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From Microscope to Monitor: The Digital Transformation of Veterinary Pathology

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Abstract:

Pathology has traditionally been synonymous with the microscope, glass slides and the trained eye of the pathologist. However, advances in imaging technology, computing and artificial intelligence are transforming this conventional approach. Digital pathology involves converting glass microscope slides into high-resolution digital images that can be viewed, stored, analysed and shared electronically. In veterinary medicine, this technology has applications in diagnosis, telepathology, education, research, disease surveillance and quantitative image analysis. Whole-slide imaging allows an entire tissue section to be examined on a computer screen, while artificial intelligence and machine-learning tools are opening new possibilities for automated image analysis and computer-assisted diagnosis. At the same time, challenges related to infrastructure, cost, data storage, standardisation, validation and cybersecurity need to be addressed. Digital pathology is therefore not simply a replacement for the microscope; rather, it represents an evolution of pathology that can extend the reach and capabilities of veterinary pathologists.

Keywords: Digital pathology, veterinary pathology, whole-slide imaging, telepathology, artificial intelligence, histopathology, image analysis

Introduction:

For generations, the microscope has been one of the most important tools in pathology. A thin section of tissue, carefully stained and mounted on a glass slide, can reveal a remarkable amount of information about disease. The pathologist examines cellular morphology, tissue architecture and pathological changes and combines these findings with clinical information to arrive at a diagnosis.

But what if the glass slide could be transformed into a digital image that could be viewed anywhere, shared instantly with another expert and analysed by a computer? This is the basic idea behind **digital pathology**.

Digital pathology has evolved from simple digital photographs of microscopic fields to sophisticated systems capable of scanning entire glass slides at high resolution. Whole-slide imaging, image analysis and artificial intelligence are now becoming important components of modern pathology. In veterinary medicine, digital pathology is increasingly being incorporated into diagnostic, research and educational workflows, with potential applications ranging from routine diagnosis and teleconsultation to quantitative image analysis and computer-assisted interpretation (Zuraw and Aeffner, 2022; Ancheta et al., 2024). (PubMed)

From Glass Slide to Digital Slide:

The transition from conventional to digital pathology begins with **whole-slide imaging (WSI)**. In conventional histopathology, a tissue section is examined directly through a microscope. In WSI, a specialised scanner captures high-resolution images across the entire glass slide. These individual images are then combined to create a single digital representation of the slide.

The resulting image can be viewed on a computer using specialised software. The user can zoom in to examine individual cells or zoom out to appreciate the overall tissue architecture. In this way, many of the functions traditionally performed with a microscope are transferred to a digital workstation.

Whole-slide imaging has already become an important component of veterinary pathology, particularly in areas such as archiving, consultation, teaching and research. Its use has also expanded into quantitative tissue analysis and artificial intelligence-based applications (Zuraw and Aeffner, 2022). (PubMed)

Digital pathology is not restricted to histopathology. Clinical pathology specimens such as cytology and haematology preparations are also being digitised. A recent review highlighted the expanding use of digital pathology in veterinary clinical pathology for diagnosis, teaching, training, research and image analysis, while also noting that clinical specimens present workflow and technical considerations different from those of traditional histopathology (Piccione et al., 2025). (PubMed)

The Rise of Telepathology:

One of the most practical advantages of digital pathology is the ability to share pathological images across geographical boundaries.

This has given rise to **telepathology**—the interpretation or consultation of pathology cases from a distance. Instead of physically sending a glass slide to a specialist, a digital image can be transmitted electronically for review.

This can be particularly valuable in veterinary medicine, where specialised pathology expertise may not be readily available in every location. A veterinarian or diagnostic laboratory can potentially share a difficult case with a veterinary pathologist located hundreds or even thousands of kilometres away.

A 2024 scoping review of veterinary telepathology found that digital technologies are being used

for histopathology, cytology, haematology and other forms of remote pathological consultation. The authors highlighted the potential of telepathology to connect veterinary practices with distant laboratories and support underserved communities, while also identifying a need for further validation of whole-slide imaging for primary diagnosis (Rogers et al., 2024). (PubMed)

For a country such as India, where veterinary services and specialist expertise are distributed across large geographical areas, this aspect of digital pathology could be particularly relevant. A difficult pathological case encountered in a field or peripheral veterinary facility could potentially be digitised and referred to a specialist without the physical movement of slides.

Beyond the Human Eye: Digital Image Analysis

Traditional pathology is fundamentally dependent on the expertise of the observer. Although this expertise remains indispensable, digital images provide another possibility: **quantification**.

Computer-based image analysis can be used to measure features such as cell numbers, tissue areas, lesion dimensions, staining intensity and other morphological characteristics. Instead of describing a pathological change only as "mild", "moderate" or "severe", image-analysis systems may allow researchers to obtain numerical measurements.

This can be especially useful in experimental studies, toxicologic pathology, vaccine research and evaluation of treatment-associated tissue changes. Digital image analysis can improve consistency and provide objective quantitative measurements, although appropriate qualification and verification of analytical methods remain essential (Zuraw et al., 2021). (PubMed)

The value of digital image analysis is particularly apparent in veterinary research, where researchers may need to compare pathological changes across large numbers of experimental samples. Once slides have been digitised, the same image can also be re-examined repeatedly without requiring access to the original glass slide.

When Artificial Intelligence Enters the Picture?

The most exciting—and perhaps most debated—development in digital pathology is the integration of artificial intelligence (AI).

AI systems, particularly machine-learning and deep-learning algorithms, can be trained using large collections of labelled images. Once appropriately developed and validated, such systems may recognise patterns associated with particular pathological changes.

Imagine a digital slide containing thousands of cells. Rather than requiring a pathologist to manually count every cell, an algorithm could potentially identify and count them within seconds. Similarly, AI-based systems may be developed to highlight areas of inflammation, identify abnormal cellular patterns or assist in quantitative assessment.

The field is rapidly developing. A 2025 review of AI in veterinary clinical pathology described

opportunities for machine learning and deep learning to enhance the workflow of veterinary clinical pathologists and emphasised that pathologists should remain actively involved in defining intended uses, qualification and responsible implementation of AI tools (Neal et al., 2025). (PubMed)

Thus, AI should not be viewed simply as a replacement for the pathologist. Pathological diagnosis is not merely pattern recognition. Clinical history, species, age, lesion distribution, gross findings and laboratory results all contribute to interpretation.

The emerging concept is therefore one of **human–AI collaboration**, where algorithms assist with repetitive or quantitative tasks while the pathologist provides contextual interpretation and final professional judgement.

Applications in Veterinary Medicine:

The potential applications of digital pathology in veterinary medicine are extensive.

1. **Diagnostic Pathology:**
   - ***a.*** Digital slides can be used for primary assessment, consultation and second opinions. They can facilitate collaboration between veterinary diagnostic laboratories and specialist pathologists and may reduce the need to physically transport glass slides.
   - ***b.*** The growing adoption of digital pathology in veterinary diagnostic laboratories has been described as part of a broader transformation of veterinary pathology, with digital workflows increasingly being integrated into diagnosis and consultation (Ancheta et al., 2024). (PubMed)
2. **Veterinary Education:**
   - ***a.*** Digital slides can transform pathology teaching. Instead of a student examining a single microscope slide during a practical session, an entire class can access the same digital specimen. Students can revisit cases outside the laboratory, zoom into specific areas and compare normal and pathological tissues.
   - ***b.*** Digital pathology can also facilitate the creation of structured digital slide libraries that can be used repeatedly for teaching and examinations.
   - ***c.*** A 2026 study specifically evaluated whole-slide imaging for veterinary pathology education and demonstrated its application in teaching cytology and haematology submission practices, reflecting the expanding educational role of digital microscopy (Garner and Schlemmer, 2026). (PubMed)
   - ***d.*** The implementation of digital pathology in veterinary academic settings, however, requires careful planning involving information technology infrastructure, hardware, software and the specific needs of students, instructors and researchers. (PubMed)
3. **Research:**
   - ***a.*** Digital slides can be archived and analysed repeatedly. Researchers can compare lesions between

experimental groups, perform quantitative measurements and share images with collaborators.

b. Digital archives can also preserve valuable pathological cases that may otherwise remain confined to physical slide collections. In toxicologic pathology and drug-development research, whole-slide imaging and image analysis are already being explored for primary assessments, peer review and quantitative evaluation (Zuraw and Aeffner, 2022). (PubMed)

4. Disease Surveillance:

a. Pathology is an important component of disease surveillance. Digitised pathological specimens could potentially be incorporated into larger laboratory information systems and disease databases, allowing pathological findings to be linked with clinical, epidemiological and laboratory information.

b. Such integration could become particularly valuable for monitoring emerging and re-emerging diseases and for retrospective examination of archived cases.

5. One Health:

a. Veterinary pathology occupies an important position within the One Health framework because many diseases involve interactions between animals, humans and the environment.

b. Digital pathology could facilitate collaboration among veterinary, medical and research institutions, particularly when investigating diseases with zoonotic significance. Shared digital resources may allow experts from different disciplines to examine pathological material and contribute to multidisciplinary investigations.



The Advantages—and the Catch:

Digital pathology offers several important advantages:

- Easy storage and retrieval of pathological cases
- Rapid sharing of slides for consultation
- Improved opportunities for teaching and training
- Quantitative image analysis
- Potential integration with AI
- Creation of large digital case repositories
- Easier collaboration between institutions
- Reduced dependence on physical transportation of glass slides

However, going digital is not as simple as purchasing a scanner.

Whole-slide images can be extremely large and require substantial storage capacity and appropriate network infrastructure. High-quality scanners, viewing software and computer systems may require considerable investment. Image quality, staining variation, scanner differences and software compatibility can also affect interpretation.

There are additional concerns regarding validation, standardisation, quality assurance and data security. A 2025 review of veterinary clinical pathology highlighted gaps in the available literature surrounding digitisation and emphasised the unique workflow and analytical considerations involved in veterinary clinical specimens (Piccione et al., 2025). (PubMed)

More recently, dedicated quality guidelines for digital cytopathology have addressed preanalytical, analytical and postanalytical considerations, including sample preparation, staining variability, scanner capabilities, software, operator training and optical-resolution limitations (Fish et al., 2025/2026). (PubMed)

Therefore, digital pathology should not be adopted simply because it is technologically attractive. It needs appropriate validation, quality assurance, trained personnel and clearly defined intended uses.

Will the Microscope Become Obsolete?

Probably not.

The emergence of digital pathology does not mean that the microscope has suddenly become irrelevant. Instead, pathology is moving towards a hybrid and increasingly digital workflow.

The pathologist remains central to the diagnostic process. Technology can make images easier to share, archive and quantify, but interpretation still depends on professional expertise.

In fact, digital pathology may ultimately allow pathologists to spend less time dealing with logistical limitations and more time on interpretation, consultation and complex diagnostic problems.

The important question is therefore not whether the microscope will disappear, but how the

microscope and digital technologies will work together.

The Road Ahead:

The future of veterinary pathology is likely to involve increasing integration of whole-slide imaging, laboratory information systems, image analysis and artificial intelligence.

Imagine a future in which a tissue sample collected in a remote veterinary hospital is processed locally, scanned digitally and reviewed by a specialist elsewhere. The digital image is automatically archived, relevant areas are highlighted by an AI-assisted system, quantitative measurements are generated and the final pathological interpretation becomes part of an integrated laboratory database.

Such a system could connect the field veterinarian, diagnostic laboratory, veterinary pathologist and researcher within a single digital ecosystem.

The veterinary pathology literature increasingly describes digital pathology as an important component of the future of diagnostic, research and educational workflows, while also emphasising the need for appropriate validation and responsible implementation (Ancheta et al., 2024; Neal et al., 2025). (PubMed)

Conclusion:

Veterinary pathology has travelled a remarkable journey—from the careful examination of glass slides under a microscope to the analysis of high-resolution digital images on a computer monitor.

Digital pathology does not replace the pathologist; it **extends the pathologist's reach**.

It can connect experts across distances, create permanent digital archives, support quantitative research, transform pathology education and open the door to artificial intelligence-assisted analysis. At the same time, responsible adoption requires attention to validation, infrastructure, standardisation, quality assurance and data security.

The microscope has served pathology for generations. The monitor does not signal its end. Instead, it represents the next chapter.

The future of veterinary pathology may not be about choosing between the microscope and the monitor—it may be about using both, more intelligently.

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