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Systematic Review Article

Roles of Artificial Intelligence in Enhancing Diagnostic Pathology and Surgical Outcomes in Laboratory Animals: A Systematic Review

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ABSTRACT

Recent advances in artificial intelligence (AI) have opened new horizons in medical sciences, especially in pathology and surgery. Although AI can enhance diagnostic accuracy and surgical outcomes, its widespread clinical use faces challenges such as validation, interpretability, and ethical and legal issues. The present study aimed to examine recent developments in AI across pathology, including automated recognition of pathological images and surgery (robotic surgical assistant systems and predictive outcome analysis). The present study analyzed current challenges in implementing AI and provided a perspective on how it can become a reliable tool to improve the quality of patient care and treatment outcomes. An initial and extensive search was conducted across reputable scientific databases, including Google Scholar, PubMed, and Scopus, using relevant keywords. Within the clinical pathology section, this review provided a comprehensive examination of how deep learning algorithms and image processing are automating and enhancing data analysis in cytology, hematology, histopathology, and digital pathology. The ability of AI to discover nuanced patterns in vast datasets, greatly improve diagnostic accuracy, and speed up reporting are all impressive capabilities. One of these challenges is the need for large, standardized datasets for algorithm training. Other challenges include clinical validation, ethical concerns, and early costs. In conclusion, this review anticipates that the integration of AI into clinical pathology and surgical workflows promises enhanced quality of care for laboratory animals alongside more accurate and reliable insights.

1. Introduction

Artificial intelligence (AI), as a powerful disruptor in the field of medical sciences, is transforming traditional paradigms of diagnosis and treatment[1]. In fields of pathology and surgery, AI provides advanced analytical methods that enable faster, more accurate, and personalized diagnosis[2-4]. While aiding clinical decision-making, it paints a clear vision for improving important indicators such as surgical accuracy and patient treatment outcomes. Clinical pathology and surgical pathology are two of the most significant pillars in the care, monitoring, and evaluation of *in-vivo* studies[5]. The field of clinical pathology provides vital information on health, disease progression, and treatment response by conducting objective studies of biological materials such as blood and tissue[6]. On the other hand, surgical techniques are of utmost significance, whether used to develop complex disease models or deliver therapeutic interventions. It is abundantly clear that the accuracy and precision of these two areas are closely linked to the

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integrity of research data and significant animal welfare indices[7].

On the other hand, procedures that are considered routine in clinical pathology and veterinary surgery are not without their own intrinsic challenges. In pathology, analyzing large volumes of data from hematology, biochemistry, and histology often involves subjective judgments, staff fatigue, and human error[8,9]. In addition to the time these treatments require, there is also the possibility that they may result in diagnostic variability. The accuracy of the preoperative pathological diagnosis and the intraoperative assessment (for example, tumor margins) are highly essential aspects in surgery[10,11]. These parameters are crucial in determining whether an operation is successful and how well the animal recovers afterward. A delayed or inaccurate diagnosis can disrupt the surgical procedure, potentially leading to the failure of the animal and the study design. In recent years, the introduction and development of technologies based on artificial intelligence, notably in the subfields of deep learning and computer vision, have promised to bring about a fundamental transformation in how these challenges are tackled[12]. There are two areas in which AI has the potential to dramatically enhance diagnostic sciences in terms of accuracy, speed, and impartiality[13,14]. These areas include automating repetitive procedures and analyzing exceedingly large, complex data. This might be done with the use of AI. The use of AI for image screening in pathology and radiology is becoming an increasingly important supplementary tool.

In veterinary clinical pathology, AI offers a broad range of applications with significant promise[15]. It is possible for AI systems to automatically count and classify blood cells in hematological smears, analyze urine samples, and sift through huge volumes of biochemical data in a short period of time. Artificial intelligence can examine scanned tissue slides at speeds beyond human capability in digital histopathology[16]. Additionally, AI can recognize specific areas of interest and assist in diagnosing tumor subtypes and subtle clinical signs that may be hidden from the pathologist's view. AI eliminates guesswork, provides clear and quantitative diagnoses, and equips surgeons with the best available information.

Veterinary surgery has evolved significantly with improved diagnostic technologies. When surgeons receive the rapid and accurate pathology results, conducted by AI, they can plan the operation with much greater confidence[17]. During cancer surgery, for instance, AI systems trained on histopathology images could aid in the real-time interpretation of frozen sections[18]. Surgical margins may also be used to determine whether the tumor has been entirely eliminated using these algorithms. The combination of these techniques often leads to better surgical outcomes and reduces the likelihood of further operations.

Given these circumstances, the purpose of this review article is to conduct a comprehensive review of the most recent developments in AI and their practical applications across various subspecialties of veterinary clinical pathology (hematology, biochemistry, and digital histopathology).

2. Materials and Methods

The methodology was based on an initial and extensive search conducted in reputable scientific databases such as Google Scholar, PubMed, and Scopus from January 2020 to December 2024, using relevant keywords such as artificial intelligence in pathology, deep learning for histological image recognition, robot-assisted surgery, and predictive medicine with artificial intelligence. The present study identified 1282 publications through keyword searching across the databases. 74 studies were included in this study, of which 38 were excluded. A total of 31 full-text articles were reviewed for eligibility. The quantitative synthesis was based on 27 articles selected after duplicates were removed and eligibility screening. After collecting the sources, the data and their findings were categorized, analyzed, and narratively synthesized into main themes including artificial intelligence applications in digital pathology, intelligent surgeon-assistant systems, prediction of postoperative complications, and challenges to clinical implementation.

3. AI in clinical pathology

The paradigms of diagnostic practice in clinical pathology are being completely transformed by this innovation. Deep learning, which employs AI neural networks with multiple layers, can automatically detect subtle and hidden patterns in vast amounts of data, whether numerical or medical imaging[19,20]. By being trained on thousands of samples (for example, microscopic photographs of normal and abnormal blood cells), these algorithms can learn to extract and classify crucial properties. The process of learning is not based on rules set; rather, it is based on training across thousands of different situations[21,22]. Because of these qualities, AI is an appealing tool for automating and enhancing the accuracy of repetitive but essential procedures in clinical pathology. Moreover, AI can provide more efficient, accurate results, as human errors and mental fatigue can contribute to diagnostic heterogeneity in clinical pathology (Figure 1)[23].

The automated analysis of blood smear pictures is one of the most significant uses of AI in medicine[24]. More advanced computer vision algorithms can perform differential counts of white blood cells with accuracy comparable to that of certified professionals. In addition, these algorithms are able to recognize abnormalities, such as immature cells, toxic neutrophils, and intracellular parasites[25,26]. This approach not only enables screening enormous numbers of samples in large-scale research projects, but also significantly speeds up the rate at which diagnoses are produced. In addition, these systems can analyze and quantify subtle morphological traits that may be hidden from human sight. This has led to the discovery of novel biomarkers and increased understanding of the physiological and pathological responses in animal models[27,28].

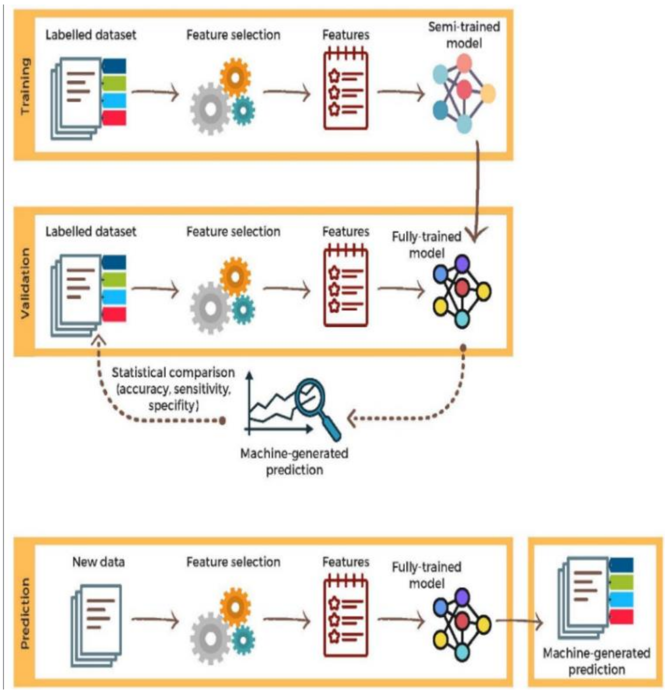

Figure 1. A brief description of the supervised learning flowchart, including training, validation, and prediction (Source: MDPI Copyright, 2022)[23].

In addition to its use in the field of image analysis, AI has a great deal of potential for the interpretation of complex biological data. In the field of clinical biochemistry, machine learning algorithms can detect patterns in multiparameter biochemical panels, which may include liver enzymes, electrolytes, and renal indicators and uncover complex, nonlinear relationships among these parameters[29]. This skill may lead to the creation of intelligent decision support systems that can comprehend not only a single aberration but also the full pattern of abnormalities, thereby assisting in making a more accurate differential diagnosis. As an example, these methods could make it easier to differentiate between the many distinct liver diseases or organ failure syndromes. This kind of analysis can provide a more comprehensive assessment of a laboratory animal's health and identify the effects of research treatments with greater sensitivity and specificity.

In the field of clinical pathology, digital pathology and histopathology section analysis has emerged as one of the most cutting-edge and promising applications of AI[30,31]. The digitization of tissue slides using high-resolution scanners has enabled deep learning algorithms to analyze these images at resolutions nearly equal to those of the originals. At the moment, these algorithms are being trained to carry out complex tasks. These tasks include accurately identifying and counting mitoses, which is an important indicator of tumor aggressiveness; classifying and grading neoplasia (for example, adenocarcinoma versus sarcoma); and even identifying microscopic areas of necrosis, inflammation, or fibrosis. The diagnostic procedure is not only made more effective as a result of this, but it also becomes more consistent and objective.

4. AI integration in veterinary surgery

Artificial intelligence is a revolutionary tool in many fields of medical science, such as disease prevention, control, and treatment[32-35]. Regarding surgery, an intelligent and responsive cycle that covers the perioperative period, starting with preoperative planning and concluding with postoperative monitoring, is replaced by a rather linear approach to surgical operations[36,37]. This cycle begins with preoperative planning and ends with postoperative monitoring. This change is achieved through this integration. For the purpose of making strategic decisions, pathological data that has been improved by AI, developed with incredible accuracy and speed, serves as the basis[38]. The accurate identification of the tumor's type, grade, and stage is of utmost significance in cancer surgery performed on laboratory animals. The reason for this is that the accuracy of the evaluation has a direct impact on the entire surgical procedure. Surgeons can determine how much tissue should be removed, whether lymph node dissection is needed, and which adjuvant therapies to use. By providing a quantitative, clear diagnostic, AI accelerates and refines the surgery procedure, giving the surgeon confidence that the surgical plan is based on the most comprehensive and reliable information currently available[39,40].

As the preoperative planning phase approaches, AI evolves from a simple diagnostic report into a powerful predictive tool. Predictive models trained on clinical and pathological data from thousands of operations that are fairly similar to one another can provide a unique estimate of the likelihood of specific issues[41,42]. The surgical team can take targeted preventive measures, such as prescribing a stronger antibiotic regimen or using more effective hemostatic procedures, for a case expected to be at high risk of infection. Not only does this proactive, customized strategy enhance Patient safety, but it also helps reduce waste of research resources by minimizing the loss of essential Case specimens due to anticipated concerns (Figure 2).

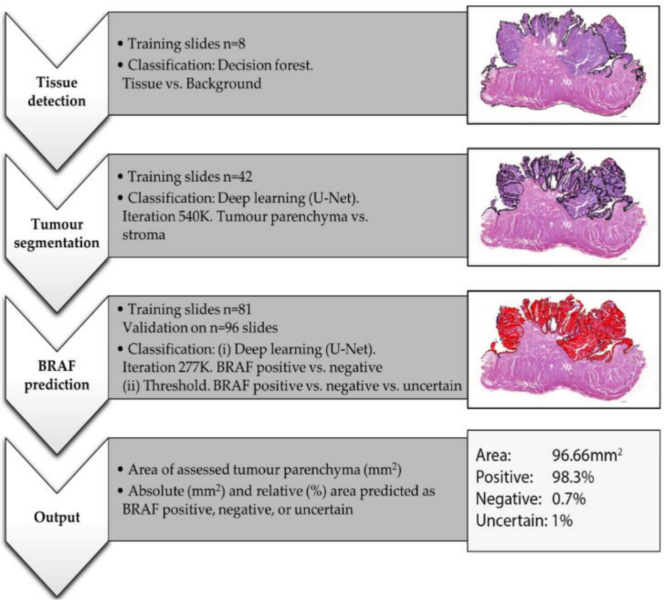

Figure 2. Workflow of the performed AI training and analysis for *BRAF* mutation prediction on whole slide images of hematoxylin and eosin-stained canine urothelial carcinomas. The images represent a case of bladder UC from an 11-year-old female neutered Jack Russell Terrier with positive *BRAF* PCR. This figure shows the output of threshold 0.6 (Source: MDPI Copyright, 2023)[43].

With the arrival of artificial intelligence in the operating room, it can be noted that the landscape of surgery has undergone a complete and comprehensive transformation[44,45]. By deploying cameras in the operating room, computer vision-based surgical support systems can detect anatomy during surgery[46,47]. It is also possible for these technologies to display additional information within the surgeon's field of vision through augmented reality. By way of illustration, these systems can highlight significant blood vessels or tumor margins that are somewhat difficult to see with the naked eye[48]. Nevertheless, the examination of intraoperative specimens (frozen sections) via the use of algorithms that are driven by AI is now one of the most significant applications of this technology[49]. Determining whether the margins excised from the tumor are free of cancer cells is of the utmost significance in tumor surgery. The images of these frozen specimens can be evaluated by algorithms driven by artificial intelligence in a fraction of a second, and the findings can achieve excellent accuracy in determining the presence or absence of neoplastic cells at the edges of the specimens[50]. Because of this speed and accuracy, the surgeon can quickly decide if removing the additional tissue is necessary during the surgery, thereby reducing the risk of subsequent treatments (Figure 3).

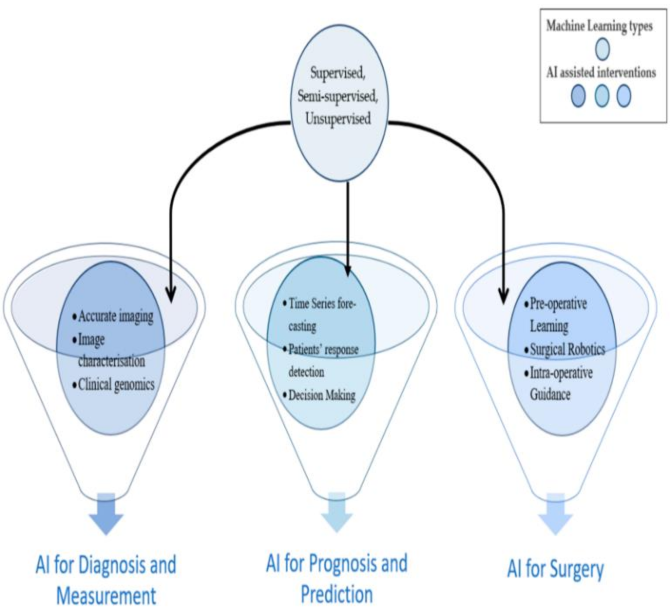

Figure 3. Popular AI techniques for diagnosis, measurement, prediction, prognosis, and surgery (Source: MDPI Copyright, 2022)[51].

After surgery, the role of AI continues. It monitors recovery in patients by tracking temperature, heart rate, and activity levels. Additionally, algorithms can evaluate the outcomes of pathological follow-up tests, such as blood inflammatory indicators.

5. Future prospects

The use of AI in clinical pathology and surgical medical sciences, despite its great promise, offers significant benefits and practical limitations[52]. Artificial intelligence, on the other hand, has the potential to deliver significant improvements in precision and repeatability. Deep learning algorithms can analyze complex data, even from compromised damages, and can identify patterns that humans might overlook[53]. As a result, diagnoses can be made with greater sensitivity and specificity. This poses a substantial issue in the context of research, which is characterized by the highest priority placed on impartiality and data integrity. Another benefit of AI is that it notably accelerates analysis, enabling the management of large volumes of samples in a fraction of the time required by traditional methods[54, 55]. This allows experts to focus on complicated cases, planning surgeries and studies, and developing new initiatives. Artificial intelligence introduces a new degree of standardization worldwide, eliminates differences between laboratories and individuals, and makes it considerably easier to compare findings across different locations[56, 57].

Despite the incredible progress achieved, many challenges remain. One of the most critical challenges is making strong, evidence-based decisions. It is essential to have access to large, high-quality datasets that have been thoroughly annotated to design reliable, robust algorithms[58]. Across a wide variety of strains and species, these databases ought to cover a broad spectrum of disorders that can affect laboratory animals. The lack of such standard databases is a significant barrier in the work process[59]. Additionally, the issue of generalizability is a pervasive concern that has to be addressed. When an algorithm trained on data from one species, such as mice, is exposed to data from another species, such as dogs, or even a different breed of the same species, it may lose accuracy[60]. This occurs when the algorithm is subjected to data from a different breed of the same species.

Additionally, there are challenges with the data, as well as significant hurdles in validation and technology[61]. Before being implemented in a clinical setting representative of the real world, every AI algorithm must undergo thorough, independent clinical validation[62]. This is necessary to establish beyond a doubt that it is both practical and safe.

6. Conclusion

Artificial intelligence has significant potential to transform clinical and surgical pathology in medical sciences. The ultimate success of this technology may depend not only on further technical advances but also on collaboration between experts from a wide range of professions, such as veterinarians, clinicians, scientists, regulators, and ethicists. Among the most important steps to overcome these challenges are the creation of consortia to produce standardized datasets, the development of transparent validation frameworks, and the development of ethical and legal standards. Artificial intelligence has the potential to fulfill its promise of improving the quality of human and animal care, increasing the reliability of research data, and accelerating scientific discovery in medicine and veterinary medicine. Despite the incredible progress achieved, there are still many challenges to overcome before AI can be fully realized. It is recommended and essential to have access to large, high-quality datasets that have been thoroughly notated to design reliable, robust algorithms.

Declarations

Competing interests

The authors declared that they have no competing interests.

Authors' contributions

All authors contributed to the conceptualization and methodology of this study. The formal analysis and investigation were conducted by Negar Ababaf Shoushtari, Amin Shahinzadeh, Elaheh Mahmoodi, Bardia Mohammadi, Marziyeh Saki, Safa Najafi, and Sirous Rafiei Asl, who also prepared the original draft. The writing was reviewed and edited by Elaheh Mahmoodi, Bardia Mohammadi, and Marziyeh Saki. Sirous Rafiei Asl supervised the project. All authors contributed to the revision steps and approved the final edition of the manuscript for publication in the present journal.

Ethical considerations

The authors declare that no generative artificial intelligence (AI) or AI-assisted technologies were used in the preparation, writing, data analysis, or editing of this manuscript. All sections of the present study were conducted and written entirely by the authors and were not submitted or published before. The source of any data used in this review is mentioned, and the authors did not produce any false or fabrication data.

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Availability of data and materials

All datasets related to this study are available in the present study and the reference list.

References

1. Singh AP, Saxena R, Saxena S, and Maurya NK. Artificial intelligence revolution in healthcare: Transforming diagnosis, treatment, and patient care. Asian J Adv Res. 2024; 7(1): 241-263. Available at: https://hal.science/hal-05104565/
2. Bera K, Schalper KA, Rimm DL, Velcheti V, and Madabhushi A. Artificial intelligence in digital pathology-new tools for diagnosis and precision oncology. Nat Rev Clin Oncol. 2019; 16(11): 703-715. DOI: 10.1038/s41571-019-0252-y
3. Shafi S, and Parwani AV. Artificial intelligence in diagnostic pathology. Diagn Pathol. 2023; 18(1): 109. DOI: 10.1186/s13000-023-01375-z
4. Acs B, Rantalainen M, and Hartman J. Artificial intelligence as the next step towards precision pathology. J Intern Med. 2020; 288(1): 62-81. DOI: 10.1111/joim.13030
5. Knoblaugh SE, Hohl TM, and La Perle KMD. Pathology principles and practices for analysis of animal models. ILAR J. 2018; 59(1): 40-50. DOI: 10.1093/ilar/ilz001
6. Echle A, Rindtorff NT, Brinker TJ, Luedde T, Pearson AT, and Kather JN. Deep learning in cancer pathology: A new generation of clinical biomarkers. Br J Cancer. 2021; 124(4): 686-696. DOI: 10.1038/s41416-020-01122-x
7. Linstädt J, Thöne-Reineke C, and Merle R. Animal-based welfare indicators for dairy cows and their validity and practicality: A systematic review of the existing literature. Front Vet Sci. 2024; 11: 1429097. DOI: 10.3389/fvets.2024.1429097
8. Mezei T, Kolcsár M, Joó A, and Gurzu S. Image analysis in histopathology and cytopathology: From early days to current perspectives. J Imaging. 2024; 10(10): 252. DOI: 10.3390/jimaging10100252
9. Khatab Z, Hanna K, Rofaeil A, Wang C, Maung R, and Yousef GM. Pathologist workload, burnout, and wellness: Connecting the dots. Crit Rev Clin Lab Sci. 2024; 61(4): 254-274. DOI: 10.1080/10408363.2023.2285284
10. Higginson JA, Breik O, Thompson AH, Ashrafian H, Hardman JC, Takats Z, et al. Diagnostic accuracy of intraoperative margin assessment techniques in surgery for head and neck squamous cell carcinoma: A meta-analysis. Oral Oncol. 2023; 142: 106419. DOI: 10.1016/j.oraloncology.2023.106419
11. Heidkamp J, Scholte M, Rosman C, Manohar S, Fütterer JJ, and Rovers MM. Novel imaging techniques for intraoperative margin assessment in surgical oncology: A systematic review. Int J Cancer. 2021; 149(3): 635-645. DOI: 10.1002/ijc.33570
12. Ogut E. Artificial intelligence in clinical medicine: Challenges across diagnostic imaging, clinical decision support, surgery, pathology, and drug discovery. Clin Pract. 2025; 15(9): 169. DOI: 10.3390/clinpract15090169
13. Tian M, Shen Z, Wu X, Wei K, and Liu Y. The application of artificial intelligence in medical diagnostics: A new frontier. Acad J Sci Technol. 2023; 8(2): 57-61. DOI: 10.54097/ajst.v8i2.14945
14. Ahmad Z, Rahim S, Zubair M, and Abdul-Ghafar J. Artificial intelligence (AI) in medicine, current applications and future role with special emphasis on its potential and promise in pathology: Present and future impact, obstacles including costs and acceptance among pathologists, practical and philosophical considerations. A comprehensive review. Diagn Pathol. 2021; 16(1): 24. DOI: 10.1186/s13000-021-01085-4
15. Zuraw A, and Aeffner F. Whole-slide imaging, tissue image analysis, and artificial intelligence in veterinary pathology: An updated introduction and review. Vet Pathol. 2022; 59(1): 6-25. DOI: 10.1177/03009858211040484
16. Bahadir CD, Omar M, Rosenthal J, Marchionni L, Liechty B, Pisapia DJ, et al. Artificial intelligence applications in histopathology. Nat Rev Electr Eng. 2024; 1(2): 93-108. DOI: 10.1038/s44287-023-00012-7
17. Varghese C, Harrison EM, O'Grady G, and Topol EJ. Artificial intelligence in surgery. Nat Med. 2024; 30(5): 1257-68. DOI: 10.1038/s41591-024-02970-3
18. Gorman BG, Lifson MA, and Vidal NY. Artificial intelligence and frozen section histopathology: A systematic review. J Cutan Pathol. 2023; 50(9): 852-859. DOI: 10.1111/cup.14481
19. Chan HP, Samala RK, Hadjiiski LM, and Zhou C. Deep learning in medical image analysis. Adv Exp Med Biol. 2020; 1213: 3-21. DOI: 10.1007/978-3-030-33128-3_1
20. Anwar SM, Majid M, Qayyum A, Awais M, Alnowami M, and Khan MK. Medical image analysis using convolutional neural networks: A review. J Med Syst. 2018; 42(11): 226. DOI: 10.1007/s10916-018-1088-1
21. Morrow E, Zidaru T, Ross F, Mason C, Patel KD, Ream M, et al. Artificial intelligence technologies and compassion in healthcare: A systematic scoping review. Front Psychol. 2022; 13: 971044. DOI: 10.3389/fpsyg.2022.971044
22. Zain Z, Almadhoun M, Alsadoun L, and Bokhari SFH. Leveraging artificial intelligence and machine learning to optimize enhanced recovery after surgery (ERAS) Protocols. Cureus. 2024; 16(3): e56668. DOI: 10.7759/cureus.56668
23. Bouhali O, Bensmail H, Sheharyar A, David F, and Johnson JP. A review of radiomics and artificial intelligence and their application in veterinary diagnostic imaging. Vet Sci. 2022; 9(11): 620. DOI: 10.3390/vetsci9110620
24. Hayes JM, Hayes MR, Friedrichs KR, and Simmons HA. Development of criteria to optimize manual smear review of automated complete blood counts using a machine learning model. Vet Clin Pathol. 2024: 10.1111/vcp.13400. DOI: 10.1111/vcp.13400
25. De Niz M, Pereira SS, Kirchenbuechler D, Lemgruber L, and Arvanitis C. Artificial intelligence-powered microscopy: Transforming the landscape of parasitology. J Microsc. 2025: 1-50. DOI: 10.1111/jmi.13433
26. Kobara YM, Akpan IJ, and Nam AD, AlMukthar FH, Peter M. Artificial intelligence and data science methods for automatic detection of white blood cells in images. J Imaging Inform Med. 2025. DOI: 10.1007/s10278-025-01538-y
27. Mann M, Kumar C, Zeng WF, and Strauss MT. Artificial intelligence for proteomics and biomarker discovery. Cell Syst. 2021; 12(8): 759-770.

DOI: 10.1016/j.cels.2021.06.006
28. Forghani R, Savadjiev P, Chatterjee A, Muthukrishnan N, Reinhold C, and Forghani B. Radiomics and artificial intelligence for biomarker and prediction model development in oncology. Comput Struct Biotechnol J. 2019; 17: 995-1008. DOI: 10.1016/j.csbj.2019.07.001
29. Cao H, Oghenemaro EF, Latypova A, Abosaoda MK, Zaman GS, and Devi A. Advancing clinical biochemistry: Addressing gaps and driving future innovations. Front Med (Lausanne). 2025; 12: 1521126. DOI: 10.3389/fmed.2025.1521126
30. Fadhail S. Article review: Advancements in veterinary histopathology: Linking tissue pathology to clinical outcomes. Wasit J Pure Sci. 2025; 4(1): 260-269. DOI: 10.31185/wjps.687
31. Fotouh A. Digitalization of veterinary pathology in the era of artificial intelligence: A comprehensive review. Benha Vet Med J. 2025; 49(1): 100-110. DOI: 10.21608/bvmj.2025.416499.1980
32. Amer MM, and Amer AM. Artificial intelligence: Current and future role in veterinary and public medicine. Egypt J Vet Sci. 2025; 56(11): 2761-2772. DOI: 10.21608/ejvs.2024.293158.2126
33. Ezanno P, Picault S, Beaunée G, Bailly X, Muñoz F, Duboz R, et al. Research perspectives on animal health in the era of artificial intelligence. Vet Res. 2021; 52(1): 40. DOI: 10.1186/s13567-021-00902-4
34. Srivastava V, Kumar R, Wani MY, Robinson K, and Ahmad A. Role of artificial intelligence in early diagnosis and treatment of infectious diseases. Infect Dis. 2025; 57(1): 1-26. DOI: 10.1080/23744235.2024.2425712
35. Sadr S, Santucciu C, Chisu V, Lotfalizadeh N, Nazemian S, Esfandiari N, et al. Pandemic prevention paradigms: Understanding global health governance. Public Health Chall. 2025; 4(2): e70051. DOI: 10.1002/puh2.70051
36. Singam A. Revolutionizing patient care: A comprehensive review of artificial intelligence applications in anesthesia. Cureus. 2023; 15(12): e49887. DOI: 10.7759/cureus.49887
37. Dabbagh A, and Sabouri AS. The role of artificial intelligence in medicine with a special focus on anesthesiology and perioperative care. Anesthesiol Clin. 2025; 43(3): 389-403. DOI: 10.1016/j.anclin.2025.04.002
38. Ahmed Z, Mohamed K, Zeeshan S, and Dong XQ. Artificial intelligence with multi-functional machine learning platform development for better healthcare and precision medicine. Database. 2020; 2020: baaa010. DOI: 10.1093/database/baaa010
39. Leivaditis V, Maniatopoulos AA, Lausberg H, Mulita F, Papatriantafyllou A, Liolis E, et al. Artificial intelligence in thoracic surgery: A review bridging innovation and clinical practice for the next Generation of surgical care. J Clin Med. 2025; 14(8): 2729. DOI: 10.3390/jcm14082729
40. Tiwari A, Mishra S, and Kuo TR. Current AI technologies in cancer diagnostics and treatment. Mol Cancer. 2025; 24(1): 159. DOI: 10.1186/s12943-025-02369-9
41. Delgado-López PD, Cárdenas Montes M, Troya García J, Ocaña-Tienda B, Cepeda S, Martínez Martínez R, et al. Artificial intelligence in neuro-oncology: Methodological bases, practical applications and ethical and regulatory issues. Clin Transl Oncol. 2025; 27(11): 4117-4130. DOI: 10.1007/s12094-025-03948-4
42. Pedük Ş. Mapping the future of early breast cancer diagnosis: A bibliometric analysis of AI innovations. Discov Oncol. 2025; 16(1): 1870. DOI: 10.1007/s12672-025-03495-y
43. Küchler L, Posthaus C, Jäger K, Guscetti F, van der Weyden L, von Bomhard W, et al. Artificial intelligence to predict the *BRAF* V595E mutation in canine urinary bladder urothelial carcinomas. Animals. 2023; 13(15): 2404. DOI: 10.3390/ani13152404
44. Duggirala HJ, and Johnson JL, Tadesse DA, Hsu CH, Norris AL, Faust J, et al. Artificial intelligence and machine learning in veterinary medicine: A regulatory perspective on current initiatives and future prospects. Am J Vet Res. 2025; 86(S1): S16-S21. DOI: 10.2460/ajvr.24.09.0285
45. Basran PS, and Appleby RB. What's in the box? A toolbox for safe deployment of artificial intelligence in veterinary medicine. J Am Vet Med Assoc. 2024; 262(8): 1090-1098. DOI: 10.2460/javma.24.01.0027
46. Chadebecq F, Vasconcelos F, Mazomenos E, and Stoyanov D. Computer vision in the surgical operating room. Visc Med. 2020; 36(6): 456-462. DOI: 10.1159/000511934
47. Birkhoff DC, van Dalen A, and Schijven MP. A review on the current applications of artificial intelligence in the operating room. Surg Innov. 2021; 28(5): 611-619. DOI: 10.1177/1553350621996961
48. Ward TM, Mascagni P, Ban Y, Rosman G, Padoy N, Meireles O, et al. Computer vision in surgery. Surgery. 2021; 169(5): 1253-1256. DOI: 10.1016/j.surg.2020.10.039
49. Kitaguchi D, Takeshita N, Hasegawa H, and Ito M. Artificial intelligence-based computer vision in surgery: Recent advances and future perspectives. Ann Gastroenterol Surg. 2022; 6(1): 29-36. DOI: 10.1002/ags3.12513
50. Choksi S, Szot S, Zang C, Yarali K, Cao Y, Ahmad F, et al. Bringing Artificial intelligence to the operating room: Edge computing for real-time surgical phase recognition. Surg Endosc. 2023; 37(11): 8778-8784. DOI: 10.1007/s00464-023-10322-4
51. Taha A, Ochs V, Kayhan LN, Enodien B, Frey DM, Krähenbühl L, et al. Advancements of artificial intelligence in liver-associated diseases and surgery. Medicina. 2022; 58(4): 459. DOI: 10.3390/medicina58040459
52. Burti S, Banzato T, Coghlan S, Wodzinski M, Bendazzoli M, and Zotti A. Artificial intelligence in veterinary diagnostic imaging: Perspectives and limitations. Res Vet Sci. 2024; 175: 105317. DOI: 10.1016/j.rvsc.2024.105317
53. Akinsulie OC, Idris I, Aliyu VA, Shahzad S, Banwo OG, Ogunleye SC, et al. The potential application of artificial intelligence in veterinary clinical practice and biomedical research. Front Vet Sci. 2024; 11: 1347550. DOI: 10.3389/fvets.2024.1347550
54. Yetgin A. Revolutionizing multi-omics analysis with artificial intelligence and data processing. Quant Biol. 2025; 13(3): e70002. DOI: 10.1002/qub2.70002
55. Zong Z, and Guan Y. AI-driven intelligent data analytics and predictive analysis in Industry 4.0: Transforming knowledge, innovation, and efficiency. J Knowl Econ. 2025; 16(1): 864-903. DOI: 10.1007/s13132-024-02001-z
56. Jayakumar S, Sounderajah V, Normahani P, Harling L, Markar SR, Ashrafian H, et al. Quality assessment standards in artificial intelligence diagnostic accuracy systematic reviews: a meta-research study. NPJ Digit Med. 2022; 5(1): 11. DOI: 10.1038/s41746-021-00544-y
57. Nagendran M, Chen Y, Lovejoy CA, Gordon AC, Komorowski M, Harvey H, et al. Artificial intelligence versus clinicians: Systematic review of design, reporting standards, and claims of deep learning studies. BMJ. 2020; 368: m689. DOI: 10.1136/bmj.m689
58. Gong Y, Liu G, Xue Y, Li R, and Meng L. A survey on dataset quality in machine learning. Inf Softw Technol. 2023;162:107268. DOI: 10.1016/j.infsof.2023.107268
59. Zemplényi A, Tachkov K, Balkanyi L, Németh B, Petykó ZI, Petrova G, et al. Recommendations to overcome barriers to the use of artificial intelligence-driven evidence in health technology assessment. Front Public Health. 2023; 11: 1088121. DOI: 10.3389/fpubh.2023.1088121
60. Ahmed MI, Spooner B, Isherwood J, Lane M, Orrock E, and Dennison A. A systematic review of the barriers to the implementation of artificial intelligence in healthcare. Cureus. 2023; 15(10): e46454. DOI: 10.7759/cureus.46454
61. He J, Baxter SL, Xu J, Xu J, Zhou X, and Zhang K. The practical implementation of artificial intelligence technologies in medicine. Nat Med. 2019; 25(1): 30-36. DOI: 10.1038/s41591-018-0307-0
62. Yin J, Ngiam KY, and Teo HH. Role of artificial intelligence applications in real-life clinical practice: systematic review. J Med Internet Res. 2021; 23(4): e25759. DOI: 10.2196/25759