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Application of Modern Animal Medicine in Animal Disease Prevention and Control

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Abstract: Modern animal medicine is undergoing a profound paradigm shift from individual diagnosis and treatment to group prevention and control, and from passive response to active warning. This article systematically examines the technological path and practical logic of reshaping animal disease prevention and control capabilities through this transformation. At the monitoring level, intelligent perception technology represented by the "Veterinary Thousand Mile Eye" system moves prevention and control decision-making nodes from clinical manifestations to physiological signal abnormalities through continuous collection and big data analysis of hypothalamic vital signals. At the level of diagnosis and intervention, CRISPR on-site detection technology and rationally designed subunit vaccines have respectively achieved rapid pathogen identification and precise antigen screening, promoting diagnosis and vaccine development from experience trial and error to data-driven. At the system level, the biosafety system has been upgraded from an operational checklist to a hierarchical architecture. The "precise elimination" strategy for African swine fever and the integrated health governance of multidisciplinary collaboration indicate that a single technology must be embedded in an institutionalized collaborative network to maximize its effectiveness. This article argues that the core transformation of modern animal medicine lies in building a full chain prevention and control capability from front-end perception to terminal governance, with the ultimate goal of achieving coordinated progress in breeding production safety, animal welfare protection, and public health safety.

Keywords: Prevention and control of animal diseases; Intelligent monitoring; Molecular diagnosis; Biosafety system

1. Introduction

In the third decade of the 21st century, the production organization of global animal husbandry has undergone fundamental changes. The popularization of large-scale and intensive farming models has significantly improved production efficiency, but also profoundly reshaped the occurrence, transmission, and prevalence of animal diseases. Under high-density feeding conditions, the spread rate of pathogens increases exponentially, and a single disease outbreak can quickly affect thousands of livestock, causing economic losses and public health risks far beyond the traditional free-range era [1,2]. At the same time, the frequency of new and recurrent animal epidemics continues to rise. The cross-border spread of major epidemics such as African swine fever and highly pathogenic avian influenza has become a normal threat, while zoonoses such as brucellosis and tuberculosis have expanded the security boundary of animal husbandry to the macro level of national public health governance. This series of changes forces animal medicine to re-examine its role positioning and ability structure in the disease prevention and control system [3].

However, the traditional paradigm lacks systematic and sustained perception of the breeding environment, animal population status, and pathogen epidemic trends, resulting in disease prevention and control always being in a passive situation of firefighting rather than fire prevention [4]. Therefore, a profound paradigm shift is accelerating in the field of animal medicine, characterized by a shift from post infection intervention to pre infection warning and blockade. The driving force behind this transformation comes not only from the practical needs of the aquaculture industry to reduce disease losses, but also from the technological possibilities brought about by interdisciplinary integration. The disciplinary connotation of modern animal medicine is far beyond the scope of clinical veterinary medicine. Molecular biology has led pathogen detection from cultivation and identification to gene recognition, information technology has led livestock farms from experience management to data-driven, and artificial intelligence has led disease warning from manual judgment to model deduction. The integration of these interdisciplinary fields makes it possible for animal medicine to build a technical system covering the entire chain of monitoring, diagnosis, intervention, and management. From pathogen enrichment monitoring in aquaculture environments, to real-time perception of vital signs at the individual animal level, and to abnormal behavior pattern recognition at the group level, modern veterinary medicine is continuously shifting the decision-making nodes of prevention and control to the forefront. This article takes this as a starting point and aims to systematically examine how modern animal medicine can substantially reshape the capability boundaries and implementation methods of animal disease prevention and control through three progressive technological paths: intelligent monitoring, precise diagnosis, new vaccines, and systematic biosafety governance.

2. Intelligent Monitoring and Early Warning Technology

The modern livestock animal medicine has reshaped the disease prevention and control chain, primarily focusing on the most front-end aspect, which is the way to perceive the health status of the breeding population. Under the traditional model, livestock farms rely on the manual inspection by farm workers and the regular clinical examinations by veterinarians to detect sick animals. The fundamental limitations of this approach lie in two points. Firstly, human resources cannot meet the continuous monitoring requirements for thousands of livestock in large-scale farms. The inspection intervals are long enough for many acute infectious diseases to complete their evolution from latent to outbreak. Secondly, the golden intervention window for most acute febrile infectious diseases occurs before the clinical symptoms become visible. When animals show lethargy, loss of appetite, or high body temperature on the surface, the pathogen has often completed multiple rounds of transmission within the population. This means that the traditional perception method is naturally lagging behind the transmission rate of the disease in the time dimension. The core contribution of intelligent monitoring technology is to shift the decision-making node of perception from "after the clinical symptoms appear" to "when abnormal physiological signals occur", providing decisive time margin for subsequent intervention [5].

In this technical direction, the "Veterinary Eye" system led by the Beijing Veterinary Research Institute of the Chinese Academy of Agricultural Sciences provides a representative technical paradigm. The technical logic of this system is different from the traditional body temperature measurement scheme, which is significantly affected by factors such as environmental temperature, hair thickness, and animal movement. The temperature data obtained has a large deviation from the actual core body temperature. The breakthrough of the project team lies in anchoring the monitoring target to the hypothalamus, a brain region that is the temperature regulation center of warm-blooded animals. Its life signals represent the most accurate source information of the physiological state [6]. By wearing health monitoring tag chips on the ears of cattle and sheep, the system continuously collects hypothalamic signals at a frequency of once every three minutes, and then transmits the data in real time to the cloud computing center through the enclosure environment monitoring base station. With the help of big data models and multi-modal self-learning algorithms for calculation and analysis, it finally outputs early warning information in four dimensions: reproduction, disease occurrence, nutritional metabolism abnormalities, and environmental stress.

The value of this technological path has been empirically tested in specific application scenarios. In the prevention and control of major animal diseases such as foot-and-mouth disease and bluetongue disease, one chip can achieve ten major warning functions. Taking delivery warning as an example, the system can issue an alert 10 to 48 hours before a cow gives birth, with an accuracy rate of 96% to 98% in multiple ranches with tens of thousands of cows. In the actual operation of a scenic ecological pasture in Zhejiang, the system can detect abnormal health of cows six hours in advance, while traditional empirical inspections often have to wait until animals show obvious clinical symptoms to detect problems. Actual test data shows that the application of this technology can reduce the loss of female livestock due to illness by 70%, the mortality rate of female livestock by 50%, the mortality rate of newborn calves and lambs by 60%, and save feed costs by more than 8%. The input-output ratio in large-scale dairy farms can reach about 1:20 [7].

The essential contribution of intelligent monitoring technology is not to replace the professional judgment of veterinarians, but to upgrade the decision support for prevention and control from "eye inspection" to "data-driven". As the chief scientist of the project stated, this system is equivalent to equipping each livestock with an electronic health code, enabling a closed-loop operation between technical and human defense. Especially during the outbreak of new major infectious diseases, all-weather monitoring of hypothalamic vital signals is the most advanced digital radar, which is a reliable defense line for human and animal disease prevention, advancing the checkpoint, and eliminating diseases in their early stages. After the perceptual level completes the upgrade from interruption to continuity, from appearance to essence, the subsequent diagnosis and intervention processes have a data foundation for precise policy implementation. This is precisely the first technological pivot for modern animal medicine to reshape disease prevention and control capabilities.

3. Molecular Diagnosis and New Vaccine Development

3.1 On-site Transformation and Precision Upgrade of Molecular Diagnostic Technologies

The diagnostic stage plays a crucial role in the entire disease prevention and control chain. The front-end monitoring detects abnormal signals, which require diagnostic techniques to provide clear pathogen confirmation; while the diagnostic results directly determine the type of intervention plan to be adopted. The traditional diagnostic path relies on pathogen isolation and culture or serological testing under laboratory conditions, and its time cost and equipment dependence constitute significant efficiency bottlenecks in large-scale breeding and grassroots prevention scenarios. The essence of this bottleneck lies in the fact that there is an uncompressible time window from sample collection to result issuance in traditional diagnosis, and this window precisely is the stage when the disease spreads the fastest. The intervention of molecular diagnostic technologies fundamentally changes this situation, and its core value lies in transforming the diagnostic logic from waiting for pathogen culture and then obtaining results to direct recognition of genetic sequences.

In this direction, the on-site detection technology of pathogen nucleic acids based on CRISPR represents a key breakthrough in the transition of diagnostic tools from laboratories to the frontline of breeding. The structural characteristics of Class 2 CRISPR system make it show unique adaptability in pathogen detection. The single protein effectors such as Cas12 and Cas13 can activate non-specific incidental cutting activity after recognizing the target nucleic acid sequence, and this characteristic is transformed into changes in fluorescence signals or color development signals of test strips, thereby achieving visual output of the test results. In the scenario of avian influenza virus detection, the Cas13 system combined with RT-RAA thermal amplification technology can complete the detection within forty minutes, with a sensitivity of one virus copy per microliter, and if combined with lateral flow test strips, the results can be interpreted without complex instruments. The portable test strip detection scheme for African swine fever enables farmers to obtain results within half an hour, winning time for the timely isolation of sick pigs and the protection of the entire herd [8].

Another technical approach focuses on the on-site adaptation of detection equipment. The precision advantage of traditional fluorescence quantitative PCR is irreplaceable, but the equipment's size and operational complexity limit its application in remote pastoral areas and grassroots stations. The intelligent rapid quantitative PCR detection device for important infectious diseases of yaks developed by Professor Li Jiakui's team at Huazhong Agricultural University integrates microfluidic chips, rapid thermal cycling systems, and artificial intelligence interpretation algorithms. The total weight of the device is less than five kilograms and it has shockproof and low-temperature resistance features, enabling it to operate directly in tents in high-altitude pastoral areas and border quarantine points. This device can complete the entire process from sample addition to result output in less than forty minutes. The detection sensitivity and specificity are improved by more than fifty percent compared to conventional test strips, and it can quantitatively provide viral load data, thereby providing a quantitative basis for medication plans and efficacy evaluations. From the perspective of technological trends, veterinary diagnosis is moving from a single pathogen confirmation to an integrated and high-throughput direction. Precision sequencing, multi-pathogen joint screening, and big data-driven risk assessment have become the practical needs in the industry consensus rather than frontier explorations. The evolution direction of molecular diagnostic technology is clear: without sacrificing sensitivity and specificity, it continuously reduces the reliance on laboratory environment and professional personnel's technical requirements, so as to enable the ability of precise diagnosis to be as close as possible to the front line of prevention and control.

3.2 Transformation of Vaccine Research and Development Paradigm

The transformation of modern animal medicine at the intervention level is equally profound, with the most iconic trend being the shift in vaccine development from the traditional experience trial and error model to a data-driven rational design model. The essence of this transformation is to transfer the search space for antigen screening from the experimental platform to the computer, using bioinformatics prediction and artificial intelligence assisted screening to prioritize the molecules with the most immunoprotective potential among hundreds of candidate antigens, thereby significantly reducing the research and development cycle and increasing the probability of success.

The development of the porcine circovirus type 2 and porcine ileitis subunit vaccine by Professor

Fan Hongjie's team at Nanjing Agricultural University after nearly a decade of research and development provides a complete case for understanding this paradigm shift [9]. The pathogen of porcine ileitis, Lactobacillus, is a strict intracellular parasite that cannot grow on ordinary culture media and must rely on live cell culture. This has long limited antigen acquisition and vaccine preparation due to technological bottlenecks, and domestic pig farms once relied entirely on imported attenuated live vaccines. The team built a training platform from scratch and successfully isolated five clinical virulent strains from the ileum tissue of infected pigs in 2019, completing a breakthrough in strain resources from scratch. Subsequently, the reverse vaccine technology route was adopted to perform whole genome sequencing on the strain. Bioinformatics tools were used to screen 128 structurally ideal candidate molecules from 236 candidate antigens, and then an artificial intelligence model was trained to predict the immunogenicity of each candidate antigen. Through high-throughput expression and animal experiments, the key protective antigen combination with the best protective efficacy was accurately identified layer by layer. After field trials with 18000 piglets, the protective efficacy of the bivalent subunit vaccine reached 95.6%, with an immunization period of over eight months. The average daily weight gain of the immunized commercial pigs increased by more than 90 grams compared to the control group, and the vaccine price was only a fraction of that of imported products. The vaccine has recently obtained the clinical trial approval for animal biological products issued by the Ministry of Agriculture and Rural Affairs and is about to enter the clinical trial stage.

At the forefront of technology, nanovaccines and mRNA vaccines represent the next stage of vaccine development. The team from the Institute of Biotechnology, Chinese Academy of Agricultural Sciences, used mesoporous silica nanoparticles as a delivery platform to achieve co loading and in vivo sustained release of immune enhancers and antigens. The newly developed nano vaccine can induce the body to produce earlier, stronger, and more sustained immune responses. MRNA vaccine has proved its technical advantages of platform based rapid response in the prevention and control of human COVID-19 epidemic, and this experience is moving to the field of animal vaccine, showing a unique potential for traditional technology to overcome pathogens in the research and development of infectious disease vaccine for livestock and poultry. The two technological paths of diagnosis and vaccine both point in the same direction, that is, modern animal medicine is advancing the ability of precise strikes from fuzzy empirical intervals to quantifiable and designable molecular precision, fundamentally changing the full chain efficiency of disease prevention and control from discovery to intervention.

4. Biosafety system and interdisciplinary collaborative governance

4.1 Upgrading the Connotation and Hierarchical Structure of Biosafety System

If intelligent monitoring solves the problem of continuity in perception, and molecular diagnostics and new vaccines solve the problem of precision in intervention, then the biosecurity system needs to answer a more fundamental question, which is how to intercept risks before pathogens enter the farm. Traditional concepts equate biosecurity with a collection of specific measures such as disinfection, isolation, and quarantine, while modern animal medicine endows biosecurity with a new connotation. It is no longer limited to the listing of epidemic prevention measures, but a systematic concept that integrates science, law, technology, and management. The essence of this concept upgrade lies in the elevation of biosafety from an "operational checklist" to a "system architecture", with the goal no longer being the blockade of a single pathogen, but the overall risk isolation between the breeding farm and the external pathogen environment.

In large-scale aquaculture scenarios, the biosafety system presents a clear hierarchical structure. A widely accepted classification method divides it into four progressive levels, namely conceptual safety, facility safety, technical safety, and managerial safety. Conceptual safety refers to the risk awareness and prevention concepts of practitioners, which is a prerequisite for the effective operation of the entire system; Facility safety covers the construction of physical barriers such as site selection, functional zoning, decontamination centers, and air filtration systems, forming the first gateway for the introduction of pathogens; Technical safety involves the standardized application of professional technical means such as diagnosis, quarantine, isolation, disinfection, and immunization, and is the operational foundation for daily prevention and control; Managerial safety ensures that all systems are truly implemented and avoids the disconnect between paper regulations and actual operations. The four levels are not parallel or parallel, but rather nested in a logical relationship. Any vulnerability in one level could lead to the failure of the entire defense line. By 2025, the proportion of pig farms with an annual output of over 500 pigs nationwide has reached 68.3%. The increase in breeding density directly exacerbates the risk of disease transmission. Major diseases such as African swine fever cause an average annual direct economic loss of over 30 billion yuan. This data confirms the urgency of building a systematic biosafety system from the negative side.

4.2 Transformation of the Biosecurity Paradigm in African Swine Fever Control

The practice of controlling African swine fever provides the best sample for understanding the value of modern biosecurity systems. When African swine fever first entered China in 2018, the traditional control strategy was "comprehensive culling within a three-kilometer radius around the epidemic point". This approach effectively controlled the spread of the disease in the short term, but it was extremely costly and the impact on the livestock industry was difficult to sustain. The Li Xiaowen team from Liaocheng University conducted field empirical research and summarized the three major clinical characteristics of early infection of African swine fever, namely depression in spirit, reduced feeding, and elevated body temperature. They also discovered that the inguinal lymph nodes were the sampling sites where the virus was most likely to accumulate in the early stage of infection. Based on this discovery, the team developed a minimally invasive sampler and a corresponding detection method, achieving early warning of the epidemic three days in advance and precise identification of positive individuals with nucleic acid, thus advancing the control strategy from "comprehensive culling within a three-kilometer radius around the epidemic point" to a new stage of "precise elimination" of infected individuals.

More paradigmatically, this team was the first in the world to confirm that the African swine fever virus can be transmitted through aerosols, with the minimum transmission distance being only ten meters. This discovery fundamentally changed the understanding of the transmission routes of African swine fever in livestock farms. The previous control system mainly focused on contact transmission, while the existence of the air transmission route meant that simple physical isolation and contact disinfection were not sufficient to completely block the introduction of the pathogen. Based on this, the research team systematically developed a series of control equipment including air samplers, large throughput air virus intelligent monitoring instruments, and air filtration and disinfection equipment, and constructed a multi-plex polymerase chain reaction rapid identification technology and virus transmission simulation tracking system, forming a complete chain of "early warning - monitoring - blocking - purification - resumption of production" technology system. The deeper rule revealed by this case is that the effectiveness of the modern biosecurity system no longer depends on the strictness of a single measure, but on the systematic identification and targeted blocking of different transmission routes.

4.3 Governance Practice of Multidisciplinary Collaboration and Integrated Health Concept

The complexity of building a biosafety system determines that it cannot rely solely on the veterinary discipline. When a livestock farm needs to manage multidimensional risks such as personnel flow, vehicle entry and exit, material disinfection, air quality, and waste disposal simultaneously, the integration of knowledge from engineering, environmental science, information technology, and management science becomes necessary. The precise biosafety prevention and control technology system for large-scale pig farms constructed by Professor Wei Zhanyong's team at Henan Agricultural University after ten years of research and development is a typical achievement of interdisciplinary collaboration. The team has established rapid detection methods for 18 pathogens including African swine fever virus and porcine deltacoronavirus, and for the first time has developed a universal fluorescent quantitative polymerase chain reaction detection method for porcine coronaviruses, which can simultaneously detect six common types of porcine coronaviruses, providing a radar system for the early warning of new diseases in pig farms. At the hardware level, the team has developed an automated cleaning equipment to address the issue of traditional cleaning equipment being less than 40% effective in cleaning vehicle chassis and tire grooves, reducing cleaning dead corners to less than 5%; At the management level, the developed intelligent management system achieves precise control of disinfection temperature, duration, and drug concentration, reducing the cross-infection rate from 8.7% to 0.5%. This practice clearly demonstrates that the modern biosafety system has evolved from a single disciplinary epidemic prevention work to a multidisciplinary collaborative system engineering.

Expanding the perspective from within the breeding farm to a larger public health framework, the boundaries of the biosafety system extend far beyond the scope of animal husbandry. According to statistics, about 60% of known infectious diseases in humans originate from animals, and up to 75-80% of newly emerging infectious diseases are related to animals or animal derived foods. The concept of preventing and controlling zoonotic diseases and moving the checkpoint forward is based on this epidemiological fact, and its policy connotation is to push the prevention and control node of zoonotic diseases from the stage of human to animal transmission to the stage of animal infection. In recent years, from cross departmental joint prevention and control of brucellosis to collaborative monitoring of rabies between humans and animals, from research on integrated health concepts for the prevention and control of leptospirosis to the construction of monitoring and early warning systems for migratory bird routes, multiple disciplines such as animal medicine, public health, ecology, and information science are forming an institutionalized collaborative network. When the physical defense line of the biosafety system is nested with the institutional defense line of interdisciplinary collaborative governance, modern animal medicine has truly completed the paradigm upgrade from technological means to systematic thinking.

5. Conclusion

This article demonstrates the technological path of modern animal medicine to enhance the effectiveness of animal disease prevention and control from four dimensions: perception, diagnosis, intervention, and governance. Intelligent monitoring will compress the response speed of prevention and control from "days" to "hours", molecular diagnosis and new vaccines will advance intervention methods from broad-spectrum empirical medication to targeted molecular recognition, and the biosafety system and interdisciplinary collaborative governance will integrate decentralized technologies into a systematic institutional defense line. The three components form a complete chain from front-end warning to terminal control, and the absence of any link will weaken the overall efficiency. The future development direction should pay more attention to the coordinated promotion of technology integration and institutional innovation, especially in areas such as cross-border disease monitoring, the construction of new vaccine rapid response platforms, and the sinking of grassroots prevention and control capabilities, which still need continuous breakthroughs. The modernization of animal disease prevention and control not only relies on the progress of laboratories and veterinary drug factories, but also on the systematic upgrading of the entire prevention and control system from concept to implementation.

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