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Harnessing Artificial Intelligence to Enhance Necropsy Workflows in Diagnostic Veterinary Pathology: A Narrative Review

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ABSTRACT

Necropsy remains a key part of diagnostic veterinary pathology, providing valuable information on causes of death, herd health status and emerging animal diseases. Traditional necropsy practice, however, often faces limitations such as time pressure, subjective judgment, inadequate record keeping and weak use of accumulated data. Artificial intelligence offers a practical way to reduce these problems and improve postmortem examinations in veterinary medicine. This review examines how specific AI-based tools can support necropsy workflows by improving consistency, efficiency and data integration. Validated applications include computer vision-based lesion detection and natural language processing systems that structure necropsy reports for surveillance and retrospective analysis. Emerging uses involve multimodal data integration and decision-support systems that assist with differential diagnosis and targeted ancillary testing. While early evidence supports improved standardization and analytical capacity, many applications remain dependent on dataset quality, species-specific validation, and professional oversight. Artificial intelligence is therefore best viewed as a decision-support technology that complements, rather than replaces, veterinary pathologist expertise.

KEYWORDS

Artificial intelligence, necropsy, pathologist, computer vision, digital pathology

INTRODUCTION

Necropsy remains a foundational pillar of diagnostic veterinary pathology, serving roles that extend far beyond determination of cause of death. Through systematic postmortem examination, necropsy provides irreplaceable insights into disease pathogenesis, host-pathogen interactions, toxicological exposure, nutritional disorders and management-related conditions across companion animals, livestock, wildlife and laboratory species[1]. At the population level, necropsy findings inform herd and flock health strategies, guide biosecurity interventions and support surveillance systems aimed at early detection of endemic, emerging and transboundary diseases[2]. In research and regulatory settings, necropsy contributes to phenotypic characterization, safety assessment and validation of experimental outcomes. The breadth of information derived from postmortem examinations positions necropsy as both a diagnostic and epidemiological instrument of high strategic value in veterinary medicine[1,2].

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Despite its importance, conventional necropsy workflows face persistent structural and operational challenges. Gross examination relies heavily on the experience and subjective judgment of the pathologist, creating variability in lesion recognition, interpretation and reporting[3]. Differences in training background, time pressure, caseload intensity and environmental conditions can influence diagnostic consistency, even among highly skilled professionals[4]. Documentation of necropsy findings often depends on free-text descriptions, hand-written notes or non-standardized digital entries and this limits data comparability across cases, institutions and regions[3,5,6]. Visual records such as photographs or videos are frequently underutilized, inconsistently labeled or stored without linkage to diagnostic conclusions[3]. These limitations reduce the capacity of necropsy-derived data to support large-scale retrospective analyses, automated surveillance or integration with laboratory and molecular diagnostics[7].

Time constraints further compound these issues. High-throughput diagnostic laboratories must balance thorough examination with rapid turnaround, which may restrict comprehensive documentation or detailed lesion quantification[6]. In field settings or resource-limited environments, suboptimal imaging conditions and incomplete ancillary testing can further compromise data quality[3]. As disease complexity increases and expectations for traceability, standardization and data reuse grow, traditional necropsy models struggle to meet modern diagnostic and epidemiological demands[1].

Despite the central role of necropsy in veterinary diagnostics and surveillance, there is a clear gap in standardized, scalable methods for capturing, analyzing and reusing necropsy-derived data. Current workflows remain largely manual, experience-dependent and fragmented, limiting reproducibility, cross-institutional comparison and real-time epidemiological use. Unlike histopathology and diagnostic imaging, necropsy has received comparatively limited attention in the development of structured digital and AI-assisted workflows[7,8].

Artificial Intelligence (AI) offers a compelling response to these longstanding challenges by introducing computational methods capable of extracting, structuring and interpreting necropsy data at scale[9,10]. Advances in computer vision allow automated recognition and quantification of gross lesions from images and videos, supporting objective assessment and reducing inter-observer variability[3,7]. Natural language processing can convert narrative necropsy reports into structured, searchable datasets, enabling consistency without constraining professional expression[4]. When linked with histopathology, microbiology, toxicology and molecular outputs, AI-driven systems can support integrative analysis that strengthens causal inference and diagnostic confidence[3].

The justification for AI in postmortem pathology lies not in the replacement of the veterinary pathologist, but in amplification of expertise through decision support, standardization and efficiency[1,11]. Artificial intelligence tools can assist with triage of complex cases, show patterns that may escape immediate recognition and facilitate early signals of emerging disease threats across populations[12]. By transforming necropsy from an isolated diagnostic event into a data-rich, interoperable process, AI aligns postmortem pathology with the broader digital transformation of veterinary medicine and public health[3].

As diagnostic workloads expand and expectations for surveillance precision intensify, the integration of AI into necropsy workflows represents a logical progression[4]. Its adoption has the potential to preserve the scientific rigor of necropsy while enhancing reproducibility, scalability and epidemiological impact in an increasingly interconnected health landscape[7]. Hence, this manuscript uniquely addresses this gap by focusing specifically on necropsy as a workflow, rather than isolated technologies and by mapping artificial intelligence applications directly onto routine postmortem tasks from gross examination to cause-of-death assessment.

OVERVIEW OF ARTIFICIAL INTELLIGENCE IN VETERINARY PATHOLOGY

Artificial intelligence is revolutionizing veterinary pathology through the enhancement of diagnostic accuracy and efficiency. Core AI concepts relevant to pathology include Machine Learning (ML) and deep learning (DL), which are subsets of AI that enable computers to learn patterns from data without explicit programming. Neal *et al.*[3] introduced these in veterinary clinical pathology and explained ML as algorithms trained on datasets to classify or predict outcomes, such as the identification of cellular abnormalities in cytology slides. Deep learning using neural networks with multiple layers excels in image analysis and mimics human vision to detect subtle pathological features like tumor margins[4].

The adoption of AI in veterinary diagnostics has advanced rapidly, particularly in imaging and clinical pathology. Tools are now used to analyze radiographs, ultrasounds and histopathology slides for diseases in orthopedics, cardiology and oncology to improve detection accuracy. In clinical pathology, AI automates cytology and hematology interpretations to reduce workload while maintaining precision: Neal *et al.*[3] showed its integration for workflow enhancement. Also, studies have shown DL models achieving over 90% accuracy in the classification of conditions from MRI or blood smears in animals[3,4,13].

The extension of AI to necropsy provides a compelling rationale through automated analysis of reports and images. Bollig *et al.*[14] demonstrated that ML classifiers effectively performed syndromic surveillance on free-text necropsy reports from over 33,000 cases, and detected gastrointestinal, respiratory, or urinary pathologies with high reliability using gross and histological findings. This enables temporal-spatial trend identification and outbreak detection. Orakpoghenor and Terfa[1] advocated AI integration for pattern recognition in necropsy data to reduce human error and accelerate diagnoses via anomaly detection. In addition, Akbarein *et al.*[15] evaluated ML on necropsy texts for surveillance and confirmed logistic regression and the efficacy of other models. These applications tend to justify expansion, as AI standardizes interpretations, handles high caseloads and supports research in zoonotic diseases.

Within necropsy workflows, these AI concepts translate into practical tools for specific tasks. Machine learning models support the classification of gross lesion patterns and syndromic groupings during postmortem examination, while deep learning approaches enable automated analysis of necropsy images and videos for lesion detection and measurement. Natural language processing facilitates structured documentation of gross findings and diagnostic conclusions, directly supporting report completeness, data retrieval, and surveillance. Where examples from human pathology are referenced, they are included to illustrate transferable methodological frameworks rather than direct performance equivalence, acknowledging species-specific and contextual differences in veterinary necropsy practice.

AI APPLICATIONS IN NECROPSY WORKFLOWS

Artificial intelligence applications are reshaping necropsy workflows by automating key tasks, improving accuracy and reducing errors in postmortem examinations. These technologies support gross examination, report generation and data integration, enabling faster and more consistent diagnostic outputs for veterinary pathologists[16,17].

COMPUTER VISION FOR GROSS PATHOLOGY

Computer vision applies image-based algorithms to detect and quantify lesions in necropsy photographs, converting complex gross observations into measurable data. Convolutional Neural Networks (CNNs) analyze images to identify tumors, hemorrhages or tissue damage with high speed and reduced observer bias. Patel *et al.*[16] reported that CNN-based systems reduce fatigue-related errors and perform reliably in challenging pattern recognition tasks, such as glomerular counting in kidney biopsies, thus, achieving correlations of up to 0.94 with expert assessments.

In a routine necropsy setting, computer vision integration would follow a stepwise workflow. Standardized image capture protocols would be applied during gross examination using calibrated cameras or mobile devices, with predefined views and lighting conditions to ensure consistency. Images would be automatically uploaded to a secure system where AI models perform initial lesion detection and measurement. Annotated outputs would be reviewed by the pathologist, who confirms, edits or rejects AI-generated labels, thereby maintaining quality control. Curated images and validated annotations would then be stored alongside necropsy reports, enabling continuous model refinement and retrospective analysis[3].

This technology is particularly effective for automated lesion detection and size estimation. In porcine lung necropsies, segmentation models distinguished normal from diseased tissue with up to 95.6% specificity during postmortem evaluation[18]. Where explicitly stated, performance metrics are derived from veterinary necropsy or animal pathology datasets; references to human pathology studies are included to demonstrate methodological feasibility rather than direct translational equivalence. Such tools allow for rapid screening of organs for infectious or proliferative lesions without extensive manual dissection so as to improve efficiency in high-volume diagnostic laboratories. Tiwari *et al.*[17] further demonstrated the utility of computer vision for analysis of whole-slide images derived from necropsy tissues to enable early identification of neoplastic changes.

Image standardization methods provide correction to inconsistencies in lighting, staining and image quality and allow gross images to be compared across cases and institutions. Automated color correction and edge enhancement improve lesion boundary recognition. Patel *et al.*[16] described CNN models trained on diverse image sets that predicted fibrosis boundaries with a correlation of 0.73, which exceeded the performance of manually annotated references. By assigning lesion scores based on measurable features such as size and color intensity, computer vision supports objective reporting. Comparable applications in human pathology achieved tumor grading accuracy approaching 98%, thus, supporting the potential for similar gains in veterinary necropsy practice[17,19].

Despite all these advantages, challenges remain, particularly the limited availability of annotated animal datasets. However, transfer learning approaches using human pathology data have shown promise. Future workflows may include real-time image capture during necropsy, automated lesion tagging and alerts for atypical findings requiring closer examination. These developments position computer vision as a key driver of standardization and objectivity in gross pathology, especially for livestock and wildlife surveillance[13,20].

NATURAL LANGUAGE PROCESSING FOR NECROPSY REPORTING

Natural Language Processing (NLP) converts free-text necropsy notes into structured, searchable formats to address inconsistencies that may arise from rapid examinations and varied reporting styles. The NLP systems extract key terms such as organ involvement, lesion type, and severity and organize them into standardized fields suitable for databases and surveillance platforms. This capability is particularly valuable in veterinary pathology, where large volumes of reports are generated across farms, abattoirs, zoological collections and diagnostic laboratories[21].

Through the structuring of narrative reports, NLP reduces the time required to retrieve historical cases and supports large-scale data analysis. Automated pipelines can link diagnostic terms to corresponding images and assign severity scores. Wi *et al.*[22] demonstrated an NLP framework that extracted diagnostic information 24-39 times faster than manual review while preserving links to animal age, tissue site and clinical context. Similar systems successfully identified grading terminology in pathology reports despite variations in phrasing, to enable consistent classification across cases[21].

Data consistency tend to improve as NLP tools flag missing information, ambiguous terminology, or deviations from standardized vocabularies such as SNOMED. Information retrieval is greatly enhanced, allowing for rapid identification of cases matching specific lesions or diseases. López-Úbeda *et al.*[23] demonstrated the role of NLP towards improvement of workflow efficiency within digital pathology laboratories. Xiao *et al.*[4] further reported that recurrent neural networks using long short-term memory accurately classified gastrointestinal and respiratory conditions from necropsy texts, thus supporting outbreak detection. While NLP systems require training on veterinary-specific terminology, their use reduces reporting errors and improves data reliability. These tools facilitate rapid literature review, grant reporting and population-level studies. As diagnostic laboratories adopt fully digital systems, NLP can transform necropsy reports into structured resources that support both research and public health monitoring[24,25].

MULTIMODAL DATA INTEGRATION

Multimodal AI integrates gross necropsy images, histopathology slides, laboratory data, and textual reports into a unified analytical framework to improve determination of cause of death[26]. By linking macroscopic lesions with microscopic features and biochemical findings, these systems identify patterns that may not be apparent through isolated data streams. Tiwari *et al.*[17] emphasized the value of linking whole-slide images with diagnostic reports to reduce uncertainty in oncologic interpretation.

The integration of gross findings with histopathology and laboratory results is central to this approach. For example, gross pulmonary lesions can be correlated with microscopic inflammatory changes and hematologic markers to strengthen infectious disease diagnosis. Xiao *et al.*[4] demonstrated models that associate necropsy images with textual findings to improve diagnostic confidence in animal disease investigations. In oncology, integrated models linking gross morphology, hematoxylin and eosin staining and immunohistochemistry achieved classification accuracies exceeding 94%, thus illustrating the potential benefit for cases such as poultry, companion animals, and exotic species[27].

Data-driven cause-of-death assessment combines multiple inputs to generate probabilistic diagnostic outputs. The AI systems weigh lesion extent, histologic invasion and laboratory abnormalities to rank likely causes. Zheng *et al.*[28] showed that graph-based models using fused datasets outperformed single-modality approaches in predicting disease progression. In veterinary pathology, similar strategies can support vaccine evaluation, toxicologic investigations and systemic disease classification[14].

Although wider adoption requires expanded animal datasets and transparent model design, multimodal AI shortens diagnostic timelines and improves accuracy during disease outbreaks[29]. Emerging platforms may soon provide integrated dashboards that summarize necropsy findings and suggest evidence-supported diagnoses. By combining image analysis, textual interpretation and laboratory data, AI shifts necropsy practice toward a more standardized and data-driven discipline, thereby, strengthening its contribution to veterinary research, disease control and health policy[13,15,20].

AI-DRIVEN DECISION SUPPORT AND PREDICTIVE ANALYTICS

The AI-driven decision support systems are becoming valuable companions in necropsy practice by assisting pathologists with complex reasoning tasks while maintaining professional control. One key contribution lies in differential diagnosis prioritization. By integrating gross lesions, histopathology, laboratory findings and historical case data, AI models can rank likely causes of death based on probability rather than providing a single output. Such ranked differentials would help pathologists focus attention on the most plausible conditions early in the workflow, especially in cases with overlapping lesions or limited ancillary data. Studies applying machine learning to necropsy texts and images have shown reliable classification of syndromic patterns, including respiratory, gastrointestinal and systemic diseases, thereby, supporting structured diagnostic reasoning rather than replacing it[4,14].

Targeted ancillary test recommendations represent another practical advantage. Decision-support tools can suggest appropriate follow-up tests, such as histopathology, microbiology, toxicology or molecular assays, based on recognized lesion patterns and prior outcomes. This approach reduces unnecessary testing while minimizing the risk of missing critical diagnostics. For example, AI systems trained on integrated datasets can identify lesion combinations that historically benefited from confirmatory PCR or immunohistochemistry and this guides efficient resource use in high-throughput laboratories[3,4]. Such guidance is particularly valuable in field investigations and resource-limited settings where test availability must be prioritized carefully.

Predictive analytics also enables pattern recognition for emerging diseases. By continuously analyzing incoming necropsy data, AI can detect deviations from baseline trends that may indicate novel pathogens, changing virulence or environmental stressors. Machine learning-based surveillance models have already demonstrated the ability to identify unusual temporal and spatial clustering of lesions before formal outbreak recognition[14,15]. When linked with geographic and production data, these systems can support early alerts that prompt targeted investigation and containment. In this way, AI-driven analytics extend necropsy impact beyond individual cases to proactive population health intelligence.

IMPLICATIONS FOR DISEASE SURVEILLANCE AND ONE HEALTH

The integration of AI into necropsy workflows has significant implications for disease surveillance and One Health initiatives. Enhanced outbreak detection and monitoring are among the most immediate benefits. Automated analysis of structured necropsy data enables near real-time tracking of disease trends across regions and species. AI systems can flag unusual increases in specific lesion types or syndromes, supporting earlier intervention than traditional reporting mechanisms[12,14]. This capability is especially relevant for transboundary and zoonotic diseases where delays can have serious economic and public health consequences.

Population-level data utilization is strengthened through AI-driven aggregation of necropsy findings. Natural language processing and image analysis convert individual case reports into standardized datasets suitable for large-scale analysis. Such datasets allow assessment of disease burden, evaluation of control measures and identification of risk factors related to management, environment or host characteristics[4,7,8]. Over time, these analyses support evidence-based policy decisions in animal health and production systems.

Within One Health frameworks, AI-enhanced necropsy contributes to integrated animal-human-environment health surveillance. Many emerging infectious diseases originate at the animal-human interface and systematic analysis of animal mortality data provides early warning signals. By linking veterinary necropsy data with environmental indicators and where appropriate, human health datasets, AI supports cross-sectoral risk assessment[9]. This integration strengthens collaboration between veterinary services, public health authorities and environmental agencies, reinforcing necropsy as a strategic tool in global health preparedness.

CHALLENGES AND ETHICAL CONSIDERATIONS

Despite clear advantages, several challenges and ethical issues must be addressed for responsible AI adoption in necropsy practice. Data quality and annotation limitations remain a central concern. The AI performance depends heavily on well-annotated, representative datasets, yet necropsy data often vary in completeness, terminology and image quality across institutions and species[7]. Limited datasets for rare species or conditions can introduce bias and reduce model reliability, emphasizing the need for collaborative data sharing and standardized reporting.

Model transparency and validation are equally critical. Many AI systems function as complex models that may not clearly explain how outputs are generated. Lack of interpretability can reduce trust and hinder clinical acceptance. Validation across independent datasets and real-world settings is necessary to confirm robustness and generalizability[20,25]. Clear performance metrics and defined use boundaries help prevent misuse or overreliance.

Ethical use, accountability and governance require careful consideration. The AI tools should support, not override, professional judgment, with clear responsibility remaining with the veterinary pathologist. Issues related to data ownership, privacy and consent are particularly relevant when necropsy data contribute to surveillance systems. Governance frameworks must define acceptable use, oversight mechanisms and pathways for addressing errors or bias[14]. Addressing these challenges ensures that AI enhances diagnostic quality while maintaining professional and societal trust.

Data ownership and governance represent a major ethical consideration in AI-assisted necropsy. Necropsy data may originate from private clients, production systems, wildlife authorities or research institutions, raising questions regarding ownership, access rights and secondary use for model training or surveillance. Clear institutional policies are required to define data stewardship, anonymization standards and acceptable sharing frameworks, particularly when data contribute to regional or national surveillance systems[3].

Accountability in cases of incorrect or misleading AI-supported outputs must also be clearly defined. While AI systems may influence lesion interpretation or diagnostic prioritization, they do not possess legal or professional responsibility. Errors arising from biased training data, algorithmic limitations, or inappropriate application can have significant diagnostic and regulatory consequences[3].

Final responsibility for necropsy findings and cause-of-death determination must remain with the veterinary pathologist. The AI tools should function strictly as advisory systems, with all outputs subject to professional review and contextual judgment. Explicit acknowledgment of this responsibility is essential to prevent automation bias, maintain ethical practice and preserve trust in veterinary diagnostic services[20].

VETERINARY PATHOLOGIST IN AI-AUGMENTED NECROPSY

In AI-augmented necropsy, the veterinary pathologist remains central to diagnosis and interpretation. Human-AI collaboration emphasizes complementary strengths, with AI handling data-intensive tasks and pathologists providing contextual understanding and critical judgment. Decision-support outputs are most effective when used as advisory tools that prompt reflection rather than dictate conclusions[8,11,30].

Preservation of diagnostic judgment is essential. Pathologists must retain authority to accept, question, or reject AI suggestions based on clinical context and experience. This balance prevents automation bias and reinforces accountability. Transparent systems that allow users to review contributing features will improve confidence and informed decision-making[25].

Training and workforce implications are significant. Future veterinary pathologists will require basic literacy in AI concepts, data quality assessment and digital workflows. Education programs may integrate computational pathology principles alongside traditional training. Rather than reducing professional roles, AI is likely to reshape them toward higher-level interpretation, quality assurance, and interdisciplinary collaboration[3,8,11].

FUTURE DIRECTIONS AND RESEARCH PRIORITIES

Future research should prioritize validation of AI tools across species, production systems, and diagnostic settings. Models trained in controlled environments must demonstrate reliability in diverse real-world conditions, including wildlife and low-resource contexts[4]. Cross-institutional studies will be essential for assessing generalizability.

Scalable implementation strategies are another priority. Integration with existing laboratory information systems, imaging platforms and surveillance networks must be practical and cost-effective. Modular designs that allow gradual adoption may encourage wider uptake[7].

Key research gaps include limited datasets for rare diseases, explainability of multimodal models, and long-term impact assessment on diagnostic accuracy and surveillance outcomes. Innovation opportunities lie in federated learning, multimodal fusion and real-time analytics that respect data privacy while expanding collective knowledge[9,25].

CONCLUSION

AI integration into necropsy workflows offers meaningful advances in decision support, surveillance and data utilization while reinforcing the central role of the veterinary pathologist. Evidence shows that AI can improve diagnostic prioritization, guide targeted testing and strengthen outbreak detection when applied responsibly. At the same time, limitations related to data quality, transparency and ethics require careful management. However, a balanced perspective recognizes AI as an enabling tool rather than a replacement for expertise. Continued validation, governance and training will determine its long-term value. With thoughtful implementation, AI-enhanced necropsy practice is well positioned to strengthen veterinary diagnostics and contribute to integrated One Health objectives in the years ahead.

SIGNIFICANCE STATEMENT

This review highlights the transformative potential of artificial intelligence in veterinary necropsy, demonstrating how AI enhances diagnostic accuracy, standardizes reporting and accelerates outbreak detection. By integrating image analysis, natural language processing and multimodal data, AI supports informed decision-making while preserving pathologist expertise, ultimately strengthening disease surveillance, research and One Health initiatives across diverse animal populations.

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