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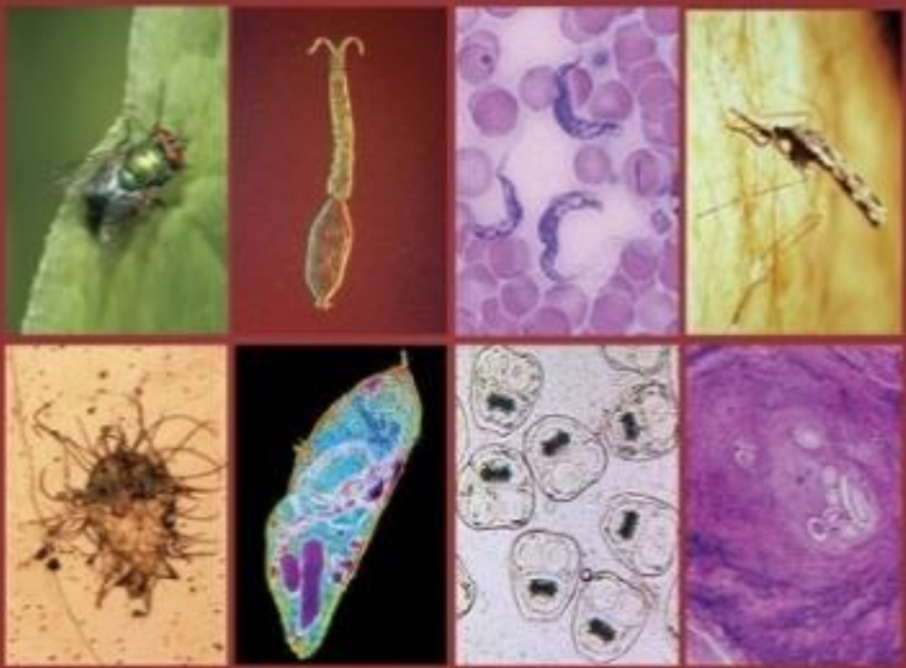
EGYPTIAN ACADEMIC JOURNAL OF
BIOLOGICAL SCIENCES
MEDICAL ENTOMOLOGY & PARASITOLOGY



ISSN
2090-0783

WWW.EAJBS.EG.NET

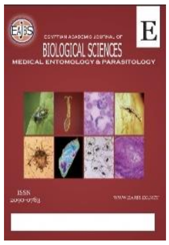
Vol. 15 No. 2 (2023)

Citation: *Egypt. Acad. J. Biolog. Sci. (E-Medical Entom. & Parasitology Vol.15(2) pp* ***35-43****(2023)*
DOI: 10.21608/EAJBSE.2023.322464

Egypt. Acad. J. Biology. Sci., 15 (2):35 –43 (2023)

Egyptian Academic Journal of Biological Sciences
E. Medical Entomology & Parasitology

ISSN: 2090–0783
www.eajbse.journals.ekb.eg



Artificial Intelligence Applications in Medical Parasitology: A Comprehensive Review

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REVIEW INFO

Review History

Received:22/8/2023
Accepted:9/10/2023
Available:15/10/2023

Keywords:
Artificial intelligence, medical parasitology, machine learning, computer vision.

ABSTRACT

Medical parasitology is a specialty of medicine that studies, diagnoses, as well as treats parasitic illnesses in humans. Numerous parasites still require human microscopic testing, which is a time-consuming operation that requires expert personnel. The creation of artificially intelligent machines that can carry out duties that traditionally need cognitive abilities is the focus of the fast-developing discipline called artificial intelligence "AI". Consequently, the usage of AI has established itself as a potent tool across a number of sectors, and its application in medical parasitology shows considerable promise. The present article seeks to offer a complete overview of the existing and potential AI tasks and applications in medical parasitology. Researchers explore AI implementation techniques including neural networks, computer vision, and processing of natural languages in parasite detection, diagnosis, classification, drug discovery, and epidemiological investigations. Furthermore, they emphasize the challenges and potential perspectives for integrating artificial intelligence in this industry.

INTRODUCTION

Infections caused by parasitic organisms provide serious health hazards and take responsibility for a major burden of disease worldwide, especially in Africa which is considered the main cause of mortality (Zhang *et al.*, 2022). Many programs have greatly lowered the illness load, however, in order to deliver the right medications and prevent abuse of drugs, it is necessary to make a precise and accurate diagnosis first. Standard techniques for identifying and treating parasite diseases can be time-consuming, labor-intensive, and necessitate specialist knowledge. For instance, due to morphological changes regarding the shape and density of the parasites, medical professionals find it difficult to examine them in microscopic photographs, although another drawback, in the case of low parasitic levels there is a limited sensitivity (Picot *et al.*, 2020).

Machine learning has recently become a potent tool in several areas of medicine, including medical parasitology. Massive amounts of data could be analyzed by algorithms of machine learning, which can then be used to recognize intricate patterns that might be difficult for human experts to identify. This skill has created new opportunities for researching and treating parasite infections.

The diagnosis of parasitic illnesses is one of the major fields where machine learning has significantly advanced. Large databases of microscopic images could be used in machine learning algorithms training to automatically identify and categorize parasitic organisms. This considerably speeds up diagnosis and lowers the risk of human error. Machine learning can also help in the creation of new medications and treatment plans for parasite diseases. Using this knowledge, targeted therapies can be designed, increasing treatment outcomes and lowering the chance of drug resistance. Additionally, the surveillance and control of parasitic illnesses can be aided by machine learning (Li *et al.*, 2023).

It is crucial to remember that machine learning algorithms in medical parasitology are supposed to supplement human expertise rather than replace it. Medical practitioners' knowledge and experience are still needed for the clinical decision-making process and the interpretation of data. Machine learning should be viewed as a supporting tool that can improve the accuracy as well as efficiency of diagnosis, treatment, and prevention strategies in the field of Medical Parasitology.

Integration with Electronic Health Records (EHR):

By combining AI technology with electronic health records (EHR) and decision support systems, parasitic infection detection and treatment can be made more efficient and accurate. In order to help in the diagnosis as well as tracking of parasite infections, artificially intelligent algorithms can assess individual patient information using EHRs, particularly symptoms, results of laboratory tests, as well as medical history. This integration allows healthcare personnel to gain immediate insights in order to make informed decisions, hence enhancing the care of patients and outcomes (Haick and Tang, 2021).

Telemedicine and Remote Diagnosis:

Telemedicine and remote medical diagnosis for parasitic illnesses can be facilitated by technologies that utilize artificial intelligence. Healthcare professionals can virtually analyze and diagnose parasite illnesses as well as offer correct suggestions for treatment by integrating AI technologies with telemedicine platforms. This strategy is especially effective in impoverished communities with little or no access to professional medical knowledge (Dacal *et al.*, 2021).

Artificial Intelligence In Parasite Transmission Modeling:

Artificial intelligence has been used to study and forecast the transmission patterns of parasitic illnesses. By combining environmental, climate-dependent, and varied data sources, for instance, posts on social media, web search trends, or socio-demographic data. AI algorithms can estimate the dissemination of diseases as well as give early warning about probable disease outbreaks by recognizing patterns and signals (Agrebi and Larbi, 2020).

For example, researchers have utilized AI-driven modelling to anticipate malaria transmission in specific places, taking into account factors related to changes in the climate, migration of people, and vector behavior. As a result, these data can be used to drive public health actions and allocate resources while tracking the efficacy of control measures as well as assessing the prevalence of diseases (Wang *et al.*, 2022).

Furthermore, zoonotic parasites are ones that can be passed from animal to human. Data derived from veterinary medicine records, animal surveillance, plus human health data can be processed by AI algorithms to find patterns and discover future outbreaks related to zoonotic parasite illnesses. AI can aid in the timely identification and prediction of zoonotic parasites by incorporating and evaluating such data (Pillai *et al.*, 2022).

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Artificial Intelligence Techniques in Parasite Detection and Diagnosis:

The development of automated systems that use artificial intelligence algorithms, particularly machine learning for parasite identification and diagnosis. Those systems make use of a wide variety of data sources, including clinical data, genetic data, as well as microscopic imaging data. Models created using machine learning are capable of analyzing microscopic images of blood, stool, as well as tissue samples to accurately identify and classify parasites. They can also be trained to recognize distinctive features and patterns in various sources of data relevant to infections caused by parasites and to make accurate predictions, which can help healthcare professionals diagnose and treat parasitic infections accurately and promptly (Parija and Poddar, 2023).

Additionally, AI algorithms have been designed to assess images of parasitic infections collected using various imaging techniques such as ultrasound images of the liver to detect and quantify liver fluke infections caused by *Opisthorchis viverrini*, which can help with the monitoring of such infections (Granata *et al.*, 2023).

Furthermore, particularly in remote areas, AI technologies can offer remote diagnostics for parasitic diseases. For instance, AI-powered smartphone applications have been created to analyze images of skin lesions and diagnose conditions such as cutaneous leishmaniasis. The application uses image recognition and machine learning algorithms to compare the lesion features with a database of known cases, providing a rapid and accessible diagnostic tool for healthcare professionals working in resource-constrained environments. So, AI-powered diagnostic tools have the potential to increase the effectiveness and precision of parasitic detection, predominantly in environments with limited resources where expert parasitologists may be scarce (Noureldeen *et al.*, 2023).

Computer Vision Applications in Medical Parasitology:

Automated microscopic image analysis for parasite detection and categorization relies heavily on computer vision, a branch of artificial intelligence. Convolutional neural networks (CNNs) have shown to be quite successful in accurately recognizing parasites using digital images. These models can be taught to distinguish between specific morphological characteristics otherwise structures associated with different parasite species. The detection and quantification of parasites can also be aided by computer vision-based AI systems, allowing researchers to examine infection rates and provide useful data for gauging treatment effectiveness and determining the progression of diseases (Ahmedt-Aristizabal *et al.*, 2021).

Artificial Intelligence in Drug Discovery for Parasitic Infections:

Traditional parasite medication exploration is a costly and time-consuming approach. By using virtual automated screening and molecular docking techniques, AI has the potential to speed up this process. Finding compounds with desirable characteristics is done using virtual screening techniques, such as high potency and low toxicity that may have potential antiparasitic activity by computationally analyzing huge chemical databases. The identification of potential medication candidates is aided by molecular docking, which predicts the interactions between these compounds and particular targets within the biology of the parasite. For the treatment of parasitic diseases, AI-driven drug discovery approaches can help identify novel compounds and repurpose existing drugs (Philip and Faiyazuddin, 2023).

In addition, AI algorithms can also help develop tailored parasitic infection treatment strategies. AI can produce therapy recommendations that are specifically suited to each patient's unique characteristics by assessing individual patient data, including genetic profiles, treatment histories, and clinical factors. This strategy can improve the effectiveness of the treatment, reduce side effects, and assist in overcoming the difficulties caused by medication resistance (Rao *et al.,* 2023).

Artificial Intelligence for Drug Resistance Monitoring:

Malaria and schistosomiasis are two parasitic illnesses that are renowned for acquiring resistance to treatment with standard antiparasitic medications. By examining genetic data and treatment response patterns, AI techniques can help track and predict medication resistance. AI can help modify treatment plans and provide novel therapeutic approaches to address drug-resistant parasites by identifying early signs of resistance (Muflikhah *et al.,* 2023; Caldwell *et al.,* 2023).

Parasite Genome Analysis:

The analysis of parasite genomes has been made easier by the use of artificial intelligence approaches, which has improved our understanding of their genetic makeup and allowed us to create diagnostic tools, treatment plans, and preventative measures that are more efficient. For instance, scientists have utilized AI algorithms to examine extensive genomic data of the malaria-causing parasite *Plasmodium falciparum*. These algorithms can detect genetic variations accompanying drug resistance, predict potential drug targets, and aid in the development of new antimalarial treatments (Tsebriy *et al.,* 2023).

Additionally, the genomic sequencing of *Trypanosoma* species, which cause Chagas disease and African sleeping sickness, produces a wealth of genetic databases. These data can be analyzed by AI systems to find relevant genetic differences linked to virulence factors as well as potential targets for vaccines (Uran Landaburu *et al.,* 2023).

Artificial intelligence -Driven Epidemiological Studies:

To conduct epidemiological studies on parasite diseases, the use of AI algorithms can integrate multiple data sources, such as demographic data, environmental factors, and genetic information. AI can help in predicting disease outbreaks, identifying high-risk locations, and comprehending the dynamics of parasitic infection spread by evaluating and modeling these various databases. The design and implementation of focused intervention methods to reduce parasite diseases can be aided by AI-driven epidemiological investigations, which can give public health experts useful insights to improve disease management and prevention efforts (Rostami *et al.,* 2023).

Artificial Intelligence for Vector Control:

The spread of parasitic illnesses frequently occurs through vectors like ticks and mosquitoes. By evaluating environmental and climatic data from remote sensors and satellite images, AI can help vector control efforts by identifying vector breeding locations, mapping high-risk areas, and forecasting vector population dynamics and disease transmission patterns. AI can assist in optimizing vector control initiatives, such as the use of insecticides, the distribution of bed nets, and environmental management, resulting in more successful disease prevention (Kaur *et al.,* 2022).

A few examples of how AI has been used in real-world medical parasitology cases

Malaria Diagnosis:

Malaria is a parasitic disease that affects millions of individuals worldwide. AI has been employed to enhance malaria diagnosis using computer vision techniques. Malaria parasite detection using thick smear images has been made possible by (Yang et al., 2019) using a deep learning system for smartphones. Additionally, several methods for processing images and analyzing thin as well as thick blood smears have been suggested by researchers for the automated identification of malaria parasites, including convolutional neural network “faster R-CNN”, single-shot multi-box detector “SSD”, RetinaNet, and

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Internet of Medical Things "IoMT" for malaria parasites identification in thick blood smear images (Nayak *et al.*, 2022).

For instance, the "iPalm" artificial intelligence system was created by researchers at the University of California, Berkeley, which employs deep learning algorithms to examine microscopic images of blood smears for malaria parasites. In comparison to conventional approaches, iPalm's high level of accuracy in detecting malaria parasites allows for a quicker and more accurate diagnosis (Cooper *et al.*, 2023).

Schistosomiasis Detection:

Schistosomiasis is considered as a neglected tropical disease which is caused by parasitic worms. Researchers have used AI algorithms to automate *schistosoma* egg detection within stool samples. By training machine learning models on large datasets of microscopic images, these algorithms can accurately identify and quantify *schistosoma* eggs. For instance, the low-cost automated digital microscope Schistoscope can automatically focus on and scan specific sections of prepared microscope slides, as well as automatically identify *Schistosoma haematobium* eggs in captured images. This automated approach dramatically accelerates the diagnosis process and reduces the burden on parasitologists, especially within areas where schistosomiasis is an endemic disease (Vlaminck *et al.*, 2021; Oyibo *et al.*, 2022).

Leishmaniasis Diagnosis:

Leishmaniasis is a parasitic disease transmitted by sandflies. AI has been utilized to develop automated systems for *Leishmania* parasite detection and identification. Leishmaniasis has been diagnosed using a variety of techniques. For example, direct microscopic examination is a straightforward and cost-effective way of finding parasites, but it requires an expert and has a low sensitivity rate. Parasite culture is another expensive way of parasite detection, and the likelihood of contamination with other microbes can impact the outcomes. Additionally, serological assays cannot distinguish between current and previous illnesses. The method with the highest sensitivity and specificity at the moment is PCR. However, PCR is a difficult, pricey, and time-consuming process that needs particular supplies (De Brito *et al.*, 2020). Consequently, investigators have examined microscopic images of tissue samples to determine the presence of *Leishmania* parasites using machine learning models, such as K-means clustering and U-Net architecture. Those algorithms can help in making the right treatment decisions and assisting in accurately diagnosing various clinical types of leishmaniasis (Zare *et al.*, 2022).

Neglected Tropical Diseases (NTDs):

Various parasitic neglected tropical diseases including lymphatic filariasis, onchocerciasis, and Chagas disease have been diagnosed and managed using artificial intelligence. To automate the detection and classification of these illnesses, machine learning algorithms have been trained on a variety of clinical records and imaging databases. Elvana and Suryanto (2022) provided a detection method for lymphatic filariasis utilizing image analysis, attaining a precise result of 70%, while Dedhiya *et al.* (2022) published the initial study which uses the machine learning over thermal imaging to estimate the survivability of *Onchocerca* worms. AI-driven systems can assist in the early detection of infections, monitor treatment responses, and contribute to the assessment of disease burden in endemic regions (Ward *et al.*, 2022).

These examples demonstrate how AI has been used in a variety of medical parasitology aspects, such as diagnosis, drug discovery, vector control, mobile health, as well as outbreak surveillance. AI-driven techniques have the potential to update the field by enhancing the speed, accuracy, and efficiency of parasitic disease management and control. We can better understand parasite illnesses and create innovative strategies against them with continued research and collaboration in this field.

Conclusion:

In conclusion, the use of artificial intelligence in medical parasitology has tremendous potential for enhancing diagnostic accuracy and treatment efficacy. It also offers a wide range of advantages, such as improved parasite identification, upgraded epidemiological analysis, tracking of drug resistance, remote diagnosis, designed vector control, decision support technologies, as well as the surveillance of public health. Researchers and healthcare professionals can improve accuracy, efficiency, and cost-effectiveness in managing these parasitic infections by utilizing the power of AI-driven approaches, leading to improved health outcomes for individuals as well as communities affected by those diseases. Nevertheless, it is crucial to address ethical considerations, ensure the privacy of data, and validate the AI algorithms to enable the appropriate and successful integration into medical parasitology practices.

Challenges and Future Directions:

While AI holds tremendous potential in medical parasitology, several challenges must be addressed. One significant challenge is the availability of high-quality data for training AI models. Access to well-annotated datasets that encompass various parasite species and clinical scenarios is essential for building accurate and robust AI systems. Additionally, ethical considerations surrounding data privacy, patient consent, algorithm transparency, and bias mitigation need to be carefully addressed. Collaborations between AI experts and medical parasitologists are crucial to ensure the development and successful implementation of AI solutions that align with clinical needs and best practices.

Conflict of interest: None.
Funding statement: None.

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