



OPEN ACCESS

EDITED BY

Mallikarjuna Korivi,
Zhejiang Normal University, China

REVIEWED BY

Chang-Mo Oh,
Kyung Hee University, Republic of Korea
Zbigniew Ossowski,
Gdańsk University of Physical Education and
Sport, Poland
Bing Bo,
Henan University, China

*CORRESPONDENCE

Jian Wu,
✉ wujiancupes@126.com

[†]These authors have contributed equally to this work

RECEIVED 06 May 2024

ACCEPTED 28 August 2024

PUBLISHED 11 September 2024

CITATION

Huang M, Yang J, Wang Y and Wu J (2024)
Comparative efficacy of different exercise
modalities on metabolic profiles and liver
functions in non-alcoholic fatty liver disease: a
network meta-analysis.
Front. Physiol. 15:1428723.
doi: 10.3389/fphys.2024.1428723

COPYRIGHT

© 2024 Huang, Yang, Wang and Wu. This is an open-access article distributed under the terms of the [Creative Commons Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Comparative efficacy of different exercise modalities on metabolic profiles and liver functions in non-alcoholic fatty liver disease: a network meta-analysis

Mingming Huang^{1†}, Jiafa Yang^{2†}, Yihao Wang¹ and Jian Wu^{1*}

¹School of Exercise Science and Health, Capital University of Physical Education and Sports, Beijing, China, ²School of Arts and Sports, Dong-A University, Busan, Republic of Korea

Objective: Research evidence suggests that exercise is a potent therapeutic strategy for non-alcoholic fatty liver disease (NAFLD). Many investigations have delved into the curative potential of diverse exercise regimens on NAFLD. This investigation synthesizes findings from randomized controlled trials via a network meta-analysis to evaluate the efficacy of exercise-based interventions on NAFLD.

Methods: We conducted a search across five electronic databases (Web of Science, EMBASE, PubMed, SCOPUS, and CNKI) to identify randomized controlled trials (RCTs) comparing the effects of different exercise modalities on metabolic profiles and liver functions in patients with NAFLD. The literature search was comprehensive up to 15, December 2023. The selected studies were subjected to a rigorous quality appraisal and risk of bias analysis in accordance with the Cochrane Handbook's guidelines, version 5.1.0. We employed Stata/MP 17 for the network meta-analysis, presenting effect sizes as standardized mean differences (SMD).

Results: This study aggregated results from 28 studies, involving a total of 1,606 participants. The network meta-analysis revealed that aerobic exercise was the most effective intervention for improving BMI in patients with NAFLD, demonstrating a significant decrease in BMI (-0.72 , 95% CI: -0.98 to -0.46 ; $p < 0.05$; Surface Under the Cumulative Ranking (SUCRA) = 79.8%). HIIT was the top intervention for enhancing HDL-C (0.12 , 95% CI: 0.04 to 0.20 ; $p < 0.05$; SUCRA = 76.1%). Resistance exercise was the most effective for reducing LDL-C (-0.20 , 95% CI: -0.33 to -0.06 ; $p < 0.05$; SUCRA = 69.7%). Mind-body exercise showed superior effectiveness in improving TC (-0.67 , 95% CI: -1.10 to -0.24 ; $p < 0.05$; SUCRA = 89.7%), TG (-0.67 , 95% CI: -1.10 to -0.24 ; $p < 0.05$; SUCRA = 99.6%), AST (-8.07 , 95% CI: -12.88 to -3.25 ; $p < 0.05$; SUCRA = 76.1%), ALT (-12.56 , 95% CI: -17.54 to -7.58 ; $p < 0.05$; SUCRA = 99.5%), and GGT (-13.77 , 95% CI: -22.00 to -5.54 ; $p < 0.05$; SUCRA = 81.8%).

Conclusion: This network meta-analysis demonstrates that exercise interventions positively affect various metabolic profiles and liver functions in NAFLD patients. Mind-body exercises are particularly effective, surpassing other exercise forms in improving metabolic profiles and liver functions.

Systematic Review Registration: <https://www.crd.york.ac.uk/PROSPERO/>, identifier registration number CRD42024526332.

KEYWORDS

nonalcoholic fatty liver disease, exercise, network meta-analysis, aerobic, physical activity

1 Introduction

Non-alcoholic fatty liver disease (NAFLD) encompasses a spectrum of hepatic dysfunctions primarily driven by metabolic dysregulation (Powell et al., 2021). Intrinsically linked to obesity, metabolic syndromes, type 2 diabetes, and insulin resistance, NAFLD's prevalence is notably increasing in parallel with obesity rates, currently estimated at 25% among adults (Younossi et al., 2018). Notably, a study projected an increase in NAFLD incidence by 13.5%–29.5% by 2030 across diverse national contexts including the United States, the United Kingdom, China, and Italy (Estes et al., 2018).

Sedentary lifestyles and poor dietary habits augment the potential risk of NAFLD, prompting researchers to explore interventions targeting modifiable factors. Lifestyle modifications have emerged as efficacious strategies in early NAFLD management (Ding et al., 2017), and adopting a Mediterranean dietary pattern shown to significantly reduce hepatic fat in overweight NAFLD patients (Trovato et al., 2015). Furthermore, prospective research indicates associations between sedentary behavior changes and alterations in waist circumference and cardiovascular metabolic risk scores (Healy et al., 2008), thus underscoring the importance of considering sedentary status alteration and increased physical activity as avenues of investigation. Exercise has been found to mitigate insulin resistance, type 2 diabetes, and obesity (Snowling and Hopkins, 2006; Romero-Gómez et al., 2017), exhibiting favorable effects on transaminase levels and dyslipidemia (Li and Huang, 2021; bib_li_and_huang_2021). Even without weight loss, consistent exercise regimens have been shown to reduce hepatic fat by 20%–30% (Hashida et al., 2017). However, despite numerous clinical interventions and randomized controlled trials targeting NAFLD, the differential impacts of various exercise modalities (aerobic, resistance, high-intensity interval training (HIIT), and mind-body exercise) remain inconclusive.

In recent years, numerous studies have focused on the impact of various forms of exercise on NAFLD (Nam et al., 2023; Hejazi and Hackett, 2023; Chun, 2023). Research has highlighted the effects of aerobic exercise and resistance training in improving liver health and overall metabolic function in NAFLD patients. Nam et al. (2023), in a systematic review of 11 studies, explored the effects of different exercise modalities on intrahepatic lipid (IHL), alanine aminotransferase (ALT), body mass index (BMI), and insulin resistance (IR) in patients with NAFLD. Their findings indicate that aerobic exercise can significantly improve IHL and ALT levels. However, a critical review of these studies reveals a predominant focus on aerobic and resistance exercises, with a noticeable lack of comprehensive examination of other exercise modalities. Furthermore, these studies often combined the effects of different exercise interventions without directly comparing their efficacy. This indicates a gap in the literature, underscoring the need for more detailed comparative studies on various exercise forms in the management of NAFLD.

Liver function and lipid biomarkers serve as common indicators for evaluating the severity of NAFLD and associated metabolic abnormalities (Wong et al., 2018). Within lipid metabolism indicators, total cholesterol (TC), triacylglycerol (TG), and low-density lipoprotein cholesterol (LDL-C) are commonly utilized to assess the severity of NAFLD and its close association with metabolic abnormalities (Wong et al., 2018; Vilar-Gomez and Chalasani, 2018). Low levels of high-density lipoprotein cholesterol (HDL-C) are frequently observed in lipid metabolism disorders (Fan et al., 2011) and are closely linked to the progression of NAFLD (Feng et al., 2020; Mato et al., 2019). Aspartate aminotransferase (AST) and ALT serve as sensitive indicators of hepatic cell damage (Senior, 2012), while sustained elevation of gamma-glutamyl transferase (GGT) may indicate progression to chronic hepatitis and is an important marker for identifying NAFLD (Kunutsor, 2016; Ha et al., 2022). BMI is considered the most commonly used measure for defining obesity and overweight populations across various genders and age groups (Daniels, 2009). Due to the close relationship between obesity and NAFLD, there are studies suggesting that BMI might be an important method for identifying NAFLD (Camhi et al., 2011). In summary, in our study, we selected eight outcome indicators closely related to NAFLD and aimed to provide relatively effective exercise modalities for adult NAFLD patients through network meta-analysis.

2 Methods

This study adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2010), with the research protocol prospectively registered in the PROSPERO database (<https://www.crd.york.ac.uk/PROSPERO/>, CRD42024526332).

2.1 Search strategy

The literature search was conducted using Web of Science, EMBASE, PubMed, SCOPUS, and China National Knowledge Infrastructure (CNKI) databases up to December 15, 2023, to identify randomized controlled trials. Keywords such as “exercise,” “obesity,” “lifestyle,” “physical activity,” “aerobic,” “liver,” and “NAFLD” were combined using the “OR” operator. Specific search strategies included.

- Web of Science: TS=(“exercise” OR “physical activity” OR “aerobic” OR “lifestyle”) AND TS=(“obesity” OR “NAFLD” OR “liver”)
- EMBASE: “exercise”/exp OR “physical activity”/exp OR “aerobic exercise”/exp OR “lifestyle”/exp AND “obesity”/exp OR “nonalcoholic fatty liver disease”/exp OR “liver disease”/exp

- PubMed: (“exercise” [MeSH Terms] OR “physical activity” [MeSH Terms] OR “aerobic exercise” [MeSH Terms] OR “lifestyle” [MeSH Terms]) AND (“obesity” [MeSH Terms] OR “NAFLD” [MeSH Terms] OR “liver” [MeSH Terms])
- SCOPUS: TITLE-ABS-KEY (“exercise” OR “physical activity” OR “aerobic” OR “lifestyle”) AND TITLE-ABS-KEY (“obesity” OR “NAFLD” OR “liver”)
- CNKI: TS=(“exercise” OR “physical activity” OR “aerobic” OR “lifestyle”) AND TS=(“obesity” OR “NAFLD” OR “liver”)

Detailed search terms are documented in [Supplementary Material S1](#).

2.2 Inclusion and exclusion criteria

Inclusion criteria: (1) Randomized controlled trials (RCTs) that investigate the use of exercise therapy in patients with NAFLD; (2) Subjects diagnosed with NAFLD via histopathological or imaging examinations; (3) No significant differences in baseline values of outcome indicators before intervention in patients; (4) Outcome indicators include BMI, TG, TC, LDL-C, HDL-C, ALT, AST, and GGT; (5) The type of intervention must be one of the following: aerobic exercise, resistance exercise, HIIT, or mind-body exercise; (6) The exercise intervention period must last at least 4 weeks.

Exclusion criteria: (1) Specific data on outcome indicators (such as AST, ALT, TC, TG, BMI, etc.) are unavailable. (2) Excluded studies include animal experiments, abstracts, case reports, reviews, systematic evaluations, and duplicate publications. (3) Studies where the type, duration, and frequency of exercise are unclear. (4) Studies focusing only on lifestyle changes without specific exercise regimens.

2.3 Data extraction and quality assessment

The data extraction process included relevant information from the literature, such as the title, authors, publication year, journal, number of patients, age, gender, intervention measures, and outcome indicators. The intervention measures encompassed four types of exercise modalities: aerobic, resistance, HIIT, and mind-body exercise. The aerobic exercise included brisk walking, cycling, jogging, and swimming, while mind-body exercise involved yoga, tai chi, baduanjin, and Wushu qigong. Definitions for each intervention modality are provided in [Supplementary Material S2](#). Outcome indicators included BMI, lipid metabolism indicators, and liver function markers. Lipid metabolism indicators comprised TC, HDL-C, TG, and LDL-C. Liver function markers included GGT, AST, and ALT. Extracted data were presented as mean \pm standard deviation (SD) before and after the intervention. Data presented as median and quartiles were converted to mean \pm SD.

We conducted a comprehensive assessment of potential biases in the included studies using the risk of bias assessment tool recommended in the Cochrane Handbook 5.1.0 ([Higgins et al., 2011](#)). Data extraction and risk assessment were independently performed by two individuals. To maintain objectivity, any discrepancies during the screening process were resolved through discussion with a third researcher.

2.4 Statistical analysis

A frequency-based network meta-analysis of outcome indicators was conducted using Stata 17.0 software. For continuous variables, the mean difference (MD) was estimated via network meta-analysis. Given the consistency of outcome indicator units, MD and SD were used to calculate indicators. All meta-analysis results are thoroughly detailed in the results section. Network plots for various outcome indicators were constructed using the “network” command, where nodes represent different intervention methods. Node size correlates with the sample size of each treatment method, with larger nodes denoting greater sample sizes. The thickness of the lines between nodes indicates the number of studies, whereas thicker lines signify more studies. The SUCRA was used to determine the probability ranking of different exercise patterns as the optimal intervention method. A higher SUCRA value indicates a higher probability that a specific intervention will be the most effective ([Rücker and Schwarzer, 2015](#)).

Comparative funnel plots were used to assess publication bias. In cases where closed loops were present, inconsistency tests were conducted. When the inconsistency tests yielded $p < 0.05$, significant inconsistencies between direct and indirect comparison results were noted. Two levels of inconsistency assessment were conducted: global and local. Overall inconsistency was evaluated first, followed by node-splitting methods to assess local inconsistencies. The global I^2 statistic was used to evaluate heterogeneity; values exceeding 75% indicated substantial heterogeneity. A random-effects network meta-analysis model was used in cases of high heterogeneity, while a fixed-effect model was employed for lower heterogeneity.

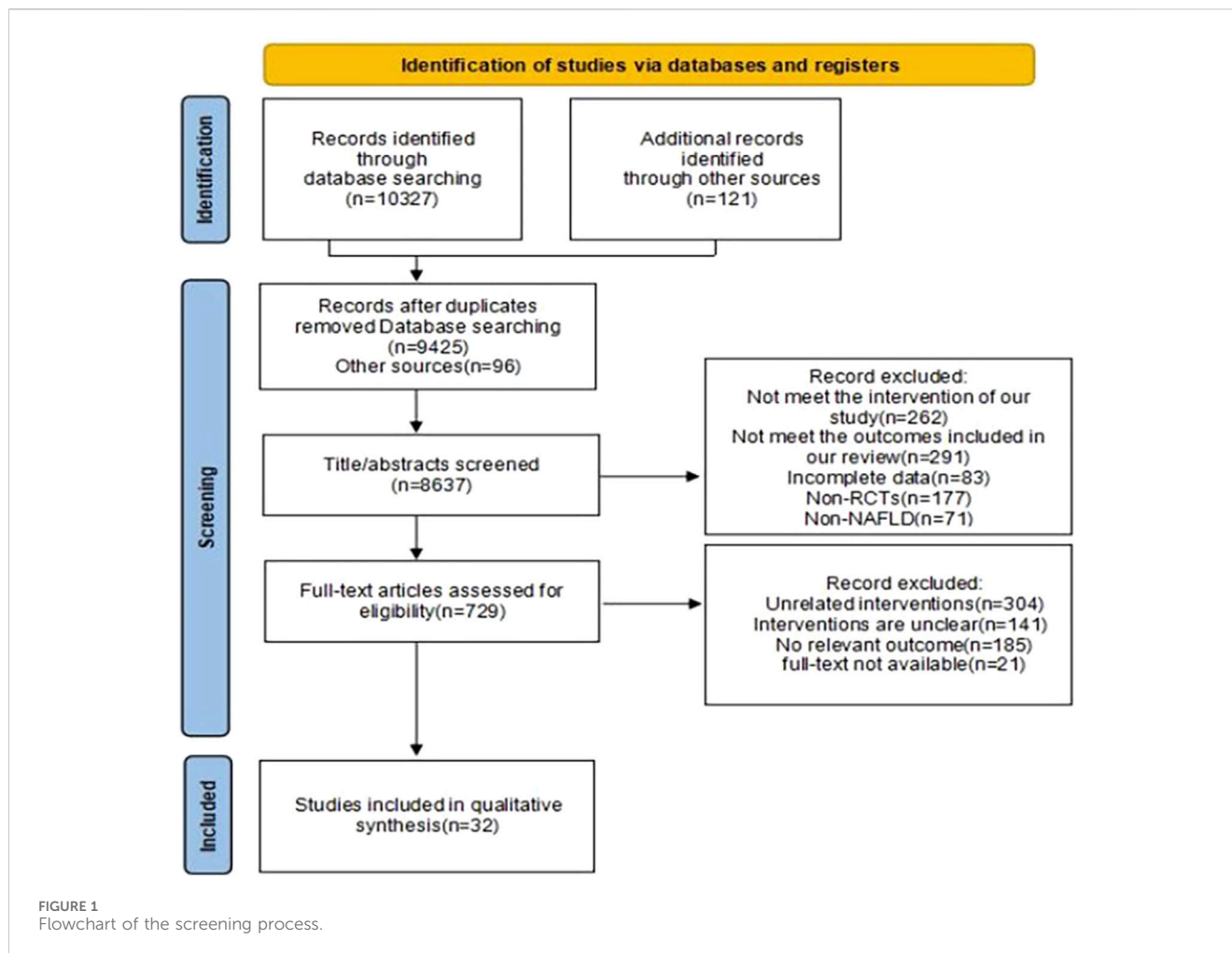
3 Results

3.1 Search results

Our search identified 10,448 articles. Through processes including duplicate removal, abstract reviews, and full-text examinations, we excluded studies that failed to meet our inclusion criteria. Ultimately, 28 studies fulfilling the eligibility requirements were selected for analysis. The specific retrieval process is depicted in [Figure 1](#). Of these, four studies compared two distinct exercise interventions ([Cai, 2023](#); [Fu et al., 2018](#); [Yang, 2016](#); [Winn et al., 2018](#)). These studies were grouped into two separate groups, A and B, resulting in a total of 32 interventions, though the number of articles analyzed remained at 28. The included studies comprised 23 on aerobic exercise, six on resistance exercise, five on HIIT, and three on mind-body exercises. This collection included two studies comparing aerobic to resistance exercises, two comparing aerobic to HIIT, and one comparing aerobic to mind-body exercises. In total, 1,606 participants were involved in the included trials, with only two studies having a duration of less than 8 weeks. The basic characteristics of the included studies are presented in [Table 1](#).

3.2 Risk of bias

This investigation incorporated 28 RCTs. Among these, 22 studies clearly described the methods used for generating



random sequences, and two studies implemented appropriate allocation concealment. On participants and personnel blinding, considering the nature and type of interventions, blinding of participants and controllers was challenging; however, an overall assessment indicated a generally low risk of bias (refer to [Figure 2](#)). Risk of bias in individual studies in [Supplementary Material S3](#).

3.3 Network meta-analysis

[Figure 3](#) illustrates the network relationships among four types of exercise interventions and a control intervention. In the diagram, “A” represents aerobic exercise, “B” denotes no intervention, “C” signifies resistance exercise, “D” stands for HIIT, and “E” indicates mind-body exercise. Each intervention type is represented by a node, with lines connecting these nodes to depict direct comparisons made in studies. The absence of a line between any two nodes suggests no direct comparative research exists for these specific interventions within the reviewed literature. The size of each node reflects the number of studies associated with each intervention type, with larger nodes indicating a greater number of studies. Similarly, the thickness of the lines between two nodes correlates with the number of studies directly comparing these interventions.

3.3.1 Effects of exercise interventions on BMI

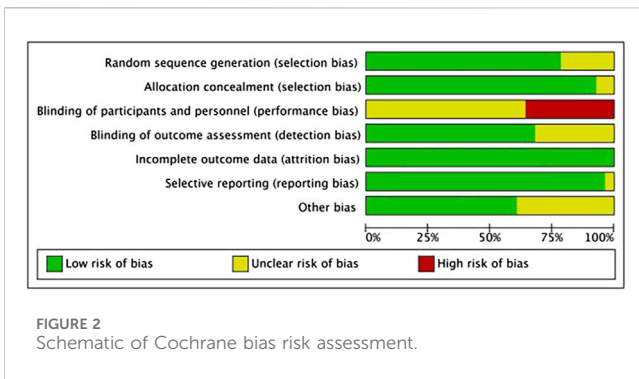
28 studies were included in this meta-analysis to investigate the effects of various interventions on the BMI of patients diagnosed with NAFLD. The findings from pairwise meta-analyses indicated that, compared to the control group, aerobic exercise (−0.72, 95% CI: −0.98 to −0.46; $p < 0.05$), HIIT (−0.65, 95% CI: −1.09 to −0.20; $p < 0.05$) were associated with significant improvements in BMI among NAFLD patients’ post-intervention. However, the effect of mind-body exercise (−0.26, 95% CI: −1.15 to 0.63; $p > 0.05$), and resistance exercise (−0.51, 95% CI: −1.37 to 0.35; $p > 0.05$) on BMI was not statistically significant. Furthermore, the SUCRA analysis, based on the consistency model, revealed that aerobic exercise SUCRA scores of 79.8, and HIIT SUCRA scores of 69.0 exhibited superior efficacy in improving BMI among NAFLD patients, while mind-body exercise SUCRA scores of 27.2, and resistance exercise SUCRA scores of 63.8 ranked the low in terms of effectiveness [Table 2](#) and [Figure 4](#)). These results suggest that aerobic exercise may be more beneficial for managing BMI in NAFLD patients compared to mind-body exercise.

Moreover, the Wald test for inconsistency in the network did not yield significant results, indicating the absence of inconsistency among the included studies. Additionally, funnel plots did not reveal any evident bias ([Figure 5](#)).

TABLE 1 Basic characteristics of the included literature.

| Author (year) | Control group | | | | Experiment group | | | | Duration (week) | Outcomes |
|------------------------------------|---------------|----------------|-------------------|-----------------------------|------------------|----------------|-----------------------|-----------------------------|-----------------|----------|
| | Number | Age | Intervention type | Intensity | Number | Age | Intervention type | Intensity | | |
| Wang et al. (2023) | 21 | 19.33 ± 1.35 | Aerobic | 60% –70%HR max | 22 | 19.50 ± 1.44 | HIIT | 90% –95%HRmax | 8 | ①②③④⑤ |
| Yang et al. (2015) | 48 | 48.4 ± 4.8 | No intervention | — | 48 | 47.1 ± 3.9 | Aerobic | Low to moderate intensity | 24 | ①②③④⑤ |
| Tan et al. (2015) | 19 | 46–59 | No intervention | — | 18 | 46–59 | Aerobic | FATmax | 24 | ①②③④⑤ |
| Liu et al. (2014) | 22 | 12.87 ± 1.46 | Medication | — | 22 | 13.02 ± 1.73 | Medication Aerobic | 140–160bpm/min | 12 | ①②③④⑤⑥⑦ |
| Peng et al. (2022) | 27 | 21.8 ± 0.8 | No sports | — | 27 | 21.3 ± 1.0 | Dietary Aerobic | FATmax | 12 | ①②③④⑤⑥⑦⑧ |
| Liu et al. (2019) | 30 | 61.5 ± 8.2 | Medication | — | 30 | 60.5 ± 8.5 | Medication Aerobic | Moderate intensity | 16 | ②③④⑤⑦ |
| Wang (2006) | 29 | 49.17 ± 8.71 | No sports | — | 42 | 51.93± 7.68 | Aerobic | 40%–60%HRmax | 12 | ①②③④⑤ |
| Babu et al. (2022) | 22 | 56.7 ± 10.7 | No intervention | — | 20 | 59.9 ± 9.8 | HIIT | 85% VO ₂ max | 12 | ①②③④⑤⑥⑦⑧ |
| Cuthbertson et al. (2016) | 31 | 46–59 | No intervention | — | 38 | 46–58 | Aerobic | 30%–60%HRR | 16 | ①②③④⑤⑥⑦⑧ |
| Charatcharoenwittaya et al. (2021) | 19 | 37.4 ± 1.9 | Aerobic | 60%–70% HRmax | 19 | 38.2 ± 2.2 | Resistance | 60% 1RM | 12 | ①②③④⑤⑥⑦⑧ |
| De Piano et al. (2012) | 14 | 15–19 | Aerobic | 50%–70% VO ₂ max | 14 | 15–19 | Resistance | Low to moderate intensity | 48 | ①②③④⑤⑥⑦⑧ |
| Abdelbasset et al. (2019) | 16 | 55.2 ± 4.3 | Medication | — | 16 | 54.4 ± 5.8 | HIIT | 80%–85%VO ₂ max | 8 | ②④⑤⑦ |
| Sullivan et al. (2012) | 6 | 47.5 ± 3.1 | No intervention | — | 12 | 48.6 ± 2.2 | Aerobic | Low to moderate intensity | 16 | ①②③④⑤⑥⑦ |
| Sánchez-Muñoz (2013) | 8 | 25–60 | Medication | — | 8 | 25–60 | Aerobic | 60–85%HRmax | 12 | ①②③④⑤⑥⑦ |
| Pugh et al. (2013) | 6 | 50 ± 3 | Routine nursing | — | 5 | 50 ± 3 | Aerobic | Moderate intensity | 16 | ①②③④⑤⑥⑦⑧ |
| Pugh et al. (2014) | 8 | 47.0 ± 2.2 | Routine nursing | — | 13 | 48.2 ± 2.1 | Aerobic | Moderate intensity | 16 | ①②③④⑤⑥⑦⑧ |
| Rezende et al. (2016) | 21 | 54.5 ± 8.9 | No intervention | — | 19 | 56.2 ± 7.8 | Aerobic | Moderate intensity | 24 | ①②③④⑤⑥⑦⑧ |
| Shojaee-Moradie et al. (2016) | 12 | 52.8 ± 3.0 | Lifestyle advice | — | 15 | 52.4 ± 2.2 | Aerobic | 40–60%HRmax | 16 | ①②③④⑤⑥⑦⑧ |
| Dong et al. (2016) | 130 | 57.94 ± 5.71 | No intervention | — | 130 | 56.68 ±5.33 | Aerobic | 60%–80% target heart rate | 12 | ①②③④⑤⑥⑦⑧ |
| Zelber-Sagi et al. (2014) | 31 | 46.6 ± 11.4 | Home stretching | — | 33 | 46.32 ± 10.32 | Resistance | Moderate intensity | 12 | ①②③④⑤⑥⑦⑧ |
| Zhu et al. (2020) | 48 | 45 ± 3 | Medication | — | 48 | 44 ± 4 | Medication Mind-body | 30%–50% VO ₂ max | 12 | ②③④⑤⑥⑦⑧ |
| Zhu (2022) | 30 | 47.6 ± 12.38 | Aerobic | 60%–70% HRmax | 30 | 45.96 ± 12.82 | Mind-body | 30%–50% VO ₂ max | 12 | ②③⑥⑦ |
| Pang and Jin (2023) | 30 | 62.0± 13.46 | Medication | — | 30 | 61.25 ± 14.65 | Medication Mind-body | 30%–50% VO ₂ max | 12 | ②③⑥⑦⑧ |
| Cai (2023) A | 6 | 52.33 ± 9.69 | Dietary control | — | 6 | 53.17 ± 9.24 | Aerobic | FATmax | 12 | ①②③④⑤⑥⑦⑧ |

(Continued on following page)



high-intensity regimens have also been shown to decrease BMI (Zhu et al., 2020), aerobic exercise remains the focus of most research concerning NAFLD interventions. Moreover, aerobic exercise has demonstrated superior effects in ameliorating BMI and other NAFLD-related metrics such as glycated hemoglobin, resting blood pressure, and serum cholesterol levels (Kelley and Kelley, 2008). It also increases serum high-molecular-weight adiponectin, which influences insulin resistance and subsequently NAFLD (Haus et al., 2013). Moreover, compared to resistance exercise, aerobic exercise has a greater effect on reducing intrahepatic lipid content in patients with NAFLD (Orci et al., 2016; Slentz et al., 2011). Therefore, this study suggests that patients with NAFLD use aerobic exercise as a means of reducing BMI.

Our research indicates that resistance exercise is particularly effective in improving LDL-C levels. The likely mechanism underlying this benefit involves the enhancement of LDL receptor activity on hepatocyte membranes. This improvement in receptor activity increases the blood's capacity to transport LDL-C, thereby lowering its concentration in the bloodstream (Chen et al., 2005). Furthermore, resistance exercise may facilitate the secretion of cytokines, known as myokines, from skeletal muscles. These myokines interact with various organs to mediate metabolic

processes (Benatti and Pedersen, 2015; Karstoft and Pedersen, 2016). Notably, the secretion of myokine Irisin during resistance exercise is associated with the induction of browning in subcutaneous fat cells, which enhances thermogenesis and energy expenditure (Boström et al., 2012). Kim et al. (2016) observed a significant increase in circulating Irisin levels during resistance exercises, with negligible changes in aerobic exercises, highlighting Irisin's potential role in improving NAFLD outcomes. Additionally, exercise may enhance insulin sensitivity and upregulate LDL-C mRNA expression, thereby accelerating LDL-C metabolism (Young and Stout, 1987). In line with previous findings, regular exercise has been shown to improve LDL-C markers in patients with NAFLD (Fu et al., 2018).

HIIT, which alternates between high-intensity exercise and lower-intensity recovery periods. Our findings indicate that HIIT is most effective in improving HDL-C levels. Previous studies have identified exercise intensity as a significant factor in the variations observed in HDL-C levels (Gao et al., 2021). Notably, studies reporting significant differences in HDL-C levels between control and experimental groups also observed higher exercise intensities (Wang et al., 2020). Despite these benefits, we recommend that individuals select an exercise regimen that is manageable over the long term. HIIT, while beneficial, may not be suitable for all populations, particularly the elderly, due to its demanding nature. This study has yielded a novel finding: mind-body exercises demonstrate superior efficacy in improving liver function markers (AST, ALT, GGT) and certain lipid metabolism indicators (TC, TG) compared to three other forms of exercise.

Most of the Mind-body exercises belong to low-intensity aerobic exercises such as yoga, tai chi, and baduanjin. In addition to its ability to increase energy expenditure and promote fat metabolism, a unique aspect of mind-body exercise is that it focuses on the unity of mind and body integrating physical movement with psychological processes. Exercise has been shown to reduce levels of TC and TG (Yu et al., 2017; Costa et al., 2020), yet the underlying mechanisms remain unclear. Some studies suggest that exercise increases the

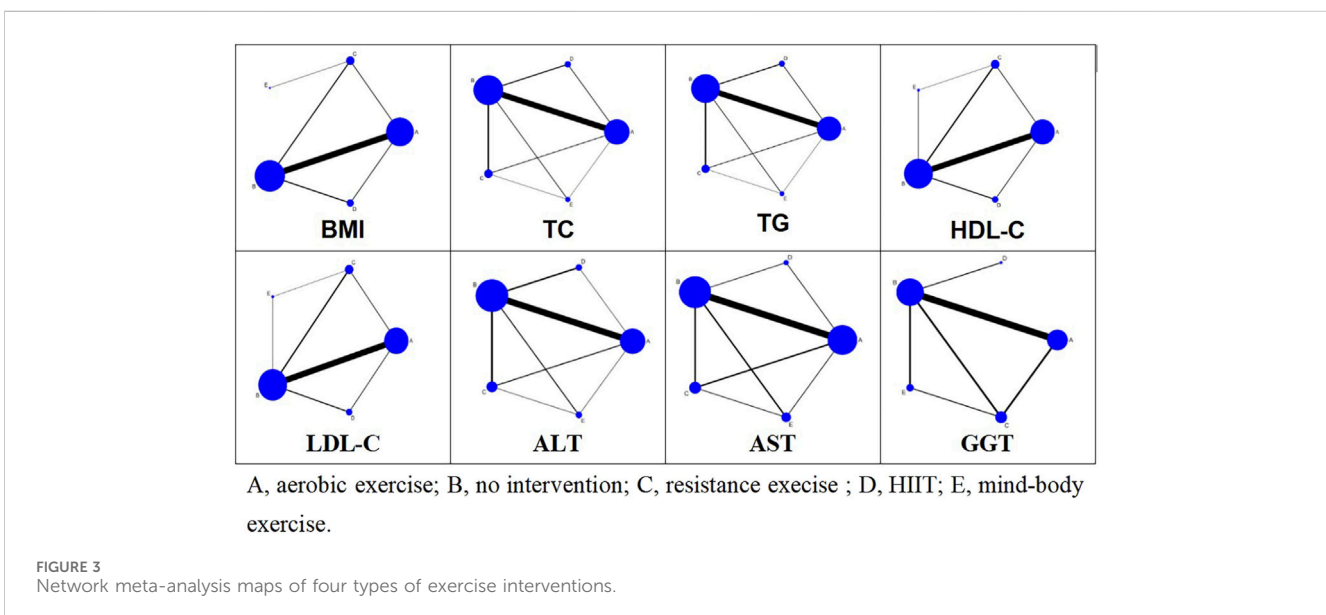


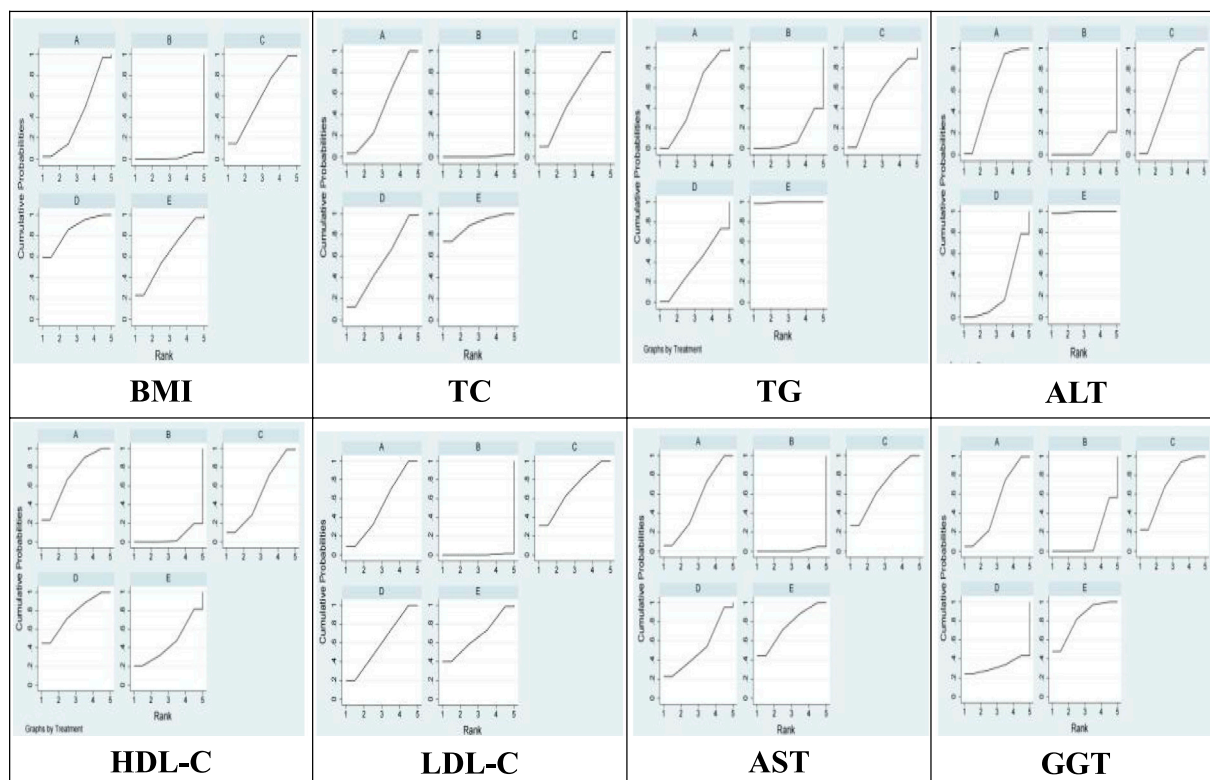
TABLE 2 Basic characteristics of the included literature.

| Treatment type | Comparison to no treatment | | Best | Worst | SUCRA(%) |
|---------------------|----------------------------|---------|------|-------|----------|
| | SMD (95% CI) | P-Value | | | |
| BMI | | | | | |
| Aerobic exercise | -0.7 (-0.98, -0.46) | <0.05 | 44.9 | 0.0 | 79.8 |
| Resistance exercise | -0.51 (-1.37, 0.35) | >0.05 | 27.1 | 0.1 | 63.8 |
| HIIT | -0.6 (-1.09, -0.20) | <0.05 | 27.5 | 0.1 | 69.0 |
| Mind-body exercise | -0.26 (-1.15, 0.63) | >0.05 | 0.5 | 28.6 | 27.2 |
| TC | | | | | |
| Aerobic exercise | -0.3 (-0.55, -0.16) | <0.05 | 3.4 | 0.0 | 47.5 |
| Resistance exercise | -0.41 (-0.74, -0.08) | <0.05 | 10.0 | 0.8 | 57.5 |
| HIIT | -0.39 (-0.74, -0.04) | <0.05 | 12.6 | 1.4 | 54.7 |
| Mind-body Exercise | -0.67 (-1.10, -0.24) | <0.05 | 74.0 | 0.1 | 89.7 |
| TG | | | | | |
| Aerobic exercise | -0.33 (-0.72, 0.05) | >0.05 | 0.1 | 2.7 | 50.2 |
| Resistance exercise | -0.41 (-0.74, -0.08) | <0.05 | 0.7 | 10.5 | 52.2 |
| HIIT | -0.39 (-0.74, -0.04) | <0.05 | 0.8 | 26.6 | 36.5 |
| Mind-body exercise | -0.67 (-1.10, -0.24) | <0.05 | 98.4 | 0.0 | 99.6 |
| HDL-C | | | | | |
| Aerobic exercise | 0.67 (0.24, 1.10) | <0.05 | 23.9 | 0.0 | 70.3 |
| Resistance exercise | 0.08 (0.00, 0.16) | <0.05 | 10.4 | 1.1 | 52.7 |
| HIIT | 0.12 (0.04, 0.20) | <0.05 | 44.8 | 0.3 | 76.1 |
| Mind-body exercise | 0.07 (-0.08, 0.22) | >0.05 | 20.9 | 18.4 | 45.6 |
| LDL-C | | | | | |
| Aerobic exercise | -0.16 (-0.24, 0.09) | >0.05 | 8.9 | 0.0 | 52.6 |
| Resistance exercise | -0.20 (-0.33, -0.06) | <0.05 | 31.2 | 0.1 | 69.3 |
| HIIT | 0.04 (-0.07, 0.15) | >0.05 | 19.9 | 0.1 | 60.0 |
| Mind-body exercise | -0.01 (-0.15, 0.13) | <0.05 | 40.0 | 1.4 | 67.7 |
| ALT | | | | | |
| Aerobic exercise | -5.98 (-9.05, -2.91) | <0.05 | 0.8 | 0.0 | 62.1 |
| Resistance exercise | -5.66 (-9.93, -1.39) | <0.05 | 0.8 | 0.3 | 58.0 |
| HIIT | -2.03 (-7.08, 3.01) | >0.05 | 0.1 | 21.3 | 25.0 |
| Mind-body exercise | -12.56 (-17.54,-7.58) | <0.05 | 98.3 | 0.0 | 99.5 |
| AST | | | | | |
| Aerobic exercise | -6.23 (-9.47, -3.00) | <0.05 | 6.3 | 0.0 | 52.2 |
| Resistance exercise | -7.33 (-11.95, -2.72) | <0.05 | 26.9 | 0.1 | 67.9 |
| HIIT | -5.97 (-12.95, 1.02) | >0.05 | 22.7 | 4.7 | 52.5 |
| Mind-body exercise | -8.07 (-12.88, -3.25) | <0.05 | 44.1 | 0.1 | 76.1 |
| GGT | | | | | |
| Aerobic exercise | -8.18 (-14.2, -2.13) | <0.05 | 5.2 | 0.2 | 50.5 |

(Continued on following page)

TABLE 2 (Continued) Basic characteristics of the included literature.

| Treatment type | Comparison to no treatment | | Best | Worst | SUCRA(%) |
|---------------------|----------------------------|---------|------|-------|----------|
| | SMD (95% CI) | P-Value | | | |
| Resistance exercise | -11.85 (-19.84,-3.87) | <0.05 | 22.8 | 0.0 | 71.1 |
| HIIT | 3.60 (-50.80, 58.00) | >0.05 | 24.2 | 56.4 | 32.4 |
| Mind-body exercise | -13.77 (-22.00,-5.54) | <0.05 | 47.8 | 0.0 | 81.8 |



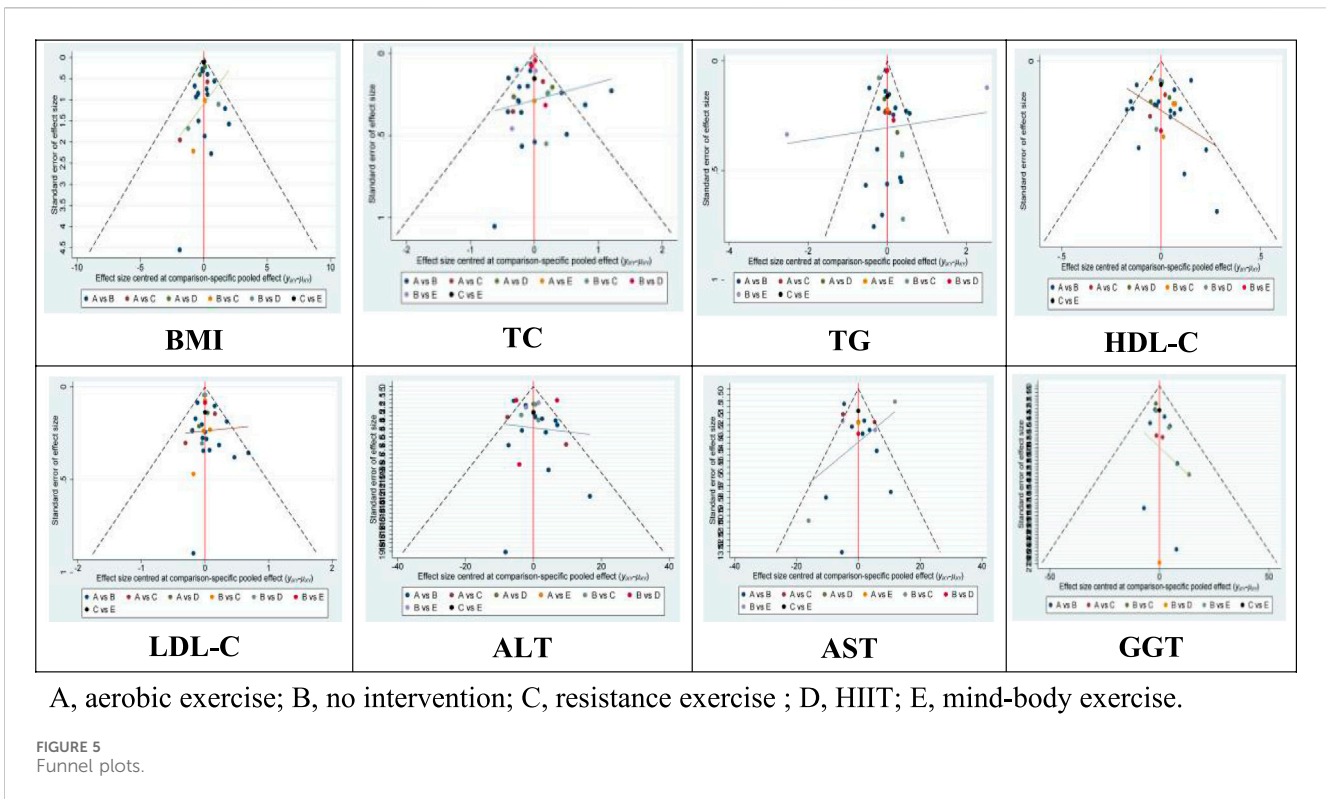
A, aerobic exercise; B, no intervention; C, resistance exercise ; D, HIIT; E, mind-body exercise.

FIGURE 4 SUCRA ranking chart.

activity of lipolytic enzymes and accelerates the rate of breakdown into mitochondrial energy supply (Bianchi et al., 2021), while others associate it with adipocyte factors such as leptin and adiponectin (Izadi et al., 2013). However, the means by which exercise improves adipose factors are not yet clear, necessitating further research for confirmation. AST, ALT, and GGT are critical markers for identifying liver function and are closely related to NAFLD. Studies reporting improvements in ALT, AST, and GGT through exercise align with our findings (Mascaró et al., 2022; Gao et al., 2021).

In addition to exercise interventions, other methods such as dietary management and pharmacological treatments are effective strategies for managing NAFLD. Controlling intake is a crucial

aspect of dietary intervention. When the body consumes excessive amounts of saturated and unsaturated fatty acids, there is a significant impact on hepatic fat accumulation (Rosqvist et al., 2014). However, there remains ongoing debate regarding optimal dietary composition and patterns for NAFLD management (El-agroudy et al., 2019; Moore et al., 2020). Pharmacological treatments predominantly target disease-related pathways, including pathogenic factors and associated metabolic disorders (Rong et al., 2023). Due to the complex pathogenesis of NAFLD, specific pharmacological treatments are still lacking (Rong et al., 2023; Romero-Gómez et al., 2017). Compared to these interventions, exercise appears more favorable, as most RCTs have demonstrated that exercise confers significant benefits for



NAFLD (Nassir, 2022). Studies have shown that exercise reduces hepatic steatosis, improves metabolic function, and ameliorates fibrosis (Huber et al., 2019; O’Gorman et al., 2020). Various studies have explored the underlying mechanisms of exercise in NAFLD management. Some research suggests that exercise regulates hepatic fatty acid synthesis and oxidation, as well as mitochondrial structure, thereby preventing liver damage (Oh et al., 2021; Rector et al., 2011; Thyfault and Rector, 2020). Additionally, exercise has been found to improve hepatic inflammation, partly by increasing sirtuin (SIRT) activity (Bianchi et al., 2021). Furthermore, exercise enhances peripheral insulin sensitivity, which in turn reduces hepatic lipogenesis (Cuthbertson et al., 2016). Beyond these physiological mechanisms, the psychological benefits of exercise have also been explored. Physical and mental exercises, such as tai chi and Yoga, can reduce anxiety, depression, and stress (Dong et al., 2024). Consequently, some studies suggest that such exercises may improve NAFLD progression by alleviating stress and anxiety, improving insulin sensitivity and hepatic fat accumulation (Shomaker et al., 2010), and regulating hormone levels, including reducing cortisol (Targher et al., 2006). However, in clinical practice, NAFLD patients often demonstrate low readiness for behavioral change and may lack motivation to adopt healthier lifestyles (Centis et al., 2013). Moreover, long and demanding exercise regimens may pose adherence challenges for these patients.

In summary, the reason mind-body exercises excel in improving liver function and lipid profile markers in NAFLD may be due to their comprehensive action on both the physical and psychological levels, promoting health through various mechanisms including but not limited to stress management, psychological health improvement, endocrine and metabolic function regulation, as

well as enhanced antioxidative and anti-inflammatory effects. This suggests that a holistic treatment approach may be more effective than singular exercise modalities in managing metabolic diseases like NAFLD. Therefore, we recommend incorporating mind-body exercise as a viable exercise modality in the treatment of NAFLD, and can also be combined with diet as an adjunct to the treatment of NAFLD.

5 Limitations and future direction

There are several noteworthy limitations in this study. Firstly, the study compared different types of exercise without strict regulations regarding exercise volume, intensity, duration, and age. The inconsistency in the methods of measuring exercise intensity across the studies and the lack of standardization may introduce a certain degree of bias to the results. Furthermore, the study encompassed research that investigated the combined effects of medication and exercise interventions. This aspect raises the possibility of synergistic effects influencing the outcomes, thereby introducing an additional layer of complexity and potential bias in interpreting the results. The final limitation arises from the specific geographic region; for instance, the mind-body exercises included in this study all originate from Asia. This is mainly due to the fact that mind-body exercises originated in Asia. However, this inadvertently increases the potential influence of cultural, genetic, and environmental factors on exercise interventions. It is important to note that the prevalence of NAFLD also varies significantly across different geographic regions. In light of these considerations, it is essential to approach the study’s conclusions

with a degree of caution. This is because they may pose challenges to the overall validity and reliability of the study's results.

To mitigate biases, future investigations should establish more stringent requirements for various exercise types. Further research is also needed to determine whether these findings can be replicated in different racial populations to understand potential race-specific responses to different exercise modalities. Additionally, combining different exercise modalities or integrating them with pharmacological interventions could provide deeper insights into their effects on NAFLD patients. Finally, there is a need for more in-depth research and exploration of the potential mechanisms underlying the therapeutic effects of different exercise modalities on NAFLD.

6 Conclusion

Our network meta-analysis revealed that aerobic exercise significantly enhances BMI in individuals with NAFLD, resistance exercise was found to be particularly effective in improving LDL-C, whereas HIIT markedly boosts HDL-C. Additionally, mind-body exercises were superior in enhancing TC, TG, and key liver function parameters (AST, ALT, GGT). Based on these findings, it is recommended that NAFLD patients incorporate mind-body exercises into their treatment regimen to optimize health outcomes.

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

MH: Writing–review and editing, Writing–original draft, Visualization, Validation, Software, Resources, Project

References

- Abdelbasset, W. K., Tantawy, S. A., Kamel, D. M., Alqahtani, B. A., Elnegamy, T. E., Soliman, G. S., et al. (2020). Effects of high-intensity interval and moderate-intensity continuous aerobic exercise on diabetic obese patients with nonalcoholic fatty liver disease: a comparative randomized controlled trial. *Medicine* 99 (10), e19471. doi:10.1097/MD.00000000000019471
- Abdelbasset, W. K., Tantawy, S. A., Kamel, D. M., Alqahtani, B. A., and Soliman, G. S. (2019). A randomized controlled trial on the effectiveness of 8-week high-intensity interval exercise on intrahepatic triglycerides, visceral lipids, and health-related quality of life in diabetic obese patients with nonalcoholic fatty liver disease. *Medicine* 98 (12), e14918. doi:10.1097/MD.00000000000014918
- Babu, A. F., Csader, S., Männistö, V., Tauriainen, M. M., Pentikäinen, H., Savonen, K., et al. (2022). Effects of exercise on NAFLD using non-targeted metabolomics in adipose tissue, plasma, urine, and stool. *Sci. Rep.* 12 (1), 6485. doi:10.1038/s41598-022-10481-9
- Benatti, F. B., and Pedersen, B. K. (2015). Exercise as an anti-inflammatory therapy for rheumatic diseases—myokine regulation. *Nat. Rev. Rheumatol.* 11 (2), 86–97. doi:10.1038/nrrheum.2014.193
- Bianchi, A., Marchetti, L., Hall, Z., Lemos, H., Vacca, M., Paish, H., et al. (2021). Moderate exercise inhibits age-related inflammation, liver steatosis, senescence, and tumorigenesis. *J. Immunol.* 206 (4), 904–916. doi:10.4049/jimmunol.2001022
- Boström, P., Wu, J., Jedrychowski, M. P., Korde, A., Ye, L., Lo, J. C., et al. (2012). A PGC1- α -dependent myokine that drives brown-fat-like development of white fat and thermogenesis. *Nature* 481 (7382), 463–468. doi:10.1038/nature10777
- Cai, Y. L. (2023). A 12-week study of the effects of different modalities of exercise intervention on patients with non-alcoholic fatty liver disease. Capital University of Physical Education and Sports. doi:10.27340/d.cnki.gstxy.2023.000157
- Camhi, S. M., Bray, G. A., Bouchard, C., Greenway, F. L., Johnson, W. D., Newton, R. L., et al. (2011). The relationship of waist circumference and BMI to visceral, subcutaneous, and total body fat: sex and race differences. *Obesity* 19 (2), 402–408. doi:10.1038/oby.2010.248
- Centis, E., Moscattello, S., Bugianesi, E., Bellentani, S., Fracanzani, A. L., Calugi, S., et al. (2013). Stage of change and motivation to healthier lifestyle in non-alcoholic fatty liver disease. *J. hepatology* 58 (4), 771–777. doi:10.1016/j.jhep.2012.11.031
- Charatcharoenwitthaya, P., Kuljiratitikal, K., Aksornchanya, O., Chaiyasoot, K., Bandidniyamanon, W., and Charatcharoenwitthaya, N. (2021). Moderate-intensity aerobic vs resistance exercise and dietary modification in patients with nonalcoholic fatty liver disease: a randomized clinical trial. *Clin. Transl. Gastroenterology* 12 (3), e00316. doi:10.14309/ctg.00000000000000316

administration, Methodology, Investigation, Data curation, Conceptualization. JY: Writing–review and editing, Writing–original draft, Software, Project administration, Methodology, Investigation, Formal Analysis, Data curation, Conceptualization. YW: Writing–original draft, Visualization, Software, Project administration, Methodology, Investigation, Data curation. JW: Writing–review and editing, Writing–original draft, Validation, Supervision, Resources, Project administration, Investigation, Data curation, Conceptualization.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

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

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fphys.2024.1428723/full#supplementary-material>

- Chen, W., Penumetcha, M., Santanam, N., Liu, Y. G., and Parthasarathy, S. (2005). Exercise might favor reverse cholesterol transport and lipoprotein clearance: potential mechanism for its anti-atherosclerotic effects. *Biochim. Biophys. Acta.* 1723, 124–127. doi:10.1016/j.bbagen.2005.03.005
- Chun, H. S. (2023). Aerobic and resistance exercise: synergistic influence for nonalcoholic fatty liver disease. *Gut Liver* 17 (4), 485–486. doi:10.5009/gnl230236
- Costa, R. R., Barroso, B. M., Reichert, T., Vieira, A. F., and Kruehl, L. F. M. (2020). Effects of supervised exercise training on lipid profile of children and adolescents: systematic review, meta-analysis and meta-regression. *Sci. and Sports* 35 (6), 321–329. doi:10.1016/j.scispo.2020.02.007
- Cuthbertson, D. J., Shojaae-Moradie, F., Sprung, V. S., Jones, H., Pugh, C. J., Richardson, P., et al. (2016). Dissociation between exercise-induced reduction in liver fat and changes in hepatic and peripheral glucose homeostasis in obese patients with non-alcoholic fatty liver disease. *Clin. Sci.* 130 (2), 93–104. doi:10.1042/CS20150447
- Daniels, S. R. (2009). The use of BMI in the clinical setting. *Pediatrics* 124 (Suppl. ment_1), S35–S41. doi:10.1542/peds.2008-3586F
- De Piano, A., de Mello, M. T., Sanches, P. D. L., da Silva, P. L., Campos, R. M., Carnier, J., et al. (2012). Long-term effects of aerobic plus resistance training on the adipokines and neuropeptides in nonalcoholic fatty liver disease obese adolescents. *Eur. J. gastroenterology and hepatology* 24 (11), 1313–1324. doi:10.1097/MEG.0b013e32835793ac
- Ding, Z., Bu, L., Lu, H., et al. (2017). Correlation of liver fat content with serum vitamin A level and insulin resistance in patients with nonalcoholic fatty liver disease. *J. Clin. Hepatology* 33 (12), 2361–2365.
- Dong, F., Zhang, Y., Huang, Y., Wang, Y., Zhang, G., Hu, X., and Bao, Z. (2016). Long-term lifestyle interventions in middle-aged and elderly men with nonalcoholic fatty liver disease: a randomized controlled trial. *Scientific reports*, 6(1), 36783.
- Dong, Y., Zhang, X., Zhao, R., Cao, L., Kuang, X., and Yao, J. (2024). The effects of mind-body exercise on anxiety and depression in older adults: a systematic review and network meta-analysis. *Frontiers in psychiatry*. 15, 1305295.
- El-agroudy, N. N., Kurzbach, A., Rodionov, R. N., O'Sullivan, J., Roden, M., Birkenfeld, A. L., et al. (2019). Are lifestyle therapies effective for NAFLD treatment? *Trends Endocrinol. Metab.* 30, 701–709. doi:10.1016/j.tem.2019.07.013
- Estes, C., Anstee, Q. M., Arias-Loste, M. T., Bantel, H., Bellentani, S., Caballeria, J., et al. (2018). Modeling nafld disease burden in China, France, Germany, Italy, Japan, Spain, United Kingdom, and United States for the period 2016–2030. *J. hepatology* 69 (4), 896–904. doi:10.1016/j.jhep.2018.05.036
- Fan, J. G., Jia, J. D., Li, Y. M., Wang, B. Y., Lu, L. G., Shi, J. P., and Chinese Association for the Study of Liver Disease, (2011). Guidelines for the diagnosis and management of nonalcoholic fatty liver disease: update 2010: (published in Chinese on Chinese Journal of Hepatology 2010; 18:163-166). *J. Dig. Dis.* 12 (1), 38–44. (published in Chinese on Chinese Journal of Hepatology 2010; 18. doi:10.1111/j.1751-2980.2010.00476.x
- Feng, G., Feng, L., and Zhao, Y. (2020). Association between ratio of γ -glutamyl transpeptidase to high-density lipoprotein cholesterol and prevalence of nonalcoholic fatty liver disease and metabolic syndrome: a cross-sectional study. *Ann. Transl. Med.* 8 (10), 634. doi:10.21037/atm-19-4516
- Fu, Y. Y., Meng, M. M., Rong, N., Liu, L., Zhang, J., Chen, S. H., et al. (2018). Study on the effect of aerobic exercise and resistance exercise on patients with non-alcoholic fatty liver disease. *J. Nanjing Med. Univ. Nat. Sci. Ed.* (04), 528–531. doi:10.7655/NYDXBNS20180422
- Gao, Y., Lu, J., Liu, X., Liu, J., Ma, Q., Shi, Y., et al. (2021). Effect of long-term exercise on liver lipid metabolism in Chinese patients with NAFLD: a systematic review and meta-analysis. *Front. physiology* 12, 748517. doi:10.3389/fphys.2021.748517
- Ha, Y., Chon, Y. E., Kim, M. N., Lee, J. H., and Hwang, S. G. (2022). Gamma-glutamyl transpeptidase dynamics as a biomarker for advanced fibrosis in non-alcoholic fatty liver disease. *J. Gastroenterology Hepatology* 37 (8), 1624–1632. doi:10.1111/jgh.15871
- Hashida, R., Kawaguchi, T., Bekki, M., Omoto, M., Matsuse, H., Nago, T., et al. (2017). Aerobic vs. resistance exercise in non-alcoholic fatty liver disease: a systematic review. *J. hepatology* 66 (1), 142–152. doi:10.1016/j.jhep.2016.08.023
- Haus, J. M., Solomon, T. P., Kelly, K. R., Fealy, C. E., Kullman, E. L., Scelsi, A. R., et al. (2013). Improved hepatic lipid composition following short-term exercise in nonalcoholic fatty liver disease. *J. Clin. Endocrinol. and Metabolism* 98 (7), E1181–E1188. doi:10.1210/jc.2013-1229
- Healy, G. N., Dunstan, D. W., Salmon, J., Cerin, E., Shaw, J. E., Zimmet, P. Z., et al. (2008). Breaks in sedentary time: beneficial associations with metabolic risk. *Diabetes care* 31 (4), 661–666. doi:10.2337/dc07-2046
- Hejazi, K., and Hackett, D. (2023). Effect of exercise on liver function and insulin resistance markers in patients with non-alcoholic fatty liver disease: a systematic review and meta-analysis of randomized controlled trials. *J. Clin. Med.* 12 (8), 3011. doi:10.3390/jcm12083011
- Higgins, J. P., Altman, D. G., Gotzsche, P. C., Jüni, P., Moher, D., Oxman, A. D., et al. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *Bmj* 343, d5928. doi:10.1136/bmj.d5928
- Huber, Y., Pfirrmann, D., Gebhardt, I., Labenz, C., Gehrke, N., Straub, B. K., et al. (2019). Improvement of non-invasive markers of nafld from an individualised, web-based exercise program. *Aliment. Pharmacol. Ther.* 50 (8), 930–939. doi:10.1111/apt.15427
- Izadi, V., Farabad, E., and Azadbakht, L. (2013). Epidemiologic evidence on serum adiponectin level and lipid profile. *Int. J. Prev. Med.* 4 (2), 133–140.
- Karstoft, K., and Pedersen, B. K. (2016). Skeletal muscle as a gene regulatory endocrine organ. *Curr. Opin. Clin. Nutr. and Metabolic Care* 19 (4), 270–275. doi:10.1097/MCO.0000000000000283
- Kelley, G. A., and Kelley, K. S. (2008). Efficacy of aerobic exercise on coronary heart disease risk factors. *Prev. Cardiol.* 11 (2), 71–75. doi:10.1111/j.1751-7141.2008.08037.x
- Kim, H. J., Lee, H. J., So, B., Son, J. S., Yoon, D., and Song, W. (2016). Effect of aerobic training and resistance training on circulating irisin level and their association with change of body composition in overweight/obese adults: a pilot study. *Physiological Res.* 65 (2), 271–279. doi:10.33549/physiolsres.932997
- Kunutsor, S. K. (2016). Gamma-glutamyl transferase—friend or foe within? *Liver Int.* 36 (12), 1723–1734. doi:10.1111/liv.13221
- Li, Y., and Huang, X. (2021). Effects of exercise prescription combined with dietary intervention on body morphology and blood biochemical indexes in patients with nonalcoholic fatty liver disease. *China Chronic Dis. Prev. Control* 29 (2), 115–118. doi:10.16386/j.cjpcd.issn.1004-6194.2021.02.008
- Liu, D. Y., Zhang, X. H., Liang, G. Q., Wang, J., and Wang, G. C. (2014). Experimental study on the intervention effect of traditional Chinese medicine combined with exercise therapy on non-alcoholic fatty liver in children. *Chin. J. Sports Med.* (05), 426–430. doi:10.16038/j.1000-6710.2014.05.004
- Liu, F., Chen, L., Jiang, Z., and Shang, J. (2019). Cognitive reappraisal in children: neuropsychological evidence of up-regulating positive emotion from an ERP study. *Chin. Foreign Med. Res.* 10 (10), 147–148. doi:10.3389/fpsyg.2019.00147
- Mascaró, C. M., Bouzas, C., Montemayor, S., Casares, M., Gómez, C., Ugarriza, L., et al. (2022). Association between physical activity and non-alcoholic fatty liver disease in adults with metabolic syndrome: the FLIPAN study. *Nutrients* 14 (5), 1063. doi:10.3390/nu14051063
- Mato, J. M., Alonso, C., Noureddin, M., and Lu, S. C. (2019). Biomarkers and subtypes of deranged lipid metabolism in non-alcoholic fatty liver disease. *World J. gastroenterology* 25 (24), 3009–3020. doi:10.3748/wjg.v25.i24.3009
- Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., and Prisma Group (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int. J. Surg.* 8 (5), 336–341. doi:10.1016/j.ijsu.2010.02.007
- Moore, M. P., Cunningham, R. P., Dashek, R. J., Mucinski, J. M., and Rector, R. S. (2020). A fad too far? Dietary strategies for the prevention and treatment of NAFLD. *Obesity* 28, 1843–1852. doi:10.1002/oby.22964
- Nam, H., Yoo, J. J., Cho, Y., Kang, S. H., Ahn, S. B., Lee, H. W., et al. (2023). Effect of exercise-based interventions in nonalcoholic fatty liver disease: a systematic review with meta-analysis. *Dig. Liver Dis.* 55 (9), 1178–1186. doi:10.1016/j.dld.2022.12.013
- Nassir, F. (2022). NAFLD: mechanisms, treatments, and biomarkers. *Biomolecules* 12 (6), 824. doi:10.3390/biom12060824
- O'Gorman, P., Naimimohasses, S., Monaghan, A., Kennedy, M., Melo, A. M., Nf, D., et al. (2020). Improvement in histological endpoints of mafld following a 12-week aerobic exercise intervention. *Aliment. Pharmacol. Ther.* 52 (8), 1387–1398. doi:10.1111/apt.15989
- Oh, S., Tsujimoto, T., Kim, B., Uchida, F., Suzuki, H., Iizumi, S., et al. (2021). Weight-loss-independent benefits of exercise on liver steatosis and stiffness in Japanese men with NAFLD. *JHEP Rep.* 3, 100253. doi:10.1016/j.jhepr.2021.100253
- Orci, L. A., Gariani, K., Oldani, G., Delaune, V., Morel, P., and Toso, C. (2016). Exercise-based interventions for nonalcoholic fatty liver disease: a meta-analysis and meta-regression. *Clin. gastroenterology hepatology* 14 (10), 1398–1411. doi:10.1016/j.cgh.2016.04.036
- Pang, L., and Jin, W. (2023). Clinical observation on baduanjin in the treatment of non-alcoholic fatty liver disease. *Bright Chin. Med.* (04), 673–676. doi:10.3969/j.issn.1003-8914.2023.04.022
- Peng, Y., Zhu, H., Yang, M., Zhou, H., Liu, X. L., and Wang, C. K. (2022). Effects of 12 weeks of FATmax intensity exercise on glycemic lipids and liver function in obese patients with nonalcoholic fatty liver disease. *Genomics Appl. Biol.* (03), 648–658. doi:10.13417/j.gab.041.000648
- Powell, E. E., Wong, V. W. S., and Rinella, M. (2021). Non-alcoholic fatty liver disease. *Lancet* 397 (10290), 2212–2224. doi:10.1016/S0140-6736(20)32511-3
- Pugh, C. J., Cuthbertson, D. J., Sprung, V. S., Kemp, G. J., Richardson, P., Margot Uempley, A., et al. (2013). Exercise training improves cutaneous microvascular function in nonalcoholic fatty liver disease. *Am. J. Physiology-Endocrinology Metabolism* 305 (1), E50–E58. doi:10.1152/ajpendo.00055.2013
- Pugh, C. J., Sprung, V. S., Kemp, G. J., Richardson, P., Shojaae-Moradie, F., Uempley, A. M., et al. (2014). Exercise training reverses endothelial dysfunction in nonalcoholic fatty liver disease. *Am. J. Physiology-Heart Circulatory Physiology* 307 (9), H1298–H1306. doi:10.1152/ajpheart.00306.2014
- Rector, R. S., Uptergrove, G. M., Morris, E. M., Borengasser, S. J., Laughlin, M. H., Booth, F. W., et al. (2011). Daily exercise vs. caloric restriction for prevention of nonalcoholic fatty liver disease in the OLETF rat model. *Am. J. Physiol. Gastrointest. Liver Physiol.* 300, G874–G883. doi:10.1152/ajpgi.00510.2010

- Rezende, R. E., Duarte, S. M., Stefano, J. T., Roschel, H., Gualano, B., de Sá Pinto, A. L., et al. (2016). Randomized clinical trial: benefits of aerobic physical activity for 24 weeks in postmenopausal women with nonalcoholic fatty liver disease. *Menopause* 23 (8), 876–883. doi:10.1097/GME.0000000000000647
- Romero-Gómez, M., Zelber-Sagi, S., and Trenell, M. (2017). Treatment of NAFLD with diet, physical activity and exercise. *J. hepatology* 67 (4), 829–846. doi:10.1016/j.jhep.2017.05.016
- Rong, L., Zou, J., Ran, W., Qi, X., Chen, Y., Cui, H., et al. (2023). Advancements in the treatment of non-alcoholic fatty liver disease (NAFLD). *Front. Endocrinol.* 13, 1087260. doi:10.3389/fendo.2022.1087260
- Rosqvist, F., Iggman, D., Kullberg, J., Cedernaes, J., Johansson, H. E., Larsson, A., et al. (2014). Overfeeding polyunsaturated and saturated fat causes distinct effects on liver and visceral fat accumulation in humans. *Diabetes* 63 (7), 2356–2368. doi:10.2337/db13-1622
- Rücker, G., and Schwarzer, G. (2015). Ranking treatments in frequentist network meta-analysis works without resampling methods. *BMC Med. Res. Methodol.* 15 (1), 58–59. doi:10.1186/s12874-015-0060-8
- Sánchez-Muñoz, V., Salas-Romero, R., Del Villar-Morales, A., Martínez-Coria, E., Pegueros-Pérez, A., and Franco-Sánchez, J. G. (2013). Decrease of liver fat content by aerobic exercise of metformin therapy in overweight or obese women. *Rev. Investig. Clínica* 65 (4), 307–317.
- Senior, J. R. (2012). Alanine aminotransferase: a clinical and regulatory tool for detecting liver injury—past, present, and future. *Clin. Pharmacol. and Ther.* 92 (3), 332–339. doi:10.1038/clpt.2012.108
- Shojaee-Moradie, F., Cuthbertson, D. J., Barrett, M., Jackson, N. C., Herring, R., Thomas, E. L., et al. (2016). Exercise training reduces liver fat and increases rates of VLDL clearance but not VLDL production in NAFLD. *J. Clin. Endocrinol. and Metabolism* 101 (11), 4219–4228. doi:10.1210/jc.2016-2353
- Shomaker, L. B., Tanofsky-Kraff, M., Young-Hyman, D., Han, J. C., Yanoff, L. B., Brady, S. M., et al. (2010). Psychological symptoms and insulin sensitivity in adolescents. *Pediatr. diabetes* 11 (6), 417–423. doi:10.1111/j.1399-5448.2009.00606.x
- Slentz, C. A., Bateman, L. A., Willis, L. H., Shields, A. T., Tanner, C. J., Piner, L. W., et al. (2011). Effects of aerobic vs. resistance training on visceral and liver fat stores, liver enzymes, and insulin resistance by HOMA in overweight adults from STRRIDE AT/RT. *Am. J. Physiology-Endocrinology Metabolism* 301 (5), E1033–E1039. doi:10.1152/ajpendo.00291.2011
- Snowling, N. J., and Hopkins, W. G. (2006). Effects of different modes of exercise training on glucose control and risk factors for complications in type 2 diabetic patients: a meta-analysis. *Diabetes care* 29 (11), 2518–2527. doi:10.2337/dc06-1317
- Sullivan, S., Kirk, E. P., Mittendorfer, B., Patterson, B. W., and Klein, S. (2012). Randomized trial of exercise effect on intrahepatic triglyceride content and lipid kinetics in nonalcoholic fatty liver disease. *Hepatology* 55 (6), 1738–1745. doi:10.1002/hep.25548
- Tan, S. J., Xu, D. Q., Cao, L. Q., and Guo, Z. (2015). FATmax exercise intervention for non-alcoholic fatty liver disease in middle-aged women. *J. Tianjin Sports Inst.* (03), 185–189. doi:10.13297/j.cnki.issn1005-0000.2015.03.001
- Targher, G., Bertolini, L., Rodella, S., Zoppini, G., Zenari, L., and Falezza, G. (2006). Associations between liver histology and cortisol secretion in subjects with nonalcoholic fatty liver disease. *Clin. Endocrinol.* 64 (3), 337–341. doi:10.1111/j.1365-2265.2006.02466.x
- Thyfault, J. P., and Rector, R. S. (2020). Exercise combats hepatic steatosis: potential mechanisms and clinical implications. *Diabetes* 69, 517–524. doi:10.2337/dbi18-0043
- Trovato, F. M., Catalano, D., Martines, G. F., Pace, P., and Trovato, G. M. (2015). Mediterranean diet and non-alcoholic fatty liver disease: the need of extended and comprehensive interventions. *Clin. Nutr.* 34 (1), 86–88. doi:10.1016/j.clnu.2014.01.018
- Vilar-Gomez, E., and Chalasani, N. (2018). Non-invasive assessment of non-alcoholic fatty liver disease: clinical prediction rules and blood-based biomarkers. *J. hepatology* 68 (2), 305–315. doi:10.1016/j.jhep.2017.11.013
- Wang, P., Liu, B. L., Liu, Y., and Jiang, D. (2023). Effects of exercise combined with dietary intervention on body composition and lipid metabolism and intestinal flora in obese female college students with nonalcoholic fatty liver disease. *Chin. Sch. Health* (08), 1169–1173. doi:10.16835/j.cnki.1000-9817.2023.08.011
- Wang, S. T., Zheng, J., Peng, H. W., Cai, X. L., Pan, X. T., Li, H. Q., et al. (2020). Physical activity intervention for non-diabetic patients with non-alcoholic fatty liver disease: a meta-analysis of randomized controlled trials. *BMC Gastroenterol.* 20, 66–12. doi:10.1186/s12876-020-01204-3
- Wang, Y. (2006). “Research on the effect of aerobic exercise on the intervention of non-alcoholic fatty liver disease,” in *Master’s thesis*. Beijing Sport University. Available at: <https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD2008&filename=2007225785.nh>.
- Winn, N. C., Liu, Y., Rector, R. S., Parks, E. J., Ibdah, J. A., and Kanaley, J. A. (2018). Energy-matched moderate and high intensity exercise training improves nonalcoholic fatty liver disease risk independent of changes in body mass or abdominal adiposity—a randomized trial. *Metabolism* 78, 128–140. doi:10.1016/j.metabol.2017.08.012
- Wong, V. W. S., Adams, L. A., de Lédinghen, V., Wong, G. L. H., and Sookoian, S. (2018). Noninvasive biomarkers in NAFLD and NASH—current progress and future promise. *Nat. Rev. Gastroenterology and hepatology* 15 (8), 461–478. doi:10.1038/s41575-018-0014-9
- Yang, S. N. (2016). *Effect of different modalities of exercise on patients with non-alcoholic fatty liver*. Nanjing University of Traditional Chinese Medicine. Available at: https://kns.cnki.net/kcms2/article/abstract?v=WSSiAUzZHh0FC7q8iz2D0J5DmTgAIX4gCbDKhcVZOR9kyskKNXixSW91vkhwjcsPpa_6LHkZDhu7RDpv_y2s2VZt gCyyo-yVYtsvtflyFcNdoPF8xSUCe0vkJFdi7rummKHWNDAAmogf1TD4s45NQ==uniplatform=NZKPTlanguage=CHS=.
- Yang, Y. H., Wang, F. L., and Mao, J. J. (2015). A comprehensive investigation of the effectiveness of aerobic exercise in patients with non-alcoholic fatty liver disease. *Mod. Pract. Med.* (08), 1055–1057. doi:10.3969/j.issn.1671-0800.2015.08.045
- Young, I. R., and Stout, R. W. (1987). Effects of insulin and glucose on the cells of the arterial wall: interaction of insulin with dibutyryl cyclic AMP and low-density lipoprotein in arterial cells. *Diabetes and Metabolism* 13 (3 Pt 2), 301–306.
- Younossi, Z., Anstee, Q. M., Marietti, M., Hardy, T., Henry, L., Eslam, M., et al. (2018). Global burden of NAFLD and NASH: trends, predictions, risk factors and prevention. *Nat. Rev. Gastroenterology and hepatology* 15 (1), 11–20. doi:10.1038/nrgastro.2017.109
- Yu, N., Ruan, Y., Gao, X., and Sun, J. (2017). Systematic review and meta-analysis of randomized, controlled trials on the effect of exercise on serum leptin and adiponectin in overweight and obese individuals. *Hormone Metabolic Res.* 49 (03), 164–173. doi:10.1055/s-0042-121605
- Zelber-Sagi, S., Buch, A., Yeshua, H., Vaisman, N., Webb, M., Harari, G., Shibolet, O., et al. (2014). Effect of resistance training on non-alcoholic fatty-liver disease a randomized-clinical trial. *World journal of gastroenterology: WJG* 20 (15), 4382–4392. doi:10.3748/wjg.v20.i15.4382
- Zhu, L. (2022). Effect of abdominal massage combined with wuqinx exercise on Nonalcoholic fatty liver (*Master’s thesis, Guangxi University of Traditional Chinese Medicine*). Available at: <https://kns.cnki.net/KCMS/detail/detail.aspx?dbname=CMFD202301&filename=1022081578.nh>.
- Zhu, L., Liu, J., Yu, Y., and Liu, W. (2020). Effectiveness of high-intensity interval training on fat loss overweight and obese adolescent: a meta-analysis. *J. Guang. Sport Univ.* 40, 96–101. doi:10.13830/j.cnki.cn44-1129/g8.2020.01.022