
THE INFLUENCE OF ARTIFICIAL INTELLIGENCE ON PATHOGENIC MICROBIAL DIAGNOSTICS: A REVIEW

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Abstract :

In microbiological diagnostics, artificial intelligence (AI) has become a potent instrument that provides quick, precise, and economical pathogen detection. Traditional microbiological approaches, such as culture-based procedures, need a lot of work and time. Complex datasets produced by mass spectrometry, microscopy, and genetic sequencing may be automatically analyzed thanks to AI technologies like machine learning (ML) and deep learning (DL). This article examines how artificial intelligence is being used in microbiological diagnostics, identifies present issues, and talks about potential future paths in clinical microbiology. Artificial intelligence (AI) has developed into a useful tool for microbiological diagnostics, offering rapid, accurate, and reasonably priced pathogen detection. Conventional microbiological methods, such as culture-based methods, are labor-intensive and time-consuming. Two AI technologies, machine knowledge and deep knowledge, allow complex datasets generated by genetic sequencing, microscopy, and mass spectrometry to be automatically interpreted.

Keywords : Artificial Intelligence Antimicrobial, Diagnostic, Monitoring, Surveillance

Introduction :

Microbial diagnostics are crucial to the identification and treatment of communicable diseases. The long incubation durations and skilled personnel required for traditional diagnostic methods may delay treatment decisions. Recent advancements in artificial intelligence have enabled the provision of more rapid and accurate diagnostic findings by evaluating enormous volumes of biological data. Clinical microbiology labs are increasingly using AI-driven technologies to increase assessment accuracy and efficiency.

The process of characterizing bacteria by imaging, culture, and molecular analysis is known as microbial diagnostics, and it is an active component of healthcare. However, traditional approaches have issues with misidentification, sample handling, culture issues, and delays in testing for antibiotic susceptibility (Franco-Duarte et al., 2019). The use of computer technology (AI) in healthcare is quickly changing traditional methods in several fields, including microbiological diagnosis. Microbiology's challenge is to detect and treat infectious illnesses. By providing cutting-edge computational tools that can accurately and



quickly comprehend complicated microbiological data, AI presents a potential alternative (Barh et al., 2020).

Advances in artificial intelligence (AI), especially in the fields of machine learning (ML) and deep learning (DL), have significantly aided the development of innovative and novel techniques for the detection of microbial illnesses (Ching et al., 2018; Vamathevan et al., 2019). Artificial intelligence (AI) uses data analysis, pattern recognition, and diagnostic processes to support early disease detection, therapeutic improvements, personalized treatment regimens, and epidemic monitoring (Bohr et al., 2020). This paradigm shift not only improves the effectiveness of antimicrobial medical treatments but also tackles the growing problem of antimicrobial resistance (AMR), which is a crucial concern in contemporary healthcare (Aslam et al., 2018).

AI Applications in Microbiological Diagnostics :

Genomic Data Investigation :

Algorithms based on artificial intelligence that aid in the analysis of whole-genome sequencing data may enable the rapid identification of disease-causing organisms and resistance genes. These tools have significantly shortened the time required for diagnosis as compared to conventional molecular approaches.

Mass Spectrometry :

Machine learning algorithms analyze spectrum fingerprints from MALDI-TOF mass spectrometry to improve the accuracy of microbiological identification.

Diagnostics on Images :

MALDI-TOF mass spectrometry spectrum fingerprints are analyzed by machine learning techniques to increase the precision of microbiological identification.

Diagnostics on Images :

Human error and effort can be reduced by using deep learning models trained on microscopic images to automatically detect and classify bacteria.

Problems and Limitations Before AI can be applied to microbiological diagnostics, a number of challenges must be resolved, notwithstanding its advantages. These include the difficulty of integrating AI systems into existing laboratory procedures, the lack of high-quality annotated datasets, and the difficulty of comprehending models. Ethical concerns and regulations are significant barriers as well.

Artificial Intelligence in the Sector of Health (Health sector AI) :

AI has the ability to provide accurate, customized diagnoses that respect patient rights and increase access to medical equipment (Naik et al., 2022; Ali et al., 2023). ChatGPT, an example of artificial intelligence, is used by over 100 million people and is growing more and



more prevalent in daily life (Eysenbach et al., 2023). According to Alto et al. (2023) and Talaei-Khoei et al. (2024), 80% of Fortune 500 companies have incorporated ChatGPT into their operations, enabling laypeople to interact with cutting-edge AI technology without any previous technical knowledge. Exploring disease-related information with next-generation AI and ML algorithms may reveal hidden patterns, including critical locations within multi-omics sequencing data. According to Deo et al. (2015), machine learning (ML) involves applying mathematical models to data in order to find relational patterns that provide insight into the complex biological mechanisms behind a variety of diseases. It encompasses both supervised learning, which trains on labeled data, and unsupervised learning, which looks for underlying patterns in unlabeled data via clustering.

The research provides valuable new data for developing gas-sensing diagnostics that might rapidly and non-invasively detect pathogenic microorganisms, potentially revolutionizing clinical diagnostics. ML techniques were used in a pan-genome approach to characterize antibiotic-resistant *Escherichia coli* strains (Her H. et al., 2018). The identification of core gene clusters and ARGs inside the auxiliary pan-genome improved the prediction accuracy for antibiotic resistance genes (AMR).

Role of AI in Microbial Detection :

Traditional microbiological diagnosis has challenges at every stage of the diagnostic process, from sample collection to identification and susceptibility testing. Problems and incorrect results might arise from improper sample processing (Fournier et al., 2013). The procedure of growing and isolating bacteria can be time-consuming and prone to false-negative findings since antibiotics are utilized in clinics (Franco-Duarte et al., 2019). Among the challenges include cross-contamination, false positives, and the lack of real-time data for effective surveillance. Furthermore, because there are no established methods, results in diagnostic laboratories are more complex and variable (Singer et al., 2016). Every step of traditional microbiological diagnosis, from sample collection to susceptibility testing, presents difficulties. Improper sample processing is the primary cause of these problems, which can lead to erroneous conclusions (Rodrigues et al., 2018; Shrestha et al., 2020; Khan et al., 2019; Parsons et al., 2011).

Diagnosis of Malaria :

Malaria, one of the several infectious diseases, is a global health concern that has never been worse. In 2020 alone, almost 240 million individuals had a malaria diagnosis, which led to around 600,000 fatalities (Venkatesan et al., 2022; Fambirai et al., 2022). This is a shocking figure. Effective treatment of malaria depends on a timely and accurate diagnosis. Peripheral blood smears (PBS) to manually detect red blood cells infected with parasites and light microscopy (LM), which is considered the gold standard, are examples of conventional methods. The time-consuming microscopic inspection procedure is the main disadvantage of this approach, though. This requires almost fifteen minutes for every slide. The complexity of distinguishing between *Plasmodium* species, which is exacerbated by the range of life stages they display, requires more work. In response to these problems, innovative AI-based solutions have emerged. These AI systems have demonstrated promising outcomes with



exceptional ranges of 80–90% for accuracy, sensitivity, specificity, and F1 scores when compared to traditional LM. They are successful in both parasite classification and parasitemia estimation (Loddo et al., 2022; Kassim et al., 2021; Rajaraman et al., 2018; Horning et al., 2021).

Diagnosis of Mycobacterial Diseases :

In 2018, an estimated 10 million mycobacterial infections were reported, causing significant morbidity and mortality, posing a major threat to global health. According to WHO et al. (2021), these disorders mostly affect those who have underlying vulnerable factors, such as immunodeficiency and malnutrition. Mycobacterium tuberculosis and atypical mycobacteria are the two main categories into which organisms in the mycobacterial group are separated. Common stains like H and E (hematoxylin and eosin) and traditional LM are not always effective in diagnosing these bacteria because of their small, bacilli-shaped characteristics. Despite efforts to enhance detection using specialist stains like Ziehl-Nielsen and Auramine O, mycobacteria in biological specimens remain challenging to manually identify. It takes 15 to 20 minutes to screen each slide, and errors are common in this procedure. The presence of at least one persistently stained bacillus is often required for a positive diagnosis of mycobacteriosis; the predictive value of this is connected with the number of acid-fast bacilli (AFB) present, which may be low in early or partially resolved infections.

Diagnosis of Infectious Diseases :

By employing machine learning (ML) algorithms to examine vast databases of microbiological samples, AI systems are able to precisely detect and classify diseases based on their distinctive features. AI may be used to automate microbial colony counts, which eliminates errors and saves time in laboratory procedures. AI-powered tools may also be able to identify a person's antibiotic susceptibility, which might assist direct the usage of appropriate treatment substitutes. By examining genetic data and spotting trends that indicate virulence or antibiotic resistance, AI also assists in the identification of microbial diseases. This enables the use of more precise medicines.

Rather than focusing just on microbe detection, artificial intelligence has revolutionized pathology by automating the recognition of morphological patterns and cytologic changes associated with infections. Recent studies have shown that image analysis significantly accords with WSI and LM in distinguishing *Helicobacter pylori*-related gastritis from autoimmune gastritis (Franklin et al., 2022). The incorporation of DL algorithms produced sophisticated tools for recognizing nuclear features, including a remarkable 92.7% accuracy in predicting HPV status in cervical samples with an average processing time of 22 seconds (Konstantinou et al., 2020).

Review Methodology :

A comprehensive review of the literature was conducted using PubMed, Scopus, Web of Science, and Google Scholar, incorporating specific search terms such as 'Artificial Intelligence and Diagnostic technology,' focusing on publications in English from the year



2015 to 2025. Studies which had a focus on research in original articles, systematic reviews, or a meta-analysis and dealt with biofilm-related disease and its treatment were eligible for inclusion. Conversely, non-English publications, conference abstracts, and studies deemed to be of low quality were excluded from consideration. Data from the selected studies were extracted and synthesized in a narrative format, emphasizing biofilm mechanisms, clinical implications, and therapeutic approaches. A quality assessment was performed using suitable evaluation tools, and the findings were organized into thematic categories, with a descriptive analysis that underscored significant trends.

Initially, 94 articles were identified from databases including PubMed, Google Scholar, Scopus, ResearchGate, and ScienceDirect. After excluding irrelevant articles (19), removing duplicates (12), and accounting for articles that couldn't be retrieved (12), 51 articles remained. Of these, 19 were excluded due to access issues or lack of relevance, resulting in 37 studies being included in the final review. Ethical approval was not required since the review relied on previously published research, with potential limitations including variability among studies and language constraints.

Identification of studies via databases and registers :

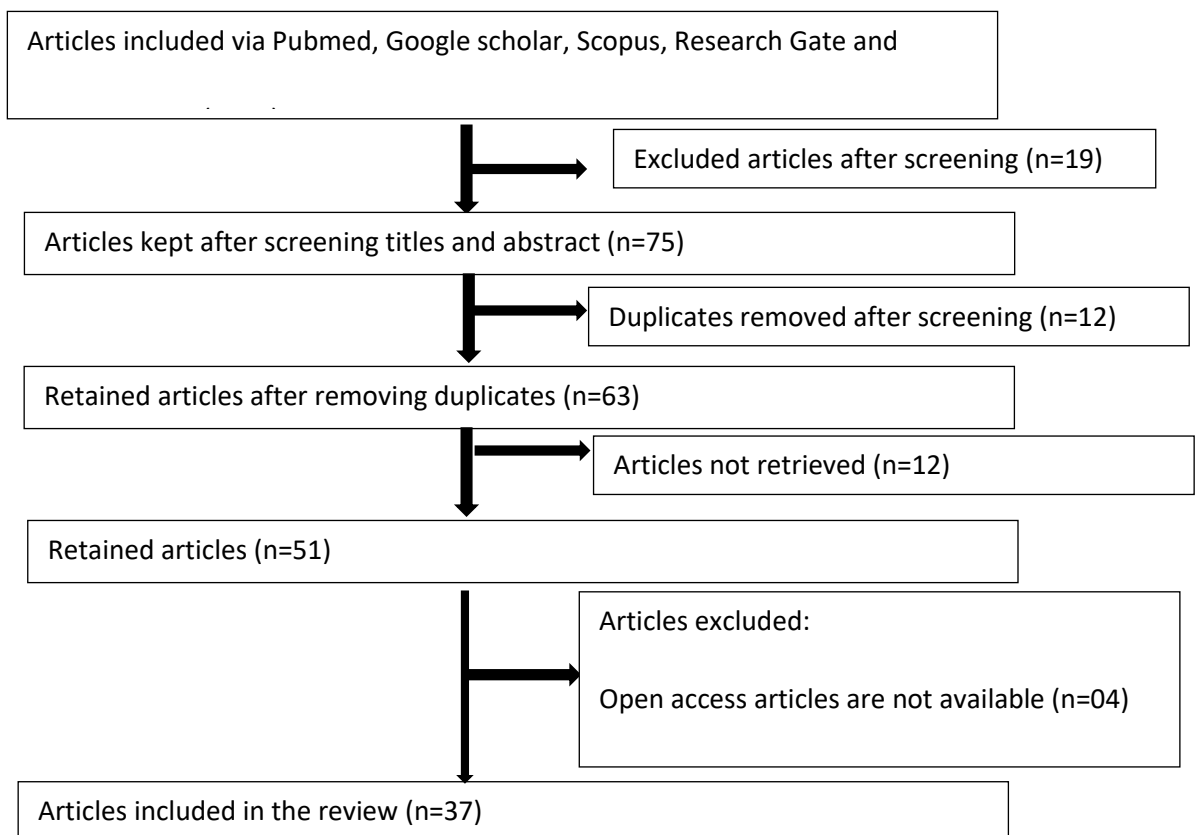


FIGURE 1: PRISMA flow chart

n: Number of studies; PRISMA: Preferred Reporting Items for Systematic Reviews

AI in Microscopy for Automated Microbial Classification :



Microscopes hold considerable potential for assisting microbiologists in examining organisms and using data for diagnostics and root cause analysis when paired with artificial intelligence. In a prior study, it was shown that an automated AI-enhanced microscopy system could effectively and rapidly identify images of bacteria (Smith K.P. et al., 2018). An automated microscope designed specifically for collecting high-resolution images of small slides was employed in the investigation.

Role in AI in Antibiotic Susceptibility :

AI is essential for detecting harmful bacteria and determining their drug sensitivity patterns, as the current study demonstrates. In microorganisms such as *Escherichia coli* and *Staphylococcus aureus*, it has been shown that AI algorithms can detect aminoglycoside resistance (Peiffer-Smadji et al., 2020). Additionally, early detection of drug-resistant insects, such as MRSA or vancomycin-resistant *Enterococcus* (VRE), has been facilitated by the use of computer vision technology in screening cultures, allowing for timely treatment and control measures (Rhoads et al., 2020).

Conclusion :

AI-powered diagnostic technologies, driven by machine learning and computing breakthroughs, are revolutionizing the healthcare industry. They are essential to public health initiatives because they can promptly identify illnesses, even novel and resistant forms. People may now closely monitor their health thanks to ongoing technology advancements, which aids in the early detection of microbial illnesses. AI in healthcare is a paradigm shift that affects AMR, vaccine development, and epidemiological surveillance. A key element of the healthcare industry's transformation is its application in microbiological diagnostics. As ethical and legal frameworks develop, artificial intelligence in microbial diagnosis is ready to offer precise and customized solutions, ensuring patient confidentiality and equitable access. AI is firmly establishing itself as a significant influence in determining the future of the healthcare industry as it transforms healthcare delivery while maintaining convenience and ethical standards.

Bibliography :

- Franco-Duarte R., Cernakova L., Kadam S., Kaushik K.S., Salehi B., Bevilacqua A., Corbo M.R., Antolak H., Dybka-Stępień K., Leszczewicz M., et al. Advances in chemical and biological methods to identify microorganisms—From past to present. *Microorganisms*. 2019;7:130. doi: 10.3390/microorganisms7050130. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Barh D. *Artificial Intelligence in Precision Health: From Concept to Applications*. Academic Press; London, UK: 2020. (Google Scholar)
- Ching T., Himmelstein D.S., Beaulieu-Jones B.K., Kalinin A.A., Do B.T., Way G.P., Ferrero E., Agapow P.-M., Zietz M., Hoffman M.M., et al. Opportunities and obstacles for deep learning in biology and medicine. *J. R. Soc. Interface*. 2018;15:20170387. doi: 10.1098/rsif.2017.0387. (DOI) (PMC free article) (PubMed) (Google Scholar)



- Vamathevan J., Clark D., Czodrowski P., Dunham I., Ferran E., Lee G., Li B., Madabhushi A., Shah P., Spitzer M., et al. Applications of machine learning in drug discovery and development. *Nat. Rev. Drug Discov.* 2019;18:463–477. doi: 10.1038/s41573-019-0024-5. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Bohr A., Memarzadeh K. *Artificial Intelligence in Healthcare*. Elsevier; Amsterdam, The Netherlands: 2020. The rise of artificial intelligence in healthcare applications; pp. 25–60. (Google Scholar)
- Aslam B., Wang W., Arshad M.I., Khurshid M., Muzammil S., Rasool M.H., Nisar M.A., Alvi R.F., Aslam M.A., Qamar M.U., et al. Antibiotic resistance: A rundown of a global crisis. *Infect. Drug Resist.* 2018;11:1645–1658. doi: 10.2147/IDR.S173867. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Naik N., Hameed B., Shetty D.K., Swain D., Shah M., Paul R. Legal and ethical consideration in artificial intelligence in healthcare: Who takes responsibility? *Front. Surg.* 2022;9:266. doi: 10.3389/fsurg.2022.862322. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Ali T., Ahmed S., Aslam M. Artificial Intelligence for Antimicrobial Resistance Prediction: Challenges and Opportunities towards Practical Implementation. *Antibiotics.* 2023;12:523. doi: 10.3390/antibiotics12030523. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Eysenbach G. The Role of ChatGPT, Generative Language Models, and Artificial Intelligence in Medical Education: A Conversation With ChatGPT and a Call for Papers. *JMIR Med. Educ.* 2023;9:e46885. doi: 10.2196/46885. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Alto V. *Modern Generative AI with ChatGPT and OpenAI Models: Leverage the Capabilities of OpenAI's LLM for Productivity and Innovation with GPT3 and GPT4*. Packt Publishing Ltd.; Birmingham, UK: 2023. (Google Scholar)
- Talaei-Khoei A., Yang A.T., Masialeti M. How does incorporating ChatGPT within a firm reinforce agility-mediated performance? The moderating role of innovation infusion and firms' ethical identity. *Technovation.* 2024;132:102975. doi: 10.1016/j.technovation.2024.102975. (DOI) (Google Scholar)
- Deo R.C. Machine learning in medicine. *Circulation.* 2015;132:1920–1930. doi: 10.1161/CIRCULATIONAHA.115.001593. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Her H.-L., Wu Y.-W. A pan-genome-based machine learning approach for predicting antimicrobial resistance activities of the *Escherichia coli* strains. *Bioinformatics.* 2018;34:i89–i95. doi: 10.1093/bioinformatics/bty276. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Fournier P.-E., Drancourt M., Colson P., Rolain J.-M. Modern clinical microbiology: New challenges and solutions. *Nat. Rev. Microbiol.* 2013;11:574–585. doi: 10.1038/nrmicro3068. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Singer M., Deutschman C.S., Seymour C.W., Shankar-Hari M., Annane D., Bauer M., Bellomo R., Bernard G.R., Chiche J.-D., Coopersmith C.M., et al. The third international consensus definitions for sepsis and septic shock (Sepsis-3) *JAMA.*



- 2016;315:801–810. doi: 10.1001/jama.2016.0287. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Rodrigues C., Groves H. Community-acquired pneumonia in children: The challenges of microbiological diagnosis. *J. Clin. Microbiol.* 2018;56:e01318-17. doi: 10.1128/jcm.01318-17. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Shrestha L.B., Pokharel K. Standard operating procedure for specimen collection, packaging and transport for diagnosis of SARS-COV-2. *JNMA J. Nepal Med. Assoc.* 2020;58:627. doi: 10.31729/jnma.5260. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Khan Z.A., Siddiqui M.F., Park S. Current and emerging methods of antibiotic susceptibility testing. *Diagnostics.* 2019;9:49. doi: 10.3390/diagnostics9020049. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Parsons L.M., Somoskövi Á., Gutierrez C., Lee E., Paramasivan C.N., Abimiku A. Laboratory diagnosis of tuberculosis in resource-poor countries: Challenges and opportunities. *Clin. Microbiol. Rev.* 2011;24:314–350. doi: 10.1128/CMR.00059-10. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - LeCun Y., Bengio Y., Hinton G. Deep learning. *Nature.* 2015; 521:436–444. doi: 10.1038/nature14539. (DOI) (PubMed) (Google Scholar)
 - Bagabir S.A., Ibrahim N.K., Bagabir H.A., Ateeq R.H. Covid-19 and Artificial Intelligence: Genome sequencing, drug development and vaccine discovery. *J. Infect. Public Health.* 2022;15:289–296. doi: 10.1016/j.jiph.2022.01.011. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Chiu H.-Y.R., Hwang C.-K., Chen S.-Y., Shih F.-Y., Han H.-C., King C.-C., Gilbert J.R., Fang C.-C., Oyang Y.-J. Machine learning for emerging infectious disease field responses. *Sci. Rep.* 2022;12:328. doi: 10.1038/s41598-021-03687-w. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Pham T.-H., Qiu Y., Zeng J., Xie L., Zhang P. A deep learning framework for high-throughput mechanism-driven phenotype compound screening and its application to COVID-19 drug repurposing. *Nat. Mach. Intell.* 2021;3:247–257. doi: 10.1038/s42256-020-00285-9. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Ong E., Wong M.U., Huffman A., He Y. COVID-19 coronavirus vaccine design using reverse vaccinology and machine learning. *Front. Immunol.* 2020;11:1581. doi: 10.3389/fimmu.2020.01581. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Ong E., Cooke M.F., Huffman A., Xiang Z., Wong M.U., Wang H., Seetharaman M., Valdez N., He Y. Vaxign2: The second generation of the first Web-based vaccine design program using reverse vaccinology and machine learning. *Nucleic Acids Res.* 2021;49:W671–W678. doi: 10.1093/nar/gkab279. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Venkatesan P. The future of malaria control in light of RTS, S. *Lancet Microbe.* 2022;3:e251. doi: 10.1016/S2666-5247(22)00070-2. (DOI) (PubMed) (Google Scholar)
 - Fambirai T., Chimbari M.J., Ndarukwa P. Global Cross-Border Malaria Control Collaborative Initiatives: A Scoping Review. *Int. J. Environ. Res. Public Health.*



- 2022;19:12216. doi: 10.3390/ijerph191912216. (DOI) (PMC free article) (PubMed) (Google Scholar)
- Loddo A., Fadda C., Di Ruberto C. An empirical evaluation of convolutional networks for malaria diagnosis. *J. Imaging.* 2022;8:66. doi: 10.3390/jimaging8030066. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Kassim Y.M., Yang F., Yu H., Maude R.J., Jaeger S. Diagnosing malaria patients with *Plasmodium falciparum* and *vivax* using deep learning for thick smear images. *Diagnostics.* 2021;11:1994. doi: 10.3390/diagnostics11111994. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Rajaraman S., Silamut K., Hossain A., Ersoy I., Maude R.J., Jaeger S., Thoma G.R., Antani S.K. Understanding the learned behavior of customized convolutional neural networks toward malaria parasite detection in thin blood smear images. *J. Med. Imaging.* 2018;5:034501. doi: 10.1117/1.JMI.5.3.034501. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Horning M.P., Delahunt C.B., Bachman C.M., Luchavez J., Luna C., Hu L., Jaiswal M.S., Thompson C.M., Kulhare S., Janko S., et al. Performance of a fully-automated system on a WHO malaria microscopy evaluation slide set. *Malar. J.* 2021;20:110. doi: 10.1186/s12936-021-03631-3. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - World Health Organization World Health Organization Global Tuberculosis Report 2021. ((accessed on 18 May 2024)). Available online: <https://www.who.int/publications/i/item/9789240037021>.
 - Franklin M.M., Schultz F.A., Tafoya M.A., Kerwin A.A., Broehm C.J., Fischer E.G., Gullapalli R.R., Clark D.P., Hanson J.A., Martin D.R. A deep learning convolutional neural network can differentiate between *Helicobacter pylori* gastritis and autoimmune gastritis with results comparable to gastrointestinal pathologists. *Arch. Pathol. Lab. Med.* 2022;146:117–122. doi: 10.5858/arpa.2020-0520-OA. (DOI) (PubMed) (Google Scholar)
 - Konstantinou C., Kostopoulos S., Glotsos D., Kalatzis I., Asvestas P., Ravazoula P., Michail G., Cavouras D., Sakellaropoulos G. Assessment of HPV Risk Type in H&E-stained Biopsy Specimens of the Cervix by Microscopy Image Analysis. *Appl. Immunohistochem. Mol. Morphol.* 2020;28:702–710. doi: 10.1097/PAI.0000000000000823. (DOI) (PubMed) (Google Scholar)
 - Smith K.P., Kang A.D., Kirby J.E. Automated interpretation of blood culture gram stains by use of a deep convolutional neural network. *J. Clin. Microbiol.* 2018;56:e01521-17. doi: 10.1128/jcm.01521-17. (DOI) (PMC free article) (PubMed) (Google Scholar)
 - Peiffer-Smadja N., Dellière S., Rodriguez C., Birgand G., Lescure F.-X., Fourati S., Ruppé E. Machine learning in the clinical microbiology laboratory: Has the time come for routine practice? *Clin. Microbiol. Infect.* 2020;26:1300–1309. doi: 10.1016/j.cmi.2020.02.006. (DOI) (PubMed) (Google Scholar)

