International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Role of Artificial Intelligence (AI) in Infection Control

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Abstract: ***Infectious diseases, pandemic/epidemic disease spread and hospital-acquired infections cause a major burden on the healthcare system. Artificial intelligence technologies such as machine learning, artificial neural networks, big data analytics and deep learning are useful in the diagnosis, prevention, treatment and monitoring of infections. Machine learning helps in the prediction of infections enabling their early management whereas neural networks enable the selection of most suitable treatment agents in multi-drug resistant cases. Big data analytics improvise decision-making processes through the analysis of gigantic data sets advancing physician's efforts in the management of infections. Artificial intelligence has been successful in the diagnosis of pneumonia, tuberculosis, hepatitis B and C infections among others as well as in person-centered treatment of infections, which is made possible by studying the genomic and panomic profiles of the patient. Because of this personal approach, it is ascertained that patient compliance and engagement with treatment and prevention protocols described by artificial intelligence will be greater than that provided by physicians. Artificial intelligence helps in identifying early signs of patient deterioration such as liver failure through the analysis of biomarkers such as bilirubin. Additionally, it assists in drug synthesis after studying mutation patterns of microorganisms and selecting the most suitable drug agents for management of infections. In the pandemic spread of COVID-19, artificially intelligent platforms such as Bluedot Global have been used for tracking, which signifies it's potential. Further, applications such as Moni and other AI-based active surveillance platforms have demonstrated superiority in monitoring of critical post-operative cases enabling their timely management.***

Keywords: Infection, Infection Control, Infectious Disease, Artificial Intelligence, Machine learning, Innovation

Infectious diseases are a major cause of death, disability, social and economic disorders throughout the world [1]. Mortality due to infections is a massive burden on the healthcare system as well as the patients and their family members [2]. Lower respiratory tract infections, tuberculosis and influenza are among the top 10 causes of death worldwide according to statistics from the WHO (refer to fig.1) [3].

In patients receiving care, there is also aa high risk of hospital acquired infections, which adds on to the overall burden of infections and negatively hampers their quality of life [1].

Physician's efforts in the management of infections are limited by the availability of healthcare facilities, their knowledge, skills and interpretation, which may not alone be enough, especially in situations of epidemics/higher patient load such as in the recent pandemic outbreak of COVID-19 [4]. This necessitates the inclusion of artificial intelligence for enhancing the overall management of infections in a global scenario [5].

Artificial intelligence refers to the use of efficient technologies to simulate intelligent behavior and critical thinking through the analysis of large data sets, which is used to improvise decision making and enhance patient outcomes [6, 7]. Its use in infection control is colossal since the foremost application of AI in medicine was for the identification and management of infections such as bacteremia and meningitis [8]. This early knowledge-based backward chaining system, developed in the 1970s, recommended antibiotic use while adjusting the dose based on patient's age and weight [8]. Moving forward, the potential of modern AI technologies in the current infection control scenario can only be speculated. Presently, it is used for the detection of infections at the earliest stages, which makes it possible to treat and manage all patients at the earliest [4, 5].

Artificial Intelligence in Infection Control

Artificial Intelligence has a momentous role in the diagnosis, prevention and treatment of infections and in determining patient prognosis [9]. AI technologies including Machine Learning and Natural Language Processing function by analyzing large amounts of patient data, maximizing physician's efforts [10, 11]. These technologies are capable of interpreting image and genetic data along with physician entered information such as patient history and notes, for participating in decision making (refer to table 1) [11].

Artificial Intelligence in the Diagnosis of Infections

For the diagnosis of infections involving the use of AI technologies, EHR data is analyzed, based on which risk stratification is compiled [12]. This enables the early detection and diagnosis of infections. Decision tree classifiers have been successfully tested in the diagnosis of Chlamydia, Pneumoniae and Hepatitis B/C infections, where they have 60 to 65 % accuracy [12, 16]. ANN-based algorithms have also been used in the diagnosis of tuberculosis (refer to fig.2) [5].

AI-based algorithms facilitate automated diagnosis through the examination of chest X-rays [17]. Trial data have demonstrated that diagnosis made through the assistance of NLP is as precise as physician-made diagnosis in most cases of pneumonia [17]. Further, they have an advantage of providing an early diagnosis, which is why they are used in clinical practice [15].

Early diagnosis is made possible through the detection of biomarkers such as procalcitonin and C–Reactive protein, which are useful in the diagnosis of bacterial infections such as pneumonia [18]. AI technologies also enable timely detection of signs of patient deterioration [18]. Organ failure is one of the most alarming signs of treatment failure and patient deterioration, which can be detected through AI-based analysis involving the analysis of biomarkers [18, 19]. Liver failure can be detected by biomarker levels of Alanine aminotransferase, Alkaline phosphatase and bilirubin, forth which severity score is assigned to the patient for deciding the priority of emergency management [18].

Artificial Intelligence provides a step ahead in the process of diagnosis through analysis involving genomic and panomic profiling of the patient with the help of ML and convolutional neural network-based algorithms [20]. Population genomics has already been successful in the diagnosis of *Staphylococcus epidermidis* and other high-risk genotypes [20]. These algorithms have a 90 % accuracy rate and are both fast and sensitive for early diagnosis [20].

Artificial Intelligence in the Prevention of Infections

AI has massive potential in infection prevention and control. Foremost, it helps in the prediction of high-risk cases, and the development of standardized prevention protocols [20]. Biomarker analysis, panomic profiling and data obtained through its gigantic datasets can be compiled for the identification of thesepatients, who are then isolated, to prevent large scale community spreads [18]. ML-based algorithms provide an edge in these predictions by offering newer insights into the spread of infection, which are not limited to the knowledge of known risk factors by the physician [16]. Previously, ML has been successful in predicting the outbreaks of methicillin-resistant Staphylococcus aureus and influenza through the analysis of data generated from EHRs and social networks of patients and caregivers [16].

Deep learning platforms combined with convolutional neural networks have demonstrated comparable efficiency to physicians/radiologists in the screening and classification of tuberculosis through image-intensive analysis involving chest radiography [5]. They have also been used in the predictions of high-risk genotypes through genomic profiling of the microorganism [20].

In addition to prediction, AI has a much larger role in prevention through improvement of prevention protocols followed by communities [20]. Intelligent technologies are used to bring about an overall behavioral change among populations increasing their compliance with infection control protocols such as the practice of efficient hand hygiene [20]. By offering a more person-centered and educative approach, the use of AI in the description of prevention protocols is more largely preferred by patients because of the real-time support and advise offered to them [22]. This support is in the form of regular reminders, performance returns and points of data collection monitoring their compliance, which can be particularly more useful for patients living in rural / remote settings [21].

Artificial Intelligence in the Treatment of Infections

AI technologies have a significant role in the treatment of infection with their use being made at all stages of patient management. Firstly, it assists in clinical decision making through the analysis of EHR data, trial data and clinical notes through ML, ANN and big data analytics [22]. *Antibiotic assistant* is a real-time NLP-based decision support system, which is used in radiology departments for the clinical control of pneumonia [17]. Clinical Decision Support Systems (CDSSs), based on a model of unsupervised learning, and application *Dxplain* are used for antibiotic selection and decision making, respectively, for the treatment of infections [23].

With high level of analysis involving patient assessment through its informative tools, AI is used to describe a change in prescription practices followed by physicians and helps in more advanced decision making [18, 23]. Along with this, random forests also assist in the personalized treatment of infections since they carefully adjust the treatment protocol based on the analysis of specific patient data [16].

One of the advantages of using artificial intelligence in the treatment of infections is that it has a greater capability of handling huge datasets, thereby supporting the efforts of the physician. It gives consistent and efficient results minimizing the risks of treatment–related biases [13, 16].

Patient centered treatment

Another major advantage of using AI in the management and control of infections is that they help in directing the treatment based on direct data obtained from the EHR of the patient, thereby enabling a patient centered approach [24]. The treatment protocol is decided based on immune status of the patient, their genomic profile and drug testing among several other parameters [20]. It is probable that some aspects of patient history may not considered in decision making by physicians due to the loss of these data when recorded manually. However, through the involvement of AI in decision making, all types of patient data are efficiently interpreted resulting in superior treatment outcomes and higher rates of patient compliance since the treatment protocol is well-adjusted to their needs [21, 22]. Thus, it is estimated that AI will help in meeting the current challenges encountered in infection control.

Artificial Intelligence in managing infections with antimicrobial resistance

One of the major issues encountered by physicians in managing bacterial infections is the emergence of multi drug resistant genes that are not susceptible to antibiotics commonly used in practice [25]. AI technologies can be used for predicting the degree of antimicrobial activity against antimicrobial agents, which helps in the selection of the most suitable treatment agent in multi drug resistant genes [16]. They closely study antimicrobial resistance, the patterns of mutations and the process of proliferation of these bacteria in the presence of treatment agents [16]. AI technologies examine various taxonomic and ecological groups to determine the survival rates and the levels of resistance of microorganisms, which is resulting in large scale resistance. ANN helps in the identification of novel antibiotic agents which can be administered in multi-drug resistant cases [18]. Support Vector Machines and semi-supervised clustering can also be used for suggesting new synthetic peptide structures for the creation of novel antibiotics, which can act against these resistant strains [26]. More advanced technologies like Long Short Term Memory artificial neural networks enable these processes by deeply studying the sequences of amino acids and improving treatment accuracy based on the patterns of resistance of the microorganism [26].

AI-based technologies have a pertinent role in drug discovery for the treatment of infections. Computer-aided drug design has been used for the creation of a number of antimicrobial drugs used for the treatment of resistant cases. Some of the drugs developed through AI include captopril, dorzolamide, boceprevir, nelfinavir, saquinavir, zanamivir, oseltamivir, and raltegravir [16]. ML-based design offers high computational powerrequired for the creation of superior quality drugs, which require lesser rounds of trial and testing [16]. Following this, decision trees and random forests are applied to aid in the discovery of best drugs based on several parameters like lipophilicity, molecular weight and polarizability [16, 18].

Artificial Intelligence and hospital – acquired infections

AI assists in automated identification and extended monitoring of patients for the detection of nosocomial infections such as urinary tract infections [27]. This is possible through the analysis of patient data arising from EHRs with big data analytics and machine learning [22, 27]. A recently developed AI-based system named *Moni* encompasses medical knowledge packages for identifying and monitoring infections among inpatient cases [28]. It consists of medical logic modules in Arden syntax, which are incorporated with the hospital information systems, ICU data or patient management systems [28]. This application is efficient in data-to-symbol conversion and can penetrate within several layers of abstraction until top level of analysis is reached, which is essential for the classification of nosocomial infections. Prior to this application, another system for the surveillance of nosocomial infections, *GermWatcher*, was in use [29].

Moni has successfully identified infections related to bloodstream along with pneumonia, urinary tract infections and central venous catheter-associated infections in patients [28]. Its interpretations are presented capably in terms of medical concepts involving terms "normal", "increased" and "decreased", making it understandable to by physicians, thus having actual implementations in early management [28].

Artificial Intelligence in the Treatment of ICU Patients with Infection

AI-based surveillance systems can assist in the management of multimodal infections in ICU patients through the estimation of the risk of infection from different points of contact of the patient [30]. These active surveillance systems are embedded at various points of sampling such as the bedside, medication carts, faucets, sinks and edges of beds and bars [31]. Along with this, the risk of hospital acquired infections is also calculated on the basis of compliance with the hand hygiene protocols of patients and physicians, personal protective equipment use by medical personnel and compliance with hospital protocols including the guidelines to be followed by ICU staff members [32]. This surveillance enables the detection of various types of infections which are commonly encountered in critical cases. This includes the surveillance of catheter-associated infections, bloodstream infections, ventilation-associated infections, pneumonia, urinary tract infections and systemic infections, risks of which is calculated based on microorganism populations, molecular genotyping of bacterial isolates and pulsed field gel electrophoresis among other technologies [31].

AI has demonstrated massive potential in the diagnosis of urinary tract infections, which are common in inpatient cases [33]. Urine sampling through ML helps in selecting patients for undertaking bacterial culture, and it also helps in identifying patients with high risk [33]. Thus, AI-based regimens help in advancing physician's efforts in the control and management of infections in intensive care and critical units.

Artificial Intelligence in Pandemic and Epidemic Situations [20, 34, 35, 36]

AI systems are used in detecting the patterns of outbreaks by analyzing its vast data sets [20]. They are also used for community surveillance in high-risk regions as well the description of generalized preventive protocols [20]. In the recent pandemic outbreak of novel Corona Virus (COVID-19), AI can facilitate efficient decision making through the analysis of large amounts of data emerging from government and national reports, social media and news outlets [20, 34]. It can also enhance the tracking and tracing process by studying the patterns of infection and the evaluation of infection control strategies used for prevention [35].

Existing platforms used in the control of COVID-19, including *Bluedot Global*, are based on ML and NLP-based algorithms, which signifies the role of AI in managing this outbreak and in averting future situations [36]. AI platforms can also be used for the training, supervision and guidance of less trained medical and paramedical personnel in rural/remote areas with a shortage of physicians [35, 36]. This is especially useful in the management of positive cases in developing and under-developed countries where suitable health care access to remote areas is limited [20, 35, 36]. In these areas, computer-aided diagnosis and management can aid in achieving higher efficiency and accuracy thereby reducing population risks [20].

AI-based models facilitate patient education without the involvement of physicians thereby minimizing person-to-person contact, which is responsible for the spread of infection [35]. AI-modulated education and training corresponds with higher levels of safety since it goes through several rounds of analysis ensuring that the key message is efficiently delivered to the target population. Other than this, AI helps in identifying the cost of inaction, modeling solutions and by supporting change [34, 35]. More on the role of artificial intelligence in the management of COVID-19 will be elaborated in our future review.

Artificial Intelligence in the Monitoring of Infections

Artificial Intelligence assists in remote monitoring of patients after their treatment as well as close monitoring of inpatient cases [36, 37]. *MERCURIO* is a potential AI-based application, which is used in the monitoring of dangerous post-operative complications such as *Staphylococcus aureus* infections [37, 38]. This platform has an accuracy of 98.5 % and a specificity of 99 % making it highly reliable [37]. Monitoring tools help in predicting survival and prognostic rates of patients as well as the risk of all-cause mortality [38]. This is possible through continuous and systematic collection of data through EHRs of the patient, following which; efficient analysis and health evaluations are made [21, 36]. They extract reliable data to infer progression patterns of the disease favoring early management of complications [21]. Big data analytics supports higher degree of analysis of special factors such as climate change data and other environment-related factors, which play a crucial role in the spread of some infectious diseases [36]. Continuous monitoring of climate change data and its correlation with the impact on the patient has enabled the management of dengue disease [36].

For remote follow up/monitoring, AI-based algorithms track data obtained from unconventional sources such as biosensors, smart city platforms, connected vehicles, internet of things)-based applications, connected smart watches, motors and social media platforms, which enable the detection of novel risk factors or exposures of the patient for determining the risk of infection [36]. These data, in combination with, other conventional forms of information available at primary health centers and hospitals, help in forming treatment-related decisions for the patient, which are highly person-centered [36].

Limitations of artificial intelligence in infection control

One of the major drawbacks of AI in infection control are the interoperability issues encountered in AI-enabled devices and apps [39]. This discourages physicians in adopting AI technologies in their medical practices, as well, it continues to be a significant cause of stress and discontent [40]. AI cannot potentially replace the patient-doctor relationship as the empathy given by doctor to a patient cannot be replicated by these technologies [39]. Data privacy is another major issue as most AI functionalities are based on collection and analysis of large amounts of data [40]. In situation of epidemics as well as in day-to-day management of the patient, the health information needs to be kept safe and must be compliant with the privacy and ethics regulations of the government [40].

A major challenge faced currently is the lack of availability of high-quality data sets and the risk of bias within the preexisting datasets. In this situation, the overuse of AI might lead to misled diagnosis; thus, it is crucial to form an international consensus on ethics and safety with the use of AI and the formation of common database, which can be accessed in designing treatment models [7]. Currently, there is no common database on non-antimicrobial peptides, so, antimicrobial activity of new treatment agents is tested on limited number of strains reducing their treatment value [16]. So, while making the use of AI technologies in the prevention and treatment of infections, physicians must be vigilant since these regimens may demonstrate excellent potential, at first, but may later retrieve redundant results due to overlapping of properties [16].

Future prospects of artificial intelligence in infection control

In the future, a much greater role of AI in infection as well as pandemic/epidemic control is expected as speculated by various experts [20]. AI technologies are expected to have a much greater precision and accuracy so that they can minimize the need for repeated invasive lab procedures such as swab testing. In managing large scale situations, it is envisaged that AI will have a paramount position in predicting future outbreaks before their actual occurrence, which can then be averted by employing early preventive measures [42, 43].

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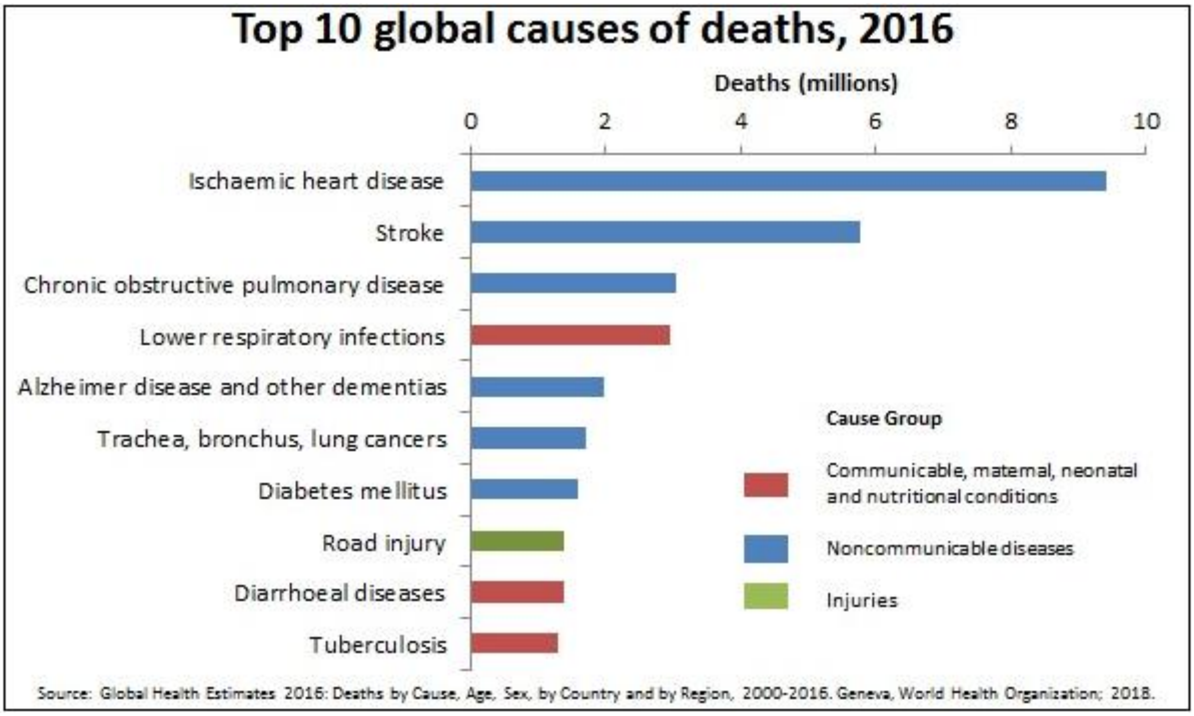

Table 1: AI Technologies and their Application in Infection Control

AI Techniques and their Role in Infection Control	
Machine Learning (ML)	ML refers to the use of statistical models and complex algorithms for the discovery of new knowledge from existing data [12, 13]. It helps in predicting the probability of infection through the creation of predictive models, based on the analysis of patient demographics and baseline characteristics such as age, gender and infection related data such as signs and symptoms along with their medication history, epidemiology of the infection and its risk factors [14]. From this data, it discerns patient outcomes such as survival rates and other prognostic factors.
Natural Learning process (NLP)	NLP analyzes unstructured data such as clinical notes, which it turns it into machine readable commands that are readable by ML for further analysis [11, 12].
Artificial Neural Networks	ANN involves the creation of links for building personalized solutions based on the analysis of wide range of information [14, 15]. It is thereby used in diagnosis and personalized treatment of infections.
Big Data Analytics	Big data analytics refers to the compilation of different types of informatics and data such as medical and health information of the patient, sensor informatics and bioinformatics, which it combines with the results of medical imaging and diagnostics for the analysis, modeling and interpretation of large data sets [12]. It is used for the diagnosis of different types of infection through the analysis of electronic health record (EHR) data and additional data points such as climate change information [13, 14].