

Precision Veterinary Medicine for Animal Health Improvement

S.S. Mehesare^{*1} and S. M. Khupse²

¹Assistant Professor, Department of Veterinary Clinical Complex (Veterinary Medicine), Mahatma Gandhi Mission, MGM's Dr. Rajendra Suryawanshi College of Veterinary and Animal Sciences, Gandheli, Chhatrapati Sambhajnagar, Maharashtra

²Subject Matter Specialist, Department of Livestock Production, MGM Krishi Vigyan Kendra, Gandheli, Chhatrapati Sambhajnagar, Maharashtra

*Corresponding Author Email: sopuvet@gmail.com

Abstract

Precision veterinary medicine is an emerging approach that combines clinical examination with digital monitoring, targeted diagnostics, biomarkers, genomic information and data-driven decision support to improve animal health at the individual and population level. Wearable sensors, smart collars, cameras and automated farm systems can continuously measure activity, rumination, feeding behaviour, temperature, location and other indicators, allowing veterinarians to identify deviations from an animal's normal pattern before obvious clinical signs develop. Point-of-care tests and biosensors can shorten the interval between sampling and treatment decisions, while molecular diagnostics, advanced imaging and genomic tools can provide more specific information about disease, inherited risk and biological response. Artificial intelligence can help analyse images and large sensor datasets, but its safest role is to prioritize and support veterinary decisions rather than replace clinical judgement. Precision approaches can also strengthen reproductive management, nutrition, welfare assessment, antimicrobial stewardship and disease surveillance by directing attention and interventions toward animals with the greatest need. Their practical value depends on reliable sensors, correct animal identification, validated algorithms, high-quality data and clear action pathways. Cost, connectivity, false alerts, data ownership and differences among species, breeds and production systems remain important limitations. This article outlines the major components of precision veterinary medicine, explains how data can be converted into clinically useful actions, and emphasizes that the future of animal health improvement lies in combining digital tools with careful examination, validated diagnostics and professional veterinary judgement.

Keywords: Precision Veterinary Medicine, Precision Livestock Farming, Animal Health, Digital Monitoring, Biosensors, Artificial Intelligence, Genomics, Decision Support

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Introduction

Veterinary medicine has traditionally been organised around clinical signs, physical examination, laboratory testing and treatment after disease becomes apparent. Precision veterinary medicine adds a new layer to this approach by using detailed information from the individual animal, its environment and its history to support more timely and more specific decisions. The information may come from wearable sensors, smart collars,

automated milking systems, imaging, laboratory biomarkers, genomic tests, electronic health records or herd-level monitoring platforms. The objective is not simply to collect more data, but to convert useful data into decisions that improve animal health, welfare and productivity.

The idea is closely related to precision livestock farming, but it is broader than farm automation. Precision veterinary medicine can be applied to dairy cattle, buffaloes, sheep,

goats, pigs, poultry, horses and companion animals. It is relevant to prevention, diagnosis, treatment selection, reproduction, nutrition and long-term disease management. In each setting, the veterinarian remains responsible for interpreting technology in the context of the animal, the population and the practical consequences of action or inaction.

A central strength of precision care is that it can recognise change from an animal's own normal pattern. A mild reduction in rumination, activity, feed intake or body temperature may not look alarming when compared only with a population average, but it may be important when it represents a clear deviation from that individual's baseline. This shift from occasional observation to continuous or repeated measurement creates opportunities for earlier detection and more targeted intervention.

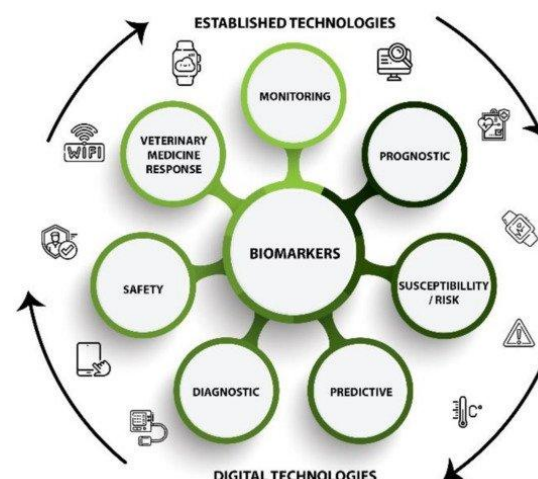
From Population Averages to Individual Animal Profiles

Conventional veterinary recommendations frequently use population-based reference intervals and standard treatment schedules. These are necessary foundations, yet animals differ in genetics, age, physiological stage, production level, previous disease exposure, environment and response to treatment. Precision medicine attempts to account for these differences. The result may be a more individualized monitoring plan, a more appropriate diagnostic test, a modified dose or treatment duration, or a management change directed to a clearly defined high-risk group rather than the whole herd or flock.

In livestock production, individualization does not mean that every animal receives an expensive set of tests. Instead, technology can help sort animals by risk. A sensor alert may identify ten cows for closer examination from a herd of several hundred. A milk-monitoring system may indicate which animals require mastitis testing. A growth or feed-intake model may identify animals whose performance has changed unexpectedly. This risk-based approach can make veterinary attention more efficient while reducing unnecessary interventions.

Digital Phenotyping and Continuous Monitoring

Digital phenotyping refers to describing an animal through continuously or frequently collected digital measurements. Accelerometers can measure movement, lying, standing and activity. Smart collars or ear tags may estimate rumination and feeding behaviour. GPS devices can show location and grazing patterns in extensive systems. Cameras can estimate body condition, posture, locomotion or social behaviour, while microphones can detect coughing or other sound patterns in groups of pigs or poultry. Environmental sensors can add information about temperature, humidity, ventilation and air quality.



The value of these technologies lies in trends rather than isolated numbers. A short episode of low activity may be normal after handling or transport, whereas a persistent decline combined with reduced feeding can justify clinical examination. Systems that combine multiple signals are often more useful than systems that depend on a single measurement. For example, temperature, activity and rumination together may provide stronger evidence of emerging illness than any one variable alone.

Continuous monitoring can also improve welfare assessment. Changes in walking pattern may support earlier recognition of lameness. Reduced social interaction can indicate discomfort. Abnormal resting behaviour may suggest environmental or health problems. The veterinarian can use such alerts to investigate causes before severe clinical disease develops,

while also checking whether the technology is producing false alarms.

Wearable Sensors, Biosensors and Point-of-Care Information

Wearable devices are among the most visible tools in precision animal health. Modern tags, collars and boluses can capture activity, temperature, rumination, location or other physiological indicators. In dairy cattle, these systems are widely used for estrus detection and are increasingly explored for mastitis, metabolic disorders, lameness and calving prediction. Similar approaches are being studied in sheep, pigs and other species. Their greatest benefit is the ability to collect information without repeated restraint or manual observation.

Biosensors extend this concept by measuring biological substances or reactions. Potential targets include glucose, ketones, hormones, inflammatory markers, pathogens and metabolites in blood, milk, saliva or other samples. Microfluidic and point-of-care devices can reduce the delay between sampling and clinical decision. When a result is available near the animal, the veterinarian can decide more quickly whether treatment, isolation, additional sampling or referral is necessary.

However, precision does not come automatically from a digital device. Sensor placement, battery performance, calibration, missing data, animal behaviour and environmental conditions can affect measurements. A system should be evaluated for the species and purpose for which it is used. Alerts should have a clear action pathway; otherwise staff may become overloaded by notifications and begin to ignore them.

Precision Diagnostics, Biomarkers and Genomic Information

Precision veterinary medicine also depends on increasingly specific diagnostic information. Molecular tests can identify pathogens rapidly, quantitative assays can estimate pathogen load, and biomarker panels can provide information about inflammation, organ function or metabolic status. The important step is to match the test to the clinical question. A highly sensitive result may be scientifically accurate but clinically unhelpful when it detects residual

nucleic acid, colonisation or a change that does not explain the animal's condition.

Genomic information adds another layer. Genetic testing can identify inherited disorders, susceptibility markers and variants related to production or disease resistance. In breeding programmes, genomic selection can reduce the frequency of damaging inherited conditions while improving traits linked with robustness and health. In companion animals and horses, genetic testing may support diagnosis of selected hereditary diseases and help owners and veterinarians plan long-term management.

Pharmacogenomics, the study of how genetic differences influence drug response, is more established in human medicine than in routine veterinary practice, but the concept is relevant. Species, breed and individual variation can influence drug metabolism and toxicity. Future veterinary decision systems may combine genetic information with age, body condition, organ function and previous response to improve drug selection and dosing. Such use will require strong validation before it becomes routine.

Artificial Intelligence, Imaging and Decision Support

Artificial intelligence is increasingly being applied to veterinary images and sensor data. Computer-vision systems can assist with body-condition scoring, locomotion analysis, lesion detection and interpretation of radiographs or ultrasonographic images. Machine-learning models can combine multiple measurements to estimate the probability of disease or reproductive events. In a busy herd or hospital, these tools can help prioritize cases that need human attention.

The appropriate role of artificial intelligence is decision support rather than independent diagnosis. Models can perform poorly when they are used in a species, breed, management system or imaging environment that differs from the data used for development. A high-performing research model may also be difficult to integrate into farm routines if it requires complex equipment or produces too many false-positive alerts. External validation, transparent performance reporting and veterinary oversight are therefore essential.

Table 1. Major tools used in precision veterinary medicine and their practical value.

Tool	Main veterinary value
Wearable activity sensors	Track movement, lying, rumination or feeding patterns and flag deviations that may indicate illness, estrus or welfare problems.
Temperature / physiological sensors	Support early recognition of fever, calving-related change, heat stress or other physiological disturbances when properly validated.
Camera and computer vision	Assist with body condition, locomotion, posture, lesion recognition and non-contact behavioural monitoring.
Point-of-care biosensors	Provide rapid information on selected metabolites, biomarkers or infectious agents close to the animal.
Genomic testing	Supports inherited-disease diagnosis, breeding decisions and future individualized risk assessment.
AI decision-support systems	Combine multiple data streams to prioritize animals, images or events that require veterinary review.

Precision Nutrition, Reproduction and Preventive Health

Precision medicine is not limited to diagnosing disease. Nutrition can be adjusted according to production stage, body condition, milk yield, growth and metabolic indicators. Automated feeders and milk-monitoring systems can provide data that help identify animals at risk of negative energy balance or abnormal intake. In growing animals, repeated weight or body-size measurements can show whether performance is following the expected trajectory. These data can guide targeted nutritional investigation rather than routine changes for all animals.

Reproductive management is another established application. Activity and rumination monitoring can support estrus detection, while changes in temperature, movement or behaviour may assist calving prediction. Precision reproductive systems are most useful when alerts are integrated with veterinary examination, reproductive history and farm goals. Technology can improve timing, but it does not replace assessment of reproductive disease, nutrition or management factors that may reduce fertility.

Preventive programmes can also become more risk-based. Vaccination, parasite control, screening and follow-up can be focused according to age, exposure, production stage and previous findings. In large herds, risk stratification helps veterinarians allocate time and diagnostic resources to animals most likely

to benefit while maintaining population-level disease control.

Antimicrobial Stewardship and Targeted Therapy

One of the most important potential benefits of precision veterinary medicine is better antimicrobial stewardship. Earlier detection and more specific diagnosis can reduce empirical treatment and help distinguish animals that need antimicrobial therapy from those that do not. Culture, susceptibility testing, molecular diagnostics and treatment-response monitoring can all contribute to a more targeted decision. At herd level, identifying the management conditions associated with repeated infection may prevent disease more effectively than repeated medication.

Precision treatment also means reviewing response. Digital records and repeated measurements can show whether temperature, activity, milk yield, appetite or other indicators are returning toward baseline after intervention. Lack of improvement can trigger re-examination rather than automatic continuation of therapy. This feedback loop can improve clinical accountability and may reduce unnecessary duration of treatment.

One Health, Surveillance and Population-Level Value

Although the focus is often on individual animals, precision systems can strengthen population surveillance. When health alerts, laboratory results and location data are aggregated appropriately, veterinarians can identify unusual clusters or changes in disease patterns. Earlier recognition is particularly valuable for contagious, zoonotic and transboundary diseases. Digital systems can also support traceability and communication between farms, diagnostic laboratories and veterinary authorities.



The One Health value depends on data quality and responsible sharing. A large volume of low-quality or poorly standardized data can create confusion. Useful surveillance requires consistent definitions, verified results and clear information about when and how measurements were collected. Privacy, farm confidentiality and ownership of commercial data also need to be respected.

Limitations, Ethics and Data Governance

Cost remains a major barrier to adoption, particularly when hardware, subscriptions, maintenance, connectivity and staff training are considered together. The economic value of a technology depends on the disease problem, herd size, labour availability and the consequence of missing an event. A system that is cost-effective in a large intensive dairy unit may not be appropriate for a small mixed farm or an extensive grazing system.

Data quality is an equally important limitation. Missing observations, sensor drift, changes in equipment and incorrect animal identification can all distort interpretation. Algorithms can also introduce bias if they are developed using data from a narrow range of breeds, farms or environments. Veterinarians should know the intended use of a system, the population in which it was validated and the consequences of false-positive and false-negative results.

Ethically, precision technology should improve the relationship between people and animals rather than reduce animals to production numbers. Automated monitoring should not justify less direct observation when hands-on examination is needed. Welfare indicators, treatment decisions and culling recommendations should remain subject to professional judgement. Data ownership, cybersecurity, consent and responsible access will become increasingly important as more veterinary information is stored in cloud platforms.

Table 2. A practical signal-to-action pathway for precision veterinary care.

Stage	Good practice
Establish baseline	Know the animal or group's normal range and the purpose of monitoring before interpreting an alert.

Stage	Good practice
Validate the signal	Check sensor function, animal identification, missing data and environmental explanations for the change.
Targeted examination	Use history and physical examination to decide whether the alert represents a clinically important problem.
Confirmatory testing	Select laboratory, imaging or other tests that answer the specific diagnostic question.
Individualized action	Choose treatment, management or preventive intervention according to diagnosis, risk and animal status.
Review response	Compare post-intervention data with baseline and re-examine the animal when recovery does not follow the expected pattern.
Record and learn	Store outcomes so future alerts and herd-level decisions can be interpreted with better context.

Future

The next stage of precision veterinary medicine will be defined by integration. Instead of separate devices producing separate alerts, clinical records, laboratory results, imaging, genomic information, environmental measurements and wearable data are likely to be combined into unified decision-support systems. Better interoperability will allow a veterinarian to see the history of an animal and the relevant population context in one place. Advances in edge computing and mobile connectivity may also make sophisticated analysis available in field settings with limited access to central laboratories.

Future progress should be judged by clinical outcomes rather than by the amount of technology used. A useful system should help detect disease earlier, improve welfare, reduce unnecessary treatment, strengthen preventive care, support efficient use of veterinary time or improve surveillance. Research must therefore move beyond technical accuracy and evaluate real-world performance, economic value, usability and the effect on animal outcomes across different production systems and regions.

Veterinary education will also need to evolve. Clinicians will increasingly require skills in data interpretation, test validation, digital records and communication of probabilistic risk. At the same time, core clinical abilities such as observation, examination, sampling and judgement will remain fundamental. Precision veterinary medicine will be strongest when digital tools extend these skills rather than attempt to replace them.

Conclusion

Precision veterinary medicine brings together continuous monitoring, targeted diagnostics, digital records, genomics, imaging, biosensors and decision-support tools to make animal health management more timely and individualized. Its greatest value is the ability to recognise meaningful change earlier and focus veterinary attention where it is most needed. This can improve disease prevention, reproductive management, welfare assessment, treatment selection and antimicrobial stewardship. Technology alone does not guarantee better care. Reliable measurements, validated algorithms, correct interpretation, strong data governance and direct clinical examination remain essential. When these foundations are respected, precision approaches can help veterinarians move from reactive treatment toward proactive and evidence-based animal health management while supporting both individual animals and population health.

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