A Prospective Review of the Artificial Intelligence Application in Diagnostic Pathology and Veterinary Clinical Sciences

Running Title: Artificial Intelligence Application in Veterinary Sciences

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Abstract

Artificial intelligence, as one of the most influential technologies of the present era, has significant potential to transform veterinary sciences, especially in pathology and clinical sciences. Despite rapid advances in machine learning and deep learning algorithms, their practical application in real clinical settings poses numerous complex challenges. This prospective review aims to comprehensively identify and analyze the challenges ahead and outline the prospects for the application of artificial intelligence in diagnostic pathology and veterinary clinical sciences. A comprehensive search of articles in the reputable databases PubMed, Scopus, Web of Science, and Google Scholar was conducted between January 2020 and December 2025 using combined keywords related to artificial intelligence and veterinary medicine. The identified challenges were categorized into three main areas: 1) technical and infrastructural challenges (including lack of standardized and labeled data, high species and breed diversity, hardware limitations, and the "black box" nature of algorithms), 2) clinical and professional challenges (including lack of independent clinical validation, difficulty in integrating with clinical workflow, professional resistance, and ambiguity in civil liability), and 3) ethical and legal challenges (including data privacy, inequality in access, data bias, and gaps in regulatory frameworks). In contrast, future perspectives included the move towards precision and predictive medicine through the integration of AI with new technologies (pathomics, IoT, augmented reality), the evolution of the veterinarian's role as a smart health manager, and improvements to the veterinary health system through early diagnosis and evidence-based management.

Keywords: Artificial intelligence, clinical sciences, pathology, prospective review, veterinary medicine

1. Context

In recent decades, the field of veterinary health has witnessed a remarkable transformation driven by technological advances, among them Artificial Intelligence (AI), which has emerged as one of the most influential forces [1]. With the increasing complexity of diagnostic systems and the growing volume of clinical and pathological data, the need for tools that can process information quickly, accurately, and intelligently is more urgent than ever [2-5]. AI, with its various subfields such as machine learning and deep learning, holds the promise of transforming many diagnostic and therapeutic processes in veterinary medicine and pandemic prevention [6]. However, the application of AI in specialized areas such as pathobiology and clinical sciences poses unique challenges that require careful, systematic examination [7]. The entry of AI into the veterinary field is no longer a mere futuristic phenomenon but a reality under development and implementation, and it is necessary to address its various dimensions from scientific and pathological perspectives [8] (Figure 1).

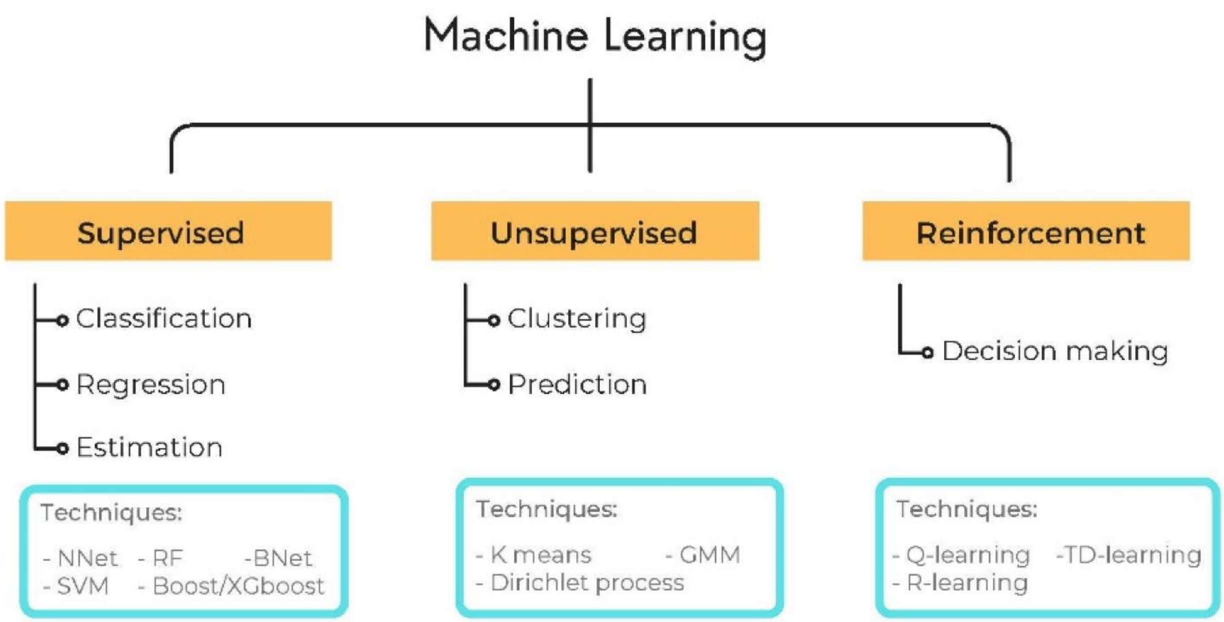

Figure 1. Supervised, unsupervised, and reinforced machine learning [9] (MDPI Copyright, 2022).

In the field of pathobiology, AI has the potential to revolutionize how tissue and cellular findings are interpreted. Traditional pathology, which is based on microscopic examination of tissue slides by experts, despite its high accuracy, is inherently time-consuming, dependent on individual skill, and sometimes subject to variability in interpretation between observers [10]. Deep learning algorithms, especially convolutional neural networks, have demonstrated an extraordinary ability to recognize complex patterns in digitized images of pathology slides (Whole Slide Imaging). This technology can help veterinarians identify microscopic lesions, differentiate benign from malignant tumors, count inflammatory cells, and even predict tumor biological behaviors based on morphological features. However, implementing such systems in practice faces obstacles, including the need for large, high-quality training data, standardized sample preparation processes, and rigorous clinical validation of algorithms, without which the desired performance in real-world clinical settings cannot be achieved [11].

On the other hand, veterinary clinical sciences are also a fertile field for the application of AI technologies. From automated interpretation of radiology and ultrasonography images to analysis of data from real-time patient monitoring and prediction of disease progression, AI is entering all clinical branches, including internal medicine, surgery, obstetrics, and infectious diseases [12].

Despite significant advances in algorithms and computational power, there remains a significant gap between AI's theoretical capabilities and its practical application in everyday veterinary practice [13]. This gap is largely due to multidimensional challenges that go beyond purely technical limitations. On the one hand, data-related issues such as the lack of high-quality labeled data, the high racial and species diversity among veterinary patients (which makes the generalizability of models difficult), and the lack of uniform standards for clinical data recording are major obstacles [14] (Figure 2).

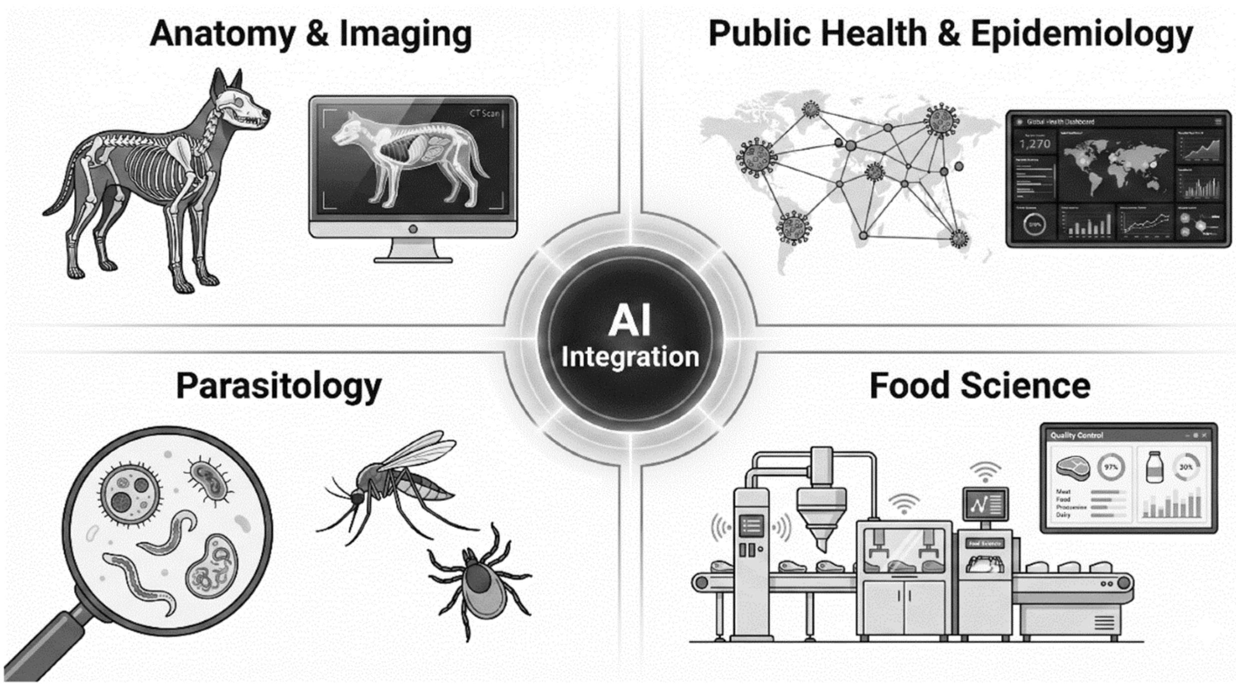

Figure 2. Schematic overview of AI integration across core veterinary disciplines, including anatomy and imaging, parasitology, food science and public health [13] (MDPI Copyright, 2026).

The ethical and legal aspects of AI in veterinary medicine are also controversial and require in-depth examination. Questions surrounding liability for diagnostic errors (civil liability), the transparency of AI model decision-making (interpretability), and the confidentiality of animal medical data and their owners' data are among the most important concerns in this field [15]. While clear legal and ethical frameworks for AI in human medicine are being developed, the veterinary field is still in the early stages of this path [16]. This legal vacuum could lead to potential abuses, reduce public and professional trust, and ultimately slow down the adoption and development of these new technologies. Therefore, any discussion about the future of AI in veterinary medicine must necessarily include an explanation of the ethical principles and legal requirements appropriate to this field [17].

Significant advancements in AI have sparked transformative potential across diverse sectors of veterinary medicine, ranging from high-throughput digital pathology to routine clinical decision-making. However, transitioning AI-based tools from controlled research settings to real-world veterinary practice introduces a complex landscape of obstacles. Before these innovations can be reliably integrated into daily workflows, it is essential to evaluate the barriers that hinder their safe, effective, and ethical deployment. Hence, the current review aims to identify and comprehensively explain the multifaceted challenges (including technical, clinical, ethical, legal, and cultural-professional challenges) encountered in the application of AI across the two core areas of pathobiology and veterinary clinical sciences in real-world and operational environments.

2. Data Acquisition

2.1. Search Strategy and Data Sources

The current review was designed and conducted as a prospective review. To obtain the most comprehensive collection of articles on the application of AI in pathobiology and veterinary clinical sciences, an extensive search was conducted across internationally recognized databases, including PubMed, Scopus, Web of Science, and Google Scholar. The search period was from January 2020 to December 2025 to cover recent advances in deep learning as well as early foundational studies. The search strategy was developed using a combination of keywords related to the subject areas and Boolean operators. These keywords were used in two main categories, including terms related to artificial intelligence ("Artificial Intelligence", "Machine Learning", "Deep Learning", "Neural Networks") and terms related to veterinary medicine ("Veterinary Medicine", "Veterinary Pathology", "Pathobiology", "Clinical Sciences", "Diagnostic Imaging").

2.2. Inclusion and exclusion criteria and screening process

After conducting the initial search and removing duplicates using reference management software (EndNote), the screening process was carried out in three stages (title review, abstract review, and full-text review) by two researchers independently (independent duplicate screening). Inclusion criteria included: 1) original research articles and systematic reviews published in English, 2) studies that specifically addressed the application of AI in the diagnosis, prognosis, treatment, or management of diseases in the field of veterinary pathology or veterinary clinical sciences, 3) studies that included experimental or clinical data from animals (whether small, large, or wildlife), and 4) articles in which the performance of the algorithm was evaluated using standard metrics (such as accuracy, sensitivity, specificity, or Area Under the ROC Curve (AUC-ROC)). Exclusion criteria included: 1) articles that only addressed theoretical aspects or computer simulations without biological data, 2) studies related to human medicine without direct relevance to veterinary medicine, 3) letters to the editor, case reports, and commentary articles that lacked original research data, and 4) studies for which the full text was not available (Table 1).

Table 1: Inclusion and exclusion criteria for this review

Category	Inclusion Criteria	Exclusion Criteria
Publication Type	Original research articles, systematic reviews, and meta-analyses published in peer-reviewed journals	Letters to the editor, commentaries, conference abstracts, case reports, and opinion pieces
Language	Articles published in English	Non-English articles without available translations
Time Frame	Studies published between January 2020 and December 2025	Studies published before January 2020
Study Focus	Studies investigating AI applications (machine learning, deep learning, neural networks) in veterinary medicine	Studies focused solely on human medicine without direct veterinary implications
Specialty Area	Studies related to veterinary pathology (pathobiology), diagnostic imaging, internal medicine, surgery, or other clinical sciences	Studies related to non-clinical veterinary fields (e.g., animal nutrition, production management without a health focus)
Data Type	Studies including experimental or clinical data from animals (companion animals, livestock, wildlife)	Theoretical studies or computer simulations without biological/clinical data
Outcome Measures	Studies reporting performance metrics (accuracy, sensitivity, specificity, AUC-ROC) for AI algorithms	Studies lacking a quantitative evaluation of AI performance
Full Text Availability	Articles with full text accessible	Articles with only abstracts available

3. Results and Discussion

3.1. Challenges

3.1.1. Technical and Infrastructure Challenges

The most important and recurring challenge in implementing AI in veterinary medicine is the quality and quantity of training data. Unlike human medicine, where large, standardized databases of medical images and clinical data are available, veterinary medicine faces several challenges of a lack of high-quality, labeled data [18]. This problem is particularly acute in pathobiology, which requires high-resolution microscopic images and accurate annotation by experienced pathologists. The wide diversity of animal species (from dogs and cats to horses, ruminants, and exotic animals), different breeds with distinct anatomy and physiology, and the wide range of clinical manifestations of a single disease across species pose serious challenges to the generalizability of AI models. A model trained on Labrador retriever data may not perform well on Chow Chows or cats [19]. In addition, the lack of uniformity in clinical data recording formats across veterinary clinics and hospitals, the absence of global standards for storing pathology and radiology images, and the dispersion of data across heterogeneous systems have made it extremely difficult and costly to collect suitable data for training complex deep learning models [20]. On the other hand, infrastructure challenges such as the need for powerful hardware to process large data sets (especially Whole Slide Imaging images in pathology, each of which can be several gigabytes in size), the lack of stable high-speed internet in many clinics, especially in rural areas, and the high costs of purchasing and maintaining digitizing equipment (slide scanners, advanced imaging devices) are serious obstacles to the widespread adoption of these technologies. Also, the "black box" nature of many deep learning algorithms and the lack of transparency in their decision-making processes have undermined veterinarians' trust in these systems for critical diagnoses [21].

3.1.2. Clinical and professional challenges

The transition from algorithm development in the laboratory to effective clinical application in the real world is accompanied by several obstacles, which are discussed in detail in the reviewed studies [22]. The first and most important challenge in this area is the lack of independent and comprehensive clinical validation for most developed AI systems. Many studies report algorithm performance on data similar to the training data (Internal Validation), which can lead to overly optimistic estimates of model performance. When the same algorithms are tested against new data from different populations or other clinics (External Validation), a significant drop in performance is usually observed [23]. This is especially important in clinical sciences, where patient conditions, treatment protocols, and equipment vary from clinic to clinic. Finally, civil and legal liability arising from diagnostic errors involving AI remains a gray and ambiguous area [24]. In the event that an algorithm provides an incorrect diagnosis that leads to patient harm or a lawsuit against the veterinarian, it is not clear whether the liability lies with the software developer, the using veterinarian, or the hospital where the service is provided. This legal ambiguity is one of the main obstacles to the widespread adoption of these technologies [25].

3.1.3. Ethical and Legal Challenges

With the growing use of artificial intelligence in veterinary medicine, the ethical and legal aspects of this field have gradually become the focus of researchers [7]. One of the most important ethical challenges is maintaining the privacy and confidentiality of patient data. Although veterinary medical data do not directly belong to humans, they are often tied to the personal information of animal owners (name, address, contact number, and even financial information) [26]. Collecting, storing, and processing this data to train artificial intelligence models carries the risk of violating the privacy of animal owners. In addition, when animal data is used for research or commercial purposes, questions arise about obtaining informed consent from animal owners and about the informed consent process [27]. Should animal owners be informed about how their animal data will be used? Do they have the right to withdraw from participation in databases? These questions require the development of clear ethical frameworks and specific protective laws [28]. Another ethical challenge is the issue of justice and equality in access to new technologies. The high costs of implementing AI systems may lead to a digital divide between large, well-equipped urban clinics and small, rural clinics. This inequality can have serious consequences for animal health in underserved and underserved areas and undermine equity in access to advanced diagnostic and treatment services. Also, the bias inherent in training data is another important ethical challenge [29] (Table 2) (Figure).

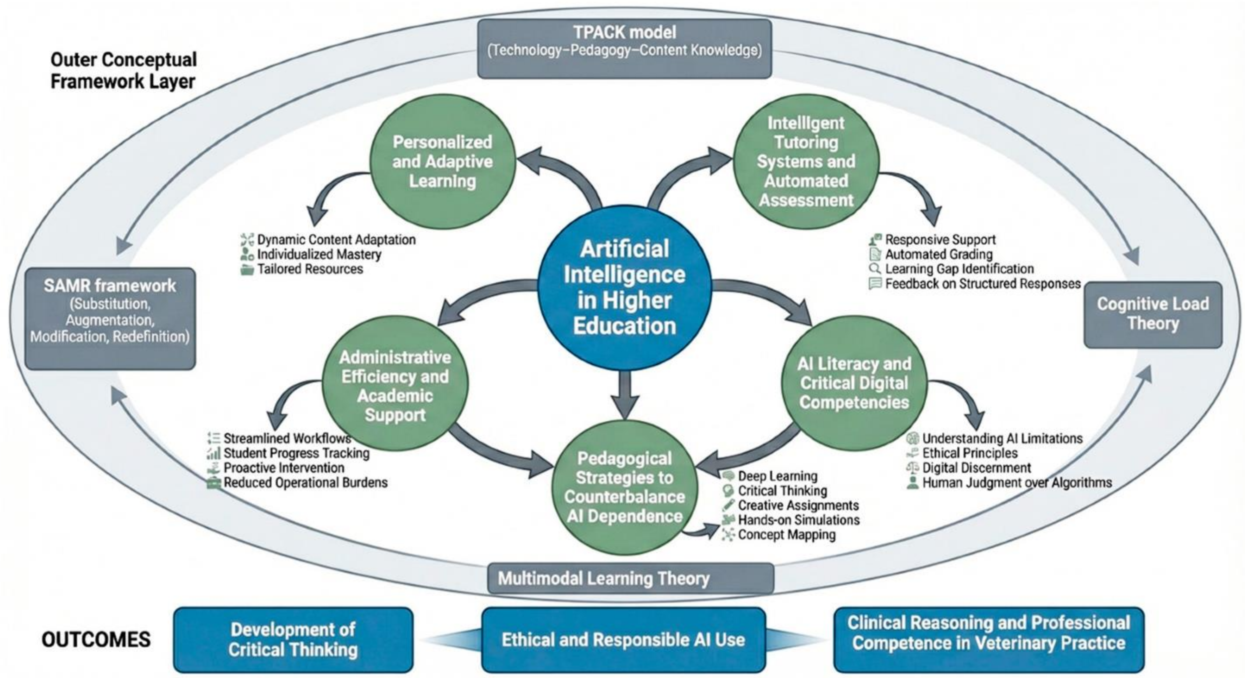

Figure 3. Conceptual framework of artificial intelligence integration in higher education and veterinary pedagogy [13] (MDPI Copyright, 2026).

Table 2: Summary of key challenges in AI implementation in veterinary pathology and clinical sciences

Challenge Category	Specific Challenges Identified	Key Findings from Reviewed Studies
Technical and Infrastructural Challenges	Limited availability of high-quality labeled data	Most studies reported difficulty in accessing sufficiently large and annotated datasets, especially in pathology
	High species and breed variability	Models trained on specific breeds showed a significant performance drop when tested on other breeds or species
	Lack of standardized data formats	Inconsistent image resolutions, file formats, and clinical record structures across institutions
	Hardware and computational limitations	Need for high-performance computing and whole-slide scanners, especially in low-resource settings
	"Black box" nature of algorithms	Difficulty in interpreting AI decision-making processes, reducing clinician trust

Clinical and Professional Challenges	Lack of independent external validation	Most algorithms are validated only on internal datasets, with a significant performance drop in external validation
	Integration with clinical workflow	Poor compatibility with existing hospital information systems and practice management software
	Professional resistance and skepticism	Concerns about job security, professional autonomy, and over-reliance on technology
	Lack of AI education in veterinary curricula	Graduating veterinarians are inadequately prepared to interact with and interpret AI outputs
	Legal ambiguity regarding liability	Unclear responsibility in case of misdiagnosis involving AI assistance
Ethical and Regulatory Challenges	Data privacy and confidentiality concerns	Risks associated with the storage and sharing of animal and owner data
	Algorithmic bias and fairness	Underrepresentation of certain breeds or geographic populations in training data leads to biased outcomes
	Inequality in access to technology	Digital divide between well-equipped urban clinics and under-resourced rural practices
	Regulatory vacuum	Lack of clear approval pathways and oversight mechanisms for AI tools in veterinary medicine
	Informed consent issues	Unclear protocols for obtaining owner consent for using animal data in AI development

3.2. Future Perspectives

3.2.1. Evolution in Diagnosis and Treatment

The findings of this prospective review indicate that the future of AI in veterinary medicine is moving towards a new paradigm in diagnosis and treatment, referred to as “Precision Veterinary Medicine”. In this paradigm, AI will play a pivotal role in simultaneously integrating and analyzing multiple layers of biological data [30]. In the field of pathobiology, the emergence of “pathomics” technology is expected to develop pathological diagnosis. In this approach, deep learning algorithms will be able to go beyond mere detection of microscopic lesions and extract quantitative, hidden tissue features (such as cell distribution patterns, nuclear features, and tissue architecture) that are not visible to the naked eye [31].

3.2.2. Integration of new technologies: from the Internet of Things to augmented reality

The future outlook for AI in veterinary medicine is strongly tied to integration and convergence with other emerging technologies [32]. One of the most important of these technologies is the Internet of Things (IoT) and wearable sensors. In the near future, it is expected that the use of smart collars, bells, and even implants for continuous monitoring of vital signs, activity levels, feeding, and sleeping patterns in equine and companion animals will become widespread [33]. Another technology that promises to develop education and even clinical practice is augmented reality and virtual reality [34]. In the future, veterinary surgeons will be able to view 3D images from CT scans or MRIs precisely on the body of the animal being operated on, using augmented reality glasses, and perform surgery with greater precision. In veterinary education, virtual reality and artificial intelligence-based simulators will offer unique opportunities to practice clinical and surgical skills in a safe, controlled environment [35]. Robotics, along with artificial intelligence, can also play an important role in performing precise and minimally invasive surgeries, targeted biopsies, and even the physical rehabilitation of animals. The integration of these technologies will form an ecosystem in which early diagnosis, precise treatment, and intelligent management of animal health become everyday realities.

3.2.3. Evolution of the role of the veterinarian and the veterinary health system

As AI becomes more common in veterinary practice, the role of the veterinarian will change fundamentally. However, contrary to some concerns, this change will not eliminate veterinarians. Instead, their duties will shift from simply diagnosing diseases to acting as intelligent health managers and final decision-makers [36]. In the future, veterinarians will spend less time on repetitive, time-consuming tasks, such as reviewing hundreds of microscope slides or routinely interpreting radiographs, as these tasks will be performed by AI systems at high speed and with high accuracy [37]. This change requires a complete redesign of veterinary school curricula. Courses related to AI, machine learning, data ethics, and medical informatics must become an integral part of veterinary education so that the next generation of veterinarians is prepared to work in this new ecosystem [38]. On a larger scale, the veterinary health system will also be transformed by the emergence of artificial intelligence. It is expected that with the expansion of early diagnosis and predictive medicine, treatment costs will decrease, and limited veterinary resources will be directed towards prevention and health management [39, 40]. Also, the vast data collected by AI systems will enable epidemiological monitoring of diseases at regional, national, and even international levels, and will assist veterinary organizations and policy-making institutions in evidence-based decision-making to control diseases and promote the health of livestock populations. Finally, the development of legal and ethical frameworks appropriate to these developments will be an essential requirement to ensure a responsible and sustainable future for AI in veterinary medicine [41, 42] (Table 3).

Table 3: Future perspectives and emerging trends in veterinary AI applications

Future Domain	Emerging Technologies/Approaches	Potential Applications	Expected Impact
Precision and Predictive Medicine	Pathomics integration	Extraction of quantitative tissue features beyond human visual capability; integration with genomics and proteomics data	Personalized treatment planning; accurate prognosis prediction; identification of novel biomarkers
	Predictive analytics with IoT/wearables	Early detection of diseases (colic, lameness, mastitis) through continuous monitoring of vital signs, activity, and behavior patterns	Shift from reactive to preventive medicine; reduced treatment costs; improved animal welfare
	Radiomics and multi-omics integration	Combining imaging features with molecular and genetic data for comprehensive disease characterization	Enhanced diagnostic accuracy; better understanding of disease mechanisms
Technological Convergence	Internet of Things (IoT) and smart sensors	Smart collars, ear tags, and implants for real-time health monitoring in companion animals and livestock	Continuous health surveillance; early warning systems for disease outbreaks in herds
	Augmented Reality (AR) and Virtual Reality (VR)	AR-guided surgeries with 3D imaging overlay; VR-based surgical simulators for veterinary education	Increased surgical precision; enhanced training opportunities without live animal use

	Robotics and AI integration	Automated minimally invasive surgeries; robotic sampling systems; AI-guided rehabilitation robots	Improved surgical outcomes; reduced recovery times; consistent rehabilitation protocols
	Natural Language Processing (NLP)	Automated analysis of electronic medical records; literature mining for evidence-based practice	Efficient data utilization; support for clinical decision-making; research facilitation
Workforce and System Transformation	Redefinition of veterinary roles	Transition from diagnostician to health manager and final decision-maker	Enhanced professional satisfaction; focus on complex cases and client communication
	Curriculum reform in veterinary education	Integration of data science, AI fundamentals, and digital literacy into veterinary training	Graduates prepared for technology-rich practice environments; effective human-AI collaboration
	Population health management	AI-powered epidemiological surveillance; real-time disease monitoring at regional/national levels	Evidence-based policy making, improved disease control strategies, and enhanced public health
	Regulatory framework development	Establishment of approval pathways, ethical guidelines, and liability frameworks for veterinary AI	Safe and responsible AI implementation; increased stakeholder trust; sustainable innovation

4. Conclusion

It can be concluded that AI, with all its transformative potential, is on the verge of creating a new era in veterinary medicine, especially in the two strategic areas of pathobiology and clinical sciences, but the full realization of this vision requires a conscious and planned overcoming of the multi-layered challenges that were discussed in detail in this study. The findings show that despite the stunning advances in the development of diagnostic algorithms and their high potential to increase the accuracy, speed, and efficiency of veterinary services, there are significant obstacles to the practical application of these technologies, the most important of which are the challenges related to the lack of standardized and high-quality data, weak technological infrastructure in clinical settings, lack of independent and comprehensive field validation, ambiguity in legal frameworks and civil liability, and lack of adequate training to prepare expert human resources. In contrast, the future prospects for this field indicate an inevitable move towards precision and predictive medicine, in which the integration of AI with new technologies such as the Internet of Things, pathomics, and augmented reality will enable early disease diagnosis, personalized treatment, and intelligent health management of livestock populations. In such a vision, the role of the veterinarian will be upgraded from a mere diagnostician to an intelligent health manager and ultimate decision-maker who, relying on combined knowledge (clinical and data-driven), is able to exploit these powerful tools to improve the quality of life of animals and promote public health. Therefore, successfully navigating this path requires a comprehensive and coordinated approach, including targeted investment in data and technology infrastructure, a fundamental overhaul of veterinary education programs, the development of clear legal and ethical frameworks by regulatory bodies, and strengthening interdisciplinary collaborations between veterinarians, data scientists, engineers, and policymakers to harness the unique potential of AI to improve animal health and welfare while preventing its risks and unintended consequences.

Declarations and statements

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Author contribution

Conceptualization: [S.R.F], …; Methodology: [S.G., A.H], …; Formal analysis and investigation: [F.S., A.H., M.M.R.K], …; Writing - original draft preparation: [F.S., A.H., M.M.R.K]; Writing - review and editing: [S.G., A.H, F.S., A.H., M.M.R.K], …; Funding acquisition: [Self-funding], …; Supervision: [S.R.F]. All authors checked and approved the final version of the manuscript for publication in the present journal

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The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declaration of the use of generative AI

Not used for any purposes

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