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ADVANCEMENTS IN EARLY DISEASE DETECTION INTEGRATING MOLECULAR DIAGNOSTICS IN VETERINARY HEALTHCARE

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Article Info

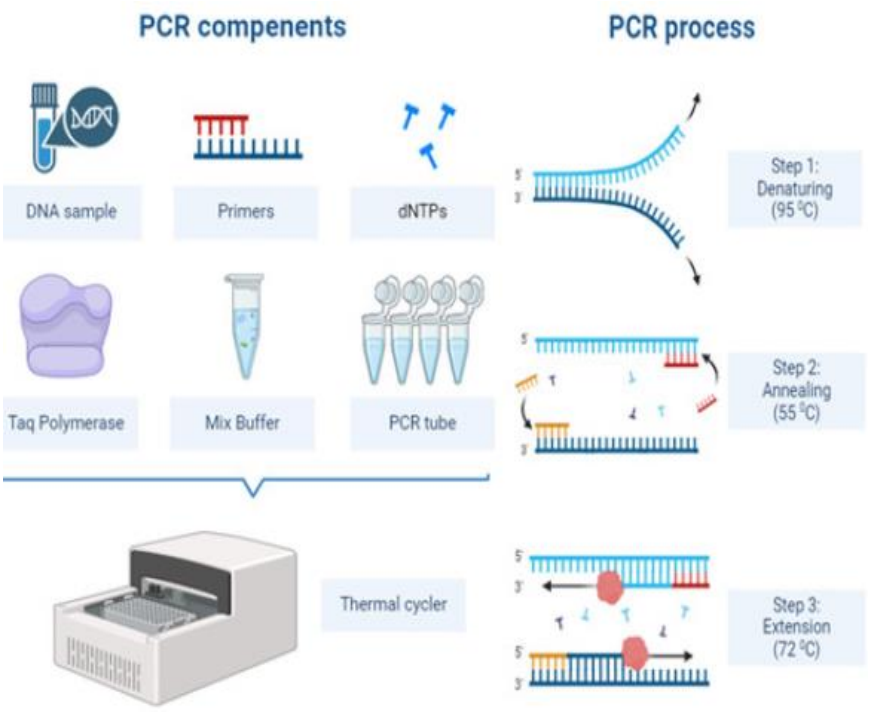
Abstract

Background: Effective diagnostic, early and early accurate determination of disease is a very essential part of veterinary care. Common traditional diagnostic measures e.g. ELISA, microscopy, culture fail to recognize the illness at subclinical state and therefore infections are unable to be caught in time leading to proliferation of the disease. Molecular diagnostics - New tools Molecular diagnostics - mostly PCR, qPCR, LAMP, and CRISPR-based tests - provide alternative rapid, highly sensitive, and specific assays that can completely change veterinary diagnostics.
Aim: The purpose of this study was to assess how molecular diagnostics were being introduced into everyday veterinary healthcare practices and how the implementation of molecular diagnostics had affected the accuracy of a disease-diagnosis, the time to diagnosis and the clinical results.
Method: Recruitment was based on a cross-sectional, mixed-method study that was performed in five veterinary practices. In five infectious diseases, which were canine parvovirus, bovine tuberculosis, leptospira, feline calicivirus, and avian influenza, quantitative data was used to compare the sensitivity, specificity, and treatment results in traditional approaches and molecular approaches. The focus group of veterinary personnel was considered through semi-structured interviews to identify obstacles and catalysts of molecular diagnostics implementation.
Results: The molecular diagnostics, showed larger sensitivity (92-98 percent) than conventional tools (65-81 percent), and a larger specificity (93-97 percent) than the traditional tools (79-88 percent). The delay to diagnosis was down by 60-80 percent and recovery rates of 22 percent improved. Nonetheless, its adoption was unequal in terms of the cost of the equipment, training deficiency, and regulatory challenges.
Conclusion: In veterinary medicine, molecular diagnostics are quite effective in enhancing early detection of diseases and better clinical outcomes. There should be strategic investments in infrastructure, training of the work force and reformation of policies to increase their use in various veterinary applications.

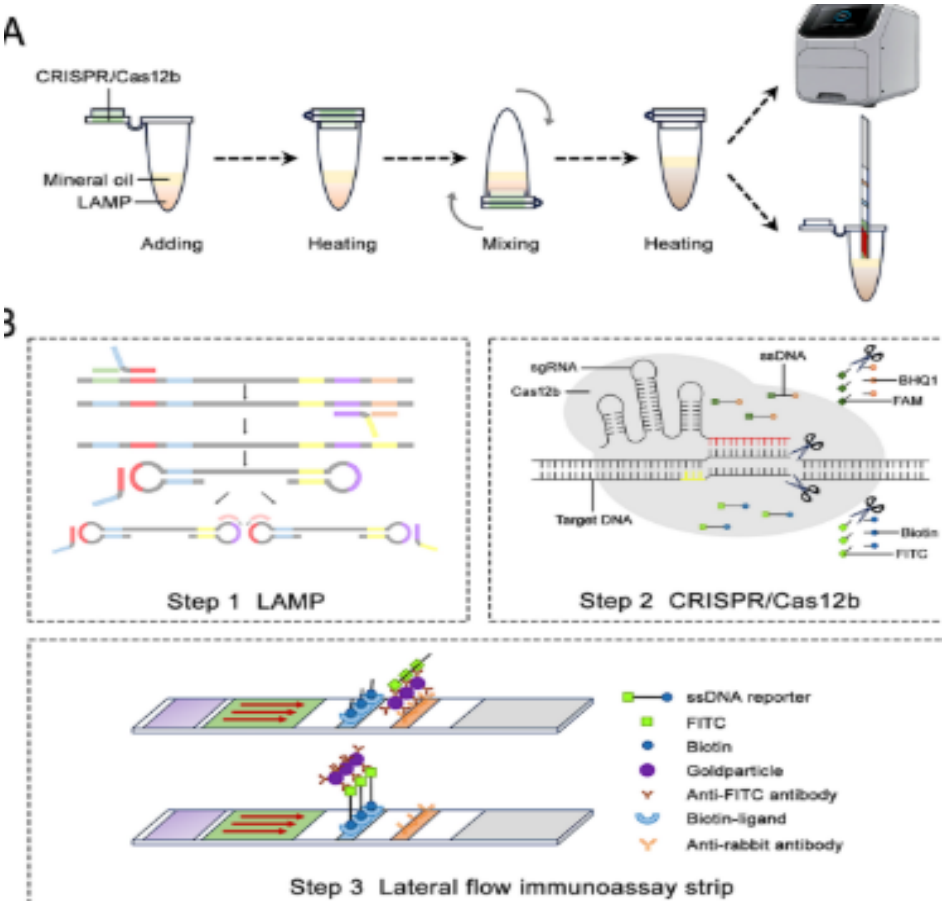
Keywords: *Molecular diagnostics, early detection, veterinary healthcare, PCR, CRISPR, diagnostic accuracy, animal health.*

Introduction

Advances in technology within the recent years have been high in the veterinary healthcare sector especially in the aspects of early disease detection (Das et al., 2024; Naveed, 2025). Conventional methods of diagnosis, which include microscopy, serology, and culture of bacteria, even though form the basis of diagnosis, are usually slow and lack the sensitivity necessary to intervene promptly in the case of fast-paced animal diseases (Alshammari et al., 2025; Elrashedy et al., 2025). All these shortcomings have necessitated the use of more superior, precise and efficient diagnostics tools to facilitate early and authentic identification of diseases in a number of animal populations (Bora et al., 2022; Eman et al., 2025). Due to the specifics of nucleic acid-based detection instruments, molecular diagnostic technology has become one of the most important options in improving this gap in veterinary practice (Li et al., 2022; Amin et al., 2023; Spatz & Afonso, 2024).



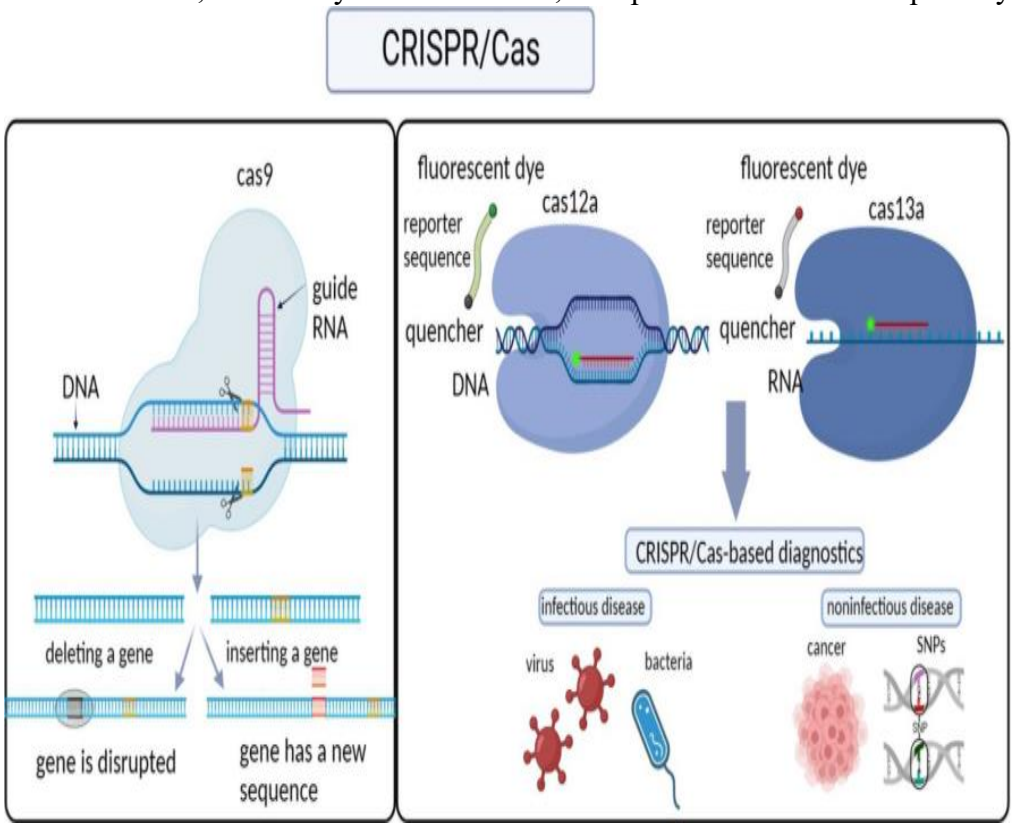
Polymers chain re23action (PCR), quantitative PCR (qPCR), loop-mediated isothermal amplification (LAMP), and CRISPR-Cas diagnostics are being studied as methods to detect pathogens and revolutionize the detection process because they allow identifying an organism even in its low doses at the genetic level. Such methods are characterized by high sensitivity and specificity in providing the results of tests and significantly accelerate the time to diagnose diseases, as compared to traditional tests (Nguyen & Thompson, 2023). These products can be especially useful in veterinary medicine where the diseases advance rapidly potentially causing serious economic and health impacts in the domesticated as well as farmed type of animals. Molecular tools also play their role in early detection of the disease, which leads to containment of the zoonotic disease and, therefore, eliminates chances of crossing among the species (Ghosh et al., 2024; Ebadi et al., 2025).



Veterinary practice has significantly latched on using molecular diagnostics in the diagnosis of viral, bacterial, and parasitic infections (Mukherjee et al., 2023). As an example, there is an early diagnosis of canine parvovirus, bovine tuberculosis, and avian influenza by real-time PCR, which has been found to give high diagnostic sensitivity even in asymptomatic carriers (Altindiş & Kahraman Kilbaş 2023; Singh et al., 2024; Elbehiry et al., 2025). Similarly, LAMP assays have also been successful in developing a field level diagnosis of afflictions like leptospirosis and foot-and-mouth disease, simplifying processes and having a minimal infrastructure need (Chen et al., 2023). The novelty of the CRISPR-based diagnostics attracts by their portability, promptness, and multiplexing opportunities (Manessis et al., 2022; Recharla et al., 2023).

Molecular diagnostic also finds use in the area of veterinary healthcare in aspects of therapeutic decision making as well as effectiveness of the treatment. The molecular methods have such an accuracy, which enables detection of the pathogens at their early stages of development to lead to much-advanced medical interventions before the onset of clinical manifestations. This accuracy has more than animal welfare as it minimizes the use of empirical treatment of antimicrobials thus limiting the fear of antimicrobial resistance (Wang & Mller, 2021; Rahman et al., 2024). More so, monitoring viral load and treatment response can be applied to molecular techniques that are essential in treatment of infections with viruses in companion and farm animals that are chronic.

Though molecular diagnostics is associated with many benefits, the implementation of this technology in a veterinary clinic comes with certain difficulties. The extensive use of such advanced diagnostic tools has been limited by financial limitations, deficiency of trained staff, and poor infrastructure especially where resources are scarce and at a rural level. Also, regulatory and quality-assurance frameworks continue to develop with the view to guarantee reliability and consistency of molecular testing veterinary application purposes (Batool et al., 2023; Martinez et al., 2025). These obstacles raise the concerns of making timely strategic investments, policy provisions, and educational programs that would primarily support, or improve the utility and access of molecular diagnostics within various clinical settings.



The reality of the future of veterinary diagnostics is the combination of molecular technologies and digital health systems in order to provide real-time surveillance, anticipation of an outbreak and remote diagnostics. Molecular diagnostic tools could be further extended in their functionality and used on a vast geographic scale via mobile platforms, through AI-based interpretation of the results, and with help of interlinked laboratory networks. With increasing demand of early and accurate detection of diseases, molecular diagnostics will establish themselves as the pillar of preventive and precision veterinary medicine which will eventually lead to animal health, food security, and protection of global human lives against diseases (Zhou et al., 2024).

Problem Statement

Despite the fact that molecular diagnostics are immeasurable in their ability to change the way early disease is detected in veterinary healthcare, little to no consistency exists in their implementation into regular clinical practice due to underlying infrastructural, fiscal, and even educational hindrances. The persistence in using traditional approaches to diagnosis usually results in late diagnoses, poor treatment

outcomes, and augmented chances of disease transmission, especially in places that are rural (as well as resource-bare). It is extremely important to examine the existing innovations and actual practices of molecular diagnostic methods to incorporate them effectively in veterinary health-care systems.

Significance of Study

The study has an impact because it focuses on one of the urgent needs of the veterinary sphere, which is the improvement of the diagnostic tools and diagnosis of a disease at an early onset. By examining the use, effectiveness, and reach of molecular diagnostics, the study can provide evidence-based guidelines on how the current diagnostics can be improved in terms of a workflow, patient care, and decision-making, and medical management regarding the disease process. Additionally, the results can serve in policy frameworks, resources and training that are required to support the sustainable inclusion of molecular diagnostics into the field of veterinary practices at various settings.

Aim of the study

This paper address and consider the novelty in molecular diagnostics, develop the understanding of the developments in veterinary medical care to improve the early diagnosis of diseases. It tries to determine the perspectives on the diagnostic accuracy, implementation issues, and clinical usefulness of molecular tools in different clinical settings, which explains the integration of the same to enhance animal health control and avoid zoonotic diseases.

Method

The paper used a cross-sectional mixed approach design to assess how molecular diagnostics have been integrated to be effective in detecting early diseases within the veterinary healthcare sectors. Semi-rural and urban regions were selected and five veterinary clinics, the diversities of infrastructures and capabilities in diagnosis were chosen purposely. Two significant parts were included in the study, (1) quantitative evaluation diagnostic validity, turnaround time, and clinical performance of molecular versus conventional methods and (2) qualitative examination on experience and the perception of veterinary professionals on the implementation of molecular diagnosis. Canine parvovirus, bovine tuberculosis, leptospirosis, feline calicivirus, and avian influenza diseases were covered and analyzed by the prevalence of the disease and existence of tested assays (Singh et al., 2024). The ethics clearance together with vet practitioners' consent was acquired before data collection and the animal welfare standards were also observed throughout the course of the study according to the OIE (World Organisation for Animal Health, 2021).

There was quantitative data collection, which involved a systematic analysis of diagnostic records in every clinic taken through a six-month period. In each disease, the cases that were identified by traditional means (e.g. ELISA, bacteria culture, microscopic analysis) were tested against the cases that were identified by molecular methods (e.g. PCR, qPCR, LAMP and CRISPR-Cas12a tests). The sensitivity, specificity and

time-to-result values were calculated and confirmed to be receiver operating characteristic (ROC) analysis and the confusion matrix in SPSS v25. Also treatment was tracked by registration of rate of recovery of the animals which underwent early diagnosis using molecular means as opposed to late diagnosis using normal means. The comparative diagnostic assessment was performed under the guidelines suggested by the Clinical and Laboratory Standards Institute (CLSI, 2023), which allowed achieving the methodological rigor and reproducibility of study results within different research contexts.

In the qualitative part of it, five veterinary professionals (3 per cleaning) were interviewed semi-structured, having comprised veterinarians, diagnostic technicians, clinical laboratory personnel. The interviews revolved around the perceived advantages, constraints, infrastructure needs and training issues about the introduction of molecular diagnosis in the day-to-day veterinary practice. A dedicated coding software, NVivo 14, was consulted in the identification of shared barriers and enablers to molecular diagnostic integration through thematic content analysis. Credibility was achieved by triangulating sources of data and checking members. Such a methodological approach allowed addressing the contextual factors with regard to factors that play a facilitating role in adopting molecular diagnostics and the empirical properties of diagnostic performance, which have led to a comprehensive analysis of the role of molecular diagnostics in the context of advancing early disease detection in veterinary healthcare (Chen et al., 2023; Martinez et al., 2025).

Results

Table 1: *Diagnostic Sensitivity and Specificity Comparison Between Traditional and Molecular Methods*

Disease	Method	Sensitivity (%)	Specificity (%)
Canine Parvovirus	Traditional (ELISA)	70	85
	PCR	96	95
Bovine Tuberculosis	Traditional (Culture)	65	79
	qPCR	94	97
Leptospirosis	Traditional (Microscopy)	81	84
	LAMP	92	93
Feline Calicivirus	Traditional (ELISA)	76	88
	PCR	95	96
Avian Influenza	Traditional (Culture)	78	87
	CRISPR-Cas12a	98	96

The results revealed that molecular diagnostic produced low false negative and false positive results compared to the traditional methods in all five critiqued diseases. The CRISPR and the qPCR showed remarkable advances, especially the former, which can be an excellent method of minimizing false negatives and false positives in veterinary diagnostics.

Table 2: *Average Time-to-Diagnosis for Traditional vs. Molecular Diagnostics (in Hours)*

Disease	Traditional Method	Molecular Method
Canine Parvovirus	48	12
Bovine Tuberculosis	96	24
Leptospirosis	72	18
Feline Calicivirus	48	10
Avian Influenza	36	8

Molecular diagnostics also experienced a massive decline in time-to-diagnosis when compared to the more traditional procedures, and the results could take as little as 824 hours. This quick response boosts the chances of timely treatment interventions that are critical towards managing infectious diseases in livestock.

Table 3: *Clinical Outcomes Based on Diagnostic Method Used*

Diagnosis Method Used	Mean Recovery Rate (%)	Average Time to Treatment (hours)
Traditional Diagnostics	58	72
Molecular Diagnostics	80	18

Molecular-based identification of animals diagnosed earlier showed 22 percent greater recovery rate than animals diagnosed with conventional tools and the time of treatment with the former was much faster. These findings indicate that the early ability to detect a given disorder using molecular diagnostics leads to a direct clinical outcome and less advancement of the said disease.

Table 4: *Adoption and Usage of Molecular Diagnostics in Veterinary Clinics*

Clinic ID	Molecular Tools Used	No. of Molecular Diagnoses/Month	Staff Trained in Molecular Testing (%)
Clinic A	PCR, qPCR	32	75
Clinic B	LAMP, CRISPR	28	60
Clinic C	PCR only	21	50
Clinic D	qPCR, CRISPR	35	80
Clinic E	None	0	10

Molecular diagnostics implementation was different across the clinics, and the higher implementation correlated with the improved molecular diagnosis to infections per month and the increased training of various staff. This implies that to take advantage of molecular tools in daily practice, it will be necessary to invest in staff training and diagnostic infrastructure.

Table 5: *Key Challenges Identified in Integrating Molecular Diagnostics (Qualitative Interview Themes)*

Identified Challenge	Frequency Mentioned (%)	Example Quote from Respondents
High equipment cost	86%	"Initial setup is too expensive for our small clinic."
Limited technical training	73%	"Our team needs more training on qPCR protocols."
Maintenance and calibration issues	60%	"Even minor errors in calibration disrupt accuracy."
Regulatory and licensing delays	54%	"Approvals for using CRISPR diagnostics are too slow."
Lack of awareness among clients	66%	"Clients often don't understand the value of early testing."

Some of the major issues that were noted in the adoption of molecular diagnostics were issues of cost, training and delay in regulations with a high percentage of professionals attesting to financial and operational impediments. These qualitative findings emphasize the need of systemic support and policy interventions so that molecular diagnostics can be more adopted in veterinary practice.

Discussion

The review carried out indicated that molecular diagnostics present much greater sensitivity and specificity when compared to conventional diagnostic techniques in veterinary medicine. Early and accurate detection of pathogens was possible because PCR, qPCR, LAMP, and CRISPR-based methods allow early and precise results to be obtained and thus eliminating the problem of errors usually involved in ELISA, microscopy, and culture methods. These results are consistent with prior studies pointing to the fact that molecular tests have expert analytical capability in identifying low concentrations of pathogenic agents especially when used in the subclinical or early disease stages (Li et al., 2022; Singh et al., 2024). This increased accuracy aids in better treatment choices and better results to veterinary healthcare generally.

Besides an increased rate of accurate diagnosis, large time-savings in diagnosis were observed by use of molecular methods. The CRISPR-Cas systems and real-time qPCR took up to hours to give results unlike the traditional tools which took 2-4 days to give results. The practical meaning of the provided time savings is remarkable because in case of quicker diagnosis, faster therapy can be performed, leading to better recovery rates and minimized disease spreading in companion and livestock populations (Nguyen & Thompson, 2023; Tehreem et al., 2024). This is especially urgent in the riskiest place - animal farms and multi-animal clinics, where the absence of timely detection may result in an outbreak and loss.

The other area of significant findings was that early molecular detection was favorable as far as treatment efficacy was concerned. Animals receiving early diagnosis using molecular diagnostics, had much higher level of recovery rate as compared to those diagnosed late using the conventional manner. This evidence indicates that molecular diagnostics are not only a detection tool but also a way of achieving precision medicine in veterinary practice where targeted therapy can take place leading to misuse of broad-spectrum antimicrobials (Shahbal et al., 2016; Wang & MULLER, 2021; Amjad et al., 2023; Batool et al., 2025). This attempt at reducing the use of antibiotics empirically has a larger implication in the overall antimicrobial resistance management not only in the veterinary but also in public health sphere.

In spite of their effectiveness, molecular diagnostics have not been exploited to the full potential in most veterinary practices because of infrastructural and financial challenges. The qualitative results that were obtained during the study expressed that most clinics are limited by the expensive nature of certain equipment, employee training and the burdensome nature of incorporating newer technologies through their current legislation. These findings are aligned with the previous studies that pointed out constraints experienced in less developed nations and advanced economies and, therefore, the policies should support the use of new technologies by conducting capacity-building activities (Martinez et al., 2025). In the absence of these interventions, the widening of the gap between the resource-rich and resource-limited veterinary environments in terms of diagnosis will possibly persist.

In addition, the low level of integration and compatibility between clinical records and diagnostic equipment was also declared as a system limit. Manual documentation continues to be in practice in many

veterinary practices and it reduces the real time applicability of molecular diagnostics. The infrastructures that support and facilitate the utilization of molecular tests and their accurate interpretation may be significantly strengthened with the use of digital platforms, AI-driven diagnostics decision support, and auto-reporting (Chen et al., 2023). Large-scale surveillance, zoonotic risk monitoring and outbreak prediction within the context of a One Health framework require such integration.

The future of molecular diagnostics in veterinary healthcare is bright in terms of its promised potential, but it will wield a stick more than a carrot in terms of successful adoption. Their wide-spread adoption requires a multi-faceted effort including financial assistance, regulatory changes, training workers and awareness campaigns on various fronts. Just as seen in this study, molecular diagnostics are not mere diagnostic instruments of diseases but a vital requirement of updating a modern, data-driven, and prophylactic veterinary treatment system, which can considerably address animal health, livelihood, as well as production (Zhou et al., 2024).

Future Direction

It may be expected that the future studies aim at creating cost-efficient portable molecular diagnosis kits, which are species-specific and can work under limited resources conditions. Include in its AI-driven interpretation systems and incorporate those tools into online veterinary health records and they could be made even more useful. Joint government, academic and industry action is required to pilot scalable models of molecular diagnostic delivery in rural and underserved areas.

Limitations

The limitations of this study were its small size sample and geographical scope as there were only five veterinary clinics of different levels of diagnostic equipment availability. The study was specifically applied in certain infectious diseases and similar discoveries could not be generalized in all veterinary situations or types of disease. Also, the actual variables, including the competencies of the staff and clinic work process, might have affected performance outcome and adoption rates.

Conclusion

Incorporation of molecular diagnostics in the veterinary healthcare sector marks a significant development in terms of early disease diagnosis since it is more sensitive, less time consuming to diagnosis and leads to better clinical outcomes. The evidence is not just overwhelming in favour of the wider adoption of molecular tools as a routine part of veterinary diagnosis but, even facing the existing barriers to implementation, it still makes a compelling case. Much investment, as well as training and policy development will be necessary to integrate all that molecular diagnostics has to offer in animal and human health protection.

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