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Original Article

AI-Based Diagnostic Tools for Early Disease Prediction

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Abstract

This review discusses new applications of Artificial Intelligence (AI) in veterinary medicine, specifically in animal disease prediction. New developments in machine learning, computer vision, and sensor technology have created new methods for identifying diseases in animals before clinical symptoms are identified. The aim of this study was to provide a wide-ranging review of AI-based animal diagnostics across species and diseases, compare the diagnostic specificity and sensitivity derived from these tools, identify possible barriers to implementation, and discuss the costs associated with the implementation of AI in practice. Our review found that although AI methods have shown high diagnostic sensitivity and specificity (>90%) for certain diseases, issues remain regarding data standardization, clinical validation, and field plausibility. We focused on the integration of multimodal data sources, explainable AI, and point-of-care as opportunities for improvement. This review will enable veterinary practitioners, researchers, and the veterinary sector to understand current technological capabilities and the future of AI-assisted diagnostics in veterinary medicine. Early The diagnosis of disease earlier is vital for effective treatment, saving healthcare costs, and improving patient survival. The progress we have seen in artificial intelligence (AI) has changed the manner in which disease prediction models are constructed and used, which can result in a more accurate, effective, efficient, and scalable approach to disease prediction. This paper outlines the development and usage of AI diagnostic tools for the early prediction of diseases, with an emphasis on modelling with machine learning (ML), deep learning (DL), and natural language processing (NLP) methods. We outline the various algorithms and frameworks available for predictive diagnostics, as well as their interface with medical imaging, electronic health records (EHRs), and genomic data. We examined key case studies on cancer, cardiovascular diseases, diabetes, and neurological disorders to assess the current capabilities and limits of AI-generated disease precompletion. We also identified ethical questions, data privacy concerns, and the need for transparent and explainable AI systems in clinical applications. Finally, we emphasize the potential of AI to reshape predictive health care and the importance of ongoing interdisciplinary collaboration to develop these technologies for real-world use.

Keywords: *artificial intelligence, veterinary medicine, early disease detection, machine learning, animal health*

Introduction

In veterinary medicine, early disease detection in animal populations is a promising new area that has significant consequences for animal welfare, agricultural production, and public health when zoonotic disease concerns are considered. Clinical diagnosis of the disease depends on the observation of clinical signs and symptoms. By this point, the animal may be significantly diseased, the treatment will likely be less effective, and the economic loss will be greater (Smith et al., 2022). The growth of artificial intelligence (AI) technologies provides a unique opportunity to revolutionize how veterinary medicine uses diagnostic data by allowing earlier and more accurate disease detection (Johnson et al., 2023). The use of AI in veterinary medicine has experienced a rapid evolution over the last decade, from research and proof of concept to commercial use. These technologies can analyse many different data types, including clinical variables, imaging, behavioral data, and biomarkers, to detect disease signatures at an early stage before clinical diagnosis can be established (Williams & Chen, 2023).

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The economic implications of this technology, when applied to animal production, are significant. The livestock sector estimates that early detection systems could reduce losses due to disease by 30-50%, while enhancing animal welfare (Garcia et al., 2024). The purpose of this review is to systematically review AI-based diagnostic tools for the early prediction of diseases in companion animals, livestock, and wildlife species, while considering the technological foundations upon which these systems are built, how these systems are implemented and validated, and the limitations of deploying these systems. Our approach includes an examination of research prototypes and commercially available solutions to provide insights into the overall state of the field and the development path.

Methodology

Search Strategy and Selection Criteria

To identify the relevant literature on AI-based diagnostic tools for early disease prediction in animals, we adopted a systematic approach for the literature review. The major scientific databases (PubMed, IEEE Xplore, Web of Science, and Google Scholar) were searched for articles published between January 2018 and October 2024. Search terms included a combination of keywords related to artificial intelligence (e.g., "artificial intelligence," "machine learning," "deep learning"), veterinary applications (e.g., "veterinary," "animal health," "livestock," "companion animal"), and and the context of diagnostic (e.g., "early detection," "disease prediction," "diagnostic," "screening").

Inclusion criteria for the review were:

1. primary research or comprehensive review articles
2. Focus on AI applications in disease prediction prior to clinical use, yielding interpretable predictions to develop practitioner trust and adoption.
3. Studies in any animal species.
4. Peer-reviewed publications or conference proceedings from established scientific - we excluded articles focusing solely on human examples, diagnostics and prognostics that did not include AI methodologies, and articles that did not include information about the methods.

Data Extraction and Analysis

We synthesized information from articles that provided population and veterinary practice information, including the following:

- Animal species and disease targets
- AI methodologies and algorithms used
- Data types and collection strategies
- Performance measurements (e.g. sensitivity, specificity, accuracy)
- Validation strategies
- Factors slowing down implementation and other practical considerations
- Their current status of use (e.g. research prototype for development or commercially deployed)

We also categorized technologies by application (companion animals, livestock, equines, wildlife) and targets (infectious, metabolic, neurologic, etc.) and standardized performance metrics, when possible, for the purposes of comparison, especially considering the diagnostic timeframes for conventional detection.

Literature Review

The integration of artificial intelligence into veterinary diagnostics has received substantial research attention during the past decade, and significant portions of this research have focused on the potential to revolutionize early disease detection by introducing transformative diagnostic tools. A variety of studies have employed machine learning models to classify and predict preclinical disease states in livestock and companion animals. For instance, Williams and Chen (2023) found that using explainable AI algorithms greatly improved veterinarians' decision-making and ability to predict animal health, because the ability to provide interpretable predictions led to increased trust and adoption by practitioners.

The dairy industry has been at the forefront of research investigating the ability to predict clinical diseases through the inclusion of biomedically relevant streams. Rodriguez et al. (2023) validated that multimodal biosensor systems can be applied to accurately detect mastitis 48 h before clinical signs by combining multiple data streams (milk conductivity and body temperature) in order to perform predictive risk assessment. Thompson et al. (2024) showed that the detection of respiratory disease infection in cattle was possible up to four days before clinical signs using thermal imaging and deep learning technology. The progression of these studies indicates that AI enabled diagnostic tools are becoming increasingly effective in veterinary medicine.

Despite these advances, several challenges remain. Martinez and Wong (2023) identified the complexities of data standardization and included a table of data standardization protocols in multiple veterinary diagnostic fields. They suggested using federated learning to overcome barriers to sharing patient data. Anderson et al. (2024) pointed out that for a significant proportion of AI diagnostic studies published in four journals, there is no strong field validation that hinders real application. What is very clear in the literature as a whole is that AI provides opportunities and progress, as well as the need for standards.

Results

Summary of AI Methods in Veterinary Diagnostics

Our search yielded 247 publications, of which 189 were identified that were included for further study. By type of animal, research was predominantly centered around cattle (32%), companion animals (27%), poultry (18%), swine (14%), and the remaining 9% consisted of other animals including equine and wildlife. The majority utilized supervised machine learning methods (64%), and the utilization of deep learning networks has also grown increasingly supported by subsequent publications. The formative modalities used in forecasting earlier diseases were as follows:

Formative data modalities utilized for early disease prediction included:

1. Image data (38%): Radiographs, ultrasound, thermal imaging video
2. Biological markers (27%): Blood factors, milk composition, and respiratory biomarkers.
3. Behavioral and physiological monitoring (14%): Temperature, rumination, vocalization

Performance Statistics of AI-Based Early Detection Systems

Table 1: Performance Statistics Ranges of AI-based early detection systems by disease category of all the disease conditions, the most positive results were the mastitis detection systems as these systems.

Disease Category	Animal Type	Sensitivity Range	Specificity Range	Early Detection Window
Respiratory Disease	Cattle, Poultry	78% – 95%	82% – 97%	1 – 4 days pre-clinical
Lameness	Cattle, Equine	85% – 92%	79% – 91%	3 – 7 days pre-clinical
Mastitis	Dairy Cattle	89% – 96%	85% – 93%	24 – 72 hours preclinical
Metabolic	Cattle, Swine	76% – 88%	82% – 95%	2 – 5 days pre-clinical
Neurological	Companion Animals	74% – 89%	80% – 92%	Variable (weeks to months)

Current Limitations and Challenges

Despite promising performance metrics, several challenges have limited the widespread adoption of AI-based early disease detection in veterinary practice.

Standardization and quality of data: Most studies are based on small, single-site datasets that might not reflect the diversity found in practice. Data collection protocols and feature definitions are still not standardized across disciplines (Martinez & Wong, 2023).

Validation strategies: Validation approaches very greatly, with the majority employing cross-validation on small datasets, rather than prospective field validation. This raises questions regarding the external validity of reported performance measures in deployment environments (Anderson et al., 2024).

Smooth integration into existing workflows: Successful uptake depends on smooth integration into existing veterinary workflows and information systems. Existing solutions are typically isolated, adding workload without improving efficiency (Peterson et al., 2024).

Cost-benefit analysis: The economic benefit proposition is poorly articulated in most applications, particularly in high-cost-sensitive farm animal environments. Few studies have provided comprehensive cost-benefit analyses of implementation and recurring costs versus anticipated health and productivity benefits (Garcia et al., 2024).

Trust and explainability: The "black box" intricacy of many high-end AI algorithms presents barriers to uptake by veterinary practitioners. Models that provide understandable reasons for predictions have improved the rates of clinical adoption (Williams & Chen, 2023).

Implementation Mechanisms and Commercial Use:

Implementation mechanisms could be categorized into three areas:

1. Continuous monitoring systems (47%): sensors for the wear and environment, automatic data collection, and real-time data analysis.
2. Point-of-care diagnostic testing systems (32%): diagnostic equipment containing AI that can be utilized at the time of veterinary examination.
3. Laboratory-based (21%): AI algorithms integrated with existing laboratory-based veterinary diagnostic processes.

To date, commercial implementation has progressed rapidly in the dairy sector, where several vendors have developed next-generation systems that are integrated into milking equipment to detect mastitis with AI-enhanced automation. The poultry sector has also embraced commercial applications supported by AI for early detection of respiratory diseases in broiler operations. While companion animal applications exist, they are primarily research-based with few commercial options available and focused primarily on screening processes rather than continuous monitoring.

Current Constraints and Challenges

Although the outcome metrics for AI-enabled early disease detection may seem promising, there are several obstacles to its widespread implementation in veterinary settings.

Data quality and data standardization: Most reports are based on small, single-site studies that probably do not embody all levels of diversity of context in practice. The standardization of data collection protocols and feature definitions remains weak across disciplines (Martinez & Wong, 2023).

Implications for Veterinary Practice

AI-driven diagnostic tools represent the next ground-breaking step towards improving veterinary practice. Early disease detection capabilities are shifting the veterinary focus from treatment in response to disease to managing health and preventing disease. This shift will require veterinary practitioners to learn new skills related to data interpretation and integration into technology-enhanced practices (Smith et al., 2022). Veterinary schools are beginning to embed digital fluency and AI basics within educational pathways, meaning that new practitioners will converge with some preparation to better fit their extraordinary practices (Peterson et al., 2024).

Existing practitioners are facing continuing education groups with a changing landscape, providing new incentives, addressing new complexities regarding AI-based diagnostic tools and liabilities, ownership of data, and performance validation standards they need to join together. Stakeholders in the veterinary diagnostic industry are actively working together to establish best- practice documents that govern the responsible use of AI technologies (Williams & Chen, 2023).

Conclusion

Diagnostic machines with artificial intelligence that can provide early disease prediction in animals represent a once-in-a-lifetime opportunity to transform veterinary medicine via earlier intervention, improved outcomes, and enhanced welfare of animals. This technology has moved from the laboratory to practice, particularly in production animal cases where there is real dollar ramifications.

Technologies currently exhibit favourable performance characteristics and early indications of disease that can be detected days or even weeks earlier than conventional diagnostic protocols.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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