



Artificial Intelligence Applications in Small Animal Medicine: The Current Status, Key Challenges, and Future Prospects with Special Emphasis on Blockchain Innovation

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ABSTRACT

Artificial intelligence (AI) and machine learning are rapidly transforming companion animal veterinary medicine. The present narrative review examined current applications, challenges, and future directions for AI in the care of dogs, cats, and other companion animals. The current study is based on a structured literature search across PubMed/MEDLINE, Scopus, and IEEE Xplore from January 2015 to April 2026, with clearly defined inclusion and exclusion criteria to ensure transparency and reproducibility. In diagnostic imaging, computer vision algorithms improve the speed and accuracy of interpreting radiographs, ultrasound, and dermatoscopic images, helping detect conditions such as hip dislocation, osteoarthritis, foreign bodies, skin lesions, and parasites. In digital pathology, AI aids in identifying abnormal cells from blood and histology slides, supporting diagnoses such as lymphoma and anemia. Wearable devices with AI algorithms continuously monitor physiological data, including activity, sleep, and early signs of pain. Natural language processing (NLP) extracts information from electronic health records to facilitate epidemiological studies. Despite this promise, several challenges remain. Technical hurdles include the need for large, high-quality annotated datasets, which are harder and more costly to obtain than in human medicine, and the high genetic diversity among dog and cat breeds, which makes it difficult to develop generalizable algorithms. Ethical and legal issues involve liability for diagnostic errors, data privacy, and algorithmic bias, requiring new regulatory frameworks. Practical barriers include high costs, integration into clinical workflows, and the need to train veterinarians to effectively use and critically evaluate AI outputs. Future progress depends on close collaboration among AI specialists, veterinarians, biologists, and industry. Priorities include developing cost-effective, user-friendly tools; creating internationally shared, standardized databases; and establishing ethical and professional guidelines. Blockchain may serve as a trust layer for recording and verifying data access events, rather than as a primary repository for large-scale medical data. Ultimately, AI is expected to act as a powerful assistant, not a replacement for veterinary expertise, enabling earlier diagnoses, personalized treatments, improved preventive care, and a better quality of life for companion animals and their owners.

Keywords: Artificial intelligence, Companion animal, Diagnostic imaging, Machine learning, Veterinary medicine

INTRODUCTION

The ability of Artificial Intelligence (AI) to learn from data, identify intricate patterns, and carry out cognitive functions is pushing the limits of what's possible in diagnosis and treatment (Gill et al., 2023; Kulkarni and Singh, 2023; Amer and Amer, 2025). Artificial intelligence is one of the most important technologies of the 21st century, and is not confined to human medicine; it has also entered veterinary medicine, particularly in the treatment of companion and small animals, including dogs and cats (Pereira et al., 2023; Albadrani et al., 2024; Arshad et al., 2025; Sadr et al., 2025a). Pets nowadays are regarded not just for their usefulness, but as beloved family members and treasured friends. As a result, the psychological and social significance of their health and well-being is considerable (McConnell et al., 2019).

The field of veterinary care for small animals continues to face a range of obstacles, such as the high cost of advanced diagnostic equipment, a shortage of specialized veterinarians in rural areas, and limited access to emergency care, despite substantial progress over the past several decades (Quain et al., 2021). One of these problems is the significant genetic variability across breeds of dogs and cats, which determines how diseases manifest, how they respond to therapy, and even their anatomy (Kurhaluk and Tkaczenko, 2025). Another issue is that the variety of paraclinical tests, including radiographic imaging, ultrasonography, and pathology, is often used in conjunction with a physical examination, the owner's medical history, and other diagnostic procedures (Abdisa, 2017). There is a significant amount of skill, extensive experience, and often a great deal of time required to interpret this data, which may be problematic in today's hectic clinical environment (Clarke and Knights, 2018; Petrovski and Kirkwood, 2025). In this context, AI can

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automate quantitative analysis, provide diagnostic recommendations, and unearth hidden links within massive volumes of health data (Akinsulie et al., 2024; Figure 1).

In the field of medical image analysis, computer vision algorithms can analyze radiographs to identify hip dislocations, osteoarthritis, or foreign bodies with high accuracy (Franco-Gonçalo et al., 2024). Machine learning algorithms can also analyze ultrasound images to examine internal viscera and dermatoscopic images to detect skin lesions (Abunadi and Senan, 2021). An AI system may be used in digital pathology to scan blood or histology slides to detect aberrant cells and assist in diagnosing diseases such as lymphoma and anemia (Zuraw and Aeffner, 2022; Piccione et al., 2025). Beyond diagnosis, wearable devices paired with AI algorithms can continuously collect and analyze physiological data in animal care. Data in animal care may include activity levels, sleep patterns, and even early indicators of discomfort (Xiao et al., 2025). By automatically extracting information from computerized animal health records, natural language processing (NLP) also enables more extensive epidemiological studies and more effective management of animal populations (Ezanno et al., 2021; Figure 2).

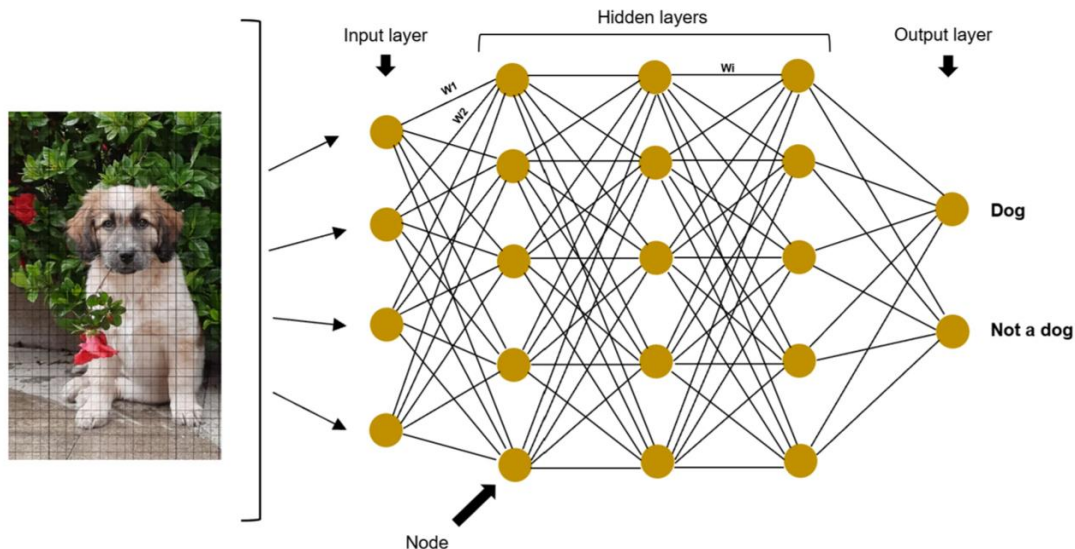


Figure 1. Architecture of an artificial neural network, in which the pixels of a digital image of a dog serve as input. There are four hidden layers and two possible outputs: Dog or not dog. The nodes are arranged in layers and joined by connections. The weights are represented by the letter W (W_1 , W_2 , and W_i in the figure; MDPI Copyright, Source of image adapted from Pereira et al., 2023). W_i typically represents a general or individual weight within the network.

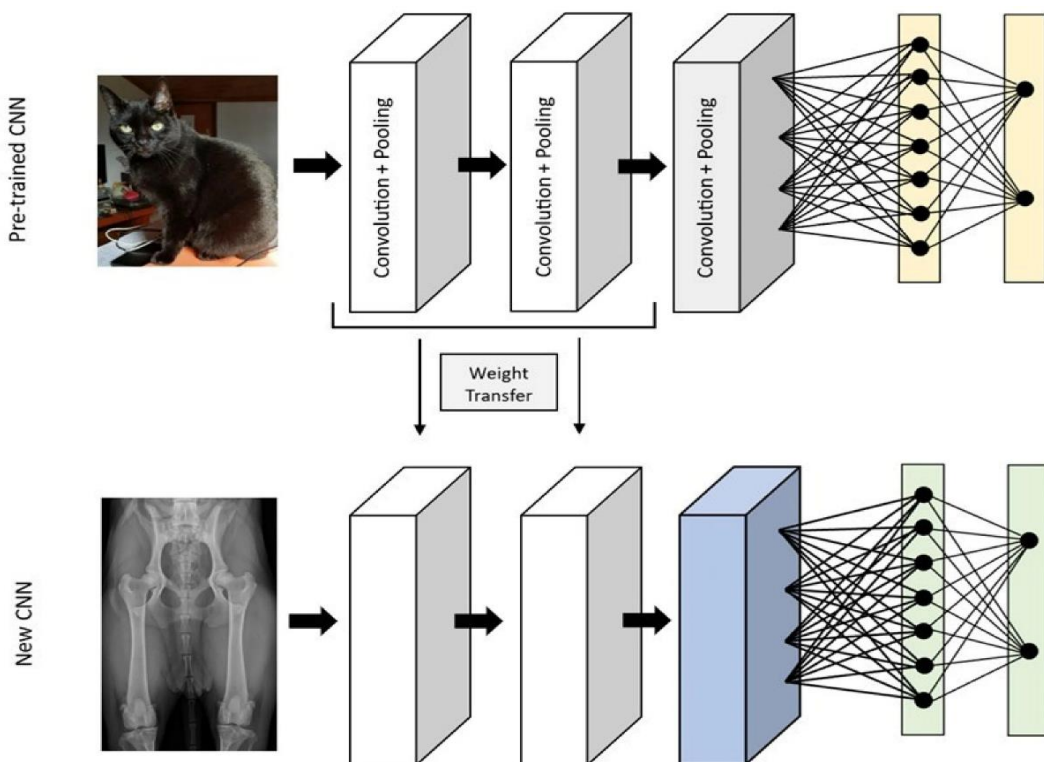


Figure 2. The transfer learning process involves using part of the weights from a convolutional neural network trained to evaluate non-medical images to classify radiographs. (MDPI Copyright, Source of image adapted from Pereira et al., 2023).

AI in veterinary treatment for small animals is not straightforward and confronts several challenges (Zhang et al., 2024; Ranjbar Kamrani et al., 2026). Technical difficulties are perhaps the first and most significant hurdle (Jia et al., 2025). Training effective AI models requires access to vast, high-quality, well-annotated datasets (Zha et al., 2025). It is more difficult and expensive to collect such data than in human medicine because treatment facilities are spread out across the country, prices are higher, and permission from veterinary specialists is required (Ezanno et al., 2021; Akbarein et al., 2025). Moreover, the substantial genetic variation across breeds might introduce bias into algorithms and diminish their generalizability. Hence, a model trained on data from one breed would not apply to another breed.

AI scientists, veterinarians, biologists, engineers, and industry professionals will need to collaborate more closely and in an interdisciplinary manner to fully grasp the promise of AI to improve the health and well-being of companion animals (Ezanno et al., 2021). Several key projects are included in the present approach, including developing user-friendly, cost-effective technologies, building standardized, global, shared databases, and adopting professional and ethical guidelines (Talebi and Nezhad, 2024; Zhang et al., 2024; Sun, 2025). AI will not replace the skill, experience, and clinical judgment of veterinarians; rather, it will serve as a strong complement to help veterinarians. AI has the potential to lead to earlier diagnoses, more individualized therapies, more efficient preventative monitoring, and eventually, an increase in the quality of life for companion animals and the people who own them. The aim of the present review was to investigate the current state of AI applications in small-animal veterinary medicine, to analyze the most significant technical, ethical, and practical challenges that this field is currently facing, and to outline future perspectives and pathways for the development and deployment of these transformative technologies in a manner that is both effective and responsible.

METHODS

The current study is presented as a narrative review to provide a comprehensive overview of the landscape, challenges, and future directions of AI and blockchain applications in small animal medicine. Given the narrative nature of the present review, a systematic, PRISMA-style methodology was not employed. However, to ensure transparency, rigor, and reproducibility of the literature synthesis, the following methodological framework was adopted regarding the scope of literature search, sources, timeframe, and selection criteria. A structured literature search was conducted to identify relevant peer-reviewed articles, conference proceedings, and industry white papers. The search was performed across three major electronic databases, such as PubMed/MEDLINE, Scopus, and IEEE Xplore, supplemented by manual searches of Google Scholar and the reference lists of retrieved articles to identify additional pertinent studies. The search strategy was designed to capture the intersection of veterinary medicine, artificial intelligence, and blockchain technology. The search was limited to literature published between January 2015 and April 2026. This timeframe was selected to focus on the period during which AI applications, particularly deep learning, gained significant traction in clinical medicine, aligning with the emergence of blockchain discussions in healthcare data management. The search utilized combinations of the following keywords and MeSH terms including of AI ("artificial intelligence" OR "machine learning" OR "deep learning" OR "neural networks" OR "computer vision" OR "large language models") AND ("veterinary" OR "small animal" OR "companion animal" OR "canine" OR "feline") and For Blockchain ("blockchain" OR "distributed ledger" OR "smart contracts") AND ("veterinary" OR "small animal medicine" OR "medical records").

Inclusion criteria and exclusion criteria

Inclusion criteria were articles were included if they described the development, validation, or clinical implementation of AI algorithms (diagnostic imaging, predictive analytics, wearable sensors) specifically in small animal (canine and feline) practice; discussed the architectural, ethical, or regulatory frameworks for blockchain integration in veterinary data management; were original research, systematic reviews, or authoritative consensus statements published in English; and addressed key challenges such as data standardization, interoperability, or data security relevant to the convergence of AI and blockchain.

Exclusion criteria were articles were excluded if they focused exclusively on large animal, exotic, or laboratory animal medicine without relevance to small animal practice; described AI applications only in a non-medical context (agricultural management or basic biological research) without clinical translational relevance; were editorials, opinion pieces, or non-peer-reviewed preprints lacking substantive technical detail; were published prior to 2015, unless they represented seminal foundational work directly cited to contextualize a historical concept; or were not available in English.

The selected literature was synthesized thematically to construct the narrative. The review was structured to first present the current status of AI across diagnostic, therapeutic, and predictive domains in small animal medicine. Subsequently, key challenges related to data silos, privacy, and algorithmic bias were analyzed. Finally, the prospective role of blockchain technology was explored as a potential solution to these challenges, with a focus on enhancing data integrity, security, and multi-institutional collaboration.

ARTIFICIAL INTELLIGENCE: CONCEPTS, ALGORITHMS, AND CAPABILITIES

Systems capable of performing activities that would normally require human intellect, such as visual perception, voice recognition, decision-making, and language translation, fall under the umbrella of AI, a large field within computer science (Buiten, 2019; Zhu et al., 2023). In recent decades, AI has transitioned from a purely academic field into an applied transformative technology across a variety of industries (Gruetzemacher and Whittlestone, 2022). This transformation has occurred as a result of the explosion in the volume of digital data, also known as big data, as well as the increase in computing power, particularly with graphics processing units, or GPUs, and advancements in algorithmic development. AI can be divided into two broad categories, including narrow AI, which is designed to perform a specific task, such as facial recognition or playing chess, and general AI, a hypothetical concept referring to a

machine with human-level cognitive capabilities capable of performing a wide range of tasks (Dellermann et al., 2021; Korteling et al., 2021). All current applications of AI, including those in medical and veterinary medicine, are considered narrow AI (Akbarein et al., 2025).

One of the most important and commonly used subfields in AI is machine learning (Sarker, 2021). Machine learning is the study of computer systems that, rather than being explicitly programmed to perform a task, learn from data and improve their performance over time through experience (Alzubi et al., 2018). A model trained on data is the fundamental component of machine learning (Sarker, 2021). Machine learning is a complex mathematical function that, after training, can be used to generate predictions or judgments when applied to new data, called test data (Uçar et al., 2020). The process of machine learning may be broken down into different categories (Taye, 2023). One of the process categories is supervised learning, which involves training the model on labeled data, for example, radiographic images (Nguyen and Patrick, 2014). Learning without supervision, in which the model uncovers previously unknown patterns and structures in unlabeled data, and reinforcement learning, a form of learning in which an agent interacts with its environment and adjusts its behavior to maximize total reward or avoid a penalty (Morales and Escalante, 2022; Figure 3).

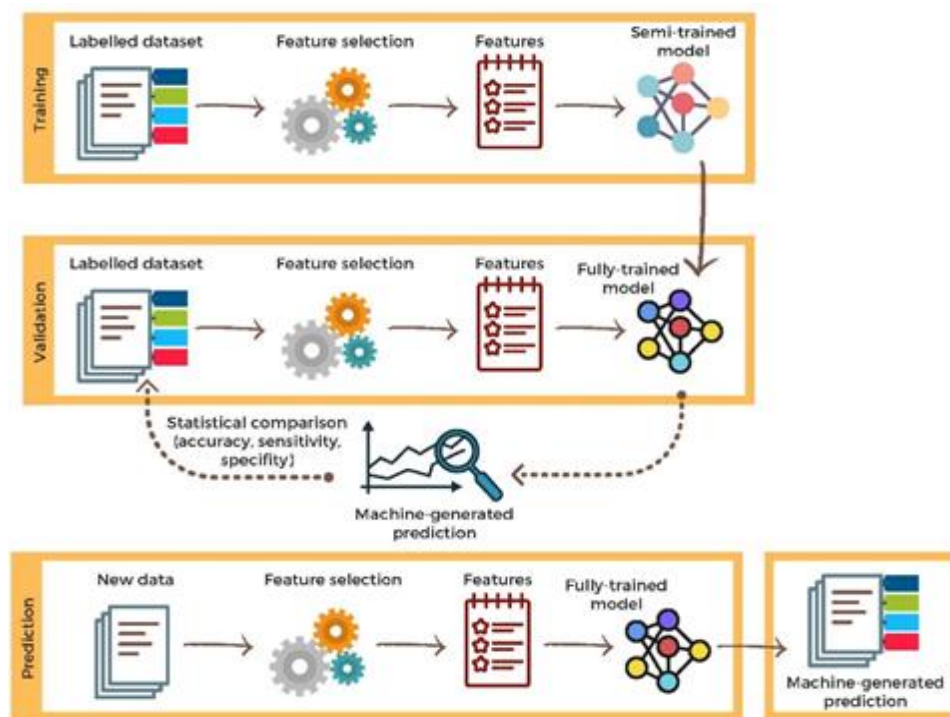


Figure 3. A brief description of the supervised learning flowchart, including training, validation, and prediction. (MDPI Copyright, Source of image adapted from Bouhali et al., 2022).

Deep learning, a subfield of machine learning, has emerged as a driving force behind the current artificial intelligence revolution (Srinivas et al., 2022). It employs artificial neural networks with complex, layered architectures referred to as deep that are inspired by the structural organization of the human brain (Taye, 2023). Deep learning networks consist of multiple layers of artificial neurons, also known as processing nodes. Each layer of these networks extracts information from the input data at a different level of abstraction (Qamar and Zardari, 2023). When processing a radiographic image, for instance, the earliest layers may be responsible for identifying edges and flanks, the intermediate layers for recognizing basic geometric patterns, and the deeper layers for extracting intricate information, such as the precise pattern of a bone fracture or a lung opacity (Mijwil et al., 2022). The remarkable achievements of AI in fields such as computer vision and NLP can be attributed, in large part, to the development of specific deep learning architectures (Chai et al., 2021). Deep learning architectures include convolutional neural networks for processing image data, as well as recurrent neural networks and transformers for processing sequential data such as transcription and speech (Xu et al., 2021; Taye, 2023).

Additionally, AI comprises a wide variety of algorithms and methods beyond deep learning (Gupta et al., 2021). The NLP, which enables machines to understand, interpret, and generate human language, can be used in veterinary medicine to analyze text-based clinical notes, automatically extract information from electronic health records, and even develop chatbots that answer questions posed by pet owners (Davies et al., 2024; Stimmer et al., 2025). The analysis of more structured data, such as blood test results, is often performed using traditional machine learning techniques (Khan et al., 2020). Machine learning techniques include algorithms such as random forests, support vector machines, and logistic regression (Boateng et al., 2020). When selecting an algorithm, it is important to consider the characteristics of the data (photos, text, or numbers), the amount of readily accessible data, and the eventual objective (classification, diagnosis, or prediction; Saturi, 2023).

Having a solid understanding of their capabilities and constraints is necessary for successful implementation in veterinary care. Artificial intelligence, and deep learning in particular, has the capacity to uncover intricate and nuanced patterns in high-dimensional

data, such as pixel data (Wilson and Anwar, 2024). Deep learning patterns may be concealed from even the most knowledgeable specialists (Rane *et al.*, 2024). Because deep learning models can handle diverse data volumes at high speed and with a high degree of consistency, these systems serve as relentless assistants (Archana and Jeevaraj, 2024). On the other hand, deep learning patterns do not possess the reasoning capability, profound conceptual knowledge, clinical intuition, or the ability to consider the broader context of a case, such as the animal's full history or environmental circumstances, as a veterinarian does. The quality and quantity of the training data are also significant factors in determining their effectiveness, and they can learn and amplify biases present in the data (Mehrabi *et al.*, 2021). Consequently, AI in veterinary medicine should be seen as a potent auxiliary tool, with the experienced veterinarian remaining responsible for making final decisions and carrying out clinical responsibilities (Basran and Appleby, 2024; Akbarein *et al.*, 2025).

APPLICATIONS OF AI IN SMALL ANIMAL MEDICINE

Radiology and diagnostic imaging

The use of AI, particularly deep learning-based computer vision, in veterinary radiography for small animals is one of the most sophisticated and promising areas (Sharun *et al.*, 2024). In the future, deep learning-based computer vision has the potential to serve as a digital assistant to radiologists and revolutionize the interpretation of a wide variety of diagnostic images (Akbarein *et al.*, 2025). Diagnostic images include conventional radiography (X-ray), computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound (Hussain *et al.*, 2022). AI-powered algorithms can quickly scan medical images and recognize patterns associated with diseases (Hespel *et al.*, 2022). For instance, in human chest radiography, deep learning-based computer vision can automatically segment the heart, lungs, diaphragm, and major arteries (Mittal *et al.*, 2017). Additionally, deep learning-based computer vision can identify anomalies such as pleural effusion, alveolarization, cardiomegaly, and foreign bodies with high accuracy in humans (Zhou *et al.*, 2021). The application of AI in musculoskeletal imaging enables screening and grading of osteoarthritis in the hip and elbow joints, detecting minor fractures or dislocations, and even evaluating bone density (Akbarein *et al.*, 2025). In addition to accelerating the diagnostic process, this automation can enhance the quality and consistency of interpretations by reducing errors caused by human fatigue or inattention (Panahi, 2025).

The development of similar systems for veterinary care, on the other hand, is fraught with significant obstacles, primarily because of the different biological heterogeneity among patients (Kurhaluk and Tkaczenko, 2025). The training dataset should be representative of a wide range of breeds, ages, and weights to be considered complete. In addition, AI is most effective in this context when it is used as a facilitator and a warning system (Tiggeloven *et al.*, 2025). For instance, it may prioritize photos, highlighting those at high risk of being pathogenic for prompt veterinary examination, mark questionable regions with antonyms, or provide accurate quantitative measures, such as heart size relative to the chest or joint angles (Maqbool *et al.*, 2025). AI enables general veterinarians to assess photos with greater confidence while freeing radiologists' time for the most difficult cases (Rubini *et al.*, 2025). It is the development of integrated, user-friendly technologies that connect directly with diagnostic imaging software such as Picture Archiving and Communication System (PACS) and provide preliminary results that will hold the key to the future of this industry (Appleby and Basran, 2024).

Clinical and anatomical pathology

The field of pathology is now experiencing a great change in AI, with the potential to fundamentally shift how tissue and cell samples are analyzed and interpreted (Khandia *et al.*, 2026). In clinical pathology or hematology, systems that are based on deep learning can automatically scan peripheral blood slides and conduct white cell differentiation, such as counting and categorizing neutrophils, lymphocytes, and eosinophils, with a level of accuracy and speed that surpasses that of conventional approaches (Rahmoun *et al.*, 2025). Deep learning algorithms can recognize aberrant cell morphologies, such as leukemic blasts or atypical serous cells, and can even evaluate micromorphological characteristics, such as cytoplasmic granulation and nuclear divisions (Maqbool *et al.*, 2025). Deep learning can recognize and categorize casts, crystals, and epithelial cells through urinalysis (Suhail and Brindha, 2021). This results in higher data uniformity, reduced variation between operators, and increased time that experienced technicians can devote to more sophisticated analytical tasks (Liou *et al.*, 2024). Digitalized tissue slides, also known as whole slide images, may be analyzed by AI algorithms, which can then quantify important diagnostic characteristics (Zuraw and Aeffner, 2022).

In histology, AI can perform tasks with high accuracy, such as identifying, categorizing, and grading neoplasms (Fitzke *et al.*, 2021; Rahmoun *et al.*, 2025). Pathologists may benefit from this quantitative analysis, as it can provide more objective information and reduce the subjective variability among assessors (Battazza *et al.*, 2024; Piccione *et al.*, 2025). In addition, AI can identify prognostic biomarkers in tissues (Lancellotti *et al.*, 2021). Prognostic biomarkers include specific patterns of protein expression or histological characteristics related to therapy response (Webster *et al.*, 2011). The need for large datasets of pathologist-annotated slides with extensive experience is the primary obstacle in this field (Balachandran, 2025). Additionally, the veterinary pathologist remains responsible for the final interpretation and diagnosis of the patient. This is because AI does not fully comprehend the patient's history and clinical symptoms, nor does it have comprehensive knowledge of pathology (Fadhail, 2025; Vickram *et al.*, 2025).

Dermatology

The diagnosis of skin diseases can be difficult because many conditions share similar clinical signs such as erythema, papules, pustules, and alopecia (Smith *et al.*, 2024). Skin disorders are among the most prevalent causes for visits to small-animal veterinary clinics (Alizadeh *et al.*, 2024). Artificial intelligence is providing an effective tool for the differential diagnosis and treatment of skin disorders (Patel and Vishwakarma, 2025). Using AI, the properties of the lesion, such as its form, border, color, and size, may be

extracted and compared with a database containing thousands of photos of known diseases (Langon et al., 2025). Early lesions that are caused by environmental or food allergies, bacterial infections such as pyoderma, fungal infections such as dermatophytosis, external parasites such as *Sarcoptes* or *Demodex* mites, and even skin neoplasia such as mast cell tumors or melanoma may be identified with the use of AI (Apostolopoulos et al., 2025).

The use of AI for analyzing dermatoscopic images is a more specific application. One type of portable light microscope is a dermatoscope, designed to provide a more detailed view of the structures of the skin and hair (Burroughs and Diaz, 2023). Dermatoscope high-magnification images can be analyzed by algorithms that detect specific microscopic patterns essential for diagnosing disorders such as mange (caused by the mite *Sarcoptes scabiei*) and demodicosis, as well as the vascular characteristics of skin moles (Alanazi, 2025). Particularly for general veterinarians with limited dermatoscopy expertise, this technique has the potential to improve diagnostic accuracy (Owens et al., 2023). Not only can AI assist with diagnosis, but it can also work to monitor how well therapy is working (Appleby and Basran, 2022). By comparing serial photos from multiple visits, the system can objectively evaluate the lesion's improvement or spread (Burroughs and Diaz, 2023; Sri et al., 2025).

Microbiology and diagnosis of infectious diseases

The field of microbiology is on the verge of a revolution driven by AI (Smith and Kirby, 2020; Pillai et al., 2022). Although most published studies focus on human medicine, the same AI principles have shown promising results in small animal veterinary microbiology, including automated antibiogram reading for canine urinary tract infections and metagenomic detection of enteric pathogens in cats with chronic diarrhea (Shan et al., 2024). The automated examination of bacterial cultures and the assessment of antibiotic susceptibility are two of the most important applications in human and veterinary medicine (Marletta et al., 2023; Wong et al., 2023). In the field of human clinical microbiology, advanced imaging devices can capture images of culture plates at predetermined intervals, and AI algorithms can monitor and even forecast bacterial colony growth (Burns et al., 2023). Advanced imaging devices can assist technicians in the initial identification of significant pathogens, such as *Staphylococcus*, *Escherichia coli*, and *Pseudomonas*, by providing preliminary colony classification based on morphology, including form, color, size, and edges (Alsulimani et al., 2024). In disk diffusion tests, also known as antibiograms, AI can estimate the zone of inhibition diameter with high precision and interpret the susceptibility result (susceptible, intermediate, or resistant) in accordance with internationally recognized recommendations, such as the Clinical and Laboratory Standards Institute (CLSI) VET01-S (Performance Standards for Antimicrobial Disk and Dilution Susceptibility Tests for Bacteria Isolated from Animals; CLSI, 2024) and the European Committee on Antimicrobial Susceptibility Testing (EUCAST) breakpoint tables (Toutain et al., 2017; Nguyen et al., 2025). Both the expediency of detecting the spread of antimicrobial resistance and the granularity of measurement are consequently enhanced (Miglietta et al., 2025).

A more advanced application of AI in microbiology is in metagenomics and next-generation sequencing (Chisompola et al., 2025; Syed et al., 2025). Given the enormous amounts of sequencing data generated from clinical samples, such as blood, urine, and tissue, AI and machine learning have emerged as powerful adjuncts for analyzing this complex data (Islam et al., 2025). From a wide range of host- and natural microbiome-derived sequences, the convolutional neural networks and random forest classifiers algorithms can recognize and categorize the genetic sequences of bacterial, viral, fungal, and parasitic pathogens (Miglietta et al., 2025). A further capability of AI is the ability to recognize genetic patterns associated with antibiotic resistance in sequencing data. The molecular patterns include the presence of specific resistance genes and may also predict which drugs may not be effective (Jia et al., 2025). This might facilitate more focused therapy and reduce inappropriate antibiotic use. On the other hand, due to the high cost of sequencing equipment and the need for sophisticated computing infrastructure, the general adoption of these technologies is now mostly restricted to research and reference labs (An et al., 2025).

The behavioural observations in animals

Beyond the analysis of molecular and imaging data, artificial intelligence is increasingly capable of detecting disease through the interpretation of behavioural observations, specifically vocalizations and movement patterns. These modalities offer non-invasive, continuous, and objective means of health assessment in small animal medicine. In the domain of acoustic analysis, deep learning models have demonstrated considerable utility. Convolutional neural networks (CNNs) can classify canine vocalizations such as barks, whines, and howls with high accuracy, and can differentiate between playful and aggressive contexts based solely on acoustic features (Gómez-Armenta et al., 2024). More importantly, machine learning has been successfully applied to detect respiratory pathologies from vocal sounds. The "BrachySound" study employed ML models to analyze respiratory audio samples from brachycephalic dogs, achieving 85% accuracy in classifying Brachycephalic Obstructive Airway Syndrome (BOAS), thereby offering a rapid, objective alternative to subjective auscultation (Oren et al., 2023). Furthermore, recurrent neural networks have been developed to automatically detect and grade stertor (snoring sounds) in laryngeal recordings, enabling widespread screening for BOAS (McDonald et al., 2024). In parallel, AI-powered movement analysis provides a window into musculoskeletal and neurological health. Markerless deep neural networks can track canine joint range of motion from standard video footage, detecting reductions as subtle as 6.1 degrees in dogs with elbow osteoarthritis (Gordon et al., 2025). Artificial neural networks analyzing inertial sensor data have also proven capable of discriminating between sound and lame dogs with approximately 86% accuracy, integrating these assessments into user-friendly clinical applications (Figueirinhas et al., 2022). Wearable sensors equipped with machine learning pipelines can even detect trained behavioral alerts for seizure events (Brady et al., 2025). Collectively, these approaches, including vocalization analysis and movement tracking, enable earlier, more objective disease detection and continuous remote monitoring. When combined with blockchain technology for secure, immutable storage of behavioral health data, such systems could facilitate multi-institutional collaboration and personalized, preventive veterinary care.

BLOCKCHAIN SYSTEM: TRANSPARENCY, SECURITY, AND DATA INTEGRITY

Blockchain, as a distributed, decentralized ledger, has the potential to address some of the fundamental challenges in pet health data management. This potential stems from the fact that it inherently provides a transparent and secure platform for recording and validating events and transactions (Chattu, 2021). One of the main advantages of this technology is that every data record is verifiable and cannot be easily changed (Giri and Dash, 2023). The blockchain structure is based on a chain of blocks, each containing a timestamp and a cryptographic hash of the previous block, and is collaboratively maintained and updated by a set of nodes (Zheng et al., 2018). Any changes to the recorded data or the addition of a new record require a majority of the network to reach a consensus; this requirement for a majority consensus mechanism makes data manipulation practically costly and difficult (Zheng et al., 2018). In the veterinary context, this immutability and the requirement for majority consensus could revolutionize the way animal records are managed (Quy et al., 2023). Data such as test results, treatment reports, and diagnostic images can be captured and referenced as reliable, immutable records (Hickman et al., 2020). In addition, information such as birth certificates, vaccination records, and disease histories can be defined as a unified digital identity for each animal; an identity that becomes more complete over the animal's lifetime, allowing for authentication and validation of information (Hickman et al., 2020). Access to this unified digital identity and its associated records can be provided in a controlled manner to stakeholders, including the animal's owner, treating veterinarian, animal shelters, insurance companies, and regulatory agencies. In such a model, reliance on centralized databases and time-consuming paper-based processes is reduced, and security risks associated with data centralization are also mitigated (Figure 4; Sharma et al., 2021).

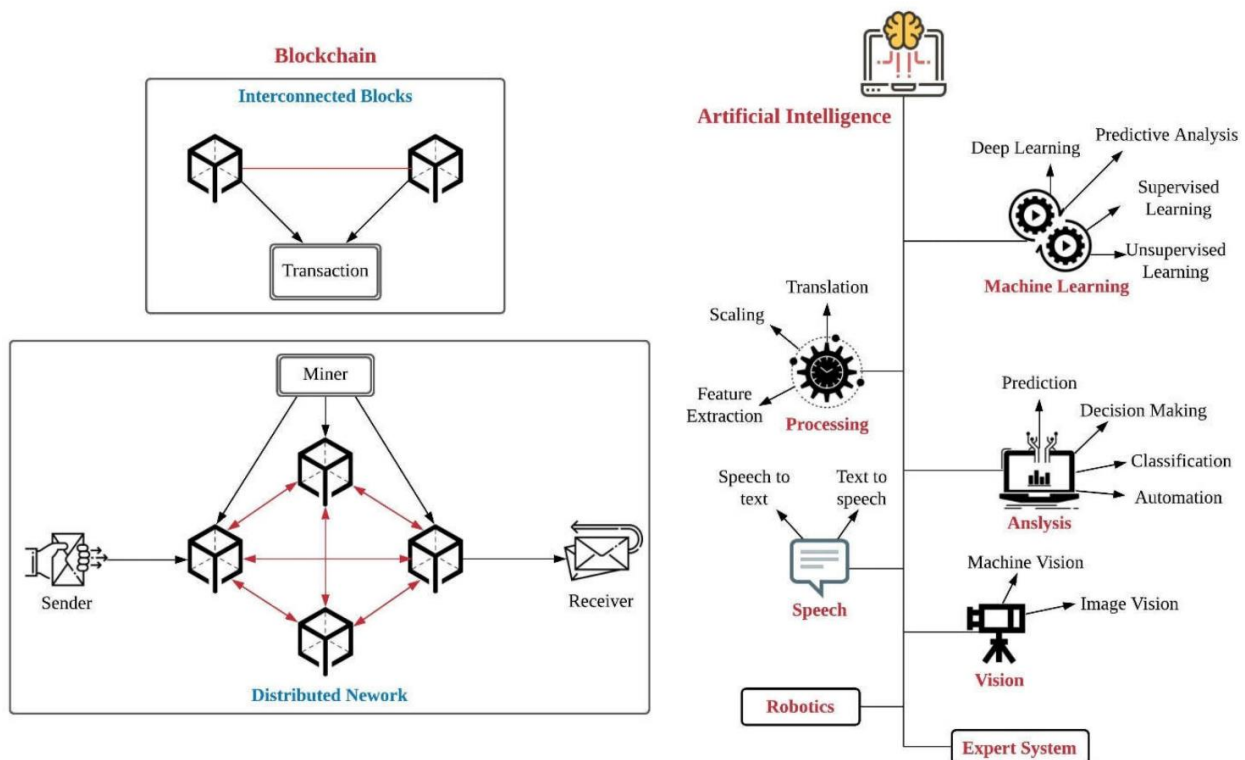


Figure 4. Overview of artificial intelligence and blockchain. (MDPI Copyright, Source of image adapted from Sharma et al. (2021).

Before detailing the applications of blockchain, it is worth explicitly stating how it concretely tackles the three major AI challenges in veterinary medicine, namely data integrity by immutably hashing training datasets and access logs, transparency via cryptographically verifiable audit trails for every data contribution and model update, and mitigation of bias by documenting data provenance, preprocessing steps, and demographic variables, making hidden biases detectable and correctable (Iqbal et al., 2021). This trust layer thus directly complements AI without acting as a primary data repository.

One of the most serious and practical applications of blockchain in pet veterinary medicine is supply chain management and the authentication of drugs, vaccines, and biological products (Makkar and Costa, 2020). Issues such as mislabeling, fraud, and the distribution of expired or counterfeit drugs pose direct threats to animal health and are especially prevalent in the online veterinary drug market (Iqbal et al., 2021). In this context, assigning a unique digital identifier to each product unit in the production line (scannable codes) creates a public, tamper-proof record of each product's movement (Iqbal et al., 2021). A unique identifier is then recorded and updated throughout the product life cycle, from production and quality control to distribution, storage, and finally supply to the pharmacy or clinic (Makkar and Costa, 2020). With a simple scan, the veterinarian or pet owner can access the product's complete history, verify storage conditions, and confirm that the drug was obtained from official, reliable sources (Makkar and Costa, 2020). Implementing such a mechanism not only increases the safety of drug treatment but also helps to combat the informal market and protect reputable brands (Iqbal et al., 2021). In addition, in the event of an adverse drug reaction, it enables rapid, accurate traceability back to the source of production, making the recall process for defective products more targeted and effective (Thakur et al., 2024).

Compared with many existing digital solutions, blockchain is a more advanced and future-proof option, as it enables large-scale sharing of research and epidemiological data without compromising data security (Sai et al., 2022). To study emerging diseases, breed genetics, treatment efficacy, and long-term outcomes, access to large datasets from animal populations is essential, and, naturally, these databases should cover a diverse range of data (Sai et al., 2022). By leveraging blockchain, researchers and institutions can securely and efficiently exchange data, including anonymized clinical data, genetic information, medical images, and results from subsequent studies (Patel, 2019; Tagde et al., 2021). Since blockchain can act as a trusted platform for recording access, every time data is recorded or accessed, the event remains recorded and verifiable in the ledger (Tagde et al., 2021). Furthermore, ledger-based mechanisms can clarify data ownership and usage restrictions and specify frameworks for data access and exploitation via smart contracts (Sai et al., 2024). In practice, such a model can facilitate international collaboration, reduce research duplication, and accelerate the production of new knowledge (Sai et al., 2024). In particular, rapid, decentralized, and reliable reporting of disease cases on the blockchain platform has the potential to enhance the surveillance and management of infectious diseases with pandemic potential, such as canine influenza or zoonotic diseases, and help animal health and public health agencies monitor outbreaks in near real-time and implement more targeted and timely interventions (Sai et al., 2024).

Beyond these applications, the convergence of blockchain with artificial intelligence creates synergistic opportunities that directly address core challenges in veterinary AI (Choi et al., 2024). First, blockchain can secure the training data lifecycle for AI models (Zhang et al., 2024). High-quality, trustworthy labeled data are essential for developing robust diagnostic algorithms; blockchain provides an immutable record of data provenance, including the origin of each image or clinical record, any preprocessing steps applied, and the identity of annotating veterinarians (Kasralikar et al., 2025). This transparency reduces the risk of data tampering or undetected bias, ultimately improving the reliability of AI models (Parlak et al., 2025). Second, smart contracts can govern AI algorithm updates (Iqbal et al., 2021). When an AI model requires retraining or a new version is released, smart contracts can automate validation, approval workflows, and deployment across participating clinics, ensuring that all users operate on the same validated version while maintaining an auditable change log (Hawashin et al., 2026). Third, distributed ledgers can track AI decision-making for auditability. In clinical practice, when an AI system recommends a diagnosis or treatment, recording the input features, model version, and output confidence score on a blockchain creates a tamper-proof audit trail. This is particularly valuable for post-hoc analysis, medicolegal inquiries, or adverse event investigations, as clinicians can verify whether the AI's recommendation was correctly interpreted and whether the model performed as expected (Hossain et al., 2025; Musamih et al., 2026). By integrating these mechanisms, blockchain not only complements AI but also addresses concerns about transparency, reproducibility, and accountability issues that have historically limited clinical adoption of AI in veterinary medicine (Choi et al., 2024).

Although blockchain-based systems offer potential advantages, several serious challenges should be addressed before they can be fully implemented in veterinary medicine (Makkar and Costa, 2020). Many public blockchains experience significant processing latency and energy consumption under high transaction volumes, such as during continuous data collection from wearables (Hawashin et al., 2026). Continuous data collection from wearables limitations largely stem from the architecture of these networks and the way transactions are designed, and they challenge scalability and efficiency (Hawashin et al., 2026). One solution proposed in this context is the use of private or consortium blockchains with stricter access controls, sometimes referred to as layer-2 solutions. In addition to technical challenges, coordination and standardization are also very important (Musamih et al., 2026). For a blockchain system to be truly effective at the industry level, it is necessary for different actors in the field, from veterinarians and laboratories to pharmaceutical companies, breed registries, and government agencies, to agree on a set of common protocols, data formats, and access models; a process that is naturally time-consuming and costly (Musamih et al., 2026). In addition, legal and governance issues should be clarified, including determining the legal ownership of data recorded on the chain, the legal status of smart contracts, and compliance with data protection requirements such as the European General Data Protection Regulation (Jabbar et al., 2021). Finally, it is essential to educate end users, especially technicians and veterinarians, to understand and use these infrastructures properly, so that these systems do not remain merely on paper (Jabbar et al., 2021; Kha et al., 2023).

Limitations and ethical rules for using AI in clinical evaluation

The conceptual and regulatory frameworks governing AI in clinical decision-making remain markedly underdeveloped in veterinary medicine compared to human healthcare, creating a landscape defined by principle-based guidance and significant regulatory lacunae, especially outside Europe (Busch et al., 2025). Professional bodies have issued foundational ethical position statements: the joint (American College of Veterinary Radiology) ACVR and (European College of Veterinary Diagnostic Imaging) ECVDI 2025 statement, emphasizing patient safety anchored in a veterinarian-in-the-loop principle and transparency, warns that currently, no commercially available veterinary diagnostic imaging AI product meets the required standards for transparency, validation, or safety (Appleby et al., 2025). However, a systematic audit of 71 commercial veterinary AI products found a mean transparency score of only 6.4%, with 63.3% of vendors failing to disclose even a single performance metric (School of Veterinary Medicine, University of Wisconsin-Madison, 2026). This transparency gap forces individual practitioners to bear the legal and ethical burden of validating AI tools without access to essential performance data (School of Veterinary Medicine, University of Wisconsin-Madison, 2026). In the FDA-regulated US market, the Center for Veterinary Medicine has not categorized veterinary AI diagnostic tools as pre-market approved medical devices similar to human AI counterparts, effectively leaving clinical validation to individual veterinarians (Duggirala et al., 2025). Conversely, the European Union offers the first legally binding framework in the form of the 2024 EU AI Act, which classifies medical AI as "high-risk" and mandates strict compliance for human health AI systems, though its direct application to veterinary medicine remains ambiguous (Busch et al., 2025; Parlak, 2025). Meanwhile, 47.2% of countries globally have no AI-specific healthcare framework (Busch et al., 2025). Given this fragmented regulatory terrain, professional consensus has coalesced around core principles, including that AI must augment rather than replace veterinary clinical

judgment, with ultimate accountability resting with the attending veterinarian (SAVC, 2024; Appleby et al., 2025). This principle-based approach mandates transparent data handling, explicit disclosure of AI use to clients, and continuous post-market surveillance.

FUTURE PROSPECT

It is not going to be discrete, standalone instruments that will be the future of AI in veterinary treatment for small animals; rather, it will be an interconnected, intelligent ecosystem (Pereira et al., 2023). Imagine a system that gathers information from a variety of sources, including the animal's extensive electronic health history; real-time findings from wearable sensors measuring heart rate, activity, sleep quality, and even aberrant feeding patterns; medical photographs; pathology reports; and genetic data (Pereira et al., 2023). A central AI-based platform will consolidate and evaluate this large stream of data across several facets using sophisticated algorithms (Wilson and Anwar, 2024). The system will be able to uncover complex patterns and hidden connections that are hidden from the view of a human expert (Wilson and Anwar, 2024). For instance, it may detect a subtle correlation between a specific pattern on an echocardiogram, an inflammatory marker in a blood test, and a behavioral change recorded by the pet owner, and it may also warn of the possibility of developing a specific cardiorenal disease at an earlier stage than the beginning (Balachandran, 2025). By using a holistic approach, the veterinarian can transition from a reactive to a proactive, predictive stance, enabling them to intervene at the preclinical stage of diseases (Amer and Amer, 2025). Artificial intelligence will serve as an auxiliary "digital brain" within the proposed blockchain-based health data management system, continuously monitoring the animal's health and delivering deep insights to support tailored decisions (Figure 5; Aguilar-Lazcano et al., 2023).

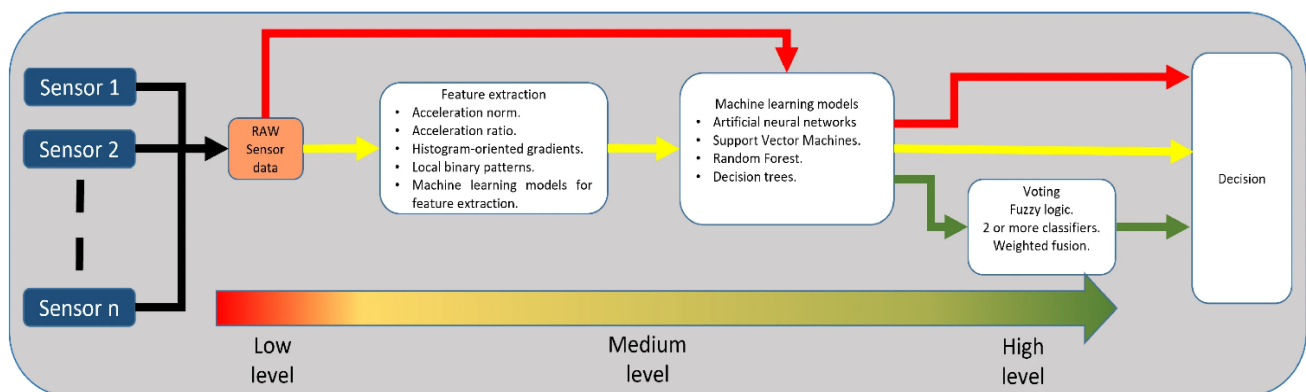


Figure 5. Representation of the three levels of sensor fusion. (MDPI, Copyright. Source of image adapted from Aguilar-Lazcano et al. (2023).

The transition toward Precision Veterinary Medicine or Personalized Veterinary Medicine will be one of the most significant effects AI will have in the future (Weiderman et al., 2025). AI algorithms will be able to predict the likelihood of developing specific diseases, such as cancer or hereditary diseases, by analyzing genomic, metabolomic, and microbiome data, as well as an animal's individual history of responses to previous treatments (Wilson and Anwar, 2024). Additionally, machine learning algorithms will be able to predict responses to specific drugs (pharmacogenomics) and design fully customized diets and treatments (Sarker, 2021). By leveraging the tumor's genetic profile and the animal's immunological history, for instance, the system may provide a recommendation for the chemotherapy regimen most beneficial for a dog diagnosed with lymphoma (Koo et al., 2021; Alshammari et al., 2025). Moreover, AI will serve as a powerful engine for discovering new information in animal biology and disease research (Alshammari et al., 2025). Using AI, it is possible to identify previously unknown risk factors for disease, discover new disease subtypes with different prognoses and treatment responses, and even create predictive models for infectious disease outbreaks, such as canine influenza or parvovirus, based on spatial and epidemiological data (Saturi, 2023). AI capabilities are achieved through the analysis of massive datasets shared across multiple centers, containing millions of animal records (Uçar et al., 2020).

AI in the future can help make healthcare knowledge more accessible to the general public (Gruetzemacher and Whittlestone, 2022). Diagnostic tools and even nanobiosensors that are powered by AI and can be placed on mobile phones or other low-cost devices might make it possible for ordinary veterinarians working in rural locations or tiny clinics to get access to a level of specialized analysis, such as radiography, pathology, or dermatology to detect even zoonotic diseases such as helminths in animals that were previously only accessible in major professional centers (Nagamori et al., 2021; Ward et al., 2022; Akbarein et al., 2025). AI has the potential to improve the overall quality of services while also reducing the care gap across areas (Sadr et al., 2025b). Nevertheless, this promising future will not be devoid of difficulties and will bring new obstacles that are more difficult to address from professional, ethical, and legal standpoints. When a system offers a therapy suggestion, the veterinarian should be able to understand the logic behind it; this is the dispute between the black box and the transparent box (Islam et al., 2025). When information from a variety of sources is combined, concerns over data privacy grow more complex and controversial (Sadr et al., 2025b). Certain legal frameworks should be explicitly stated to determine accountability for system errors (Islam et al., 2025). Legal frameworks should be established between the software developer, the user veterinarian, and the service provider (Islam et al., 2025). Additionally, the education of the next generation of veterinarians should be rethought to include digital literacy, the capacity to engage critically with AI outputs, and the important clinical skills that should be maintained alongside their use. This educational reorientation also ushers in a new era of precision, predictability, and personalized care in veterinary medicine.

CONCLUSION

The field of small-animal veterinary care is poised for a paradigm shift in diagnostics, therapeutics, and management, driven by AI. The ability of deep learning and computer vision algorithms to increase the speed, accuracy, and objectivity of interpreting complex clinical data is demonstrated by their practical, promising applications in specialized fields such as radiology, pathology, dermatology, and microbiology. AI applications demonstrate the unparalleled ability of machine learning algorithms to help improve the interpretation of clinical data. However, the successful development of these technologies depends heavily on overcoming fundamental challenges. The most important of these challenges include the absence of large datasets that are of high quality and diverse, as well as accurate annotations; the extensive genetic and anatomical variation among breeds that hinders the generalizability of models; and the absence of clear ethical, legal, and professional frameworks regarding accountability, data privacy, and the reduction of algorithmic bias. In conclusion, it is essential to emphasize that AI in veterinary medicine will not replace human judgment, experience, and communication; rather, it will serve as an intelligent assistant and a distinctive supplement to these aspects of the veterinarian's practice. A balanced approach that focuses on the tremendous potential of AI and wisely addresses the challenges ahead is required to realize the ultimate vision of improving the health and well-being of companion animals through earlier diagnosis, personalized treatments, and effective preventive care. Alongside AI, it is important to consider the infrastructure layers of trust and data governance, such as blockchain, to record verifiable events and manage data access. These layers complement AI, and their practical success will depend on solving technical, legal, and adoption challenges. Key limitations include the algorithm's sensitivity to image quality and lighting angle, as well as its inability to eliminate the need for additional diagnostic procedures such as cytology, culture, or biopsy. Moreover, AI cannot replace a comprehensive clinical evaluation and history-taking; its utility is therefore confined to screening and to serving as an initial guidance tool. To strengthen the technical basis of the systems by creating internationally shared and standardized databases, and to facilitate adoption by the veterinary community by designing user-friendly tools and integrating them seamlessly into clinical workflows, the future of this field depends on the establishment of sustainable interdisciplinary collaborations between veterinarians, AI experts, regulators, and industry. Collaborations between veterinarians, AI experts, regulators, and industry are necessary for the future of this field.

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Authors' contributions

Pouria Ahmadi Simab and Fatemeh Shiri were responsible for the conception and design of the study, acquisition and analysis of the data, interpretation of the findings, and drafting and critical revision of the article. Amin Shahinzadeh, Arya Heidari, and Amirreza Safaie contributed to the study's design and the interpretation of the results, and critically revised the manuscript. Sina Ghanbari and Pouria Ahmadi Simab were involved in drafting the article and critically revising its intellectual content. Amir Hossein Atazadeh designed and wrote the blockchain section of the manuscript. All authors have read and approved the final edition of the manuscript before publication.

Availability of data and materials

All reviewed datasets during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethical considerations

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