# Introduction of a mobile application platform as a decision support tool to enhance antimicrobial stewardship: an experience from the United Arab Emirates

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Antimicrobial resistance, mainly driven by inappropriate antibiotic use, is a global
threat to health, requiring strategies to optimize antimicrobial usage. Antimicrobial
stewardship (AMS) programs in hospitals promote the appropriate use of antibiotics
to treat infections effectively, protect patients from the harmful side effects
associated with unnecessary exposure, and reduce the risks of antimicrobial
resistance emergence. Educating clinicians through antimicrobial guidelines has
been a key function of AMS programs. However, monitoring access and utilization of
printed booklets or intranet-hosted guidelines is complex and may not provide
helpful feedback to the AMS leadership regarding their uptake by clinicians. Sheik
Shakhbout Medical City, in partnership with Mayo Clinic, is the first hospital in the
United Arab Emirates to adopt a mobile application platform for antimicrobial
guidance and clinical decision support, including tailored antimicrobial choices
based on local and national antibiograms and formulary. We describe the journey
for adopting a mobile application platform, its content development, migration, and
roll-out, and provide early insights on its impact through a descriptive analysis of
user statistics.

KEYWORDS

antimicrobial stewardship, guidelines, antibiogram, antibiotics, mobile application,
digital health

# Introduction

The World Health Organization's (WHO) global strategy for the containment of antimicrobial resistance (AMR) provided a framework to reduce the emergence and the spread of antimicrobial-resistant microorganisms, and task forces were subsequently created within countries to monitor the implementation of interventions and their subsequent progress (1, 2). In 2015, the health authorities in the United Arab Emirates (UAE) launched an initiative to combat AMR that paved the way for forming the Higher Committee for AMR. The latter encompasses a network of clinical microbiology laboratories providing diagnostic and surveillance services from all regions and facilities across the country. Recent UAE AMR surveillance data, presented as detailed cumulative antibiograms and annual trends for several AMR priority pathogens, highlight the urgent need to curb AMR (3).

Antimicrobial Stewardship (AMS) programs have been implemented to guide appropriate antimicrobial prescribing for prophylactic and therapeutic purposes, reduce the risk of antimicrobial resistance emergence, and facilitate the delivery of value-based care by reducing the costs associated with antimicrobial consumption (4–6). AMS programs optimize antimicrobials' choice, dose, and route of administration, monitor antimicrobial prescriptions and AMR patterns, and provide prospective feedback to prescribers (7–9). However, implementing AMS programs can be challenging, and despite best efforts, inappropriate antimicrobial prescribing may continue unabated (10, 11). While local antimicrobial guidelines, usually shared in soft or hard copy formats, inform appropriate antimicrobial prescribing, guidelines change, and the increasing complexity of care demands continuously updated and easily accessible guidelines.

In the current information technology (IT) age, many healthcare systems and processes have been digitalized, and IT has become an intrinsic part of modern medicine. IT interventions have been shown to improve the appropriateness of antimicrobial prescribing but had no impact on the length of hospital stay or mortality, indicating the need for more sophisticated tools and studies in this domain (12–14).

The unprecedented increase in the use of mobile phones in the last decade, reaching approximately 98% of healthcare professionals, with 84.5% bringing their mobile phones to the hospital daily, provides unique opportunities for these devices to augment clinical care (15, 16). Furthermore, the advent of internet-connected digital devices enabled mobile applications (apps) to be utilized using smartphones, tablet computers, and smartwatches. Furthermore, apps offer several other advantages, which include frequently updated content, quick start-up time, computerized decision support and administration rights to inform users of updates and new features. In 2017, over 318,000 mobile health (mHealth) apps were available in app stores (17–19). Furthermore, healthcare professionals have high smartphone ownership rates and perceive them as valuable when performing clinical duties (20). Therefore, smartphone apps have a high potential for becoming crucial components of AMS programs (21–26).

Established in 2019, Sheik Shakhbout Medical City (SSMC), in partnership with Mayo Clinic, is a tertiary hospital in Abu Dhabi

with a total capacity of 750 beds. SSMC provides a broad range of general and specialist medical, surgical, and critical care services. A 3-month retrospective outpatient clinical audit conducted at SSMC in 2020 showed that compliance with intranet-hosted antimicrobial guidelines was only 57% for the selection and 58% for the duration of therapy. Furthermore, a 48% increase in the volume of inpatient intravenous Vancomycin prescriptions was observed in the first quarter of 2021 compared to the same period in 2020, raising concerns about local prescribing practices. At that time, there were no reliable means available to SSMC's AMS team to verify if clinicians accessed antimicrobial guidelines and whether the education provided impacted their prescribing practice.

Given the ubiquity of smartphones and the availability of free Wi-Fi to all SSMC staff, using a mobile application platform to host antimicrobial guidelines and facilitate clinical decision support was considered an attractive and feasible tool to encourage clinicians of all grades to read guidelines and access antibiogram data when prescribing. Furthermore, sharing detailed antimicrobial monographs in an easily accessible format may help reduce antimicrobial prescribing errors made by high-volume prescribers such as junior physicians (27–29).
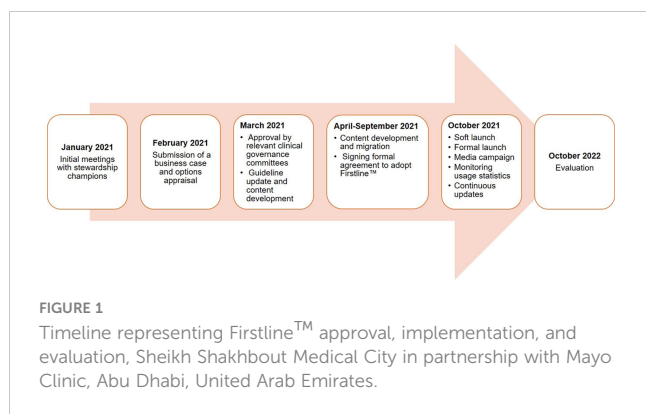
# Methods

## Planning, selection, and implementation

Antimicrobial guidelines based on local antimicrobial resistance patterns have been published and hosted on SSMC's intranet. However, many obstacles impeded access to and utilization of these guidelines. Intranet access required a series of steps, including a slow log-in process, which was a deterrent to clinicians under pressure to find and use the most relevant guideline. Furthermore, hard copies of an abbreviated version of the guidelines, including treatment recommendations for common infections, were also made available as quick-reference cards to prescribers working in busy emergency and ambulatory care settings in SSMC. Over time, updating and disseminating these "antibiotic cards" to clinicians and new staff became costly, impractical, and labor-intensive.

In January 2021, the AMS program at SSMC teamed with a physician champion group from the internal medicine division to enhance access and utilization of antimicrobial guidelines. Following presentations to relevant hospital committees, a decision was made to pursue the introduction of a mobile application platform, and an options appraisal exercise was started to select the most suitable platform after securing the green light from SSMC leadership. A timeline of the different stages leading up to Firstline[TM] implementation and evaluation is represented in Figure 1.

Three stand-alone mobile application platforms were appraised: Bugs and Drugs[TM], Firstline[TM] (formerly Spectrum[TM]), and Microguide[TM]. These platforms were assessed and compared regarding cost-effectiveness, simplicity of content development and migration, ability to release guideline updates in real-time,

Timeline representing Firstline™ approval, implementation, and evaluation, Sheikh Shakhbout Medical City in partnership with Mayo Clinic, Abu Dhabi, United Arab Emirates.

ability to capture guideline utilization metrics, and ease of use for the AMS team and clinicians. The applications differed on set-up fees, availability of a free trial version, depth and breadth of utilization metrics, and availability of information on healthcare cost savings.
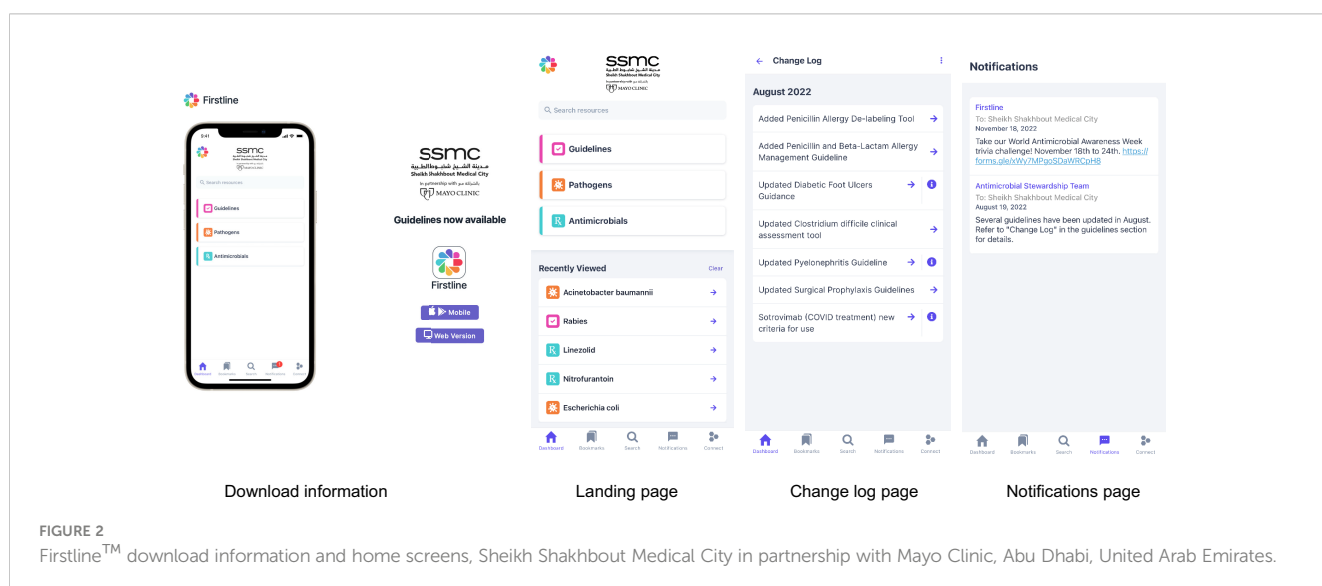
SSMC's AMS team decided to adopt Firstline™ (https://firstline.org) for several reasons: the ability to host local guidelines together with antibiogram data and antimicrobial formulary (Figure 2), access to an extensive library of guidelines and decision tools developed by other hospitals around the world that could be adapted for local use, the ability to notify clinicians with updates *via* a messaging system (Figure 2), a free 6-month trial period, and unlimited technical support at no extra cost. Furthermore, Firstline™ users could use the search function to navigate to a specific guideline, pathogen or antimicrobial agent and bookmark it for future reference. In addition, user statistics and experience could be monitored, and guideline accessibility could potentially be correlated with antimicrobial prescribing patterns and costs. Furthermore, Firstline™ developers shared with the AMS team preliminary data indicating potential annual cost savings of approximately 226 USD/bed (personal communication). Later, this figure was revised following the implementation of Firstline™ in two

Canadian hospitals in Newfoundland to 403.98 CAD/bed/year (~ 301.48 USD) based on reduced inpatient antimicrobial usage and 82,078 CAD/year (~ 61,251.86 USD) based on reduced toxin positive *Clostridioides difficile* cases (30). Providers of other evaluated mobile application platforms did not have cost-saving data to present to the AMS team during the options appraisal period. From March to September 2021, the AMS team worked on updating or developing guidelines and eventually migrating them to the Firstline™ platform. In September 2021, the AMS team gave a grand round presentation on introducing Firstline™ as a tool for antimicrobial guidance and clinical decision support. SSMC guidelines on Firstline™ went live by the end of October 2021. The app was made freely available to iOS and Android users (Figure 2). Firstline™ users completed a brief questionnaire upon signing up to indicate their location (SSMC, non-SSMC but within UAE, or outside UAE) and role (e.g., nurse, pharmacist, physician, other).

In addition to the app, a web link to Firstline™ was provided to replace the old intranet-hosted guidelines. The web version has been used primarily for teaching purposes. For example, a clinician could open the web version in front of a group of interns and residents while using a mobile computer workstation during ward rounds, ask questions, navigate through guidelines and decision tools, and discuss treatment options, drug dosage and monitoring requirements. Like the app, web analytics can be collected and reviewed. Although the number of web sessions and page views can be captured, the number of users cannot be accurately determined as the web version can be accessed on shared computers without a unique sign-in requirement for each user.

## Data collection

Data from Firstline™ was directly extracted and downloaded as comma-separated values (CSV) files. Information on user statistics, including location, role, and page views, was collected and analyzed. A monthly active user is a user who has accessed the app at least once in the previous 28 days. If the same user uses the app several

Firstline™ download information and home screens, Sheikh Shakhbout Medical City in partnership with Mayo Clinic, Abu Dhabi, United Arab Emirates.

times over the month, they are counted only once as an "active user". Furthermore, a session is defined as using the app or the web version for >10 seconds. The user would have to leave the app or web version for >30 minutes to have a new session logged in after coming back.

In this pilot study, we were principally interested in user uptake and the viewings of guidelines, pathogens, and antimicrobial monographs from January to March 2022. In the long term, we would be interested in assessing whether physicians' guideline access influenced their antimicrobial prescribing practice, antimicrobial consumption, days of antimicrobial therapy, the incidence of healthcare-associated infections, and healthcare costs. Therefore, we intend to correlate Firstline™ usage data with clinical audit findings, antimicrobial stewardship metrics, and infection prevention and control surveillance data.

## Ethics statement

The study is part of a quality improvement project (QIP) endorsed by the antimicrobial stewardship subcommittee and the quality department at SSMC to assess the impact of adopting a mobile application as a clinical decision tool on antimicrobial stewardship (reference: SSMC/CA/2022/002). SSMC's ethics review board has granted a waiver to QIPs. Neither the mobile version of Firstline™ nor its web interface were linked to any patient electronic medical records. Similarly, the antibiogram data was not linked to any potentially identifiable patient information. Firstline™ does not collect any personally identifiable information about its users.

## Results

The AMS team regularly reviewed the app's usage statistics and received periodic updates on the access and utilization of the web interface from the Firstline™ team. Firstline™ information available to users is SSMC's antimicrobial guidelines, local antibiogram, and detailed antimicrobial drug monographs.

In the first quarter (Q1) of 2022 [January–March], the Firstline™ app had 418 unique active SSMC users (Figure 3A). The number of app sessions in Q1 was 3,146, and the corresponding number of pages viewed was 55,419. In contrast, there were 461 web sessions and 5,136-page viewings during the same period.

As SSMC staff voluntarily identified their role and location when they signed up for the Firstline™ app, it was possible to assess the app's uptake among physicians and pharmacists. As per the human resources department data, SSMC had 224 consultants, 197 specialists, 28 fellows, 100 residents, 50 interns, and 140 pharmacists at the time of writing this manuscript. Figure 3B provides an overview of the app's active use by clinical role (specifically pharmacist, intern, resident, fellow, specialist and consultant) during Q1 2022 and shows that the residents were by far the most frequent active users (89%, 89/100), followed by the pharmacists (77%,108/140). Overall, the uptake over Q1 2022 among pharmacists and physicians was 52% (381/739).

Figures 4A–C are Firstline™-generated plots of guidelines, pathogens, and antimicrobial viewings according to active users' roles. Overall, COVID-19 was the most frequently viewed guideline in Q1; *Escherichia coli and Pseudomonas aeruginosa* were the top-viewed pathogens; and Amoxicillin-Clavulanate, Ciprofloxacin, Nitrofurantoin, and Flucloxacillin monographs were the most frequently accessed.

Firstline™-generated graphs were subsequently replotted by representing each variable (viewings of guidelines, pathogens, and antimicrobials) per the number of active users to normalize the data and minimize bias (Figures 4D–F).

Examining the normalized usage data of the proportion of views per active user, residents, specialists, and consultants viewed guidelines on respiratory (e.g., pneumonia and COVID), urinary (e.g., cystitis, ureosepsis and pyelonephritis), and skin and soft tissue infections (e.g., cellulitis) the most (Figure 4D). With 48.1% viewings, users identifying themselves as "other" viewed surgical prophylaxis guidelines the most, a finding that calls for a better definition of this group. Furthermore, residents accessed antibiogram information on *C. difficile, P. aeruginosa*, *E. coli*, and *Enterococcus faecalis* while interns and consultants mainly focused on *E. coli* and *Stenotrophomonas maltophilia*, respectively. Specialists viewed *C. difficile, S. maltophilia*, and *Staphylococcus aureus* the most. *Acinetobacter baumannii* had 49.5% views per active fellow user, but no other pathogens were viewed by the fellows who account for the smallest subset of active users by role [*n*=5] (Figure 4E). On another front, monographs on Teicoplanin, Meropenem, Vancomycin and Cefepime were viewed the most by pharmacists. The top antimicrobials viewed by residents were Flucloxacillin, Piperacillin/tazobactam, Ciprofloxacin, Cefepime, Amoxicillin-Clavulanate, and Amikacin. Of the interns' viewings of antimicrobial monographs, Nitrofurantoin was viewed the most (43.9%). Fellows had generally lower monograph viewings per user, which were 18.6% for Amoxicillin-Clavulanate, 16.5% for Amikacin, and 9.1% for Ciprofloxacin (Figure 4F).

## Discussion

We report the findings of the first UAE study on implementing a mobile application as part of an antimicrobial stewardship strategy aiming to improve the quality of antimicrobial prescribing by providing locally tailored antibiotic choices and decision support tools in an easily accessible format. Usage statistics provided helpful utilization metrics to SSMC's AMS team and gave reassurances that antimicrobial prescribers are reading antimicrobial guidelines, antibiograms, and antimicrobial monographs.

The ability to view and analyze usage statistics and directly communicate with users gives the AMS team considerable opportunities to ramp up interventions at a scale that is impossible with paper-based guides or traditional intranet-hosted versions. With Firstline™, the AMS team can push notifications through the app and get in direct contact with users, e.g., raising concerns about spikes in antibiotic consumption, alerting clinicians about the release of new guidelines, or notifying them of antibiotic supply chain problems (Figure 2). Furthermore, embedding the app
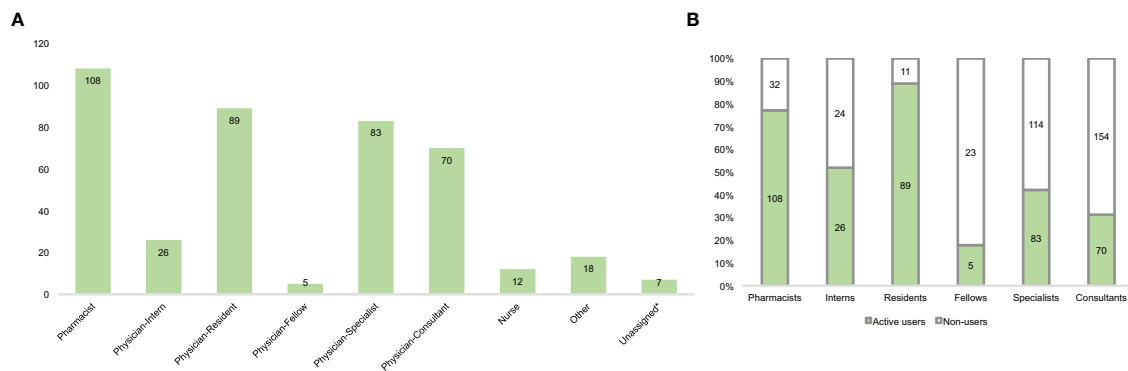
FIGURE 3

(A) Firstline™ active users by role, January-March 2022, Sheikh Shakhbout Medical City in partnership with Mayo Clinic, Abu Dhabi, United Arab Emirates *Unassigned users are those who may have logged on to the app and logged out without reviewing the content. (B) Stacked bars of Firstline™ active users among pharmacists and physicians, January-March 2022, Sheikh Shakhbout Medical City in partnership with Mayo Clinic, Abu Dhabi, United Arab Emirates.

training into SSMC's induction sessions for new joiners and the teaching program for junior doctors provides excellent opportunities for engaging prescribers with AMS initiatives.
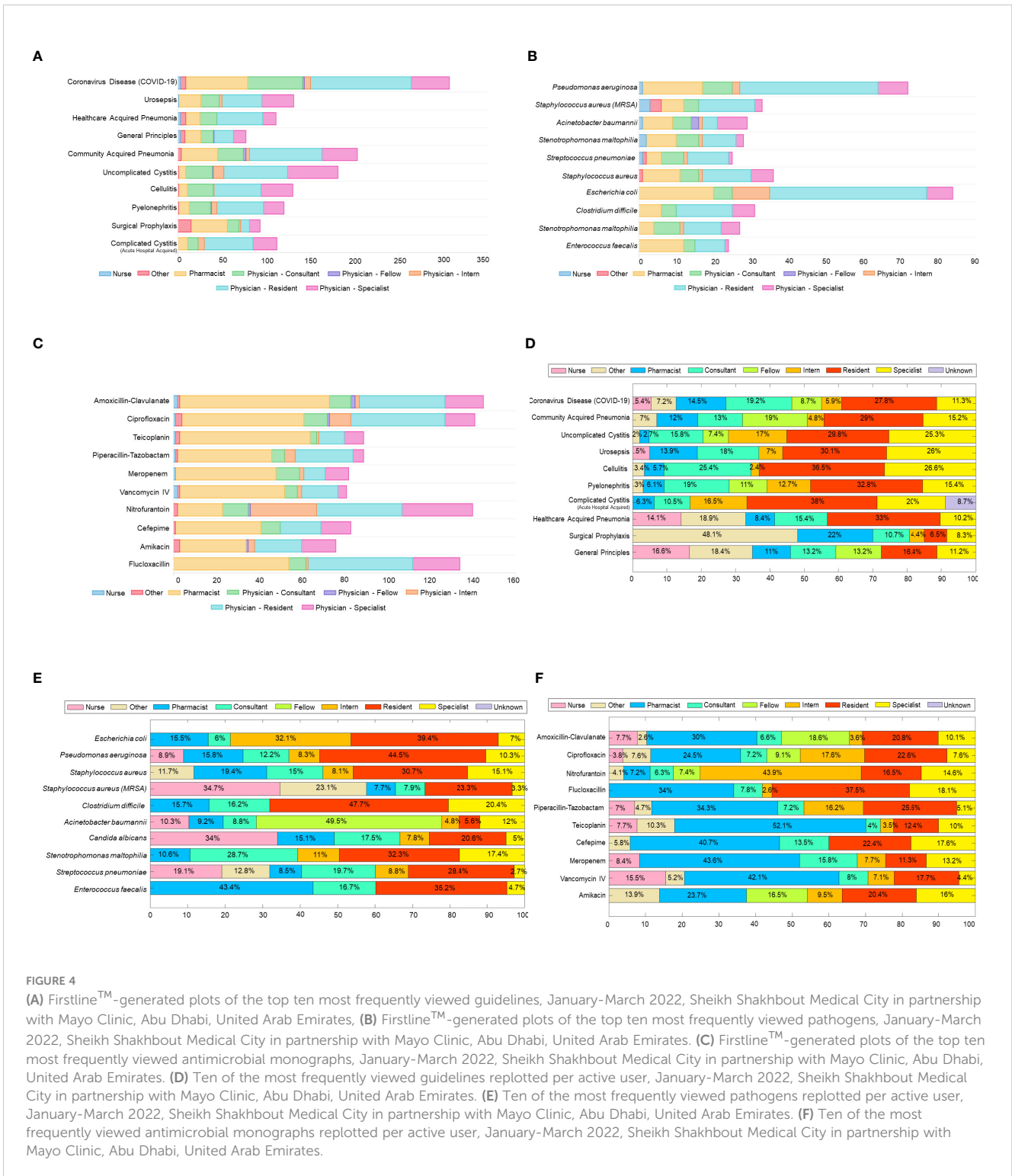
This study gives a snapshot of the uptake of Firstline™ in terms of usage by role and the frequency of viewings of guidelines, antimicrobial monographs, and local antibiograms. Commonly encountered infections in hospital medicine, such as respiratory, urinary, and skin and soft tissue infections, were viewed the most in Q1. With 89% uptake, residents have been the most avid app users in Q1 2022. However, the overall uptake among physicians and pharmacists was low at 52%. Although these figures may provide a rough estimate of the app's uptake, caution must be exercised when interpreting these figures as the total number of staff per role fluctuates with new staff joining, leaving, and rotating between hospitals. Furthermore, the "active user" definition, which is unique to each month but not necessarily for the rest of the year, makes it possible for users to be counted more than once during any given quarter or year. Therefore, it may not be possible to precisely know the number of healthcare workers who have downloaded the app and continued to use it consistently.

Normalizing the data gave us a more accurate picture of the proportion of views of guidelines, pathogens and antimicrobial monographs per active user. Interns and fellows, in particular, are insignificant in the Firstline™-generated plots (Figures 4A–C). However, they have more presence in the normalized plots (Figures 4D–F). For example, interns mostly viewed guidelines on urinary tract infections and Nitrofurantoin monographs, whereas fellows viewed mainly guidelines on community-acquired pneumonia, antibiogram data on *A. baumannii*, and Amoxicillin-Clavulanate monographs. Of note, the percentage of views per active fellow and intern users was <20%, with very few exceptions. For example, 49.5% views per active fellow user were observed for *A. baumannii*, but the number of views for all other pathogens was zero. Furthermore, Nitrofurantoin attracted 43.9% of views from active intern users. A closer look across different roles shows that interns (n=26), residents (n=89) and specialist

physicians (n=83) viewed it 31, 40 and 33 times, respectively, resulting in approximately 1.19, 0.45 and 0.4 views per active user for each of these roles. This observation indicates a much bigger ratio of views per intern user than others and underscores the importance of addressing bias issues when interpreting Firstline™ usage data.

Knowledge of common pathogens and local susceptibility patterns is essential in determining appropriate empiric antibiotic therapy. This crossroad of healthcare and smartphone technology facilitates reaching clinicians with timely, up-to-date, and locally tailored antimicrobial prescribing guidelines. Of the top ten antimicrobial monographs on the app, those most frequently viewed were Flucloxacillin, Amoxicillin-Clavulanate, Ciprofloxacin, Piperacillin/tazobactam and Clindamycin. This is likely reflective of the effectiveness of SSMC's antimicrobial restriction policy that requires using preauthorization codes for antimicrobials of serious concern, such as Carbapenems, Echinocandins, and Linezolid. It is encouraging that the pathogens listed as a critical and high priority in the AMR Surveillance Report, 2019 and their corresponding antibiotic treatments were frequently viewed (*A. baumannii, P. aeruginosa* and *E. coli, E. faecium, S. aureus and Salmonella* spp.) (3).

A cross-sectional study from the United Kingdom found that 34% of junior doctors reported unsupervised antimicrobial prescribing, 67% encountered difficulties accessing out-of-hours support for antimicrobial prescribing, and 20% were less confident writing an antimicrobial prescription (31). Although Firstline™ provided our junior doctors with up-to-date and readily accessible guidelines and decision support tools, the app's uptake among our junior doctors was variable, with the residents outperforming the interns and the fellows. It is premature to conclude whether this high uptake and viewings would translate into better antimicrobial prescribing by residents. However, it is hoped they would feel more confident prescribing antimicrobials with the help of the continuously updated app content that enriches their knowledge and the embedded decision support tools that boost their prescribing confidence. Fellows can prescribe

**FIGURE 4**

**(A)** Firstline[TM]-generated plots of the top ten most frequently viewed guidelines, January-March 2022, Sheikh Shakhbout Medical City in partnership with Mayo Clinic, Abu Dhabi, United Arab Emirates, **(B)** Firstline[TM]-generated plots of the top ten most frequently viewed pathogens, January-March 2022, Sheikh Shakhbout Medical City in partnership with Mayo Clinic, Abu Dhabi, United Arab Emirates. **(C)** Firstline[TM]-generated plots of the top ten most frequently viewed antimicrobial monographs, January-March 2022, Sheikh Shakhbout Medical City in partnership with Mayo Clinic, Abu Dhabi, United Arab Emirates. **(D)** Ten of the most frequently viewed guidelines replotted per active user, January-March 2022, Sheikh Shakhbout Medical City in partnership with Mayo Clinic, Abu Dhabi, United Arab Emirates. **(E)** Ten of the most frequently viewed pathogens replotted per active user, January-March 2022, Sheikh Shakhbout Medical City in partnership with Mayo Clinic, Abu Dhabi, United Arab Emirates. **(F)** Ten of the most frequently viewed antimicrobial monographs replotted per active user, January-March 2022, Sheikh Shakhbout Medical City in partnership with Mayo Clinic, Abu Dhabi, United Arab Emirates.

antibiotics, and while our interns cannot directly prescribe, they can initiate a prescription that a senior physician should countersign. Plans are already underway at our institution to assess adherence to local guidelines, including the safety and appropriateness of antimicrobial prescribing and whether there is any correlation with the app's viewings. Furthermore, specific user feedback will be sought to identify potential barriers impeding access to the app.

Active promotion of Firstline[TM] app is ongoing internally to improve its visibility and subsequent uptake amongst SSMC staff. Information on its utility has been reinforced during SSMC's World Antimicrobial Awareness Week activities in 2022 and will be periodically boosted for the foreseeable future. Antibiotic awareness must be maintained across the continuum of care, from nurses and pharmacists to medical students undertaking

clinical clerkships to interns, residents, fellows, specialists and consultants, irrespective of whether they can prescribe.

This pilot study describing the implementation of a mobile application to guide antimicrobial choices and facilitate clinical decision-making has several points of strength. The study describes an innovative approach to improve antimicrobial prescribing practices, including an attempt to influence prescribers' behaviors by presenting relevant and locally tailored data in an accessible format to inform appropriate prescribing. Furthermore, the versatile application platform allowed us to gain helpful insights into our guidelines' access and utilization for the first time, which is highly beneficial for the AMS team in developing further interventions to optimize antibiotic utilization. Regarding weaknesses, we have only presented data pertaining to the first quarter of 2022 with no prior data to compare. Furthermore, the analytics of the web version of Firstline™, provided on a demand basis by the developers, is limited by the inability to identify unique users since some of them may use existing log-in credentials to access it. While inferences can be made about the preliminary data on the viewings of guidelines, monographs, and antibiograms hosted on the Firstline™ app, we cannot, at this stage, state categorically that guideline viewings were directly translated into appropriate prescribing at this early stage of the roll-out. Furthermore, we cannot verify the accuracy of the app users' self-reported roles and places of work. Nonetheless, the data remains valuable to assess the success of implementation, and it can inform further AMS quality improvement initiatives.

Our next step is to evaluate the impact of Firstline™ intervention on the adherence to antimicrobial guidelines and AMS outcome metrics such as days of antimicrobial therapy, the incidence of healthcare-associated infections, length of hospital stay, and savings in the cost of antimicrobials. Furthermore, we will correlate users' viewings of the app and the influence on antimicrobial prescribing. We will also gauge user experiences of the app through focus group interviews, qualitative data collection and quantitative satisfaction surveys, which will triangulate user experience with uptake and prescribing influence.

## Conclusions

Mobile applications are a powerful tool for educating and supporting frontline clinicians prescribing antimicrobials. Through thoughtful design and implementation of a mobile clinical support tool, an AMS team is more able to provide cutting-edge, up-to-date clinical recommendations directly to the fingertips of prescribers. Our experience has been highly encouraging for our hospital-based AMS program, which is needed to combat the menace of an ever-increasing AMR burden. Further research is needed to evaluate the impact of apps on prescriber behavior and the key performance indicators of antimicrobial stewardship.

## Data availability statement

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

## Author contributions

JS, AS, DE, ZB, and SO'S concept of paper and review of drafts; SO'S and ZB literature review and manuscript writing; FJ provision of antibiogram data, JS and AS, provision of pharmacy data; MH data cleaning and analysis; JS, AS, RA, EN and ZB are core members of the AMS program; FF, KY, AAN, and AA are members of the physician champion group that worked closely with the AMS program in conceiving the transition to a mobile application platform. 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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