0.001

*Value of p from Mann–Whitney U test for numeric variables and Chi-square for categorical variables. IQR, interquartile range; DM, type 2 diabetes mellitus; RA, rheumatoid arthritis. **Attends religious service analysis was performed with data from 1,142 participants who answered yes to the question: "*Respondent attends religious services*". ***Loss of appetite refers to "frequently feeling with a loss of appetite." ****Visual impairment refers to using glasses and having an excellent-regular vision with them.

TABLE 2 Cognitive domains description between the healthy and non-healthy aging groups in the MHAS-2012 sample.

Cognitive domain Median, (IQR)	Total *n*=9,160	Healthy aging *n*=1,080	With no healthy aging *n*=8,080	*p* value*
Verbal learning memory	5 (4–5)	5 (4–6)	4 (4–5)	<0.001
Verbal fluency	2 (2–2)	2 (2–3)	2 (2–2)	<0.001
Visual scanning	21 (9–33)	27 (18–39)	20 (8–32)	<0.001
Orientation	3 (2–3)	3 (2–3)	3 (2–3)	<0.001
Numeracy	4 (3–4)	4 (3–4)	3 (2–4)	<0.001
Visuospatial abilities	6 (5–6)	6 (6–6)	6 (4–6)	<0.001
Visual memory	5 (2–6)	5 (4–6)	5 (2–6)	<0.001
Verbal recall memory	4 (2–5)	5 (3–5)	4 (2–5)	<0.001
Total CCCE, mean (SD)	46.2 (22.4)	57.0 (16.9)	44.8 (22.6)	<0.0.001

Value of *p* from Mann–Whitney U test for numeric non-parametric variables and *t*-student for parametric variables which refers to the total CCCE scores. IQR, interquartile range; CCCE, Cross Cultural Cognitive Examination; SD, standard deviation.

scanning, visual memory, and the verbal recall domains appeared to have lower scores in the 3 year follow-up.

Discussion

In the cross-sectional analysis by age group from the MHAS 2012-wave, we found that cognitive domains such as visual scanning, verbal learning memory, visual memory, verbal recall memory, numeracy, and total CCCE scores were lower at older ages. These changes were not evident in the 3 year follow-up analysis among individuals who fulfilled healthy aging criteria. An 11.8% (CI: 11.1–12-4) prevalence of healthy aging in adults aged 60 years or older was found in the 2012 MHAS-wave.

Different concepts have been proposed when defining healthy aging. Rowe and Khan model of successful aging is one of the most used by several authors (12–14). For instance, a study involving 14 European countries established a "successful" aging prevalence of 8.5% (30). In China, Yin et al. found a prevalence of 15.8% and a 12.6% frequency was reported in western Mexico in 2012 (31, 32). The latter prevalence is like that found in our study (11.8%) but lower than that reported in China. It is important to note that we used the WHO healthy aging definition which does not consider the strict absence of comorbidities (22). Additionally, our definition included a "life close to ideal" self-perception criterion, as it has been considered beneficial to functional health and described as a predictor of future morbidity and mortality in numerous empirical studies but, nevertheless, is not included as essential in the two concepts previously mentioned (33, 34). Moreover, cognition in our study was thoroughly evaluated with a different instrument, which has proven useful in cross-cultural epidemiological research, from that included in other studies (35). The strictness and number of criteria considered to establish healthy or successful aging should be considered when comparing results and could account for differences or similarities in the prevalence rates reported.

Unlike developed countries, Mexico's population is still undergoing a demographic transition in which people over 65 years of age are expected to greatly increase in proportion by 2050 (36). Regarding the age characteristics of our study's sample, the healthy aging group had a median age of 67 (IQR: 63–73) years, lower than the means previously reported in Europe (74.0 ± 3.8) and the United States of America (72.41 ± 8.47). Our results are only comparable to the findings by Arias-Merino et al. in Mexico, in which a greater frequency of successful aging (18.9%) was found in the 60–69 age group, when compared to older groups (32). Like what was reported by Schietzel et al. in European countries, the female sex was the most prevalent in the healthy aging group, while being married was the most common civil status, similar to that reported in other studies, probably because it has been suggested that marriage provides social benefits and has been previously associated with health and survival in the older age (31, 37–40). The group with healthy aging also had a higher level of education compared to the group without healthy aging, as reported by Schietzel et al (37). However, consistent with what has been reported in developing countries, the mean for years of education was higher in the latter study (13.4 ± 3.5), when compared to the median value reported in our study [6 (IQR: 3–8) years, (41)].

Our findings were like the results described by Cañedo et al. in Brazil, in which healthy aging individuals had a BMI in the overweight range (34%) and 21% were cataloged with obesity (38). Bowling et al., found a possible null relationship between overweight and mortality in older adults and in another study, it was found that neither overweight nor obesity were associated with mortality in univariate and multivariate models (42, 43). Authors in the latter study concluded that being underweight, unlike being overweight or obese, increased the risk of premature death in older people (44). As expected from a country with a reported high prevalence of overweight (49.4%) and obesity (28.7%) and as a result of including comorbidities in the healthy aging definition, in our study, obesity was higher in the healthy aging group (45).

We did not find differences between individuals with or without healthy aging with respect to the presence of chronic diseases such as hypertension, diabetes mellitus, or heart attack. The presence of comorbidities has been identified as one of the most demanding criteria to define successful aging (12–14, 46). However, this would hardly apply to our population since chronic diseases are prevalent in Mexico due to socioeconomic conditions and the overall level of sub-development (47). Moreover, it has been described that successful aging can coexist with chronic diseases and functional limitations if sufficient compensatory mechanisms exist (48). Additionally, it has been observed that the preservation of functionality associated with a good self-perception of health is possible in the presence of comorbidities (38).

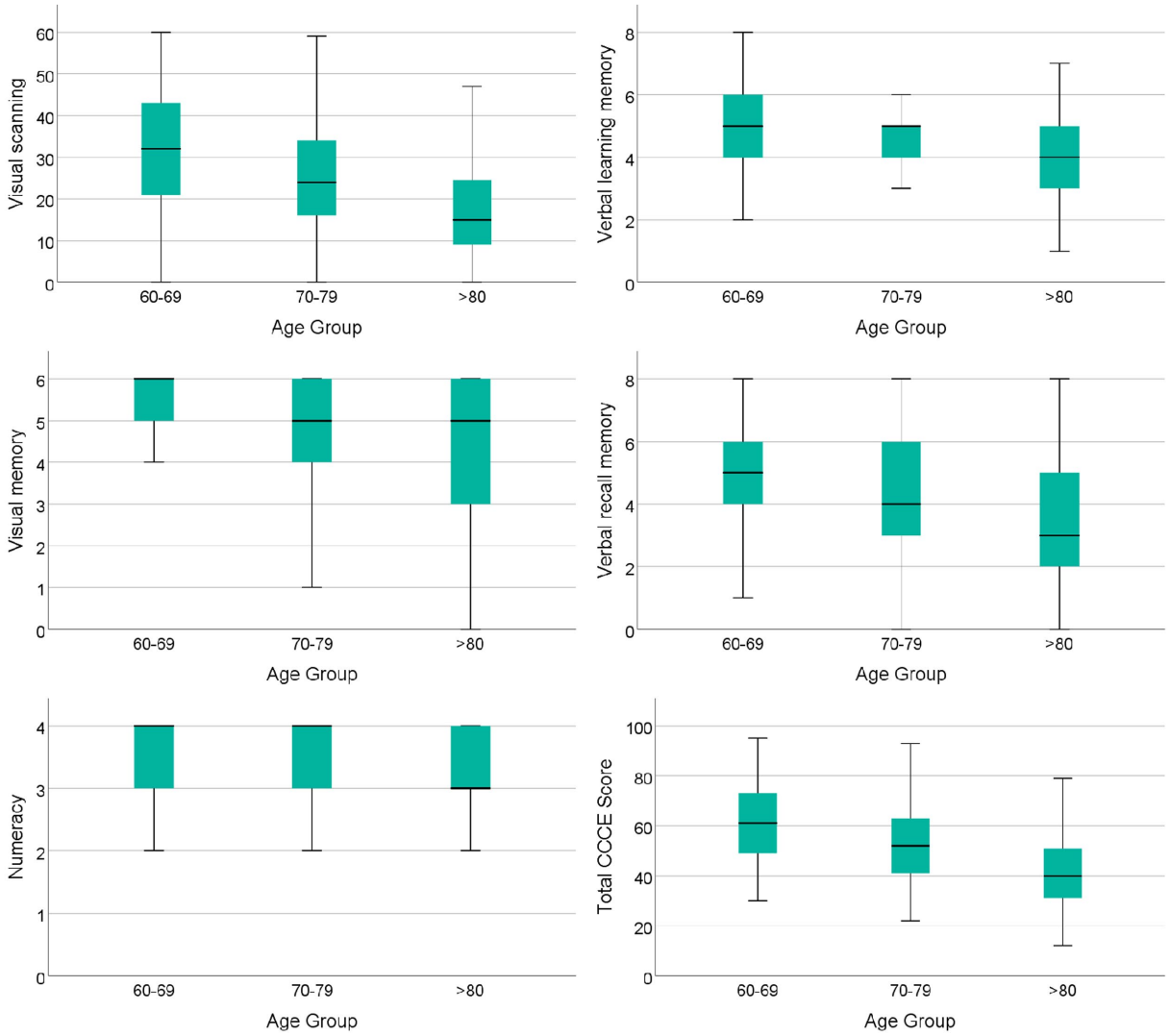

FIGURE 3
Box plots showing cognitive domain changes by age group in adults with healthy aging from the MHAS-2012 wave. *p* values from all comparisons between age groups in each cognitive domain and CCCE scores shown in the figure were <0.001. Individual cognitive domain comparisons were analyzed with a Kruskal–Wallis test and a *t*-student test was used for the total CCCE scores. CCCE, cross cultural cognitive examination.

Regarding geriatric syndromes, individuals with healthy aging in our study had a lower presence of depression and loss of appetite. A previous study by Cañedo, et al. found that depression is associated with fewer social engagement and less physical activity, which causes greater functional deterioration (38, 49). In addition, as previously described, individuals with visual impairment have a higher risk of functional impairment, which could explain our results (50).

In the cross-sectional analysis, by age group, we found lower cognitive domain scores in higher age groups. The CCCE used in the MHAS evaluates verbal memory (learning and recall) through an eight-word list (26). We found that both domains (verbal learning memory and verbal recall memory) scores seemed to be lower at older age. Similarly, Young Hoogendam et al., in an analysis of the Rotterdam Study, found that compared to other domains, the smallest, but present, effects of age over performance were found in the immediate and delayed recall word tests (16). Furthermore, the CCCE assesses working memory with the use of the numeracy domain (counting backwards from 20 to 0 in a maximum time of 60 s) (51). We also observed lower scores in this task with passing age. Described as produced by a change in frontal-striatal circuits, executive function has been found reduced in older adults without cognitive impairment along with working memory (17, 52).

Attention, evaluated in the CCCE through a visual scanning task (detecting stimuli among other similar stimuli), was also found reduced with advancing age (51). Age has been found to have a more significant effect on complex attention tasks such as selective attention, which involves the capacity to focus on specific information while ignoring irrelevant stimuli (17). Similarly, the most noticeable difficulties described in older adults above their ninth decade of life, were cognitive slowing and diminished attention skills (52). On a separate note, visual memory was measured in the MHAS by requesting individuals to remember figures they had previously copied (51) and it was also found reduced with older age. Verbal and visual working memory have both

TABLE 3 Cognitive changes between 2012 and 2015 MHAS waves.

Cognitive domain Median, (IQR)	Healthy aging 2012 *n*=225	Healthy aging 2015 *n*=225	*p* value*
Verbal learning memory	5 (4–6)	5 (4–6)	0.430
Verbal fluency	2 (2–3)	2 (2–3)	0.341
Visual scanning	30 (20–41)	31 (20–43.5)	0.079
Orientation	3 (2–3)	3 (2–3)	0.111
Numeracy	4 (3–4)	4 (3–4)	0.050
Visuospatial abilities	6 (6–6)	6 (6–6)	0.659
Visual memory	6 (5–6)	6 (5–6)	0.294
Verbal recall memory	5 (4–6)	5 (3–6)	0.044
CCCE, mean (SD)	60 (48–71)	60 (48–75)	0.391

*p-value from Wilcoxon signed-rank test between healthy aging participants from the 2012 and 2015 MHAS waves. **p-value from paired t-student test. CCCE, Cross Cultural Cognitive Examination; SD, standard deviation.

been found in like manner affected by normal aging (53). Total CCCE scores in older adults with healthy aging were also lower at higher age groups in the cross-sectional analysis. The Rotterdam study reported rapid cognitive decline in global Mini-Mental State Examination (MMSE) scores after the age of 70 (16).

In our study, the orientation (knowledge about the day, month, and year), visuospatial abilities, and verbal fluency (animal naming for 1 min) (26) domains had no visible change with advancing age. Unlike the Rotterdam Study in which a decline in the verbal fluency and visuospatial abilities (copy two figures), mostly the latter, were found affected by age (16). The latter was also like the findings of Harada et al., who reported that visual construction skills decline with age, in contrast to familiar object recognition and spatial perception which remain unchanged with age (17). Lastly, temporal orientation is considered a reflection of semantic and episodic information (54). It has been found that while semantic memory remains relatively stable with advancing change, a reduced episodic memory has been associated with aging (55, 56).

A decline among cognitive domains evaluated in adults aged 60 years or older that participated in the MHAS was not evident in the 3 year follow-up analysis, except for a slight IQR lower score in the verbal recall memory domain. Other longitudinal studies, with greater follow-ups, have reported a similar decline on immediate and delayed recall tests (16, 57), highlighting the need for longer assessments.

This study has several strengths. First, to the best of our knowledge, it is the first study in Mexico that evaluates healthy aging using the WHO definition, which does consider the presence of comorbidities. Second, a cross-sectional and longitudinal analysis was performed describing changes over time in cognitive domains of individuals with healthy aging. Third, in our study we used the CCCE for the evaluation of cognitive domains, which evaluates multiple cognitive areas, unlike other more commonly used scales (32, 58). Fourth, our study is based on a large representative sample of the Mexican population.

Our study is not without weaknesses. First, we performed a 3 year follow up which was not enough to detect significant changes among the cognitive domains evaluated. A longer follow-up period is warranted. Second, perhaps because our criteria for healthy aging were too strict, our sample size was smaller than it would have been if functional capacity had not been evaluated as it was. Third, we must consider that other studies measured cognitive domains with broader neuropsychological tests, which could account for the difference in results (59).

Conclusion

Cross-sectionally, this study shows cognitive domain changes, concerning lower scores in the higher age groups in the visual scanning, verbal learning memory, visual memory, verbal recall memory, and numeracy domains, of Mexican older adults with healthy aging that participated in the MHAS-2012 wave. However, changes were not observed in the 3 year longitudinal analysis, hence a longer follow-up is warranted to better describe changes through time.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

SY-C, RM-D, and JG-G designed the study. SY-C, RM-D, CG-G, and JG-G searched the literature. SY-C, GA-D, JG-G, and RM-D collected and analyzed the data. SY-C and GA-D interpreted the data. SY-C and RM-D wrote the manuscript draft. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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Evaluating the design of the Integrated Care for Older People: a theory of change approach

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Introduction: Given the progressive aging of the population, there is an urgent need at the health system level to implement effective models to care for older people (OP). Healthy aging is imperative to reach the Sustainable Development Goals. The World Health Organization (WHO) developed the Integrated Care for Older People (ICOPE) strategy to address this challenge. Implementing ICOPE requires its adaption to a specific context. We propose a pathway for such adaptation through an evaluation of the design of ICOPE; thus, we aim to describe the Theory of Change (ToC) of ICOPE and evaluate it for its implementation in Mexico City.

Methods: Based on the WHO and published literature documentation, we drafted an initial ToC for ICOPE. Then, we validated the ToC with experts in ICOPE, after which we evaluated and refined it by discussing the causal pathway, intervention required to activate it, rationale, and assumptions in consecutive workshops with 91 stakeholders and healthcare workers, using the nominal group technique to reach a consensus.

Results: The resulting ToC has the potential to contribute to healthy aging by three expected impacts: (1) prevention, reversal, or delaying of the decline of intrinsic capacity (IC) in OP; (2) improvement of the quality of life of OP; and (3) increase of disability-free life expectancy. The ICOPE causal pathway had ten preconditions, including the availability of resources, identifying at-risk individuals, available treatments, and evaluating results.

Discussion: We adapted ICOPE to a specific implementation context by evaluating its ToC in a participatory process that allows us to identify challenges and address them, at least in terms of the guidelines to operate the strategy. As ICOPE is an approach for a primary healthcare system, its adoption in a community healthcare program is promising and feasible. Evaluation as a tool could contribute to the design of effective interventions. The evaluation of the design of ICOPE for its implementation contributes to the strength of its potential to improve care for OP. This design for implementing ICOPE has the potential to be applied to similar contexts, for example, in other lower-middle-income countries.

KEYWORDS

ICOPE, design evaluation, theory of change, community health services, older people

Introduction

According to the World Health Organization (WHO), by 2050, more than 1 in 5 people will be 60 years or older (1), a population group with increasing needs in terms of healthcare. Older people (OP) utilize more health services than younger adults, usually with a larger share of specialized care (2, 3). In Mexico, OP currently represent 14% of the total population, a share that will almost double by 2050. Mexico is just below the United States, where the current share of OP is 16.2%. As the proportion of the OP increases, healthcare models must adapt their approach to fulfill their needs.

Existing healthcare models in general were developed based on a different population profile, and their adaption to the specific needs of OP is not straightforward (4, 5). Aligned with the Sustainable Development Goals, the United Nations declared the current decade of the 2020s as the decade of Healthy Aging as a strategy for achieving and supporting actions to build a society for all ages (6), inclusive for OP and avoiding so-called ageism, i.e., discrimination based on age.

The WHO developed the Integrated Care for Older People (ICOPE) approach to strengthen how existing healthcare models provide care for OP, which focuses on preventing decline or loss and restoring individual intrinsic capacity (IC). IC is the composite of all physical and mental capacities an individual can draw (7). The implementation of the ICOPE approach includes 19 actions classified into essential and non-essential and further categorized into three levels: (i) macro (e.g., strengthen governance and accountability systems), (ii) meso (e.g., orient services towards primary care), and (iii) micro (e.g., guidelines for dimensions on IC) (8). For the micro level, ICOPE comprises guidance on person-centered assessment with six guides for multiple types of healthcare workers (9).

These multiple components acting independently and in conjunction with the health system operation make the ICOPE approach complex. The WHO developed the ICOPE approach for its implementation worldwide, requiring further adaptation to each specific country or subnational area. This adaptation involves how the proposed actions align with the existing healthcare model and the refinements required. An evaluation of the design of ICOPE is a promising approach to identify such refinements, as it could identify potential limitations and challenges to accomplish the desired outcome and thus distill the intervention to increase its potential. That is, analyzing the implicit Theory of Change (ToC) of ICOPE and refining it by evaluating it. The ToC approach is a tool that helps to identify how an intervention expects to reach its long-term outcomes through a logical sequence of intermediate outcomes (10, 11). It has extensive applications, reported in the literature, to evaluate and design healthcare interventions (11). Several studies have demonstrated the extra benefits of the model of action and the unforeseen consequences of the intervention (12). A ToC evaluation can effectively assess the expected mechanism through which the intervention could produce a change and how the context may modulate these effects. The ICOPE approach can profit from the design evaluation as it will inform how to adapt it to a specific context. Therefore, this study aims to evaluate the design of the ICOPE by making its ToC explicit and assess it from the perspective of implementing ICOPE within a primary care health program in Mexico City.

Materials and methods

This evaluative study used a documental review and qualitative tools to draft and assess the ToC model of ICOPE for its implementation within a primary care program in Mexico City. The provision of health services in Mexico is segmented by population labor condition, with 40.4% of the population covered by the social security services that provide care for formal employees and their families, 16.1% by the private sector, and 43.5% by public services (13).

Setting

We analyzed the potential of ICOPE in Iztacalco, one of Mexico City's 16 boroughs. Iztacalco had a population of 404,695 people in 2020; around 16% were aged 60 years or above (14). About 37% of that population was attending local public health services, while the remaining population was receiving care from social security (51%) or private (12%) subsystems (14). Iztacalco is a municipality with 25.2% of the population living in poverty and 25.4% reporting lack of access to health services (14). Public health services for OP in Iztacalco without social security comprise five primary health facilities, one geriatric clinic, and a healthcare program to provide health services in their homes. This health program, called "*Salud en tu Casa*," is staffed by general physicians, nurses, dentists, health officers, physiotherapists, nutritionists, psychologists, and social workers. None of them has formal training to provide health services, promotion, and prevention activities to OP. These healthcare workers (HCWs) provide health services for around 5,000 OP in their residences and liaise with them in other government programs.

Drafting the theory of change of ICOPE and ToC workshop participants

To draft a ToC for ICOPE, a documental review was implemented, focusing on the official publications from the WHO. Initially, we met with two stakeholders from the National Institute of Geriatrics in Mexico, who had extensive experience in the ICOPE approach to further review the initial draft and ensure it reflected the scope of the strategy. Two workshops were conducted in 2022 to evaluate the design of ICOPE for its implementation in Iztacalco within *Salud en Tu Casa*. The first was with five persons, directors, and stakeholders from the healthcare program and the geriatric clinic from Iztacalco. In the second workshop, 82 persons participated; they were HCWs from Iztacalco. All the participants had diverse professional backgrounds (geriatrics, public health, primary care, education, nursing, social work, nutrition, psychology, physiotherapy, and dentistry).

Procedures

The evaluation of the design of ICOPE underwent two stages: (a) drafting and validating of an initial ToC and (b) evaluating and redefining of the ToC. The first stage implicated a provisional ToC development using a literature review and a meeting with a structured discussion about revising the scope of ICOPE. This discussion was conducted in a videoconference in February 2022 facilitated by both authors (SEGB and JPG). For the evaluation in the second stage, we conducted two workshops

in Iztacalco borough in April 2022. Two researchers, experts in program evaluation and ToC, facilitated the workshops. During the workshops, both facilitators (AAA and SEGB) emphasized that the focus of involvement with the ToC components for some participants went beyond the HCW duty. Moreover, we established the work's objectives, provided a brief description of the ToC approach, and used the nominal group technique to reach an agreement. We used the approach suggested by Breuer and collaborators to develop and report the ToC (11, 15). The first step recommended to validate the ToC during the workshops was the definition of the impacts and long-term outcomes. Then, we iteratively worked backward to map out the preconditions, interventions, assumptions, and indicators to generate the desired outcomes (15). The process used a multi-voting system to reach a consensus on each element, and in case of disagreement, we performed a guided discussion.

In evaluating the design of ICOPE, we refined the ToC, considering the written feedback and expert consultation on the program evaluation. Then, in a meeting with the stakeholder group (two geriatricians and two program health directors), we discussed and redefined the ToC. This structured discussion was held at the National Institute of Geriatrics in Mexico City in June 2022. After a presentation and recap of the ToC process and existing ToC map, the group discussed the practical problems encountered in the borough, e.g., the specific context barriers.

Data collection

We searched for published documents that described the features and characteristics of the ICOPE approach. From this search, we identified two primary documents (8, 16) that described four main categories of ICOPE: (1) resources needed, (2) ability to identify at-risk individuals, (3) available treatments, and (4) long-term outcomes. For the workshops, the first author collected the ToC workshops' data *via* audio-recorded real-time notes. The two workshops lasted 2:00 h and 1:30 h, respectively. We have used the documental review and workshop data to evaluate the ICOPE design and describe the ToC for its implementation in Mexico City.

Results

Table 1 describes the characteristics of the 91 HCWs and stakeholders' participants at the meeting and the two ToC workshops. In the following sections, we detailed (1) the finally agreed ToC with the main elements (Figure 1) and (2) the findings from the evaluation of the design of the ICOPE approach, including the narrative of the ToC with its preconditions, assumptions, interventions, and rationales.

While we found that all participants supported using the ICOPE approach (to which they were previously exposed in training), they also expressed their need to gain experience in its application by using the guidelines to provide care services. From the HCWs perspective, critical barriers to activating the causal pathway included limited supervision and feedback in their daily work, lack of collaboration between the HCWs' to provide integrated care, and technical issues using cognitive aids such as mobile applications to assess OP. All HCWs recognize the need for more courses to provide better care for OP. Also, they realized they would need a system to consult with a geriatrician or other specialist if they could not give further care to the OP. The findings of this study acknowledged that the development of the ToC, particularly to triangulate all the components, requires external stakeholders that support the project; that is, more is needed for the staff.

TABLE 1 Participants in the development of the ToC workshops.

Participants	*N*	Females
Structured discussion	4	0 (0%)
Geriatricians	2	0
Researchers	2	0
ToC 1	5	3 (60%)
Stakeholders	2	0
Administrator	1	1
Nurse	1	1
Dentist	1	1
ToC 2	82	56 (68%)
Geriatricians	2	2
Physicians	14	9
Nurse	16	15
Health promoter	20	10
Stakeholders	3	0
Social worker	4	3
Administrator	9	7
Psychologist	4	2
Nutritionist	2	2
Audiologist	1	1
Physiotherapist	3	2
Dentist	4	3

Long-term outcomes and impacts

In the literature review, the researchers proposed that the long-term outcome was that (i) OP would have a personalized care plan. In the first workshop, as the second long-term outcome, the participants added (ii) OP would improve in ICOPE dimensions. Concerning the impacts in the literature review, three impacts were established, and through the workshops, those remained as (i) preventing, reversing, or delaying the loss of intrinsic capacity (IC), (ii) improve the quality of life of OP, and (iii) raising disability-free life expectancy. The HCWs expressed concerns about the long-term outcomes and impacts. The main concern was the lack of a guideline that specifies (a) how to prioritize the treatments needed for OP with deficits of one or more dimensions, (b) how to reference OP needing to visit the geriatric clinic, and (c) the referral and back-referral mechanisms for OP between all the HCWs. To help tackle these concerns, the stakeholders in the last redefinition of the ToC proposed using a procedural manual and mobile app to conduct the follow-up. An additional concern was related to the feasibility of the defined impacts, as for some HCWs, only some of the dimensions of the ICOPE would produce a change.

The positive changes in all the workshops were that using the ICOPE approach would positively impact the daily work of the HCWs. The stakeholders and HCWs identified the need for

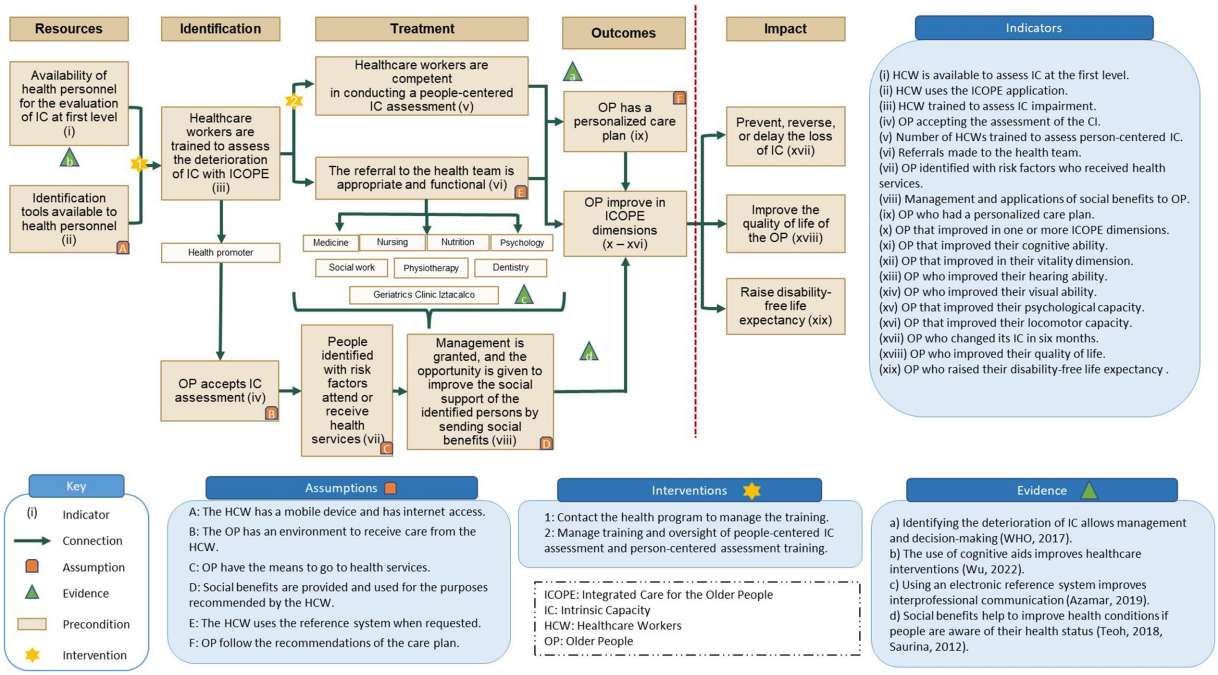

FIGURE 1
Theory of Change of the Integrated Care for Older People in Salud en tu Casa.

interventions and several preconditions to achieve long-term outcomes and contribute to the impacts.

Narrative of the ToC

The expected long-term outcomes are that (i) OP have personalized care plans and (ii) they improve in the ICOPE dimensions; the expected impact is the improvement in IC (17, 18). The outcomes imply that OP will change their health-related behaviors based on the recommendations of their personalized care plans. This outcome will modify some of the IC's dimensions, e.g., improving their locomotion by using or receiving mobility aids, such as a cane. The long-term outcome indicators are time constrained and depend on the behavior of OP.

Interventions

The first intervention marked in Figure 1 as a star is the reach of the health program to manage the training. Before the first interventions and to activate the causal pathway of the ToC program, two preconditions are required: (1) availability of health personnel for the evaluation of IC at the first level and (2) availability of identification tools to health personnel. The second precondition assumes that the HCWs have access to an internet connection and a mobile device. As a rationale, there is evidence that using cognitive aids improves healthcare interventions (19). The indicators of both preconditions are that (i) a HCW is available to assess IC at the first level and (ii) a HCW uses the ICOPE application.

The second intervention is managing training and the supervision of people-centered IC and person-centered assessment training. The preconditions before this intervention were that (3) healthcare workers were trained to assess the deterioration of IC with ICOPE and (4) OP would accept IC assessment. The fourth precondition assumes that OP have an environment to receive care from HCWs. During the third workshop, the health promoters mentioned that OP sometimes need a proper place to receive healthcare in their residences.

Furthermore, in the workshop, they proposed explicitly identifying within the causal pathway the composition of the team responsible for providing healthcare at the different levels of diagnosis and treatment. The indicators for these preconditions are that (iii) HCW are trained to assess IC impairment and (iv) OP accept the assessment of the CI.

At the "Treatment" level, the preconditions are that (5) healthcare workers are competent in conducting a people-centered IC assessment, (6) the referral to the health team is done appropriately and functionally, (7) people identified with risk factors attend or receive health services, and (8) management and opportunity are given to improve the social support of the identified persons by sending them social benefits. The referral system's precondition depends on using the existing system when requested. This assumption was discussed during the third workshop by the HCWs, who expressed concerns about the reference system's lack of supervision. The rationale for using an electronic reference system is the evidence supporting its use to increase interprofessional communication and leadership (20). The sixth and seventh preconditions assume that the other social programs offered to OP are used for the purposes recommended by HCWs and that OP have the means to attend health services. The stakeholders discussed these preconditions in the second workshop; the central comment was the motivation of HCWs to provide care and of OP to

use the available resources to improve their health. The rationale is that social benefits improve health conditions if individuals know their health status (21, 22). The indicators for the preconditions were (v) the number of HCWs trained to assess person-centered IC, (vi) referrals made to the health team, (vii) OP identified with risk factors who received health services, and (viii) management and applications of social benefits to OP.

Discussion

By evaluating the design of ICOPE for its implementation in Mexico City using a Theory of Change approach, we have produced a change model that could contribute to the wellbeing of OP if implemented accordingly.

During this evaluation, we identified a set of attributes required to strengthen the design of ICOPE. Our refined ToC has the potential to achieve the expected outcomes of ICOPE in Iztacalco. It describes the required interaction between HCWs and OP in Iztacalco and explicitly states that both the demand and supply sides are needed to achieve ICOPE's goals (12, 23–27).

Using an evaluative approach, we were able to identify a feasible pathway in the Iztacalco context of *Salud en Tu Casa* to reach the long-term outcomes that are expected to ultimately contribute to (1) reversing, preventing, or delaying the loss of IC, (2) improving the quality of life of OP, and (3) raising disability-free life expectancy. Drafting the validated ToC was possible through a participatory process with key stakeholders and the HCWs that critically discussed the intermediate outcomes, assumptions, and rationale for ICOPE, with similar results reported by the WHO in their ready phase study (28).

The ToC consists of four significant levels, namely, resources, identification, treatment, and long-term outcomes, to activate the causal pathway. The identification and treatment levels are equivalent to the activities reported in other ToC developments (11). These involve the essential activities proposed by the WHO implementation framework (4, 29). The causal pathway explicitly articulates how the community healthcare program would provide care to OP to achieve sustainable change (30). One of the examples was that the external stakeholders identified the social benefits that OP could benefit from at the treatment level with less caregiver support.

During the workshops, the HCWs discussed the likelihood of implementing ICOPE within Salud en tu Casa with the ToC and redefined their daily work. They also discussed and agreed on some of the resources needed for the operation of the ToC, like other studies (28, 31). As previously discussed, resource constraints have been a significant barrier to improving healthcare services in Mexico and lower-middle-income countries (LMIC) (2). Moreover, the accomplishment of the preconditions could increase the motivation of HCWs and enhance their delivery of quality care. ICOPE, as operationalized in the developed ToC, relies on the available resources for a community-based health program already operating in Mexico City, which is feasible. At the resources level, using a mobile app to run the ICOPE approach has presented several benefits (32–34). The discussions with stakeholders in the redefinition stage were valuable in overseeing the barriers mentioned in the previous workshops. For example, the directors must supervise the health promoter using the screening evaluation guide (9). In addition, we established the necessity of giving the promoters headphones to apply the audition test carefully. The screening tool used in ICOPE had good sensitivity but depended on the training (35), so the directors recognized the necessity of the continuous training of HCWs. A key element for the success of new interventions is to ensure the buy-in from the relevant stakeholders (36); the participatory process used in evaluating and refining the ToC contributes to this by generating a sense of ownership of the approach. At the ToC treatment level, the healthcare program has all the disciplines of the six domains for the ICOPE approach. The main barrier discussed was integrating the services between the levels of care and the system to collect the indicators' data (the community health program and the geriatrics clinic). The proposal of a straightforward approach in the ToC and improved communication with a mobile application could guide the clinical pathway to provide health services for older adults. Using an electronic referral system improves interprofessional communication and services (20).

Conclusion

The long-term outcomes of the ToC regarding IC were coherent with the ICOPE program goal of healthy aging. After evaluating its design and further refinement of its ToC, ICOPE implementation in a community healthcare program has been shown to be promising and feasible. The results could contribute to monitoring the trajectory of IC and its domains. The specific interventions of the model were found to be possible to implement by the relevant stakeholders and personnel in charge of the operation. The design evaluation of ICOPE in the community healthcare program showed evidence of validity for improving clinical care management for OP. This strategy for implementing ICOPE has the potential to be applied in similar contexts, for example, other LMICs.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Ethics Committee and Institutional Review Board of the Masters and Doctorate Program in Medical, Dental, and Health Sciences, the National Autonomous University of Mexico Program. The patients/participants provided their written informed consent to participate in this study.

Author contributions

SEG-B and JP-G: conceptualization, study design, data interpretation, original draft preparation, project administration, reviewing, and editing. ES-T and AA-A: data acquisition, interpretation, original draft preparation, project administration, and reviewing. OR-C and ZD-N: data acquisition, interpretation, original draft preparation, reviewing, and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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A comparative study for accessing primary healthcare between planning assessment and actual utilization for older adults: a case from Dalian City, China

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Introduction: As China has rapidly evolved into an aging society, the Chinese government has developed a community-oriented primary healthcare system to vigorously expedite the transfer of primary health care (PHC) from higher-level hospitals to community health centers (CHCs). However, current planning standards for CHCs have not considered the heterogeneity of older adults in supply-demand services, such that the areas with severe aging may comprise of underestimated levels of accessibility.

Methods: This study focuses on the gap in PHC access between planning assessment and actual utilization for older adults. We conducted an empirical study in the city area of Dalian based on the check-in and survey data from CHCs during the COVID-19 pandemic. A comparison model was built to calculate matching probability using a modified Gaussian Two-Step Floating Catchment Area (G2SFCA) method.

Results: As indicated by the results, the communities in the primary healthcare shortage area (PHCSA) increased 6.8% by considering the heterogeneity of older adults; these communities with underserved PHC were ignored by the current planning assessment. Based on the comparison of actual and theoretical accessibility for older adults, we found that the average matching probability was about 76.6%, which means approximately a quarter of older adults have been misestimated the accessibility of PHC.

Discussion: Further analysis for the older adults with mismatched accessibility showed two causes of the gap, one is the lack of connection between the spatial distribution of facilities and the allocation of service supply, and the other is the subjective cross-catchment visit to CHCs for older adults.

KEYWORDS

healthy aging, community-oriented, primary health care, accessibility, planning assessment

1. Introduction

The unprecedented challenge for China's public healthcare in the 21st century is the increasingly aging population (1). According to the Seventh National Population Census (2), China has over 2.64 billion adults aged over 60 years (3), representing nearly 18.7% of the total population (4). This number is predicted to reach over 30% by 2050, which means that the population will enter an advanced stage of aging (5). The pronounced consequences in the wake of the fast-aging society involve surges in the prevalence of chronic non-communicable diseases (CNCDs) and the elevated risk of death from infectious diseases (6). As indicated by the data originating from the Global Burden of Diseases, Injuries, and

Risk Factors Study (GBD) 2017, CNCDs have already been the leading cause of death in China (nearly 86.6% by population) (7). Moreover, the prevalence of CNCDs in people aged over 60 years is as high as 76%, which is much higher than people aged between 15 and 64 years (52%) (8, 9). Based on early tracking data during the COVID-19 pandemic in China, the fatality ratio (CFR) increased with age, from 0.4 % or lower in patients aged 40 years or younger but 3.6 % in patients aged over 60 years (10), and over 80% of deaths are among older adults (11). The above data fully reveal the vulnerability of older adults to health risks. In order to respond to the social structure of population aging, a powerful primary healthcare (PHC) system is regarded as the key to solving the aging problem (12–14).

Back in 1978, the declaration of Alma-Ata defined PHC as the first level of contact of healthcare services (15) that which should be provided as close as possible to where people live and work (16). In most countries, PHC is primarily provided by community hospitals, clinics, and general practitioners (GPs) (17). By contrast, the PHC service in China has long been provided by high-level general hospitals (GHs) instead of community health facilities (18, 19). As societies age, China soon realized that the current hospital-centric delivery system was costly and did not serve the changing needs of the aging population, which is undergoing an epidemiological transition (20). Thus, China started a new health reform in 2009 to build a community-oriented PHC system that aims to prevent and manage chronic diseases and infectious diseases, supporting a healthy aging society. In the past decade, the government has increased funding 10-fold in community settings (20, 21); as Figure 1 shows, this promoted a transfer of PHC from GHs to community health centers and their subordinate stations (CHCs) (22). CHCs have become the core facilities of PHC, mainly providing prevention, early diagnosis, treatment, and rehabilitation (23).

The planning of CHCs, as the key part of the Urban Healthcare Facilities Plan, is established together by the regional public health department and urban planning commission, and the purpose is to facilitate the equalization of PHC and enhance the coping ability of the major epidemic and public health security events (23, 24). Figure 2 illustrates the planning process of CHCs, which includes four steps. The first step is to define the CHCs' allocation following the supply–demand equilibrium. The supply–demand scale is determined by a quantitative target of local health needs and the population size of health service zoning, including primary care physicians (PCPs) and beds per 1,000 of the population. The second step is to select the candidate locations based on the traffic and land use. The catchment area is set to a time threshold that meets the range of neighborhood living circle to ensure residents can access CHCs within a walkable distance, i.e., 15 min in urban areas, 20 min in remote plains, and 30 min in mountain areas (25, 26). The third step is to design the construction or re-construction scheme of CHCs. In general, it cooperates with the new community development or the old community transformation. In the last step, to ensure the rationality and equity of the CHC planning process, the local government will revise the plan (every 5 years) to identify the primary healthcare shortage area (PHCSA) by examining the accessibility of CHCs.

Although the current planning plays a positive role in ensuring that residents can access adequate PHC services, it has still been doubted and criticized by people because a gap exists in the results between theoretical assessment and actual utilization (14), notably for older adults (25). A limitation of the current planning is that the planning assessment using subdistricts (administrative districts) as assessment units (AUs) remains a macro-scale scheme (urban or region area scale), and there has rarely been detailed data and empirical research at the micro-scale (community scale) to validate the results. Another important limitation is that the planning standards did not consider the demographic heterogeneity in service needs. Specifically, the 2-week visiting rate in older adults was ∼2.5 times the average (8). Relative to younger adults, older adults are more dependent on the community settings (27, 28) due to poorer health status and limited mobility options (e.g., walking difficulties and driving restrictions) (29). Research by Liu et al. indicated that the acceptable distance for older adults in seeking PHC was 200–600 m, and 800 m is a walking limit, which is far lower than general capabilities (30). As a logical consequence, the current planning, which defined the catchment and population sizes of CHCs based on general walkable distance and indistinctive-age population, may cause the misestimation of PHC accessibility in the areas with a high aging rate.

Based on the above inference, we searched parallel literature and found that most studies that have explored the gap in healthcare between potential access (supply) and realized access (utilization) focus on a large scale (city, county, or village scale) (31–33). In China, the restricting factor could be linked to the uncompleted constructed database at the community level and undisclosed information of CHCs (private or public–private partnership). Fortunately, closed-off management of CHCs provided a good opportunity for investigation during the COVID-19 pandemic such that our research could narrow the scale of assessment to explore the gap in PHC access between planning assessment and actual utilization for older adults. Ultimately, the aim of this study was to improve the problems of current planning and re-define the PHCSA in an aging society. Based on the data from a CHC survey in Dalian and the geographic data of PCPs, the theoretical and practical accessibility for older adults from communities with different aging levels was measured, and we identified which communities have misestimated accessibility, specifically including two aspects as follows.

(1) Whether a gap exists between the theoretical accessibility in planning assessment and the practical accessibility in real-world utilization.

(2) Whether there is a gap in accessing CHC services between the communities with different aging levels.

2. Methodology

2.1. Study area

The empirical survey for this study was conducted in the city area of Dalian, located in the northeast peninsula of China (Figure 3). Dalian represents a unique geographic and societal setting for the research on access to PHC with the background of the aging population. Dalian has a population of more than 450,000 older adults. The aging rate of Dalian reached 24.7% in 2020 (34), which means that society has entered an advanced stage of aging. In addition, the city area of Dalian is composed of gentle slope hills and mountains such that residents mostly rely on walking for

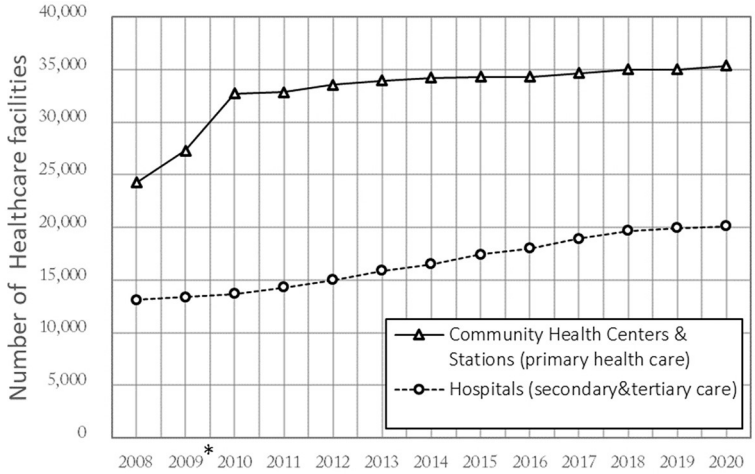

FIGURE 1
Number of healthcare facilities in China 2008–2020. *The Chinese government conducted a reform in 2009 that transferred "City-District-Street" 3-level to "City-Community" 2-level.

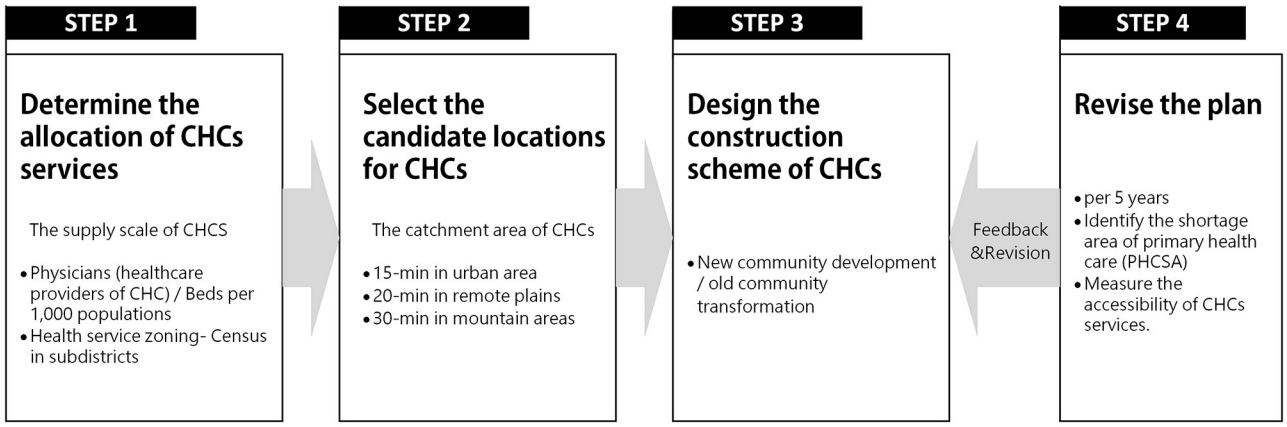

FIGURE 2
CHC planning process and standards.

short-distance travel rather than using bicycles or electric vehicles. Thus, Dalian can serve as a typical study case to assess PHC based on a pedestrian neighborhood network, and it can also provide references for other cities in which society is at an early stage of aging. Following the planning scope of the Dalian Regional Healthcare Plan (2016–2020) (30), the study area for this study was five administrative districts (i.e., Zhongshan, Xigang, Shahekou, Ganjingzi, and Gaoxinyuan districts), including 1,359 communities and 95 CHCs (Figure 4).

2.2. Data and pre-processing

The data of this study were collected from the related official information and questionnaire surveys. Data from the statistical department of the Dalian Health Commission and Dalian Planning Board were highly conducive to this study. The spatial location and basic supply of CHCs presented in Figure 5 were based on Dalian Health Statistics in 2022. Moreover, the spatial distribution of the community older adults presented in Figure 6 was obtained and then determined based on the Seventh National Population Census taken in Dalian. Furthermore, the pedestrian network adopted to measure accessibility was developed based on a revised line file provided by the Dalian Municipal Transportation Bureau. Since the original government data comprised a motor vehicle network at the city scale, the data were supplemented with more detailed internal roads in the neighborhood environment based on the satellite imagery from Baidu Maps.

The questionnaire was conducted from 18 to 20 April 2021 with the support of the administrators of public CHCs. We selected 18 CHCs that were allowed to survey based on the supply–demand ratio (Rj) for the older adults (High-Rj, Middle-Rj, and Low-Rj), including 938 older adults (aged over 60 years). During the COVID-19 epidemic period, all visitors to CHCs were asked to register their identifiable information (e.g., home address and personal identity). Accordingly, after asking respondents for permissions, we obtained their registered information and questionnaire results. All respondents were

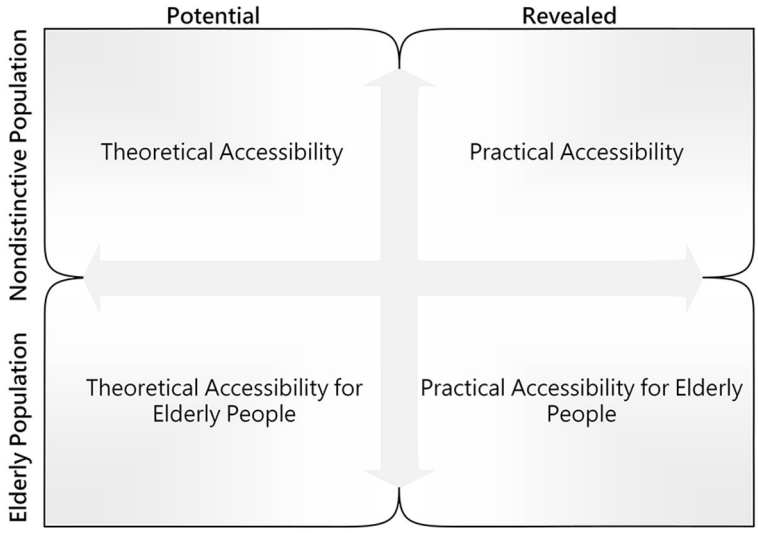

FIGURE 3
Comparison framework for accessibility.

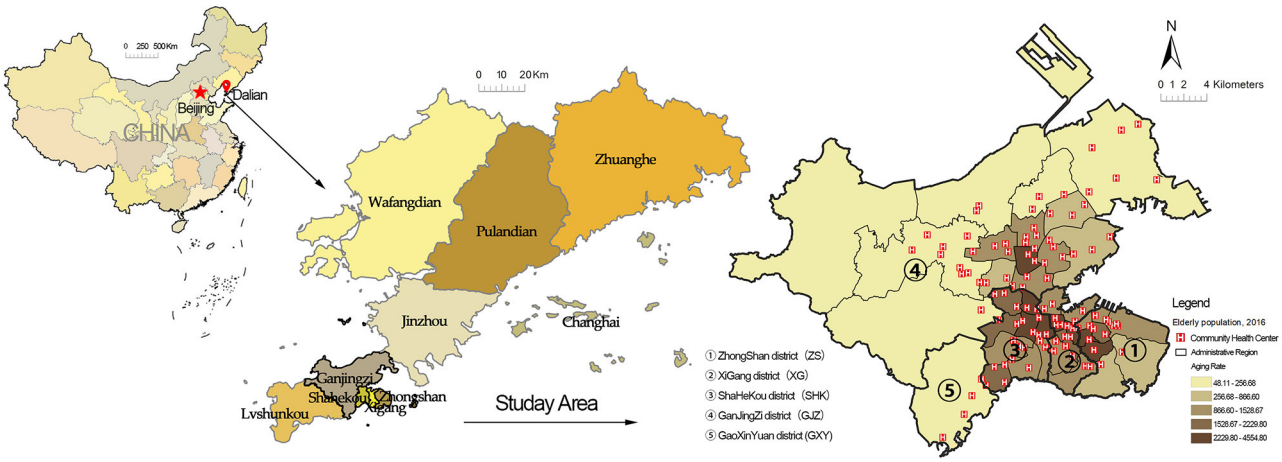

FIGURE 4
Location, aging rate, and community health center distribution of the study area. *The distribution of older adults (aged over 60 years) is based on the 2021 population census.

voluntary and were informed of the investigation objective. Their privacy is strictly protected.

Table 1 lists the descriptive statistics of respondents. The variables that represent the social characteristics of older adult patients are categorized into four dimensions, namely demographic characteristics, socioeconomic status, health condition, and service utilization. The first dimension reflects the aging level and composition. As Table 1 shows, the proportion of older men (46.38%) and women (53.62%) is relatively even. The old-old (aged 75–89, WHO) makes up about a fifth of the older adults, and the rest is the young-old (aged 60–74, WHO). The second dimension is the annual income of older adults, which has been proven to be an important socioeconomic constraint in health access (27). The third dimension is older adults' health conditions, including chronic diseases, long-term disease, and postoperative care, which indirectly reflects their pressing needs for PHC. For example, almost all have chronic diseases, more than half have long-term disease, and a third need postoperative care. Finally, the last dimension is the service utilization for older adults, including the visit frequency, travel time, and average access time. This directly reflects older adults' needs for CHC services; for example, 55.02% of older adults' access to CHC is beyond the preset time threshold of planning, and the old-old in poor health seldom visit CHC. To sum up, the results for the preliminary processing of survey data confirmed our suspicions that older adults have more difficulty accessing PHC in practice.

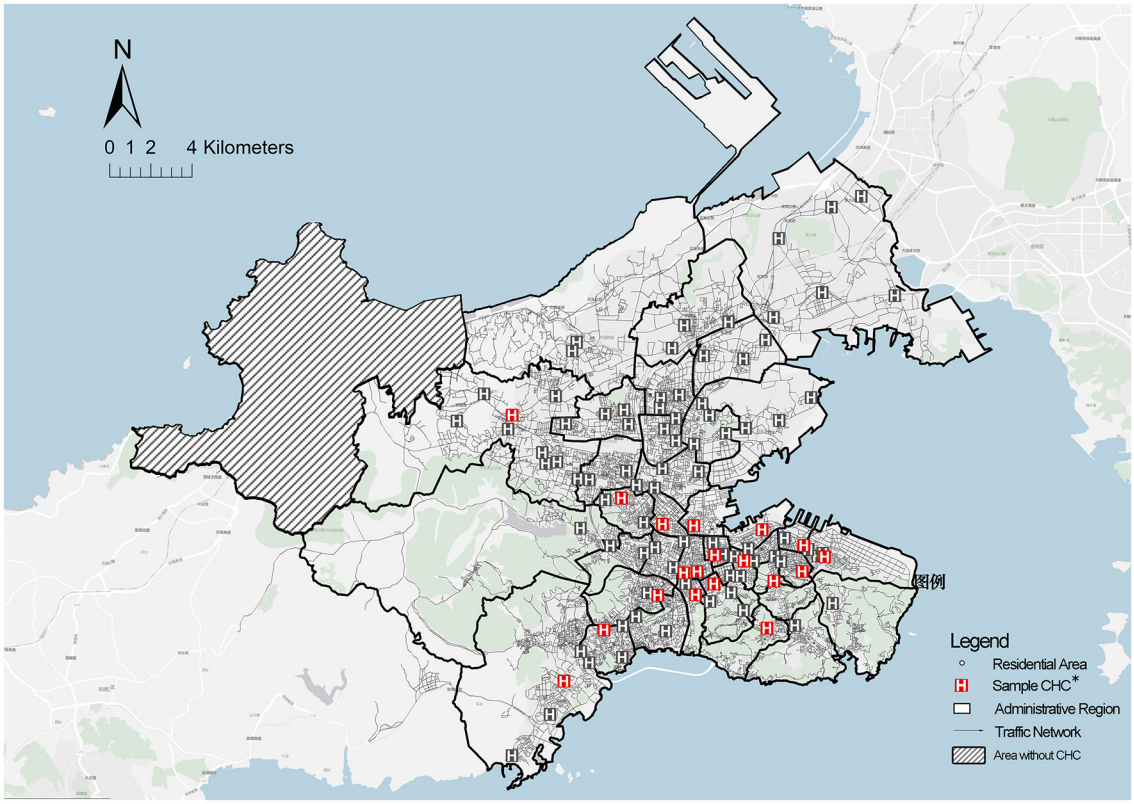

FIGURE 5
Spatial distribution of older adults at the community scale. *Community = 1,359. Data from the Seventh Population Census of Dalian.

2.3. Measurement for the accessibility of PHC

As GIS-based spatial measurement models developed more practically (14), accessibility becomes the main basis to quantitatively assess the spatial equity and allocation rationality of public healthcare resources in urban planning, which is an aggregative index considering geographic locations and the demand–supply equilibrium distribution (35, 36). For the associated measurement methods, the series of two-step floating catchment area (2SFCA) method (37), provided by Luo et al. following the Floating Catchment Area (FCA) method, has been most extensively employed (38). The accessibility in the 2SFCA method was defined as a ratio of population to providers in the predefined health service and the population catchments (39). Furthermore, given the multi-modal traffic (40) and the diversity demand from subpopulation (39, 41), the extension models of 2SFCA (e.g., E2SFCA, KD2SFCA, 3SFCA, and i2SFCA) (36, 42–45) further improved the demand-supply scales and interaction (46) to match the real-world applications.

For high-level health services, PHC has different supply and demand sizes in accessibility measurement. First, the population size was generally smaller than 30 km, which was originally proposed by Luo et al. (47, 48) [e.g., 3 km catchment for general practitioners (GPs) in Canada (49), 4 km catchment for GPs in New Zealand (50), and population grid cell at 250 × 250 resolution in Finland (51)]. Given the population attribute, Lan et al. modeled a requirement difference among the population in ages by introducing a demand weight index (39). Second, the catchment area was calculated according to pedestrian and public transport networks instead of motor traffic networks (52). Yu et al. demonstrated the differences in healthcare accessibility measured based on the pedestrian network and motor traffic network in Shenzhen China, and they used the Delaunay triangulation skeleton model to simulate the intra-community street network that provided positive reference to our study (53). Related to the age-appropriate studies, the travel mode of older adults was considered in defining the pharmacy catchment, such as a 10-min walk or 15 min by mixed transport (54). Moreover, older adults' travel behavior was more widely considered in calculating the probability of subjective choice (39). Moreover, the reference of most significance for our study was from Di et al., where they established an indicator system to assess the spatial equity of community care services for older adults. To be specific, the accessibility of older adults was divided to three dimensions, including potential accessibility, realized accessibility, and sustainable accessibility (55).

Following the accessibility concepts proposed by Khan et al. (56) and the analytical framework for older adults accessing community care from Di et al. (55), the accessibility in this study was expressed as two dimensions and then compared horizontally and vertically. Figure 3 presents the comparison framework for

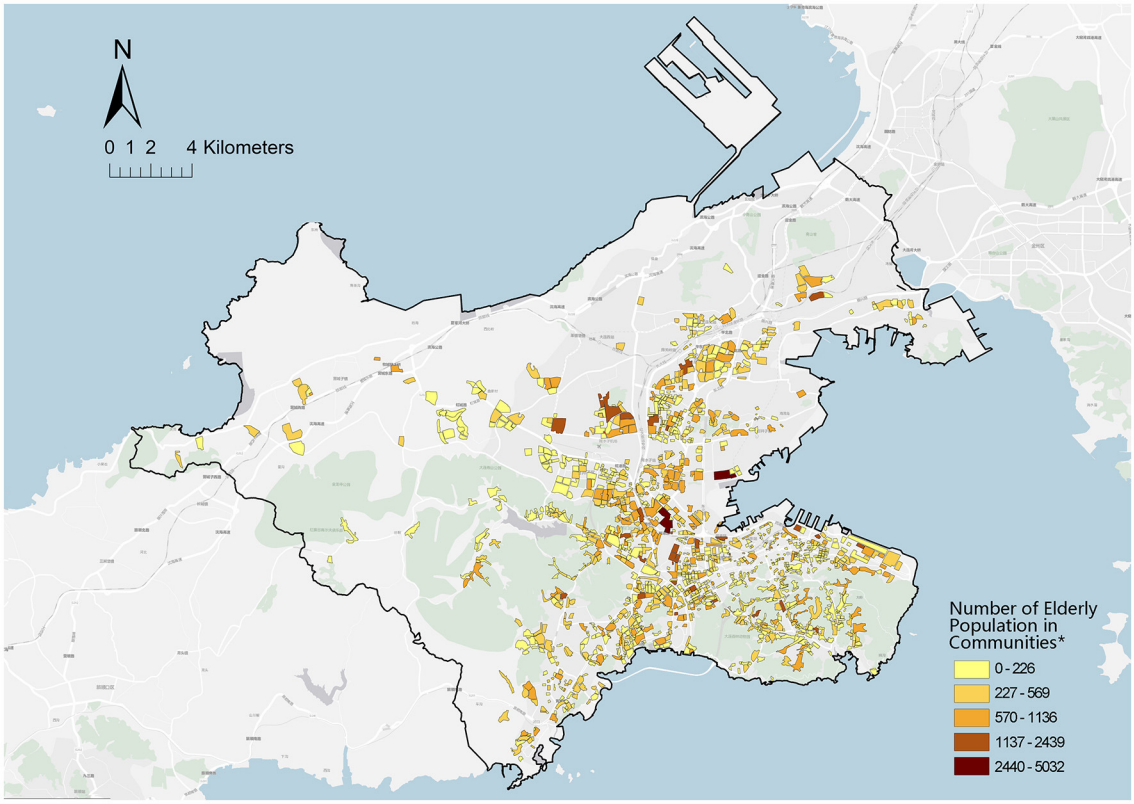

FIGURE 6
Spatial distribution of community health centers. *CHCs = 95 (including 22 CHSs); Sampled CHCs = 18; Data from Dalian Health Agency and Municipal Transportation Bureau.

accessibility. A modified Gaussian 2SFCA method was employed for accessibility measurement. Compared with other distance decay functions, the Gaussian function declined at a slower rate close to the origin, such that it was adopted to express the impedance factor for a short-distance journey. Furthermore, a comparison model was developed to determine the matching probability between theoretical accessibility and practical accessibility for older adults. The specific calculation steps are elucidated as follows:

Step 1: Defining the demand variance index. In this study, we set this index based on the prevalence rate of NCD patients for different ages rather than the common weight value (3–5) in existing research (57). First, the proportion of older adult patients ($\boldsymbol{D}_k$) is calculated by the following equation:

$$D_k = \frac{V_{old} \times D_{old}}{D_{all}} \quad (1)$$

where $\boldsymbol{D}_{all}$ denotes the total patients of NCD; $\boldsymbol{D}_{old}$ is older adults, and $\boldsymbol{V}_{old}$ is the average NCD prevalence rate of older adults aged over 60 years. The population demand $\boldsymbol{P}_k$ is revised as follows:

$$P_k = P_{kall} + (DW - 1)P_{kold} = P_{kall} + \left(\frac{D_k}{1 - D_k} - 1\right) P_{kold} \quad (2)$$

where $\boldsymbol{P}_{kall}$ denotes the population of location $\boldsymbol{k}$; $\boldsymbol{P}_{kold}$ is older adults of location $\boldsymbol{k}$; and $\boldsymbol{DW}$ is the demand weight index and set to 1.94 following function (1).

Step 2: Computing the supply–demand ratio $\boldsymbol{R}_j$, which is the ratio of service supply to all demand in the catchment area.

$$R_j = \frac{S_j}{\sum_{k \in \{t_{kj} \le t_0\}} P_k f(t_{jk})} \quad (3)$$

where $\mathbf{S}_j$ denotes the service supply capacity of CHC $\boldsymbol{j}$ $\boldsymbol{(j = 1,\ldots,95)}$; $\boldsymbol{P}_k$ represents the total population demand of community $\boldsymbol{k}$ $\boldsymbol{(k = 1,\ldots, n)}$ in the catchment area $\boldsymbol{j}$; $\boldsymbol{t}_{kj}$ expresses the travel time between $\boldsymbol{j}$ and $\boldsymbol{k}$; $\boldsymbol{t}_0$represents the time threshold specified by the standard (23, 30, 58); and $\boldsymbol{F(t_{jk})}$ $\boldsymbol{(t_{jk} \le t_0,\ t_0 = 30min)}$ is the impedance function in a walkable distance.

$$f(t_{jk}) = \begin{cases} 1, & t_{ij} \le 15 \\ \dfrac{e^{-\frac{1}{2} \times \left(\frac{t_{jk}}{t_0}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}}, & 15 < t_{jk} \le t_0 \\ 0, & t_{jk} > t_0 \end{cases} \quad (4)$$

where t_{ij} represents the potential access time from community $\boldsymbol{i}$ to CHC $\boldsymbol{j}$, which is computed by the average pace of adults in general (90m/min) and older

TABLE 1 Descriptive statistics of individual characteristics ($N = 938$).

	Variable	N	%		Variable	N	%
Demographic characteristics	Gender			Health condition	Physical health		
	Women	503	53.62		Very bad	29	3.09
	Men	435	46.38		Bad	181	19.3
	Age				Average	480	51.17
	60–65	146	15.57		Good	224	23.88
	65–70	292	31.13		Very good	24	2.56
	70–75	310	33.05		**Long-term diseases**		
	75–80	130	13.86		Not have	396	42.22
	Above 80	60	6.4		Have	542	57.78
Socioeconomic status	Annual income				Chronic diseases		
	<RMB¥ 10,000	43	4.58		Cardiovascular disease	316	33.69
	RMB¥ 10,000–30,000	241	25.69		Mental health issues	56	5.97
	RMB¥ 30,000–80,000	455	48.51		Osteoporosis	231	24.63
	RMB¥ 80,000–300,000	184	19.62		Hypertension	550	58.64
	Above RMB¥ 300,000	15	1.6		Diabetes	369	39.34
Primary care of service utilization	**Frequency**		None	2	0.21		
	Almost every day	35	3.73		**Postoperative care**		
	5–10 times/month	183	19.51		No need	646	68.87
	3–5 times/month	388	41.36		Need	292	31.13
	Very seldom (>3/mo)	332	35.39				
	Travel time						
	<15 min	421	44.88				
	15–20 min	285	30.38				
	20–30 min	179	19.08				
	Above 30 min	53	5.65				
	Average access time						
	<10 min	53	5.65				
	<15 min	497	52.99				
	<20 min	883	94.14				
	<30 min	938	100.00				

*Sample older adults = 938; sample CHCs = 18.

adults (58m/min) (54), and the initial impedance with no decay is set to 15 min following the planning standard (23, 25).

Step 3: Computing the accessibility for community ***i (i=1,...,1359)*** accessing CHC services in the catchment area A_i^F.

$$A_i^F = \sum_{j \in t_0} R_j f(t_{ij}) \tag{5}$$

where t_{ij} denotes the access time from Community ***i (i=1,...,1359)*** to CHC ***j (j=1,...,95)***.

Step 4: Using the comparison model to calculate the matching probability, which estimated the matches between potential access time and perceived travel time.

$$E_t = \frac{\sum_{t \in \{t_r \le t_i\}} f_{t_r}}{f_j} \tag{6}$$

where $\mathbf{E_t}$ denotes the matching probability between theoretical accessibility and practical accessibility; t_r represents the travel time of older adults, including four time segments (i.e., 0–15, 16–20, 21–30, and above 30); t_i expresses the potential access time, which is the average value of communities in the catchment area; $\mathbf{f}_j$ denotes the sampled older adults of the respective CHC, which is derived from 2% of older adults in the catchment area; $\mathbf{f}_{t_r}$ represents statistics

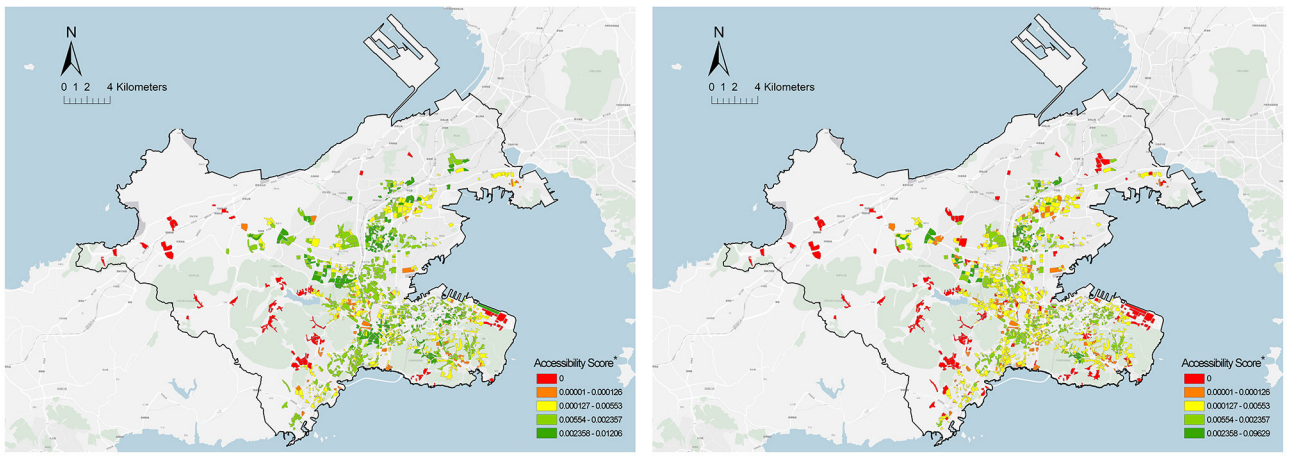

FIGURE 7
Spatial distribution of theoretical accessibility of PHC at a community scale. **(A)** All populations. **(B)** Older adult population. *Community health center = 95; Community = 1,359.

matching t_i, suggesting that the time segment is not consistent with access time as the two-dimensional judgment function.

$$f_{t_r} = \begin{cases} 1, if\ t_r \leq t_i \\ 0, if\ t_r > t_i \end{cases} \quad (7)$$

where f_{t_r} denotes a binary variable; $f_{t_r} = 1$ represents two variables that are matching each other; and $f_{t_r} = 0$ if they do not.

TABLE 2 Results of the paired samples of the Wilcoxon test.

Variable	SD	Z	P	S-W	Cohen's d
Ai_pop	0.001	-	-	-	-
Ai_popold	0.001	-	-	-	-
Matches	0.001	23.052	0.000*	0.754 (0.000*)	0.763

*p < 0.001. Ai_pop is the accessibility score for all populations. Ai_popold is the accessibility score for the older adult population. Cohen's d indicates the effectiveness of difference; <0.20 is a too-small effect, 0.20–0.50 is a small effect, 0.50–0.80 is a larger effect, and above 0.80 is a large effect.

3. Results

3.1. Comparison of two theoretical accessibility

To prove that the current planning assessment using a non-distinct population age may cause a gap in accessibility measurement, the results of two theoretical accessibilities that were measured based on all populations and the older adults population were first compared, respectively. Figure 7 presents the spatial distribution of two theoretical accessibility at a community scale. The accessibility score fell into five grades (None, Low, Middle, High, and Very High) by using a natural break method (59). Furthermore, the rank of accessibility score from high to low is displayed as colors from cool to warm (red to green). The red blocks represent the communities in the PHCSA, i.e., residents' access to CHC services in the time threshold of planning standards.

The potential access time for all populations was <15 min, whereas it was nearly 23 min for the older adults population, far beyond the time threshold of the planning standard. In addition, the comparison of communities suggested that the proportion of communities with good accessibility (High level and Very High level) for the older adults population declined by 26% (61.7%−35.2%) relative to all populations, and the proportion of communities in the PHCSA increased by 6.8% (7.5%−14.3%). Notably, most communities with lower accessibility scores were distributed in the fringe areas surrounded by mountains, such that a poor pedestrian neighborhood environment was generally created (e.g., more ramps and long paths). Lastly, the degree of difference between the two theoretical accessibility was investigated. Both theoretical accessibilities displayed non-normal distributions, which were dependent on the result of the Shapiro–Wilk test. Thus, the degree of difference was obtained by paired samples of the Wilcoxon test. As depicted in Table 2, there was a significant gap between the two theoretical accessibilities ($p < 0.001$), and Cohen's d value indicated a moderate degree of difference (60).

3.2. Comparison of practical and theoretical accessibility

Based on the survey data of CHC services, we further compared the theoretical and practical accessibility for older adults. Table 3 shows the statistical results of the matching probability (E_t) for older adults in the survey. The average matching probability (Et) was 76.6%, meaning that approximately a quarter of older adults experience a misestimated accessibility for PHC. In the association analysis between Et and the variables from the planning standards, we found six variables associated with matching probability ($p < 0.01$), namely actual travel time, potential access time, visit

TABLE 3 Results of the matching probability (E_t) in the survey.

Variable	E_t	X^2	*p*	Variable	E_t	X^2	*p*
Gender				Physical health			
Women	76.14%	0.082	0.716	Very bad	86.21%	6.918	0.140
Men	77.01%			Bad	77.35%		
Age				Average	75.42%		
60–65	74.66%	2.390	0.664	Good	58.33%		
65–70	77.05%			Very good	79.02%		
70–75	77.69%			**Long-term diseases**			
75–80	83.33%			Not have	78.28%	0.939	0.295
Above 80	76.55%			Have	75.28%		
Annual income				**Chronic diseases**			
<RMB¥ 10,000	60.47%	11.804	0.019*	Cardiovascular disease	76.47%	71.374	0.000**
RMB¥ 10,000–30,000	73.86%			Sub-optimal mental health	58.93%		
RMB¥ 30,000–80,000	77.36%			Osteoporosis	82.68%		
RMB¥ 80,000–300,000	66.67%			Hypertension	76.00%		
Above RMB¥ 300,000	82.61%			Diabetes	70.28%		
Frequency				None	75.36%		
Almost every day	80.00%	26.643	0.000**	**Postoperative care**			
5–10 times/month	68.31%			No need	80.03%	13.457	0.000**
3–5 times/month	72.16%			Need	68.84%		
Very Seldom (>3/mo)	85.84%						
Travel time							
<15 min	100.00%	523.262	0.000**				
15–20 min	84.91%						
20–30 min	30.73%						
Above 30 min	0.00%						
Average access time							
<10 min	50.94%	17.273	0.002**				
<15 min	66.80%						
<20 min	75.09%						
<30 min	76.55%						

Sample size = 938. E_t is the matching probability. *$p < 0.05$, **$p < 0.01$.

frequency, long-term diseases, chronic diseases, and postoperative care. The result was discussed in the following four aspects: (1) demographic characteristics (age and gender) have no associations with Et ($p > 0.05$); (2) economic status (physical health) has a positive association with Et ($p<0.05$), which shows the number of matches in the lowest income group is significantly less than in other groups; (3) health conditions (chronic diseases and postoperative care) were negatively associated with Et ($p < 0.001$), and it is worth noting that the older adults who already suffer from mental health issues has the lowest Et (60%) among all chronic diseases; (4) service utilization (visit frequency, actual travel time, and potential access time) was significantly associated with Et ($p<0.001$). The most interesting thing we found was that Et declined to 31% when older adults' actual travel time was beyond 20 min, whereas their potential access time showed good matching on the whole.

Subsequently, we explored the endogenous association between the matching probability (Et) and six associative variables. Table 4 lists the results of the Pearson correlation analysis. As indicated by the result, Et was negatively correlated with the actual travel time for older adults, whereas it was positively correlated with their potential access time, suggesting that long travel times in actual utilization and the short-distance access in planning assessment can contribute to the mismatch between practical and theoretical accessibility. Moreover, we noted that the supply and demand ratio (Rj) negatively correlated with Et, but it was not correlated with the

TABLE 4 Pearson's correlation analysis of two accessibility and matching probability.

Accessibility	Correlation coefficient	Matching probability (Et)	Travel time	Average access time
Practical accessibility	Age	0.019	−0.011	0.110**
	Annual income	0.014	0.001	0.176**
	Frequency	−0.152**	0.149**	0.072**
	Health condition	0.016	−0.031	−0.189**
	Postoperative care	−0.122**	0.166**	0.034
	Chronic diseases	−0.035	0.074**	0.102**
	Travel time	−0.717**	-	0.128**
Theoretical accessibility	Supply–demand ratio (Rj)	−0.351**	0.304**	0.005
	Potential access time	0.231**	0.128**	-
	Matching probability	-	−0.717**	0.231**

*p < 0.05, **p < 0.01.

TABLE 5 Correlation analysis of the proportion of cross-catchment visits (x) and matching probability (y).

	Non-standardized coefficients		Standardized coefficients	*t*	*P*	VIF	R^2	F
	b	SE	Beta					
E_t	0.882	0.038	-	23.303	0.000**	-	0.904	$F_{(1,17)} = 159.192$, $p = 0.000$
	−0.853	0.068	−0.921	−12.617	0.000**	1.000		

Sample size = 938. The proportion of cross-catchment visits (x). Et is the matching probability (y). *p < 0.05, **p < 0.01.

potential access time of older adults. This illustrated that there was a lack of links between the spatial distribution and service allocation of CHCs, which may also contribute to mismatching.

Another notable finding is that 95% of older adults with mismatched practical and theoretical accessibility selected a farther distance CHCs for PHC rather than the adjacent one. This suggests that the cross-catchment access to CHCs for older adults was probably a subjective factor of mismatched accessibility. To verify the speculation, the correlation between the proportion of cross-catchment visits (x) and the matching probability (y) was studied through a linear regression (Table 5). Linear correlation analysis indicated that they showed a significant negative correlation ($b = -0.853$, $t = 12.617$, $p < 0.01$) and passing F-test ($F = 159.192$, $p = 0.000 < 0.05$), and x can explain 90.4% variance of y.

Figure 8 presents the spatial distribution of older adults with cross-catchment visits to CHCs, and the above-described communities are classified into two categories. The first category is communities with a high aging rate but scarce services, located on Dalian Airport Street, Dalian Square Island, China. Notably, the reason for the older adults cross-catchment to visit CHCs was to seek better medical services. The second category is communities with a high aging rate and overabundant services (primarily covering the residential areas in Chunliu Street, Malan Square, and Taoyuan Street). These areas were intensively developed in the 1990s such that the surrounding infrastructure was mostly old and creaky. Through follow-up phone calls to interview these older adults after the questionnaire, we found that they always did other activities on the way to CHCs (e.g., grocery shopping, fitness, and care massage), which led to the cross-catchment visits to CHCs.

4. Discussion

4.1. Main findings

The above results show that both comparisons have a gap in accessibility measurement for PHC, where one is between the theoretical accessibility based on all populations and the older adult population, and the other is between the practical and theoretical accessibility for older adults. The former considered the heterogeneity of older adults in the supply–demand of PHC. The results found that 10.3% of communities were identified as PHCSA, distributed across Yingchengzi, Lingshui, Xishan Reservoir, Tiger Beach, Eastport, and Dalian Bay Districts. Specifically, these areas were distributed in the fringe areas or the residential areas around mountain ranges, where poor transportation is most likely worsening an already difficult situation for older adults. The latter is based on the analysis of the variables affecting the matching probability and their endogenous effects. The analysis indicated that the factors in the aspects of socioeconomic status, health conditions, and service utilization were correlated with the matching probability of older adults. Notably, the difference of aging development between regions widened the gap between theoretical assessment and actual utilization. In addition, an unexpected finding shows that the actual travel time and potential access time have an opposite correlation with the matching probability of older adults, suggesting that both the overserved and underserved PHC affected the older adults' matches between actual utilization and planning assessment. Thus, the main reasons of mismatched accessibility can be summarized as two points. One is the lack of connection between the spatial distribution of facilities

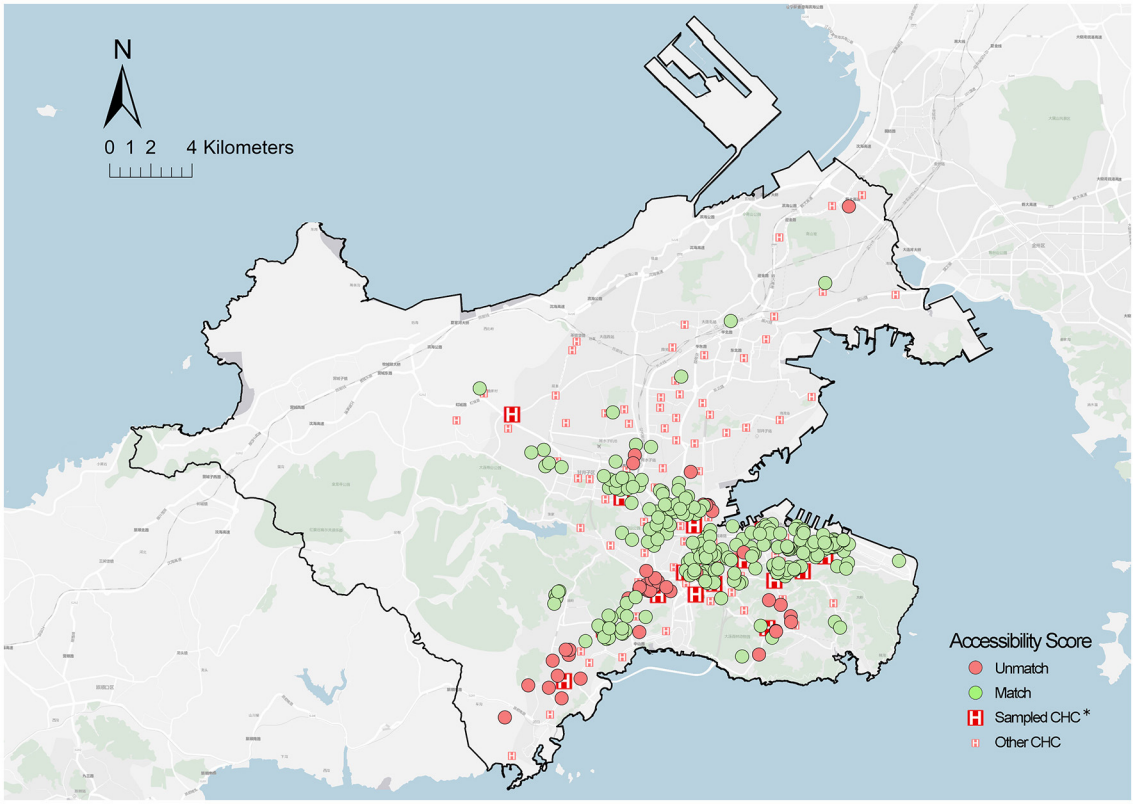

FIGURE 8
Spatial distribution of cross-catchment visit locations. *Sampled CHCS = 18; the community of sampled older adults = 579.

and allocation of service supply, and the other is the subjective cross-catchment visit to CHCs for older adults.

4.2. Policy implications

Based on the above findings, some age-friendly implications for PHC planning were proposed to improve the current gaps of accessibility. On the one hand, flexible standards should be developed for planning assessments to accommodate the regional differences in the aging level. For the allocation of CHC services, given the proportion of older adults in different health service areas, the supply amountof CHCs (physicians and beds per 1,000 people) can be increased appropriately, and some special communities should be designated (e.g., a senior-friendly community and super-aged community). Furthermore, the supply scope standard for CHCs should adjust multiple catchments by considering poor mobility among older adults, which can be determined according to the pedestrian-friendly index in the catchment area. In addition to the supply amount and scope of CHCs, the spatial aggregation of CHCs with other facilities should add to the considerations in planning standards, for instance, building a 30-min transport network between CHCs and adjacent higher-level hospitals for healthcare service at the city scale, and a collaboration network between CHCs, older adults care facilities, and other living facilities for older adult care services on a community scale. On the other hand, planning should adopt reasonable PHC zoning by using finer assessment units, specifically re-clustering the population size instead of simply using census data. It is necessary to develop a comprehensive assessment framework for PHCSA considering aging level, traffic conditions, market capacity, existing facilities, and the results of Community Health Impact Assessment (CHIA). Moreover, rather than building new facilities, ensuring the dynamics and supply–demand equilibrium of service allocation are more efficient means to improve the gap in accessibility measurement. One of the communities in the PHCSA is the community of Yingcheng District, located in a sparsely populated and high-aging fringe area, which has limited access to shopping facilities and poor transportation, where there should be an increase in dynamic services (e.g., home care, specialist visits, and treatment online). Another is the community of Eastport District, where apartments were developed with a new central business district (CBD) and are mainly used by white-collars with good mobility; therefore, PHC should combine with other public services to build multi-functional public constructions.

4.3. Limitations and future work

Several limitations remain in this study. Since health statistics at the community scale are non-public data in China, the samples in this study originated from older adults who were patients

of CHCs, and the questionnaire did not survey older adults who were not seeking CHC services. Moreover, the actual travel time of the older adults was a self-reported subjective value, regardless of the individual differences in physical fitness and perceptive ability. Thus, more interactive tools and GPS should be adopted to measure the travel behavior of older adults in practice, and more multi-dimensional surveys should be conducted in a pedestrian environment in future research. In the aspect of analyzing factors for matching, subsequent studies should further consider environmental factors that have been confirmed to affect the accessibility for older adults (e.g., taking into account slopes and intersections).

5. Conclusion

Although China has been vigorously building community-oriented primary healthcare systems in recent years, spatial inequities have existed or even been ignored due to the lack of integrated, systematic, and age-appropriate planning frameworks. In the past, researchers have attempted to improve models of accessibility measures or to establish fuzzy evaluation frameworks to provide a basis for decision-making under uncertainty[62, 63]. However, few have strived to find the causes for the discrepancy between theoretical findings and practical measurements. This study demonstrated and analyzed the accessibility gap between theoretical assessment and actual utilization in PHC access for older adults and described the problem of ignoring the heterogeneity of older adults in the current planning assessment for CHCs. The proposed method has important advantages over the accessibility measures available in the literature: (i) a precise scale, (ii) combined survey experiences with planning standards, (iii) supply–demand allocation based on a population model instead of population size, and (iv) supporting sustainable planning.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Author contributions

JB and WL: conceptualization, validation, and supervision. JB: methodology, software, investigation, data curation, writing—original draft preparation, visualization, and resources. WL: writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Associations of intrinsic capacity, fall risk and frailty in old inpatients

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Introduction: This study explored the associations of intrinsic capacity (IC), fall risk, and frailty in geriatric inpatients.

Methods: A total of 703 hospitalized patients aged 75 years or older were recruited for this retrospective observational study from Zhejiang Hospital using a comprehensive geriatric assessment. The IC composite score was constructed from the scores of the Chinese version of the Mini-Mental State Examination, Short Physical Performance Battery, Short Form Mini Nutritional Assessment, 15-item Geriatric Depression Scale, and self-reported hearing and vision impairment. Adverse outcomes were recorded as the fall risk and frailty using the Morse Fall Scale and the Clinical Frailty Scale. Spearman's correlation coefficient analyses and multivariate logistic regression models were used to explore the associations between IC, high fall risk, and frailty.

Results: Declined IC composite scores were associated with increased risks of falls [odds ratio (OR) = 0.64, 95% confidence interval (CI): 0.57–0.72] and frailty (OR = 0.45, 95%CI: 0.37–0.54) among older hospitalized patients after adjusting for the related potential confounders. In addition, decreased cognitive, vitality, locomotion, and psychological scores were associated with increased adverse health conditions, with ORs ranging from 0.26 to 0.70. Vision impairment was observed to increase the risk of frailty (OR = 0.42, 95%CI: 0.23–0.76) after adjusting for the related potential confounders.

Discussion: This study indicated that declined IC was associated with fall risk and frailty in older inpatients. Further prospective studies are needed to explore the longitudinal associations between baseline IC and subsequent risk of falls and frailty.

KEYWORDS

older adults, hospitalized, intrinsic capacity, fall, frailty

1. Introduction

Due to the rising population of older adults in China, the number of hospitalized older patients is increasing annually. Increased complicated conditions and functional declines brought by age and hospitalization, older patients aged ≥75 years old are a high-risk group for frailty and falls (1–4), and these adverse geriatric conditions can persist long after discharge (5–7). The long-term adverse effects of frailty and falls include subsequent loss of independence, disability, increased care needs, health expenditures, and mortality (8–12). Based on the reversibility of frailty and fall risk (13, 14), falls and frailty prevention during hospitalization may complement the in-hospital quality of medical and care goals of advancing disability and adverse events. Adopting person-centered interventions and care plans is critical for reducing adverse outcomes during and after hospitalization.

Intrinsic capacity (IC) is the core concept of functional ability proposed by the World Health Organization (WHO) to promote healthy aging (15). IC is defined as the physical and mental capacity of an individual, including cognition, locomotion, vitality, psychological, and sensory abilities (16). Previous studies have focused on community-level IC screening, assessment, and intervention among older adults (17, 18). Studies in community dwellings and nursing homes have revealed that IC validly predicts falls, frailty, disability, and mortality (19, 20). Impaired vitality, locomotion, and psychology domains have been reported to predict the incidence of future falls within two years, and cognitive decline was reported to be associated with an increased risk of activities of daily living dependence in the future (21). Another study from Singapore showed that a higher composite IC was associated with decreased risk of frailty progression, incident frailty, falls, health deterioration, and functional decline (22). However, few studies have integrated IC into rapid functional screening and assessment of older inpatients in general hospitals (23–25). A recent study investigating the association between IC and poor outcomes one year after discharge in an older hospitalized population found that higher IC composite scores at admission indicated a lower likelihood of disability and death (23). Despite effective tools and interventions for prevention, poor outcomes caused by recurrent falls and frailty progression remain common and expensive among older adults (10, 26). Indeed, the World Fall Guideline recommends that fall prevention and management can partly be achieved by improving IC domains, such as mobility, sensory function, cognitive function, and nutrition status (27). Consensus guidelines also emphasize that nutrition and exercise, which correspond to the two important components of IC nutrition and locomotion, are important intervention strategies for frailty prevention and management (28). Thus, it is important to explore the associations of in-hospital IC levels, fall risk, and frailty in older inpatients.

In addition, although the conceptual framework and dimensions of IC generally agree, the assessment methods of the five domains differ across studies, and no consensus has been reached on the best approach to compute a global composite score of IC to account for all dimensions holistically (29, 30). Considering the clinical utility of a summary score for routine geriatric assessment, Lopez-Ortiz et al. proposed an IC composite score that consisted of the characteristics of all five dimensions and weighted each dimension equally by reviewing the existing evidence (30). Based on the characteristics of vulnerability and variability among older inpatients, the proposed tools may avoid the risk of specific deficits compared to the ICOPE tools. Thus, we adopted an IC composite score to assess the holistic functional status of an individual and further explored the association between IC, fall risk, and frailty in geriatric inpatients.

2. Methods

2.1. Study design and participants

This retrospective observational study was based on the existing comprehensive geriatric assessment (CGA) database of older hospitalized patients in Zhejiang Hospital in China. The CGA database was established in 2014 to collect data on geriatric syndromes for older hospitalized patients. A total of 1624 potential patients were consecutively recruited between March 2014 and July 2022, and all data were obtained when the patients were in relatively stable condition. The inclusion criterion was older inpatients aged ≥75 years. The exclusion criteria were as follows: outpatients, inability to cooperate or refusal to complete the CGA, and incomplete data of importance such as IC, fall risk, and frailty. Ethical approval was obtained from the Medical Ethics Committee of Zhejiang Hospital (2013-25), and all patients provided written informed consent prior to data collection.

2.2. Data collection

Data were collected by trained professional nurses at the CGA through face-to-face interviews between March 2014 and July 2022. Demographic information including collection time, age, sex, educational level (coded as junior high school and below, higher school and above), marital status (categorized as married, unmarried, widowed, or divorced), religion, cigarette smoking, alcohol use, reason for admission, and medication use was collected. The body mass index was calculated using the height and weight measurements. Comorbidity was assessed using the Cumulative Illness Rating Scale for Geriatrics (CIRS-G). It includes 14 systemic disease categories, with severity in each category assessed on a scale of 0 to 4. Higher total CIRS-G scores indicate a higher comorbidity burden (31). Polypharmacy was determined as the concomitant use of ≥ five medications (32). The history of falls in the past year, fear of falling, walking aid use, dentures, and eating problems were also recorded. Pain was measured using the Numerical Rating Scale (NRS) (33), and an NRS score of ≥1 indicated the presence of pain. Urinary incontinence was considered when the score on the International Consultation on Incontinence Questionnaire-Short Form (ICIQ-SF) was 1 or higher (34).

2.3. IC assessment

Based on the WHO's conceptual framework on IC and the existing literature, we integrated the five domains of cognition, locomotion, vitality, psychology, and sensation into a composite score (30). Each domain was scored a 0–2 range to stratify three statuses of functional impairment (0 = severely impaired; 1 = partially impaired; 2 = slightly impaired or fully preserved). The total IC composite score ranges from 0 to 10, with a higher composite score indicating a higher IC reserve.

Cognitive impairment was ascertained using the Chinese version of the Mini-Mental State Examination (35), and scores of 0–9, 10–26, and 27–30 points were computed as 0, 1, and 2, respectively. Locomotion was evaluated using the Short Physical Performance Battery (SPPB) (36, 37), which comprises a 4 m gait speed, five-repetition maximum chair rise, and static balance. SPPB scores of 0–2, 3–9, and 10–12 points were computed as 0, 1, and 2 points, respectively. The short form Mini Nutritional Assessment (MNA-SF) was used to assess vitality, with cut-off values of 0–7, 8–11, and 12–14 points (38). Depressive symptoms using the 15-item Geriatric Depression Scale (GDS-15) were used to determine psychological capacity (39). The cut-off GDS-15 scores used to classify depression severity were 5 and 10 (40). The sensory domain was assessed using self-reported hearing and vision impairment, which was categorized as total or severe loss (0 points), moderate loss (0.5 points), and normal or mild loss (1 point). Based on the available IC assessment database, vitality, and psychology domains were replaced

with the MNA-SF and GDS-15 scale instead of the recommended assessment tools.

2.4. Fall risk assessment

Falls risk was assessed using the Morse Fall Scale (MFS) (41), which consists of six items: history of falling within three months, secondary diagnosis, ambulatory aid, intravenous or heparin lock, gait, and mental status. The total MFS score ranges from 0 to 145, with a score greater than 45 points indicating a high fall risk.

2.5. Frailty assessment

Frailty was evaluated using the Clinical Frailty Scale (CFS) (42), which has been validated in a Chinese hospital setting. The scale ranges from 1 (very fit) to 7 (severely frail), and a CFS score of ≥5 indicated frailty (43).

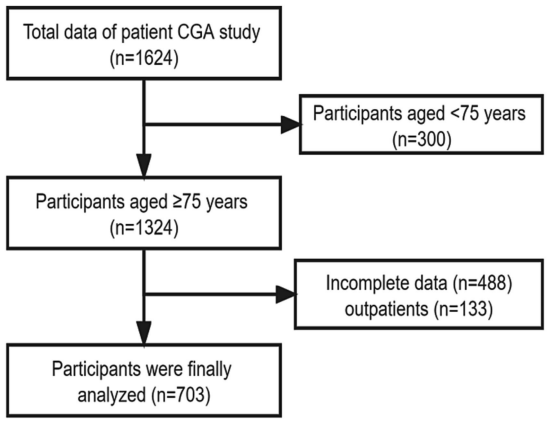

FIGURE 1
The flow chart of patients selection.

2.6. Statistical analysis

Data were analyzed using SPSS (version 26.0; SPSS, Chicago, IL, United States). The continuous variables were expressed as the mean ± standard deviation or median and interquartile range (IQR) as appropriate. Categorical variables are expressed as frequencies (N) and percentages (%). Differences in fall risk and frailty status among the baseline characteristics were assessed using the unpaired t-test, Mann-Whitney U-test, and chi-square test, where appropriate. Spearman's correlation coefficient analyses were used to evaluate the associations between the IC composite, MFS, and CFS scores. Furthermore, multivariate logistic regression models to estimate odds ratios (ORs) and 95% confidence intervals (CIs) were used to explore the effect of IC on high fall risk and frailty, adjusted for potential variables in the univariate analysis. The potential variables with $P < 0.05$ in bivariate analysis and some critical variables reported by experts were selected in the multivariate logistic regression analysis. A P-value of <0.05 was considered statistically significant.

3. Results

Figure 1 presents a flowchart of the patient selection. A total of 703 inpatients were included in the analysis. Among the included inpatients, 249,199 and 255 older inpatients were collected in the 2014–2016 year, 2017–2019 year, and 2020–2022 year, respectively. Among them, 57.3% were male, with a median age of 85 years, 66.1% were married, 55.3% had high school and above level of education. Figure 2A shows the distribution of the IC composite scores; the median IC composition score was 7.5 points (2–10 points). Additionally, the median IC composition score was 7.5, 7.5, and 7.0 points in the 2014–2016 year, 2017–2019 year, and 2020–2022 year,

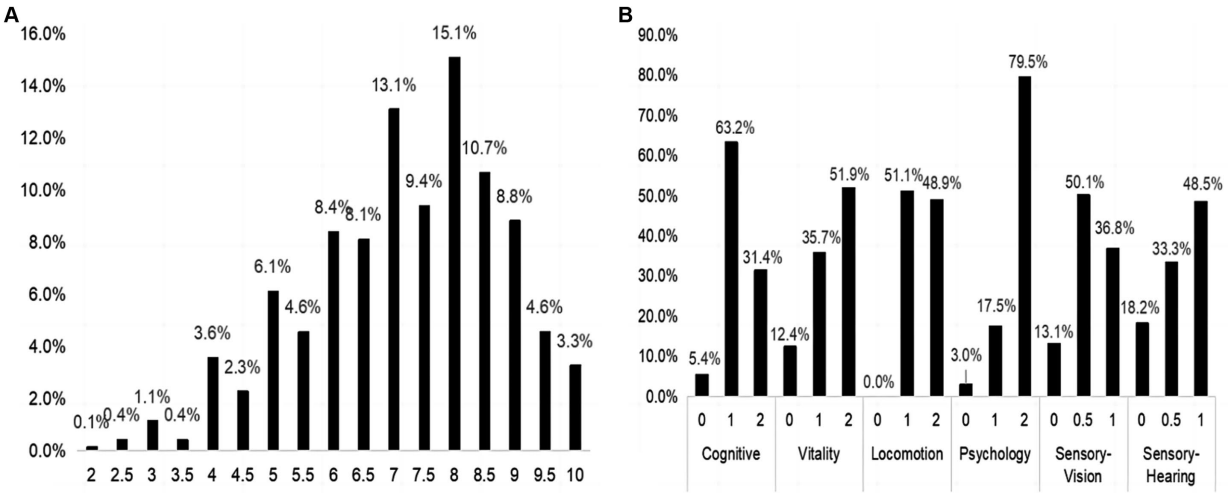

FIGURE 2
The distribution of IC composite score and its five domains. **(A)** The distribution of IC composite score in the total sample. **(B)** The distribution of IC domains in the total sample. IC, intrinsic capacity.

TABLE 1 General characteristics and sex-specified characteristics of the total sample.

	Total sample (n = 703)	Males (n = 403)	Females (n = 200)	P-value
Collection time, n (%)				**0.003**
2014–2016	249 (35.4)	**164 (40.7)**	**85 (28.3)**	
2017–2019	199 (28.3)	**106 (26.3)**	**93 (31.0)**	
2020–2022	255 (36.3)	**133 (33.0)**	**122 (40.7)**	
Age, [median (IQR), years]	85 (81, 88)	**85 (81, 89)**	**84 (80, 87)**	**<0.001**
Married, n (%)	465 (66.1)	**297 (73.7)**	**168 (56.0)**	**<0.001**
High school or above, n (%)	389 (55.3)	**239 (59.3)**	**150 (50.0)**	**0.014**
Religion, n (%)	87 (12.4)	**28 (6.9)**	**59 (19.7)**	**<0.001**
Current or former smoker, n (%)	171 (24.3)	**162 (40.2)**	**9 (3.0)**	**<0.001**
Current or former drinker, n (%)	152 (21.6)	**131 (32.5)**	**21 (7.0)**	**<0.001**
BMI, [mean±SD, Kg/m^2]	23.2 ± 3.7	23.3 ± 3.6	23.1 ± 3.7	0.386
Fall history in the past year, n (%)	170 (24.2)	100 (24.8)	70 (23.3)	0.650
Fear of falling, n (%)	409 (58.2)	**218 (54.1)**	**191 (63.7)**	**0.011**
Walking aids, n (%)	262 (37.3)	155 (38.5)	107 (35.7)	0.448
Dentures, n (%)	479 (68.1)	277 (68.7)	202 (67.3)	0.693
Eating problems, n (%)	316 (45.0)	173 (42.9)	143 (47.7)	0.212
Reason for admission, n (%)				**0.001**
Cardiovascular diseases	105 (14.9)	**64 (15.9)**	**41 (13.7)**	
Peripheral vascular diseases	332 (47.2)	**189 (46.9)**	**143 (47.7)**	
Nervous system diseases	70 (10.0)	**33 (8.2)**	**37 (12.3)**	
Respiratory diseases	56 (8.0)	**45 (11.2)**	**11 (3.7)**	
Other	140 (19.9)	**72 (17.9)**	**68 (22.7)**	
CIRS-G score, [(Median, IQR), scores]	9.0 (7.0, 9.0)	**10.0 (7.0, 13.0)**	**8.0 (6.0, 11.0)**	**0.001**
Polypharmacy (≥5 medications), n (%)	419 (59.6)	251 (62.3)	168 (56.0)	0.093
IC composite score, [median (IQR), scores]	7.5 (6.0, 8.5)	7.5 (6.5, 8.5)	7.3 (6.0, 8.5)	0.467
Pain, n (%)	308 (43.8)	**156 (38.7)**	**152 (50.7)**	**0.002**
Urinary incontinence, n (%)	272 (38.7)	**138 (34.2)**	**134 (44.7)**	**0.005**
High fall risk, n (%)	327 (46.5)	193 (47.9)	134 (44.7)	0.397
Frailty, n (%)	460 (65.4)	254 (63.0)	206 (68.7)	0.120

BMI, body mass index; CIRS-G, Cumulative Illness Rating Scale for Geriatrics, IC, intrinsic capacity. Significance difference $P < 0.05$ was shown in bold.

respectively. Regarding the IC domains, cognitive impairment (68.6%) was the most common, followed by sensory (vision 63.2%, hearing 51.5%), locomotion (51.1%), vitality (48.1%), and psychological impairments (20.5%), as shown in Figure 2B.

The general characteristics and sex-specified characteristics of the sample are listed in Table 1. Among the total inpatients, 327 (46.5%) exhibited a high fall risk, and 460 (65.4%) experienced frailty. Significant sex differences were observed in variables about age, marriage status, educational level, religious belief, smoking and drinking history, fear of falling, reason for admission, CIRS-G score, pain, and urinary incontinence (all P for trend <0.05), but not in IC composite score, fall risk, and frailty. As presented in Table 2, compared with inpatients without a high fall risk and frailty, inpatients who experienced these negative health conditions were older, had a higher percentage of fall history in the past year, had a fear of falling, used a walking aid, had eating problems, comorbidities, polypharmacy, urinary incontinence, and lower IC composite scores (all $P < 0.05$). As shown in Figure 3, the IC composite scores were negatively associated with the MFS and CFS scores (all $P < 0.01$). Furthermore, Table 3 shows that declined IC composite scores were associated with an increased risk of falls (OR = 0.64, 95%CI: 0.57–0.72) and frailty (OR = 0.45, 95%CI: 0.37–0.54) among older hospitalized patients after adjusting for the related potential confounders. Regarding the relationships between IC domains and negative health outcomes, multivariate regression models revealed that declined capacities in the cognitive, vitality, locomotion, and psychological domains were associated with increased adverse health conditions, and the ORs ranged from 0.26 to 0.70. However, vision impairment in the sensory domain was observed to increase the risk of frailty (OR = 0.42, 95%CI: 0.23–0.76) after adjusting for the related potential confounders.

TABLE 2 Comparison of the general characteristics divided into the status of fall risk and frailty.

	High fall risk (n = 703)			Frailty (n = 703)		
	No (n = 376)	Yes (n = 327)	P-value	No (n = 243)	Yes (n = 460)	P-value
Collection time, n (%)			**<0.001**			**<0.001**
2014–2016	**151 (40.2)**	**98 (30.0)**		**98 (40.3)**	**151 (32.8)**	
2017–2019	**117 (31.1)**	**82 (25.1)**		**82 (33.7)**	**117 (25.4)**	
2020–2022	**108 (28.7)**	**147 (45.0)**		**63 (25.9)**	**192 (41.7)**	
Age, [median (IQR), years]	**84 (80, 87)**	**86 (83, 89)**	**<0.001**	**82 (78, 86)**	**86 (83, 89)**	**<0.001**
Male, n (%)	210 (55.9)	193 (59.0)	0.397	149 (61.3)	254 (55.2)	0.120
Married, n (%)	257 (68.4)	208 (63.6)	0.185	**185 (76.1)**	**280 (60.9)**	**<0.001**
High school or above, n (%)	219 (58.2)	170 (52.0)	0.096	**147 (60.5)**	**242 (52.6)**	**0.046**
Religion, n (%)	39 (10.4)	48 (14.7)	0.084	23 (9.5)	64 (13.9)	0.089
Current or former smoker, n (%)	**74 (19.7)**	**97 (29.7)**	**0.002**	60 (24.7)	111 (24.1)	0.869
Current or former drinker, n (%)	75 (19.9)	77 (23.5)	0.247	54 (22.2)	98 (21.3)	0.779
BMI [mean±SD, Kg/m^2]	23.1 ± 3.4	23.3 ± 3.9	0.443	23.3 ± 3.1	23.2 ± 3.9	0.643
Fall history in the past year, n (%)	**38 (10.1)**	**132 (40.4)**	**<0.001**	**38 (15.6)**	**132 (28.7)**	**<0.001**
Fear of falling, n (%)	**200 (53.2)**	**209 (63.9)**	**0.004**	**110 (45.3)**	**299 (65.0)**	**<0.001**
Walking aids, n (%)	**66 (17.6)**	**196 (59.9)**	**<0.001**	**31 (12.8)**	**231 (50.2)**	**<0.001**
Dentures, n (%)	247 (65.7)	232 (70.9)	0.136	167 (68.7)	312 (67.8)	0.808
Eating problems, n (%)	**153 (40.7)**	**163 (49.8)**	**0.015**	**87 (35.8)**	**229 (49.8)**	**<0.001**
Reason for admission, n (%)			0.451			0.266
Cardiovascular diseases	60 (16.0)	45 (13.8)		43 (17.7)	62 (13.5)	
Peripheral vascular diseases	185 (49.2)	147 (45.0)		114 (46.9)	218 (47.4)	
Nervous system diseases	32 (8.5)	38 (11.6)		17 (7.0)	53 (11.5)	
Respiratory diseases	29 (7.7)	27 (8.3)		20 (8.2)	36 (7.8)	
Other	70 (18.6)	70 (21.4)		49 (20.2)	91 (19.8)	
CIRS-G score, [median (IQR), scores]	**8.0 (6.0, 11.8)**	**10.0 (7.0, 13.0)**	**0.001**	**8.0 (6.0, 11.0)**	**10.0 (7.0, 13.0)**	**<0.001**
Polypharmacy (≥5 medications), n (%)	**211 (56.1)**	**208 (63.6)**	**0.043**	**113 (46.5)**	**306 (66.5)**	**<0.001**
Pain, n (%)	**147 (39.1)**	**161 (49.2)**	**0.007**	95 (39.1)	213 (46.3)	0.067
Urinary incontinence, n (%)	**124 (33.0)**	**148 (45.3)**	**0.001**	**74 (30.5)**	**198 (43.0)**	**0.001**
IC composite score, [median (IQR), scores]	**8.0 (7.0, 8.5)**	**7.0 (5.5, 8.0)**	**<0.001**	**8.5 (7.5, 9.0)**	**7.0 (5.5, 8.0)**	**<0.001**
IC subdomains						
Cognition, [median (IQR), scores]	**1.0 (1.0, 2.0)**	**1.0 (1.0, 1.0)**	**<0.001**	**1.0 (1.0, 2.0)**	**1.0 (1.0, 1.0)**	**<0.001**
Vitality, [median (IQR), scores]	**2.0 (1.0, 2.0)**	**1.0 (1.0, 2.0)**	**<0.001**	**2.0 (1.0, 2.0)**	**1.0 (1.0, 2.0)**	**<0.001**
Locomotion, [median (IQR), scores]	**2.0 (1.0, 2.0)**	**1.0 (1.0, 2.0)**	**<0.001**	**2.0 (2.0, 2.0)**	**1.0 (1.0, 2.0)**	**<0.001**
Psychology, [median (IQR), scores]	**2.0 (2.0, 2.0)**	**2.0 (1.0, 2.0)**	**0.004**	**2.0 (2.0, 2.0)**	**2.0 (1.0, 2.0)**	**<0.001**
Vision, [median (IQR), scores]	**0.5 (0.5, 1.0)**	**0.5 (0.5, 1.0)**	0.300	**0.5 (0.5, 1.0)**	**0.5 (0.5, 1.0)**	**<0.001**
Hearing, [median (IQR), scores]	**0.5 (0.5, 1.0)**	**0.5 (0.5, 1.0)**	0.283	**1.0 (0.5, 1.0)**	**0.5 (0.5, 1.0)**	**0.004**

Significance difference $P < 0.05$ was shown in bold. BMI, body mass index; CIRS-G, Cumulative Illness Rating Scale for Geriatrics; IC, intrinsic capacity; IQR, inter-quartile range.

4. Discussion

This study indicated that a higher IC composite score was associated with a decreased risk of falls and frailty in older hospitalized patients. Declines in cognition, vitality, locomotion, and psychology were the domains most susceptible to the impact of falls and frailty. Additionally, visual impairment was significantly associated with an increased risk of frailty.

This study found that IC impairments were common among older patients in hospital settings. Cognitive, sensory, and locomotor impairments were the three most prevalent domains of impairment, with percentage rates of more than 50%. The reported rates were higher than those in the Chinese community (44, 45) and inpatients with relatively healthy status at Xuanwu Hospital (25), but similar to those reported in Beijing Hospital (24), which may be attributed to advanced age, complex multimorbidity, and multiple functional loss due to hospitalization.

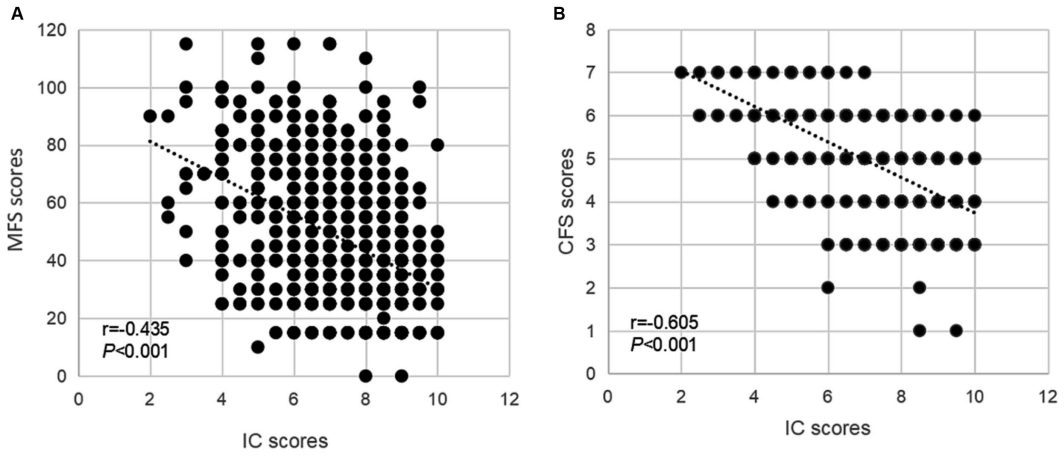

FIGURE 3
The associations of IC and geriatric health outcomes during the hospital stay. Spearman correlation coefficients were calculated between IC scores and **(A)** MFS scores, **(B)** CFS scores in older inpatients. IC, intrinsic capacity; MFS, Morse Fall Scale; CFS, Clinical Frailty Scale.

TABLE 3 Multivariate regression models of the associations of IC composition score and its subdomains, fall risk, and frailty.

	High fall risk[a]		Frailty[b]	
	OR (95%CI)	*P*-value	OR (95%CI)	*P*-value
IC composition score	**0.64 (0.57, 0.72)**	**<0.001**	**0.45 (0.37, 0.54)**	**<0.001**
IC subdomains				
Cognition	**0.38 (0.28, 0.53)**	**<0.001**	**0.33 (0.22, 0.48)**	**<0.001**
Vitality	**0.52 (0.40, 0.66)**	**<0.001**	**0.33 (0.24, 0.47)**	**<0.001**
Locomotion	**0.26 (0.19, 0.38)**	**<0.001**	**0.26 (0.17, 0.40)**	**<0.001**
Psychology	**0.70 (0.47, 0.94)**	**0.022**	**0.39 (0.24, 0.62)**	**<0.001**
Vision	1.07 (0.65, 1.77)	0.789	**0.42 (0.23, 0.76)**	**0.004**
Hearing	1.06 (0.68, 1.66)	0.793	0.80 (0.47, 1.36)	0.408

[a]After adjusting for collection time, age, sex, smoking history, fear of falling, eating problem, CIRS-G score, polypharmacy, pain, and urinary incontinence. [b]After adjusting for collection time, age, sex, marriage status, educational level, falling history, fear of falling, walking aids, eating problem, CIRS-G score, polypharmacy, and urinary incontinence. IC, intrinsic capacity; CIRS-G, Cumulative Illness Rating Scale for Geriatrics; OR, odds ratio; CI, confidence interval. Significance difference $P < 0.05$ was shown in bold.

Studies have shown that falls are influenced by multiple factors in older individuals, among which functional capacity impairment plays a critical role in preventing the occurrence of falls (27, 46). Consistent with this study, we identified that higher IC levels, especially those related to the preservation of cognitive, vitality, locomotion, and psychological independence, were associated with a lower risk of falls. Liu et al. demonstrated that impaired vitality, locomotion, and psychology domains predicted the incidence of future falls within two years and that cognitive decline was associated with activities of daily living dependence in the future (21). Another study suggested that older adults with falls or those at risk of falls had at least three domains of IC decline (47). Thus, older inpatients with low IC composite scores and their domains constitute a high-risk group for falls in hospital settings. Fall prevention strategies in hospital settings should address IC assessment and management upon admission. The effect of low IC levels on fall risk may be explained by both direct and indirect mechanisms. First, impaired cognitive functions such as executive function, orientation, and memory dysfunction may influence the sensory information related to maintaining balance while walking and the ability to perceive and judge falls risk in older adults (48, 49). Second, poor nutritional status, especially inadequate protein intake and vitamin D deficiency reduces muscle mass and function and leads to the development of sarcopenia (50–52). These negative conditions may lead to a slow gait, poor balance, and immobility, thereby increasing the risk of recurrent falls (50, 53). Third, various depressive symptoms, including a negative self-evaluation, cognitive changes, poor sleep quality, and decreased physical activity, may cause fear of falling and falls (54–57). Fourth, evidence showed that sensory impairments were predictors of an elevated risk of falls (58, 59). Despite no significant difference between sensory impairments and falls risk in this study, it may be attributed to a high incidence of sensory impairments in older adults across fall risk groups. In addition, interactions between various impaired IC domains and multiple comorbidities may contribute to functional deterioration and fall occurrence.

With regard to the association of IC and frailty, our study documented that a higher IC composite score was associated with decreased risks of frailty. Older inpatients with IC domain impairments, except hearing loss, were found to be more prone to frailty. This is consistent with recent studies arguing that IC impairments are associated with frailty (60–62). A longitudinal study

of the Multidomain Alzheimer's Preventive Trial confirmed that each additional IC impairment was associated with a 47% increase in the risk of incident frailty (61). Mobility limitation, depressive symptoms, and vision impairment were associated with incident frailty at the five-year follow-up in community-dwelling older adults, but no significant associations between cognitive decline, malnutrition, or hearing impairment with frailty were observed (61). Another study conducted in China found that IC was significantly associated with incident frailty, and individuals with impaired vitality and locomotion domains were more likely to be frail compared with other domain combinations (62). In addition, IC impairment and frailty were regarded as overlapping and coexisting and had a synergistic effect on adverse outcomes. Liu et al. found that newly impaired vitality and locomotion domains were related to transitions from non-frail to frail status (63). Data from a study conducted in Singapore revealed that older adults with low IC who were prefrail/frail were more prone to exhibit poorer outcomes, including a higher proportion of transitioning to frailty or remaining frail, decreased activity of daily life function, and quality-of-life at one year when compared with older adults with high IC and robust or intermediate IC and prefrail (64). The 12-week Vivifrail multicomponent exercise program has been found to be an effective strategy to enhance IC, especially in terms of the locomotion, cognition, and vitality IC domains, in community-dwelling older adults with pre-frailty/frailty and mild cognitive impairment/mild dementia, compared to usual care (65). However, the above-mentioned evidence was mostly from the community rather than hospital settings. Further evidence from a larger sample, based on hospital settings, is warranted. Therefore, IC may better characterize frailty in older individuals in the hospital setting, and targeting a high-risk group based on low IC composite scores and its domain scores may provide additional intervention recommendations that go beyond current nutrition and exercise recommendations for physical frailty and help to optimize individualized care plans during hospitalization.

The results highlighted the negative associations of IC, fall risk, and frailty in older inpatients. In addition, the current study included a well-characterized older inpatient population and comprehensive assessment information from the CGA database of the geriatric department in our tertiary hospital. Nevertheless, this study has several limitations. First, because IC is a dynamic but reversible construct (66), regular monitoring of IC on admission and during hospital stays may contribute to detecting potential IC declines ahead of clinical adverse events, such as falls and frailty. However, the cross-sectional design hinders the possibility of examining the change in IC composite scores and negative events during the hospital stay. Further longitudinal studies to confirm causality are warranted. Second, convenience sampling strategies for hospital admissions and significant differences were observed in some characteristics between the included patients and the excluded patients, such as age and medication usage may have led to an inevitable selection bias. Therefore, these results should be generalized with caution. Finally, some domains were collected using subjective measurements, which may have introduced a subjective bias.

5. Conclusion

This study indicated that a decline in IC was associated with fall risk and frailty in older inpatients. Further prospective studies are needed to explore the longitudinal associations of in-hospital baseline IC and subsequent risk of falls and frailty.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was obtained from the Medical Ethics Committee of Zhejiang Hospital (2013-25). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SS, YX, and XC contributed to conceptualization and methodology. SS and YX analyzed the data and wrote the original draft. XZ, YY, and XW contributed to data collection. LC and HG participated in functional assessment. All authors contributed to implementing and revising the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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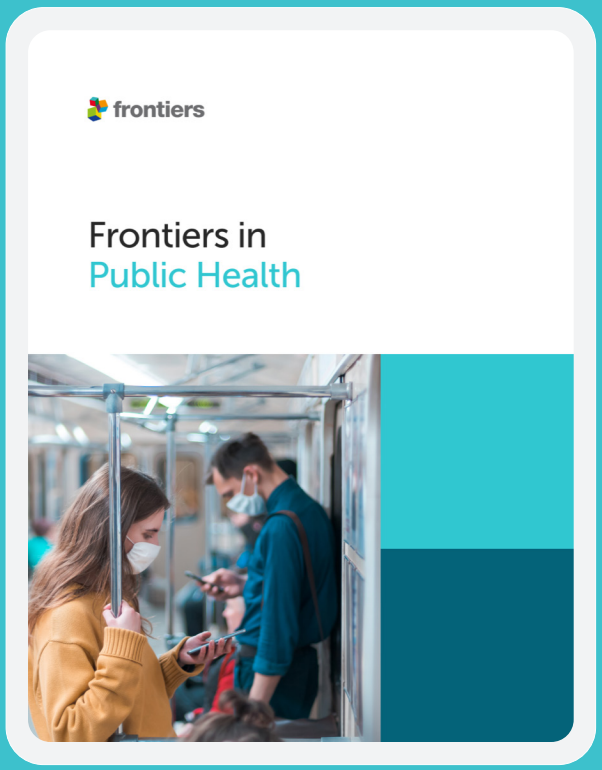

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