Transforming multidrug-resistant tuberculosis care: The potentials of telemedicine in resource-limited settings

Abstract

Multidrug-resistant tuberculosis (MDR-TB) is a significant challenge in low-resource settings owing to limited healthcare access and quality. However, telemedicine can potentially improve healthcare delivery by overcoming geographical barriers. This comprehensive review aimed to provide an overview of the current trends in utilizing telemedicine for MDR-TB control in low-resource settings. A systemic literature search using electronic databases, including PubMed and Google Scholar, was conducted to identify relevant articles on telemedicine and MDR-TB control in low-resource settings. The selected articles were analyzed and synthesized to provide a comprehensive overview of telemedicine's current trends and applications in MDR-TB control. Telemedicine allows remote screening and diagnosis, facilitating early detection and timely treatment, provides access to experts through teleconsultation, which ensures optimal treatment outcomes, fosters training and education of healthcare providers, and supports follow-up care through teleconsultation and remote monitoring. Furthermore, telemedicine integration with data collection methods can improve MDR-TB surveillance and intervention. Findings from this review show the potential of telemedicine to improve MDR-TB control and patient health in low-resource settings. This makes it a promising prevention and management option. However, successful implementation requires overcoming limitations such as connectivity, infrastructure, and cultural barriers. Telemedicine can considerably improve MDR-TB control and reduce disease burden in underserved populations by utilizing possibilities and addressing the challenges.

Keywords: Multidrug-resistant; Digital health; Tuberculosis; Telemedicine; Resource-limited setting

Introduction

Multidrug-resistant tuberculosis (MDR-TB) does not respond to the two most potent first-line drugs used in standard TB treatment, namely isoniazid and rifampicin [1]. Globally, MDR-TB is a major health issue, especially in low-resource settings where healthcare systems lack the infrastructure for diagnosis, treatment, and control [2]. These settings face challenges in detecting and treating MDR-TB due to a lack of quality healthcare services, including diagnostic facilities, specialized expertise, and effective treatment regimens [3]. Furthermore, the lack of adequate follow-up care and treatment adherence support, as well as socioeconomic factors, including poverty, malnutrition, and overcrowding, contribute to the burden and risk of MDR-TB within these settings [4].

Telemedicine constitutes the delivery of medical care and general health services remotely. It has considerable potential to improve healthcare delivery and combat MDR-TB in low-resource settings [5]. Telemedicine can help prevent and treat MDR-TB by enabling remote diagnosis and screening, providing expertise, supporting treatment adherence, facilitating training and education, ensuring follow-up care, and improving data collection and surveillance [5-7]. Although telemedicine can improve patient outcomes and service delivery, increase access to specialized care, and provide expert guidance, its successful implementation in low-resource settings requires careful consideration of various factors such as reliable internet connection, community awareness, healthcare worker training, adequate funding, and supportive policies [8, 9]. A comprehensive review of telemedicine's current trends and applications in MDR-TB prevention will contribute to the existing knowledge and inform healthcare service providers and policymakers about the opportunities and challenges of implementing telemedicine in resource-limited settings. Furthermore, understanding the rationale and evidence for telemedicine in MDR-TB care could guide future research, policy development, and program implementation. Therefore, this review aimed to explore the potential of telemedicine as a tool for preventing MDR-TB in low-resource settings.

Methods

This narrative review provides an extensive overview of telemedicine's current trends and applications to prevent and manage MDR-TB in low-resource settings. The review synthesizes information from various sources, including online articles, research studies, clinical guidelines, and reports from reputable organizations. A comprehensive literature search was conducted using electronic PubMed and CINAHL databases, as well as Google Scholar and relevant organizational websites, to identify publications and resources aligning with the review objectives. The search terms included combinations of keywords such as "telemedicine," "MDR-TB," "low-resource setting," "remote diagnosis," "treatment adherence," "training and education," "follow-up care," "data collection," and "surveillance."

The selected articles were assessed for their relevance to the topic and contribution to understanding telemedicine applications in MDR-TB prevention in low-resource settings. The inclusion criteria comprised English-language articles published within the last five years, focusing on telemedicine interventions for MDR-TB in resource-limited settings. Articles providing insights into current trends, challenges, opportunities, and outcomes were prioritized.

Data from the selected articles were extracted and organized based on the identified themes, including remote diagnosis and screening, access to expertise, treatment adherence support, training and education, follow-up care, and data collection and surveillance. Key findings, trends, and examples of telemedicine applications in each theme were synthesized and presented in a narrative format. Throughout the review process, efforts were made to ensure the inclusion of diverse perspectives and a balanced representation of the current literature.

The potential of telemedicine in healthcare delivery

Through teleconsultations, healthcare professionals can assess patients' symptoms, review medical histories, and order diagnostic tests, enabling earlier detection and intervention [9], [10], [11], even for MDR-TB cases. This timely diagnosis is crucial in preventing the spread of MDR-TB and initiating appropriate treatment. Furthermore, telemedicine facilitates access to expertise and specialized care [12]. In resource-limited areas with a shortage of TB specialists, teleconsultations allow healthcare providers to seek guidance from experts elsewhere. This collaboration ensures accurate diagnosis, optimal treatment decisions, and ongoing management of MDR-TB cases [12].

Telemedicine aids treatment adherence, a significant challenge in MDR-TB management [13]. Through remote monitoring, telemedicine platforms can track medication compliance, provide medication intake reminders, and offer patients educational material. Regular video or phone consultations enable healthcare providers to address patients' challenges or concerns during treatment, enhancing outcomes [13]. In addition to patient care, telemedicine offers opportunities for training and education [14]. Remote training programs, webinars, and virtual workshops can equip healthcare workers in low-resource settings with the knowledge and skills necessary for effective MDR-TB management [14]. This capacity-building approach strengthens local healthcare systems and enhances the quality of care provided to MDR-TB patients [14]. Telemedicine also facilitates follow-up care for MDR-TB patients [5]. Regular teleconsultations allow healthcare providers to monitor treatment progress, assess treatment responses, and remotely address any side effects or complications [5]. This reduces patients' long commutes to healthcare facilities, easing the burden on strained transportation systems and improving overall patient satisfaction [5].

Telemedicine simultaneously enables efficient data collection and surveillance of MDR-TB cases. By integrating telemedicine platforms with electronic health records, healthcare providers can gather real-time data on MDR-TB incidence, treatment outcomes, and drug resistance patterns [15]. This data is invaluable for monitoring trends, evaluating program effectiveness, and informing evidence-based interventions to control the spread of MDR-TB in low-resource settings [15]. Connectivity issues and limited access to technology pose significant challenges in remote areas. Reliable internet connectivity, sufficient bandwidth, and access to devices capable of supporting telemedicine platforms are crucial for seamless communication and teleconsultations [9].

Language and cultural differences may hinder healthcare provider-patient interactions in diverse settings. Adapting telemedicine platforms to multiple languages, providing interpreters, and recognizing cultural differences can help overcome these barriers and promote patient-centered care [16]. Furthermore, the sustainability of telemedicine programs in low-resource settings depends on strong collaborations and partnerships between various stakeholders, including government, healthcare organizations, and technology providers.

Table 1 highlights current trends in telemedicine for MDR-TB prevention.

Table 1: Current Trends in Telemedicine for MDR-TB Prevention

Dimension of Telemedicine	Application	Examples/Tools/Apps Used
Remote Diagnosis and Screening	-Teleconsultations -Diagnostic Testing and Interpretation	-Teladoc Health [17], eHealthpoint [18], video conferencing, Emocha [19], 99DOTS [20], SureAdhere [21] -GeneXpert System [22], Dermatology apps
Access to Expertise	-Teleconsultations -Collaborative Care Models	-Project ECHO [23], CDC's TB RTMCCs [24], WhatsApp for healthcare providers -Virtual multidisciplinary meetings and online communities for MDR-TB support
Treatment Adherence Support	-Real-time Monitoring and Reminders -Education and Counseling	-MHealth apps (e.g., Emocha), SMS-based reminders, pillbox systems -TB Alert, WhatsApp for patient support groups, teleconsultations for psychological support
Training and Education	-Telemedicine for Training -Webinars, Virtual Workshops	-OpenWHO courses [25], interactive tele-education programs, virtual patient cases for training -Global TB Conferences, e-learning platforms, institution-specific virtual training sessions
Follow-up Care	-Remote Monitoring of Progress -Teleconsultations for Follow-up	-WhatsApp for healthcare providers, eHealth platforms with progress tracking features -Video conferencing platforms and telemedicine apps for regular patient check-ins
Data Collection and Surveillance	-Integration with Electronic Health Records -Leveraging Telemedicine Data for Surveillance	-Epic Systems [26], EHR systems, RedCap [27] -TB Reach [28], Digital Health Platforms, EHR-integrated analytics and reporting tools

Teleconsultations for symptom assessment and medical history collection

The reviewed literature showed that teleconsultations could be crucial in remote diagnosis and screening of individuals suspected of having MDR-TB in low-resource settings. Video or phone consultations allow patients to communicate symptoms, including chronic cough, weight loss, night sweats, and fever, to healthcare providers [6], [29]. This assessment helps healthcare providers determine MDR-TB risks and the need for further diagnostic testing.

Teleconsultations offer a convenient way for healthcare providers to gather crucial medical history information remotely [30]. Patients can discuss their previous TB treatment, exposure to others with TB, and drug resistance risk factors, such as non-adherence to medication. This information plays a significant role in diagnosis and treatment decisions [31]. Moreover, teleconsultations enable healthcare providers to assess comorbidities or complications that may impact MDR-TB management. They can inquire about underlying health conditions, such as diabetes or HIV infection, which may affect treatment outcomes and require tailored management approaches. Teladoc Health, a widely used telemedicine application, facilitates remote video consultations for analyzing symptoms and medical history [17]. Another is eHealthpoint, which is utilized in various low-resource settings to provide remote consultations [18], enabling healthcare practitioners to make referrals for further testing or treatment [32].

Utilizing telemedicine for diagnostic testing and interpretation

Telemedicine offers the potential to facilitate diagnostic testing for MDR-TB in resource-limited settings, where access to specialized laboratories and infrastructure is limited. Various diagnostic tests can be conducted remotely, and the results can be interpreted by experts through telemedicine platforms [33].

a) Remote specimen collection: In some cases, telemedicine can assist in remote specimen collection for diagnostic testing. For example, sputum samples can be collected by patients at home under healthcare provider guidance via video consultation [34]. Patients can be instructed on proper sample collection techniques, ensuring the samples' quality and reliability for laboratory testing. However, remote specimen collection can present several limitations. For example, inadequate sample collection by an inexperienced person or lack of proper supervision can potentially lead to erroneous test results [6]. Additionally, there is a chance of sample contamination that may occur during transportation, which could lead to inaccurate results. Moreover, the lack of direct physical examination may result in missed diagnostic clues [10]. Some tests, such as blood cultures and biopsies that require particular conditions or specialized equipment, may not be possible to do remotely [6], [10], limiting the scope of telemedicine. Although remote specimen collection improves accessibility, it requires strict protocols to address these limitations and ensure accurate diagnosis.

b) Point-of-care (POC) diagnostic devices: Telemedicine can leverage point-of-care diagnostic devices for MDR-TB testing [35]. These portable devices enable rapid testing for TB and drug resistance, reducing the need for sample transportation to centralized laboratories. Healthcare providers can guide patients in the proper use of these devices through teleconsultations, interpret the results in real time, and initiate appropriate treatment plans accordingly. Nevertheless, POC diagnostic devices have limitations. These devices may not be as sensitive as laboratory testing, which can lead to misdiagnosis [36]. The accuracy can be further compromised by insufficient training, operator error due to unfamiliarity with instrument maintenance and calibration or quality control protocols, and environmental conditions [36]. The cost and maintenance of POC devices pose financial burdens, preventing their widespread use, particularly in resource-limited settings [37]. Additionally, diagnostic capabilities may be limited because POC devices may not cover a comprehensive range of health conditions [36], [37], [38].

c) Remote laboratory interpretation: Once diagnostic samples are collected, telemedicine platforms can facilitate the transmission of laboratory results to experts elsewhere. Laboratory technicians can upload test results, including drug susceptibility testing for TB medications, onto the telemedicine platform. Experts can then remotely access and interpret the results, providing timely guidance on appropriate treatment regimens based on drug resistance patterns [39]. Telemedicine utilization in diagnostic testing and interpretation ensures that patients in resource-limited settings can access accurate and timely results, even in areas with limited laboratory capacity. This allows for early initiation of appropriate treatment, reduces delays in diagnosis, and prevents the further spread of MDR-TB within communities [6]. For example, the GeneXpert system, a molecular diagnostic platform used to detect TB and drug-resistant TB [22], [40] rapidly can be operated remotely, and the results are transmitted electronically to healthcare providers. Patients can provide sputum samples at local clinics, and the results can be interpreted remotely, allowing for timely diagnosis [22], [41]. In some cases, skin tests are used for TB diagnosis. Dermatology apps with high-resolution image capture capabilities can capture images of skin reactions to TB tests [42]. These images can then be transmitted to experts for interpretation, allowing for remote diagnosis.

However, remote laboratory interpretations have several limitations. Digital transmission, which might be affected by technical issues or slow internet speed, can cause diagnostic delays or errors [6], [43]. Privacy and data breaches are also a possibility. Moreover, there may be miscommunication between remote healthcare professionals and patients or laboratory technicians [6], complicating the interpretation process.

Teleconsultations with tuberculosis specialists and experts

Teleconsultations with tuberculosis specialists and experts play a vital role in providing healthcare providers in low-resource settings with access to specialized knowledge and guidance. Healthcare providers can remotely consult with tuberculosis specialists through telemedicine platforms, ensuring patients receive the best care and management for MDR-TB. Teleconsultations enable healthcare providers in resource-limited areas to seek expert opinions on complex cases, challenging treatment decisions, and management strategies. This allows for comprehensive evaluation and tailored recommendations based on individual patients' needs and challenges [6].

In regions where tuberculosis specialists are scarce, teleconsultations can bridge the gap in expertise by enabling healthcare providers to access specialists located elsewhere, thus ensuring that patients in remote areas have access to the same level of specialized care as those in urban or well-resourced settings. This collaboration facilitates accurate diagnosis, optimal treatment decisions, and ongoing management of MDR-TB cases [5]. For instance, Project ECHO (Extension for Community Healthcare Outcomes) is a widely recognized telehealth program that connects primary care providers with specialists, including TB specialists [23]. Primary care providers can participate in virtual ECHO sessions where they present cases and receive guidance and mentoring from TB experts. This collaborative approach helps improve the expertise of primary care providers in managing complex TB cases. Regional Training and Medical Consultation Centers (RTMCCs) [24], operated by the Centers for Disease Control and Prevention (CDC), provide expert consultation and training on TB management [44, 45], as well as access to TB specialists and guidance on diagnosis and treatment [46].

Collaborative care models for remote guidance and support

Collaborative care models incorporating telemedicine emerged as a salient area from the present review. These can enhance remote guidance and support for healthcare providers dealing with MDR-TB in low-resource settings. Collaborative care models involve a multidisciplinary approach, bringing together different healthcare professionals, including primary care physicians, nurses, community health workers, and specialists, to provide comprehensive care remotely [47]. Through regular communication and remote consultations, they exchange information, discuss treatment plans, and address challenges encountered during patient care. This collaborative approach enhances patients' quality of care, guarantees compliance with evidence-based guidelines, and improves treatment outcomes. Moreover, collaborative care models can extend beyond remote consultations to include case conferences and tumor boards. These virtual meetings bring together healthcare providers from various disciplines to review complex cases, discuss treatment options, and collectively make informed decisions [48].

Collaborative care models also promote capacity building and knowledge transfer. Through telemedicine, specialists can provide training and educational sessions to healthcare providers in remote areas, including sharing best practices, discussing the latest research findings, and conducting interactive sessions to enhance the skills and knowledge of healthcare professionals involved in MDR-TB management [49].

Teleconsultations with tuberculosis specialists and experts and collaborative care models using telemedicine offer opportunities to overcome the limitations of expertise in low-resource settings.

Messaging apps such as WhatsApp are increasingly used for collaborative care in remote areas. Healthcare providers can form groups and networks on WhatsApp to discuss cases, seek expert advice, and share updates on MDR-TB patients [50]. This informal collaboration can provide immediate support and guidance. Similarly, telehealth platforms such as Doxy.me [51] and Vidyo 52] offer collaborative features like screen sharing and secure messaging. These features allow healthcare teams to work together remotely, share patient data, and seek guidance from specialists during teleconsultations.

Real-time monitoring and reminders through telemedicine platforms

Treatment adherence is a critical factor in the successful management of MDR-TB. Poor adherence can lead to treatment failure, increased drug resistance, and the persistence of MDR-TB within communities [53]. Telemedicine platforms can be integrated with mobile applications or connected devices to monitor and track medication adherence remotely. Patients can receive automated reminders through text messages or mobile app notifications, reminding them to take their medication as prescribed. These reminders can be customized based on individual treatment regimens and scheduled dosing times.

Furthermore, telemedicine platforms can provide healthcare providers with real-time data on patients' medication adherence. Remote monitoring lets healthcare providers spot non-adherence risks and intervene quickly using teleconsultations or phone calls to help patients overcome adherence issues and motivate them [54]. Real-time monitoring also enables healthcare providers to assess treatment responses and adjust medication regimens. Suppose a patient is not responding as expected; telemedicine platforms allow healthcare providers to remotely evaluate the situation, explore potential reasons for the lack of response, and make necessary adjustments to the treatment plan [6]. This proactive approach ensures that patients receive appropriate and timely interventions, maximizing the effectiveness of MDR-TB treatment.

For example, Mobile health (mHealth) applications such as Emocha [19], 99DOTS [20], and SureAdhere [21] offer real-time medication adherence support [55]. These apps use various methods, including video-based directly observed therapy (VDOT), to monitor patients taking their medications [55]. Patients record themselves taking medication doses on their smartphones, and healthcare providers can remotely verify adherence.

Patient education and counseling via mobile apps and teleconsultations

Patient education and counseling play a vital role in promoting treatment adherence and self-management skills among MDR-TB patients [56]. Telemedicine platforms offer innovative ways to remotely deliver patient education and counseling, even in resource-limited settings. Mobile applications can serve as educational tools, providing patients with essential information about MDR-TB, treatment regimens, potential side effects, and strategies to manage them. These apps can deliver educational content in a user-friendly format, including videos, interactive modules, and text-based information. Patients can access these resources at their convenience, empowering them with knowledge and promoting treatment adherence [5].

Healthcare providers can discuss treatment goals, address patient concerns, provide emotional support, clarify any misconceptions or doubts about treatment, and emphasize the importance of adherence to achieve successful outcomes [11]. Additionally, healthcare providers can assess patients' understanding of treatment plans and medication regimens using visual aids, such as diagrams or virtual medication organizers, to help patients grasp the complexities of their treatment schedules. This interactive approach fosters patient engagement and empowerment, increasing their sense of ownership and responsibility for their treatment [6].

Teleconsultations also provide a platform for patients to ask questions, seek clarification, and share any challenges they may be facing during their MDR-TB treatment journey. Healthcare providers can offer approaches to help patients manage side effects, medical interactions, and social and economic variables that may affect treatment.

Moreover, telemedicine platforms can facilitate peer support and group counseling sessions for MDR-TB patients. Virtual support groups allow patients to connect with others going through similar experiences, providing a sense of community, motivation, and shared learning. These sessions can be led by healthcare providers or facilitated by trained peer counselors, further enhancing the psychosocial support network for patients [57].

Utilizing mobile apps, such as the TB Alert mobile app, provides educational resources and information on TB and MDR-TB [58]. For instance, patients and their families can access information about the disease, treatment, and preventive measures. The app also includes features for symptom tracking and medication reminders [59]. It enables patient education, fosters self-management skills, and ensures ongoing support and counseling, ultimately improving treatment outcomes and reducing the spread of MDR-TB [59, 60]. This proactive approach reduces the likelihood of missed doses and improves treatment compliance [61]. The combination of real-time monitoring, reminders, patient education, counseling, and peer support creates a comprehensive support system that addresses MDR-TB patients' unique challenges [62, 63].

Telemedicine for training healthcare workers in MDR-TB management

Telemedicine plays a crucial role in training and educating healthcare workers in managing MDR-TB in low-resource settings. It offers remote learning, mentoring, and skill development, addressing the challenges of limited access to specialized training programs and expertise in these regions [64]. Telemedicine platforms offer various modalities for training healthcare workers in MDR-TB management. These include webinars, video conferences, online courses, and virtual lectures. For instance, OpenWHO [25], an initiative by the World Health Organization (WHO), offers online courses on various aspects of MDR-TB management. These courses are accessible globally and train healthcare workers, including doctors, nurses, and public health professionals, in diagnosing and treating MDR-TB. Through these platforms, healthcare workers can access training materials, presentations, and interactive sessions facilitated by experts in the field. Telemedicine platforms enable the dissemination of up-to-date information, evidence-based guidelines, and best practices in MDR-TB management, ensuring that healthcare workers stay informed and knowledgeable about the latest developments in the field [5].

One significant advantage of telemedicine-based training is its flexibility. Healthcare workers in resource-limited settings can access training modules at their convenience, allowing them to balance their clinical responsibilities with ongoing professional development. This flexibility is valuable for healthcare workers who may have limited time and resources for attending in-person training programs [12]. Telemedicine also enables mentoring and supervision of healthcare workers in remote areas, which fosters continuous learning and skill development, enhancing the capacity of healthcare workers to deliver quality care for MDR-TB patients [11].

Webinars, virtual workshops, and interactive sessions

Webinars, virtual workshops, and interactive sessions are emerging trends in training and education for MDR-TB management. Webinars are live online presentations that cover specific topics related to MDR-TB management, where experts deliver sessions, providing in-depth knowledge, research updates, and practical insights [65]. Additionally, webinars allow healthcare workers to interact with presenters, enhancing engagement and promoting active learning.

Virtual workshops provide hands-on training experiences through telemedicine platforms. These workshops simulate real-world scenarios and allow healthcare workers to practice skills such as sputum sample collection, laboratory interpretation, and treatment decision-making [34, 61]. Participants can receive feedback and guidance from facilitators, ensuring they develop competency in the critical aspects of MDR-TB management.

Interactive sessions bring together healthcare workers from different locations to analyze complex MDR-TB cases collectively [65]. Likewise, participants can present cases, share diagnostic information, and discuss treatment approaches [66]. These sessions foster critical thinking, problem-solving skills, and collaboration among healthcare professionals involved in MDR-TB care. Furthermore, telemedicine platforms can facilitate online communities of practice, where healthcare workers can connect with peers, share experiences, and discuss challenging cases, creating a supportive learning ecosystem [6].

With limited resources and geographical constraints, traditional in-person training programs may be challenging for healthcare workers in remote areas [6]. Therefore, telemedicine bridges this gap by bringing the training directly to the worker's location, allowing them to access training materials and participate in educational activities at their convenience. This flexibility is vital in supporting healthcare workers with demanding schedules or limited opportunities for professional development.

Remote monitoring of treatment progress and side effects

Follow-up care is crucial in the management of MDR-TB to ensure treatment efficacy, monitor progress, and address any potential side effects [29]. Telemedicine platforms have emerged as valuable tools for remote monitoring of treatment progress and the timely identification of adverse events or complications. Connected devices, such as spirometers or pulse oximeters, allow patients to measure their lung function or oxygen saturation levels at home. The data collected from these devices can be transmitted to healthcare providers through telemedicine platforms, providing real-time information on patient's health status [67, 68]. Additionally, telemedicine platforms facilitate the remote assessment and management of treatment side effects. Timely management of side effects improves patients' tolerance to treatment and minimizes treatment disruptions [69].

Furthermore, artificial intelligence (AI) algorithms and machine learning models can be integrated into telemedicine platforms to assist in analyzing patient data. These algorithms can help detect trends, identify early warning signs of treatment failure or adverse events, and provide decision support to healthcare providers. AI in remote monitoring enhances the efficiency and accuracy of patient assessments and enables proactive interventions [70].

Teleconsultations for regular follow-up and care provision

Teleconsultations have become an integral part of follow-up care for MDR-TB patients in low-resource settings. Teleconsultations allow patients to receive tailored care without in-person visits, especially in locations with inadequate healthcare facilities [7, 30]. It also helps patients who have trouble getting to healthcare centers for follow-ups maintain continuity of care. Moreover, teleconsultations allow multidisciplinary care team involvement between healthcare providers from different specialties to provide comprehensive care for MDR-TB patients [66]. They also facilitate better communication and rapport-building between patients and healthcare providers [11].

To ensure the effectiveness of teleconsultations for follow-up care, healthcare providers must ensure patient privacy and data security. Compliance with patient confidentiality regulations and the use of secure telemedicine platforms protect patient information and maintain trust in the healthcare system [12]. Furthermore, teleconsultations can be combined with other telemedicine tools, such as remote monitoring devices and mobile applications, to enhance the quality and efficiency of follow-up care [71]. Patient-reported outcomes and self-assessment questionnaires can be integrated into telemedicine platforms, allowing patients to provide valuable information about their symptoms, treatment responses, and quality of life. These data can inform healthcare providers' decisions during teleconsultations, facilitating personalized care and treatment adjustments [6].

Integration of telemedicine with electronic health records

The integration of telemedicine with electronic health records (EHRs) is a significant development in data collection and surveillance for the management of MDR-TB [72]. Telemedicine platforms can be seamlessly integrated with EHR systems, enabling the efficient capture and storage of patient data generated during telemedicine encounters [73]. Integrating telemedicine with EHRs can help healthcare providers ensure that relevant patient information is readily accessible during teleconsultations. This integration streamlines data collection, eliminates duplicate data entry, and improves patient record accuracy and completeness [6]. Telemedicine-EHR integration allows real-time teleconsultation documentation and exchange of data between healthcare facilities and providers involved in the care of MDR-TB patients. Clinical notes, treatment decisions, and patient responses from teleconsultations can be recorded directly into the EHR. Such real-time documentation improves data-collecting efficiency and eliminates data loss and inaccuracies [72]. Additionally, seamless data sharing promotes care coordination and facilitates continuity of care, allowing healthcare providers to access comprehensive patient information, regardless of the patient's location or the healthcare facility they are attending [5]. Furthermore, the integration of telemedicine with EHRs also enables the use of decision-support tools and clinical guidelines. EHR systems can incorporate algorithms and reminders to assist healthcare providers in complying with best practices and evidence-based protocols for MDR-TB management [74].

Leveraging telemedicine data for surveillance and interventions

Telemedicine platforms generate a wealth of data that can be used for MDR-TB surveillance and interventions. The data collected during teleconsultations, remote monitoring, and other telemedicine interactions can provide valuable insights into disease trends, treatment outcomes, and areas requiring intervention [7]. Telemedicine data can be aggregated and analyzed to identify patterns and trends in MDR-TB prevalence, treatment success rates, and geographical distribution. This can serve as a valuable source of real-time surveillance information, supplementing traditional reporting systems and enhancing the timeliness of data analysis [7, 30]. This information can guide interventions aimed at improving treatment outcomes, such as targeted patient education initiatives, adherence support programs, or modifications to treatment protocols. Furthermore, telemedicine data can be utilized to monitor treatment outcomes and identify potential gaps in care. TB Reach is a program that uses data collected during teleconsultations and other healthcare encounters to identify trends and patterns in MDR-TB cases [28], such as targeted outreach to high-risk populations. Telemedicine data can also support proactive interventions and early detection of treatment failures or adverse events [75]. This may involve closer monitoring, personalized counseling, or treatment modifications. Additionally, telemedicine data can be used to evaluate the impact and effectiveness of telemedicine interventions in MDR-TB management. By assessing patient outcomes, patient satisfaction, and healthcare provider experiences, researchers can gain insights into the strengths and limitations of telemedicine programs [76]. This information can guide the refinement and scaling of telemedicine interventions to optimize their impact on MDR-TB care delivery.

Connectivity issues and infrastructure limitations

One of the primary challenges in implementing telemedicine for MDR-TB in low-resource settings is the limited connectivity and infrastructure. Many areas lack reliable Internet access and have inadequate technological infrastructure, hindering the widespread adoption of telemedicine platforms [14]. Connectivity issues can disrupt teleconsultations, compromise data transmission, and impede real-time monitoring of patients. Limited bandwidth and unstable Internet connections may result in poor video and audio quality, leading to communication difficulties between healthcare providers and patients. Additionally, the lack of access to reliable Internet services can hamper the integration of telemedicine with EHRs and hinder the timely exchange of patient data [77, 78]. To address connectivity challenges, innovative solutions are being developed. Mobile-based telemedicine applications with lower bandwidths and offline capabilities are designed to cater to areas with limited connectivity. The use of satellite-based internet services and telemedicine kits that include offline data storage and transmission capabilities are also being explored.

Addressing cultural and language barriers

Cultural and language barriers present significant challenges when implementing telemedicine for MDR-TB in diverse and multicultural settings. Effective communication and understanding of patients' cultural context are vital for delivering quality care and ensuring patient engagement and adherence [79]. Language barriers can hinder effective communication between healthcare providers and patients during teleconsultations [16]. Patients may struggle to understand treatment instructions or ask questions, while healthcare providers may face challenges in accurately interpreting patients' concerns or delivering culturally appropriate care. To address language barriers, telemedicine platforms are incorporating features such as real-time translation services and interpreter services, enabling seamless communication between patients and healthcare providers who speak different languages [80]. Additionally, the use of trained healthcare interpreters or multilingual healthcare professionals can bridge the language gap and ensure effective communication during teleconsultations [79].

Cultural sensitivity and awareness are equally important in telemedicine implementation. Healthcare providers must be trained to understand and respect the cultural beliefs, practices, and values of patients. This includes adapting communication styles, considering cultural norms, and addressing health literacy levels. Culturally tailored patient education materials, visual aids, and multimedia resources can support patient understanding and engagement [81].

Collaborative efforts for sustainable implementation

The implementation of telemedicine for MDR-TB in low-resource settings requires collaborative efforts among various stakeholders to ensure long-term sustainability and effectiveness. Partnerships between healthcare organizations, government agencies, non-governmental organizations (NGOs), and technology providers are essential [5]. Collaborative efforts enable the pooling of resources, knowledge, and funds to address infrastructural, training, and program implementation issues. Joint initiatives can build telemedicine networks, standardize protocols, and promote MDR-TB management best practices.

Telemedicine in MDR-TB care requires capacity building and training. Healthcare providers must be taught digital health literacy and teleconsultation platforms. Training programs should also cover MDR-TB management problems such as remote diagnostic test interpretation, treatment response monitoring, and side effects [82].

Sustainable financing models are crucial to ensure the long-term viability of telemedicine programs. Governments, international organizations, and funding agencies should prioritize investment in telemedicine infrastructure, including internet connectivity, technology devices, and maintenance. Adequate financial resources should be allocated to support ongoing training, data management, and program evaluation [83].

Community engagement and patient involvement are vital for the successful implementation of telemedicine in MDR-TB care. Engaging local communities, patients, and their families through awareness campaigns, education programs, and community-based support groups fosters a sense of ownership and encourages active participation in telemedicine initiatives. Community leaders and local healthcare providers can play a pivotal role in promoting telemedicine, addressing concerns, and building trust among community members. Patient feedback and experiences should be regularly solicited and integrated into program improvement efforts [84].

Monitoring and evaluating telemedicine programs can provide valuable insights into their impact on patient outcomes, cost-effectiveness, and scalability. Research studies can focus on evaluating the efficacy of telemedicine interventions, identifying best practices, and exploring innovative technologies that can further enhance remote healthcare delivery [85]. The COVID-19 pandemic has accelerated the adoption of telemedicine globally, creating a unique opportunity to leverage existing telemedicine infrastructure and experiences for MDR-TB management. Lessons learned from the rapid deployment of telemedicine during the pandemic can inform the development of sustainable telemedicine models tailored to MDR-TB care in low-resource settings.

Table 2 below highlights the benefits, challenges, and opportunities of telemedicine in MDR-TB prevention.

Table 2: Benefits, Challenges, and Opportunities of Telemedicine in MDR-TB Prevention

Benefit	**Description**	**Challenge**	**Description**	**Opportunity**
Improved access to specialized care	Patients can consult with TB specialists regardless of location.	Connectivity issues and infrastructure limitations	Remote areas may lack reliable internet and equipment.	Investment in telecommunication infrastructure
Enhanced patient adherence	Real-time monitoring and reminders increase treatment compliance.	Addressing cultural and language barriers	Diverse patient populations require tailored approaches.	Cultural competency training for healthcare providers
Cost savings	Reduced travel expenses for patients and healthcare workers.	Data privacy and security concerns	Protecting sensitive health data is paramount.	Development of robust data protection regulations
Timely diagnosis and treatment initiation	Early detection and treatment reduce the spread of MDR-TB.	Limited trust among healthcare providers and patients	Building confidence in telemedicine is crucial.	Community engagement and awareness campaigns
Enhanced healthcare worker training	Continuous education and peer support improve expertise.	Fostering collaboration for sustainable implementation	Partnerships can optimize resources and expertise.	Public-private partnerships and international cooperation

Limitations

Telemedicine offers significant opportunities for addressing the challenges associated with MDR-TB in low-resource settings, but several limitations exist. First, inadequate infrastructure, such as unpredictable internet connectivity and shortage of electricity, may hinder regular access to telehealth services. Furthermore, a lack of digital literacy and technological proficiency among healthcare providers and patients can limit the effective utilization of telemedicine systems. Additionally, cultural and language barriers may delay the acceptance of telemedicine services. Regulatory concerns, including data privacy and lack of standardized protocol, pose additional difficulties. Finally, telemedicine's usefulness in delivering comprehensive healthcare solutions can be compromised by limited integration with existing healthcare systems and the potential for poor quality of care resulting from the absence of physical examinations.

Future directions

Telemedicine initiatives should be supported by infrastructural improvements and healthcare facility resources. Governments, healthcare organizations, technology providers, and international agencies should work together to integrate telemedicine into healthcare systems. This includes establishing appropriate policies, allocating resources, and educating healthcare workers on utilizing telemedicine platforms effectively. Mobile apps and offline data transmission are needed to solve connectivity and infrastructure concerns. Real-time translation and cultural sensitivity training will improve healthcare provider-patient communication and patient knowledge and participation. Healthcare workers should receive extensive telemedicine, MDR-TB, and cultural competency training.

To scale and sustain telemedicine efforts, stakeholders should collaborate to develop sustainable telemedicine networks, share best practices, and promote knowledge exchange and experiences. Telemedicine programs should be rigorously evaluated and monitored to enhance and inform future plans. Telemedicine strategies for MDR-TB prevention should be tested for efficiency, affordability, and scalability. Policymakers should implement supportive laws and regulations to integrate and reimburse telemedicine services to promote their general use and sustainability for MDR-TB prevention.

Telemedicine can continue to evolve as a vital tool in preventing and managing MDR-TB in low-resource settings by incorporating the above-mentioned directions into future research and implementation efforts, improving healthcare outcomes and reducing the burden of this challenging disease.

Conclusion

Telemedicine is effective in preventing MDR-TB in low-resource settings. Current MDR-TB prevention trends include remote diagnosis and screening, teleconsultations with tuberculosis specialists, treatment adherence support through real-time monitoring and patient education, healthcare worker training and education, follow-up care via remote monitoring and teleconsultations, and data collection and surveillance using telemedicine data. These trends improve MDR-TB management by improving access, results, and healthcare professional support in resource-limited settings. Telemedicine has great potential to improve MDR-TB healthcare outcomes. It allows early diagnosis and treatment, rapid follow-up and monitoring, optimal treatment adherence through real-time reminders and patient education, as well as professional guidance and support. Telemedicine provides access to quality healthcare services to remote and underserved patients by overcoming geographical barriers. Telemedicine and electronic health records improve data gathering, care coordination, and evidence-based decision-making. Telemedicine can improve surveillance, identify illness trends, and direct public health actions. Overall, telemedicine has the potential to improve MDR-TB prevention, treatment delays, and patient outcomes in low-resource settings.

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Declaration of Competing Interest

No Conflict of interest to declare.

CRediT authorship contribution statement

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