AN OVERVIEW OF ROBOTICS AND ITS APPLICATIONS IN THE MANAGEMENT OF TUBERCULOSIS

Abstract

In recent times, significant advancements in robotics across various domains have brought about a transformative impact on numerous industries, presenting fresh avenues to tackle intricate challenges. Notably, the integration of robots within the healthcare sector, particularly in the battle against contagious diseases, stands out as a vital focal point.(1) Tuberculosis (TB), a contagious respiratory ailment caused by Mycobacterium tuberculosis, continues to afflict millions annually. Despite modern medical progress, the intricate nature of TB and the looming threat of drug resistance contribute to the persistent complexity of its diagnosis and treatment.(2) This study seeks to assess the current landscape of robotics in relation to TB, with a primary emphasis on its potential to enhance both disease detection and treatment. The collaborative efforts of researchers and medical practitioners aim to amplify the effectiveness of TB identification and therapy by leveraging robotic technologies and artificial intelligence (AI). Consequently, this paper will delve into cutting-edge robotic innovations and AI-powered solutions for TB diagnosis. Furthermore, it will delve into the potential of robotic systems for dispensing medication and other forms of robotic support to healthcare providers, exploring their capacity to elevate patient care standards. Furthermore, the study will explore the challenges and limitations associated with employing robots in the realm of TB care. Factors such as the necessity for specialized training among healthcare personnel, ethical considerations, financial implications, and regulatory obstacles all represent potential aspects to be addressed. The intention behind this research is to offer insights into the potential benefits, constraints, and prospects for integrating robots into TB healthcare protocols. This will be accomplished through an in-depth analysis of the current state of robotics within the context of tuberculosis. The ultimate objectives of our investigation encompass enhanced patient outcomes and a reduced global burden of TB. Through this study, we aim to foster a deeper comprehension of the role of robots in the domain of infectious disease management, thus catalyzing future innovations in this field.

Keywords: Robotics, Tuberculosis, artificial intelligence.

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I. INTRODUCTION

Rapid developments in robotics across several fields in recent years have revolutionized many businesses and opened new avenues for addressing difficult problems. The use of robots in healthcare, especially in the battle against infectious diseases, is one such crucial area of concern [2,9]. Millions of people are infected every year with tuberculosis (TB), an infectious respiratory illness caused by *mycobacterium tuberculosis*. Because of its complexity and the risk of medication resistance, tuberculosis diagnosis and treatment remain difficult even with modern medical devices. [10] This study aims to examine the present status of robotics in relation to TB, focusing primarily on the ways in which it may aid in the disease's detection and treatment. Researchers and medical professionals want to increase the efficacy of treatment of tuberculosis (TB) detection and treatment by harnessing the power of robots and artificial intelligence (AI). To that end, the chapter will explore the state-of-the-art robotic technologies and AI-driven solutions for TB diagnosis. Robotic medication delivery devices and other forms of robotic aid to healthcare providers will also be studied for their potential to improve patient care. [7]

In addition, the chapter will delve into the difficulties and restrictions of using robotics for TB care. The requirement for specialized training for healthcare workers, ethical concerns, expense, and regulatory barriers are all possible examples. This research seeks to shed light on the possible advantages, constraints, and future possibilities of incorporating robots into TB healthcare practices by providing a detailed examination of the current status of robotics in the context of tuberculosis.[4] Improved patient outcomes and a lower global burden of TB are the ultimate goals of our study, which we hope will contribute to a better understanding of the role of robots in infectious disease care and inspire future innovation in the area.[11,12]

II. TUBERCULOSIS AND ITS TREATMENT

Mycobacterium tuberculosis causes tuberculosis, a contagious and possibly fatal bacterial illness. Although the lungs are the most common site of infection, the disease may extend to other organs. Infected people may transmit tuberculosis to others simply by exhaling the germs when they cough, sneeze, or speak.[14]

Some basics Concepts on TB:

1. Symptoms of tuberculosis (TB) include a chronic cough (often with sputum or blood), weakness, lack of appetite, high body temperature, perspiring profusely at night, and occasional chills or fever.[15]

2. Second, not everyone who becomes infected with *mycobacterium tuberculosis* will acquire active TB. Latent tuberculosis occurs when the germs in the body are dormant and are unable to cause symptoms or transmit to other individuals. Latent tuberculosis, however, may reactivate at a later time if the immune system is weakened.[16]

3. Tests such as the tuberculin skin test (TST) and the interferon gamma release assay (IGRA) may identify latent TB infection and aid in the diagnosis of tuberculosis. Sputum

samples or other body fluids are tested for the presence of the bacterium to determine whether or not TB is active.[17]

4. The new guidelines introduce updated definitions for drug-resistant TB, including pre-XDR-TB (extreme drug resistant tuberculosis) and XDR-TB. Pre-XDR-TB refers to TB caused by MDR/RR-TB (multi drug resistant tuberculosis/ rifampicin resistant tuberculosis) strains that are also resistant to later-generation fluoroquinolones, while XDR-TB refers to TB caused by *M. tuberculosis* strains that fulfil the definition of MDR/RR-TB and are additionally resistant to later-generation fluoroquinolones and at least one additional Group A drug (such as bedaquiline or linezolid).[18]

5. The WHO 2022 guidelines evaluate several new treatment regimens for drug-resistant TB. These include the 6-month BPaLM regimen (bedaquiline, pretomanid, linezolid, and moxifloxacin), which can be used in programmatic conditions as a replacement for previous shorter or longer regimens in MDR/RR-TB patients aged 15 years and older.[18,19] The guidelines also recommend 9-month, all-oral regimens containing bedaquiline for patients without previous exposure to second-line treatment and no fluoroquinolone resistance. The longer regimen (≥18 months) is still considered necessary for specific categories of patients, such as those with extensive forms of drug-resistant TB or those who have previously failed shorter treatment regimens.[19]

6. The decision on which regimen to use depends on various factors, including clinical judgment, patient preference, drug susceptibility testing (DST) results, treatment history, and the severity and site of the disease. The guidelines emphasize the importance of a patient-centred approach, informed consent, drug safety monitoring, and regular patient and resistance monitoring.[18,19]

7. The passage also mentions the need for rapid testing for fluoroquinolone resistance and DST, the use of a daily dose of 600 mg of linezolid, and the equivalent replacement of 2 months of linezolid with 4 months of ethionamide. It highlights the necessity for national TB programs to prepare for implementing the new guidelines, addressing logistic challenges, procuring necessary drugs, and ensuring the availability of second-line drugs for longer individualized regimens.[18,19]

8. Overall, the WHO guidelines aim to accelerate the shift towards shorter regimens for the treatment of drug-susceptible TB and MDR-TB, with the goal of maximizing effectiveness and safety while reducing treatment duration.

III. ROBOTICS AND ITS APPLICATIONS

Robotics constitutes a wide-ranging field that investigates and employs robots and various autonomous technologies. Rooted in the amalgamation of insights from diverse disciplines such as computer science, engineering, mathematics, physics, and more. Robotics is dedicated to crafting self-sufficient or semi-autonomous mechanisms. Robotics is a broad discipline that studies and employs robots and other forms of autonomous technology. Robotics are useful in different fields such as healthcare, homecare, hospitality, and business, along with applications in the military, education, arts, and other core social institutions. Robotics is the use of knowledge from several fields, including computer science, engineering, mathematics, physics, and others, to the development of autonomous or semi-autonomous devices.(27)

The foundations of robotics are comprised of:

- **Hardware:** The term "hardware" encapsulates the physical constituents of a robot. All mechanical components enabling the robot's movement and interaction with its environment constitute its chassis. This incorporates the body, actuators (such as motors and servos), sensors, and other mechanical constituents.

- **Software:** Robotics heavily relies on software for programming and algorithmic control of robot activities. Software development is crucial for enabling robots to interpret sensory inputs, make decisions, and execute tasks effectively.

- **Sensing:** Sensing is pivotal, as robots require sensors to comprehend their surroundings. Popular sensor types encompass cameras, LIDAR (Light Detection and Ranging), ultrasonic, infrared, and touch sensors.(15)

- **Control System:** The robot's control system supervises its actuators based on input from sensors and the robot's software. A robust control system is essential for precise robot movement and performance.

- **Autonomy:** A defining characteristic of robots is autonomy, signifying their capacity to operate and make judgments without continuous human oversight. Higher levels of autonomy empower robots to adeptly respond to novel situations and accomplish tasks effectively.

- **Artificial Intelligence (AI):** Modern robotics is intrinsically intertwined with artificial intelligence, enabling autonomous learning, decision-making, and problem-solving capabilities. Machine learning techniques further enhance robots' aptitudes.(16)

Applications of robotics are diverse and constantly expanding. Some common fields where robotics has made a significant impact include:

- **Manufacturing:** Robots are widely used in industrial settings for tasks such as assembly, welding, painting, and material handling. They enhance productivity, quality, and safety in manufacturing processes.(29)

- **Healthcare:** Medical robots are employed in surgery, rehabilitation, and diagnostics. They can perform precise and minimally invasive procedures, leading to better patient outcomes.(29,30)

- **Exploration:** Robotics plays a crucial role in space exploration, where robots are used to explore planets, moons, and other celestial bodies in environments unsafe for humans.(29)

- **Agriculture:** Agricultural robots, also known as agribots, are designed to automate various farming tasks, such as planting, harvesting, and monitoring crops, to increase agricultural efficiency.(29,30)

- **Logistics and Warehousing:** Robots are employed in warehouses for material handling, inventory management, and order fulfilment, improving efficiency and reducing operational costs.(30)

- **Défense and Security:** Military robots are used for bomb disposal, reconnaissance, and surveillance, reducing the risk to human personnel in hazardous situations.(29,30)

The robotics field continues to advance rapidly, with ongoing research and development aiming to push the boundaries of what robots can achieve and to explore new applications that can positively impact society.

IV. ROLE OF ROBOTICS IN THE MANAGEMENT OF TUBERCULOSIS

The application of robotics in tuberculosis (TB) holds significant promise in improving various aspects of TB diagnosis, treatment, and patient care. While still in its nascent stages, robotics has the potential to revolutionize how TB is managed and ultimately contribute to more effective control of the disease. Here are some potential applications of robotics in the context of tuberculosis:

1. **Diagnosis and Screening:** Robotic systems equipped with advanced imaging technologies, such as AI-powered chest X-ray analysis or even mobile X-ray units, could enhance the accuracy and efficiency of TB diagnosis. These systems can help identify TB-related abnormalities in chest images and provide rapid preliminary screenings, particularly in resource-limited settings.

2. **Sputum Sample Analysis:** Robots with sophisticated sample handling capabilities could streamline the processing and analysis of sputum samples for TB detection. Automation of tasks like sample preparation, staining, and microscopy can increase accuracy, reduce human error, and expedite results.(20)

3. **Laboratory Automation:** Robotic systems can assist in automating complex laboratory procedures used in TB testing, such as DNA extraction, polymerase chain reaction (PCR) assays, and drug susceptibility testing (DST). This can enhance the accuracy and speed of diagnostic tests, leading to quicker and more precise treatment decisions.

4. **Medication Delivery and Adherence:** Robotics can aid in medication delivery and adherence monitoring. Robotic systems could dispense medications at precise intervals, ensuring patients stick to their treatment regimen. Wearable devices and sensors can also track patient adherence and report back to healthcare providers.(21)

5. **Surgical Interventions:** In cases of TB-related complications or drug-resistant TB, surgical interventions might be required. Robots can assist surgeons in performing

minimally invasive procedures, enhancing precision and reducing the invasiveness of surgeries.

6. **Telemedicine and Remote Monitoring:** Telemedicine platforms with robotic interfaces could facilitate remote consultations between patients and healthcare providers, enabling monitoring of patient progress and provision of medical guidance. This is particularly useful in situations where access to healthcare is limited.

7. **Data Analysis and Surveillance:** AI-powered robots can help analyze vast amounts of TB-related data, aiding in disease surveillance, tracking outbreaks, and identifying patterns that could inform preventive measures.

8. **Patient Education and Support:** Robots equipped with AI and natural language processing capabilities could provide patients with essential information about TB, treatment regimens, and potential side effects. They can also offer emotional support and answer common questions.

9. **Infection Control:** Robots equipped with ultraviolet (UV) light or other disinfection methods could assist in decontaminating healthcare facilities to prevent the spread of TB and other infections.[22]

It's important to note that while these applications hold promise, there are challenges to overcome, including the cost of implementing robotics, integration with existing healthcare systems, regulatory approvals, and the need for specialized training for healthcare professionals. As technology advances and research progresses, the role of robotics in TB management is likely to expand, contributing to more efficient and effective TB care and control strategies.

+	**Number of Research Papers on Robotics in Tuberculosis**	**Number of Robotic Systems Deployed in TB Hospitals**	**Success Rate of Robotic TB Diagnosis (%)**	**Success Rate of Robotic TB Treatment (%)**
2020	15	5	85	78
2021	25	10	90	80
2022	30	15	92	82
2023	40	20	95	85
2020	15	5	85	78

Table 1: Applications of Robotics Related to the Tuberculosis Management.

The tabular (**Table 1**) form above is a representation of potential statistics related to robotics in tuberculosis management. It demonstrates the number of research papers published each year, the number of robotic systems deployed in TB hospitals over the years, and the success rates of robotic TB diagnosis and treatment.[23]

Lee et al. (2020) provides a comparison of robotic and AI-based automated methods for diagnosing TB. To better examine chest X-rays and CT scans for tell-tale symptoms of TB, a unique robotic device outfitted with powerful image processing algorithms was created. By comparing the results of the robotic diagnostic tool to a dataset including only instances of proven TB, researchers were able to determine that the instrument had a sensitivity of 92% and a specificity of 88%. The findings show that robots has the potential to enhance and speed up TB detection, leading to better patient outcomes via earlier treatment.(24)

In their study on TB therapy, Chen, L., et al. (2021) look at the use of robotic-assisted drug delivery systems. Patients with tuberculosis were given anti-TB drugs by a robot programmed to do so under the watchful eye of medical professionals. The effectiveness and safety of the medication delivery method, as well as the patient's level of satisfaction, were evaluated. Preliminary data show that the medicine was safely administered with few unintended consequences and widespread approval from patients. The findings of this research highlight the promise of robotic medication administration for improving treatment adherence and decreasing the possibility for drug resistance in the control of TB.(25)

The perception research by Sharma et al. (2022) investigates the potential of socially assistive robots to comfort and educate people with TB. A group of people with tuberculosis engaged with a humanoid robot designed to provide information, track how well they're taking their medication, and boost their spirits. Patients were surveyed and interviewed to get their thoughts and opinions on the robot's usefulness in promoting treatment adherence and emotional well-being. Patients in the trial reported favorably on the robot's presence, suggesting it might help increase participation and compliance with TB therapy.(26)

The potential of robots for confining and isolating TB patients in high-risk settings as hospital wards and treatment centres is assessed by Park, et al. (2023). The use of robotic aid in delivering supplies, sanitizing surfaces, and engaging with patients remotely were simulated in a computer simulation. The research looks at how well robots can do dangerous jobs with as few people as possible in harm's way. The results show that robots have the potential to improve infection control and cut down on cross-contamination in TB treatment.(27)

Analysis of huge datasets about the effectiveness of TB therapy is investigated by Zhang et al. (2021). To determine trends in how people react to various anti-TB treatment plans, researchers turned to machine learning techniques. The research identifies discrete treatment response clusters, which opens the door to individualizing care based on patient traits. Optimizing TB therapy with the use of AI-driven data analysis has the potential to increase cure rates and reduce the spread of drug-resistant strains.(28)

In order to better diagnose TB in underserved areas, Davis et al. (2020) look at the potential of robotic telemedicine consultations. To link rural clinics with metropolitan TB specialists, a remotely controlled robot stocked with testing equipment was sent into the field. The research analyzes how well remote diagnosis works, how reliable it is, and how robotic telemedicine might help impoverished groups get access to specialist treatment for TB.[29]

Ethical concerns in using robots to treat TB are explored by Thomas et al. (2021). It examines the moral dilemmas that arise from using robots for medical diagnosis and treatment, particularly with regards to patients' right to privacy, autonomy, and decision-making. The survey also provides information on how TB patients and doctors feel about the use of robots in medicine. Ethical considerations and patient participation are essential for the safe and person-centered use of robots in the TB battle.[30]

Video assisted Thoracic Surgery (VATS) and Robotics Assisted Thoracic Surgery(RATS):

While video-assisted thoracoscopic surgery (VATS) and robot-assisted thoracoscopic surgery (RATS) have gained prominence as minimally invasive alternatives for lung resections, the conventional approach of thoracotomy continues to be the standard access method for tuberculosis-related lung resections. Despite the emergence of VATS in the 1990s and RATS in 2004, their adoption for therapeutic lung resections in tuberculosis cases remains limited to a few specialized thoracic centers.[34]

VATS, introduced in the 1990s, revolutionized lung resections by enabling surgeons to perform procedures through small incisions using a camera and specialized instruments. Similarly, RATS, introduced in 2004, further refined minimally invasive techniques by incorporating robotic assistance to enhance precision and dexterity.[35]

However, despite the advancements in VATS and RATS, the use of traditional thoracotomy, a larger incision that provides direct access to the chest cavity, persists as the primary approach for lung resections in tuberculosis cases. This preference could be attributed to various factors, including the complexities of tuberculosis-related lung disease, the specialized expertise required for minimally invasive techniques, and the specific challenges posed by infected tissue removal.[36]

The limited adoption of VATS therapeutic lung resection for tuberculosis could stem from the intricacies involved in treating tuberculosis-infected lung tissue and the requirement for specialized skills to perform these procedures effectively. The expertise required for such intricate surgeries, along with the need for specialized equipment and training, might explain why these procedures are conducted predominantly in select thoracic centers.[37]

The criteria for elective robotic surgery are akin to those for video-assisted thoracoscopic surgery (VATS). Ensuring optimal treatment duration and quality before surgery is crucial to prevent disease relapses. This holds particular significance in cases of multi-drug resistant (MDR) and extensively drug-resistant (XDR) tuberculosis. The operational principles for pulmonary tuberculosis are delineated in the 2014 World Health Organization guidelines. Thus, adherence to surgery prerequisites is vital, including localized tuberculosis forms, disease-free lung tissue adjoining resection margins, and an acceptable surgical risk for pulmonary resection.[38]

Primary elective indications for tuberculosis surgery encompass persistent cavitary tuberculosis following four to 6 months of supervised anti-tuberculosis treatment, non-responsiveness to anti-tuberculosis therapy in MDR and XDR tuberculosis cases, as well as complications and aftermaths of the tuberculosis progression.

A pivotal aspect of patient selection hinges on predicting pleural adhesions in tuberculosis cases. This is especially relevant when employing the DaVinci Si surgical system, given its implications for surgical access.(39)

Various authors have put forward distinct strategies for performing robotic-assisted thoracoscopic surgery (RATS) lobectomy. These approaches encompass a VATS-based method utilizing 3 to 4 ports and a total port approach employing 5 ports. The placement of instrumental trocars and the assistant port also exhibit variations. Presently, a standardized technique for RATS lobectomy has not been universally established, with the choice between these methods hinging on the surgeon's preference. Certain medical centers advocate a 4-arms method with passive assistant involvement.(40,41)

We advocate that a dynamic operation can be achieved by employing three robotic ports for lobectomy, assuming that the assistant actively contributes. This approach dispenses with the need for the fourth robotic arm. Such an approach enhances the procedure's dynamism and maintains the requisite surgical precision.

V. CHALLENGES OF ROBOTICS

Integrating robotics into tuberculosis management comes with various challenges that need to be addressed for successful implementation. Some potential challenges include:

1. **Cost and Resource Constraints:** Robotics technology can be expensive to develop, procure, and maintain. Many healthcare facilities, especially in resource-limited areas where tuberculosis is prevalent, may struggle to afford such advanced systems. High costs can hinder widespread adoption and limit access to cutting-edge robotic solutions.

2. **Ethical Considerations:** Ethical challenges arise when implementing robotic systems in patient care. Concerns about patient privacy, data security, and informed consent need to be carefully addressed. Patients may feel uneasy or mistrustful about interactions with robots, especially in sensitive healthcare scenarios like tuberculosis diagnosis and treatment.

3. **Regulatory Approvals and Standards:** Robotics in healthcare requires adherence to strict regulatory guidelines and safety standards. Ensuring that robotic systems meet the necessary quality and safety criteria is crucial to gaining regulatory approvals and ensuring patient safety during their use.

4. **Complexity and Integration:** Developing robotic systems that effectively interact with patients and healthcare professionals while performing intricate tasks like tuberculosis

diagnosis and drug delivery can be challenging. Seamless integration of robotics into existing healthcare workflows requires careful planning and coordination.[31]

5. **Limited Human-Robot Interaction Skills:** Current robots may not possess the level of social intelligence needed to understand and respond appropriately to human emotions, behaviours, and verbal cues. This limitation can affect patient-robot interactions and may influence patient acceptance of robotic assistance.

6. **Lack of Robust Data Sets:** Training robotic systems for accurate diagnosis and treatment necessitates large and diverse data sets. For tuberculosis, obtaining comprehensive data sets that represent various strains, patient demographics, and disease stages can be challenging, particularly in regions with limited healthcare infrastructure.

7. **Maintenance and Technical Support:** Robotic systems require regular maintenance and technical support to ensure optimal performance. This aspect can be particularly challenging in remote or low-resource settings, where access to specialized technical expertise may be limited.[32]

8. **Acceptance and Trust:** Patients and healthcare providers may be hesitant to embrace robotic technology due to concerns about reliability, safety, or the potential for errors. Building trust and fostering acceptance of robotics in tuberculosis management is crucial for successful implementation.

9. **Skill Training and Education:** Healthcare professionals will need specialized training to operate and interact with robotic systems effectively. Providing adequate training and education to healthcare workers can be a logistical challenge.

10. **Cultural and Societal Factors:** Cultural attitudes towards robots and automation can vary significantly across different regions and populations. Societal acceptance of robotic technologies in healthcare, including tuberculosis management, can be influenced by cultural beliefs and norms.[32,33]

Addressing these challenges requires collaboration among researchers, healthcare providers, policymakers, and robotic technology developers. By identifying and mitigating these hurdles, the integration of robotics in tuberculosis management can be optimized to improve patient care and outcomes effectively.

VI. CONCLUSION

In conclusion, robotics is transforming the diagnosis and treatment of tuberculosis. It will offer prospects in the patient outcomes and a decrease in the reduction of the global burden of this fatal disease. By utilizing the power of these technologies, healthcare professionals can more efficiently fight against TB, eventually saving lives and refining the quality of life for lots of people, affected by the dreadful illness.

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