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Digital Pathology and Artificial Intelligence: Transforming Veterinary Diagnosis, Research and Education Introduction

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Abstract

Digital pathology is transforming veterinary diagnostic practice by enabling the digitisation, storage, analysis and remote sharing of histopathological specimens. The integration of artificial intelligence (AI), machine learning (ML) and deep learning (DL) has further expanded its potential through automated cell counting, tissue classification, lesion detection and quantitative image analysis. Whole-slide imaging (WSI) allows comprehensive examination of tissue architecture at high resolution, facilitating telepathology, collaborative research and the development of digital teaching resources. In veterinary medicine, these technologies offer particular advantages in improving access to specialist diagnostic expertise, enhancing diagnostic efficiency and supporting veterinary education. AI-assisted image analysis also provides opportunities for quantitative assessment of inflammation, fibrosis, necrosis and cellular populations in experimental pathology. Recent research has demonstrated the potential of deep learning models to predict molecular characteristics, including c-KIT exon 11 mutation status in canine mast cell tumours, using routine histological images. Despite these advances, several challenges remain, including high implementation costs, substantial data storage requirements, interoperability issues, staff training, data security and variability in image quality. Furthermore, AI models require representative training datasets, independent validation and continuous evaluation to ensure diagnostic reliability across different laboratory settings. Digital pathology is therefore best considered a complementary approach rather than a replacement for conventional microscopy and professional pathological interpretation. Its gradual integration, supported by validated analytical tools, standardised imaging protocols and collaborative digital databases, holds considerable promise for advancing veterinary diagnostics, research and education, particularly in developing countries such as India.

Keywords: Digital pathology, Artificial intelligence, Whole-slide imaging, Deep learning, Telepathology, Veterinary diagnostics

1. Introduction

Digital pathology is revolutionising the way we examine, share and interpret tissue. In vet medicine it has the potential to improve diagnosis, research and education but there are still considerable technical and scientific hurdles to overcome.

For many generations the light microscope has been the workhorse of pathology. It's been used to diagnose infectious disease, to look at tumours and to assess tissue damage. It's still absolutely fundamental to the discipline. The sheer volume of work that needs to be done and the need for collaboration has in turn led to the development of a number of digital solutions.

Digital pathology involves the conversion of glass slides into high resolution digital images for computerised analysis, electronic storage and remote sharing. When coupled with AI it allows for automated measurements and can identify patterns which would be very difficult to assess in a consistent manner by visual inspection alone. These are particularly significant in the field of veterinary medicine where access to specialist expertise and to specialist diagnostic facilities is very uneven. Digital technology is not a direct substitute for the conventional microscope. Its value is in providing better access to pathological information and in supporting the professional interpretation rather than replacing it.

2. What is Digital Pathology?

Digital pathology is the acquisition, management, interpretation and sharing of digitised images of pathological specimens. It starts with a tissue section on a glass slide which is then scanned using specialist equipment to produce a digital image.

2.1 Whole-slide imaging

Whole slide imaging (WSI) takes a whole tissue section at high resolution. It's not just a single field photograph as such, you can navigate the slide, zoom in on areas of interest and compare areas. This enables the pathologist to get a feel for the overall tissue architecture prior to looking at the individual cells. The digital images can be annotated, measured and stored for future reference (for consultation or research). However, scanning produces very large files which in turn require a lot of storage, a lot of computing power and a good deal of network bandwidth. Image quality is a function of specimen preparation, staining and scanning conditions.

2.2 Conventional microscopy versus digital pathology

Both of the approaches require an understanding of tissue morphology and disease processes. The key difference is in the way the specimen is obtained and the way it is then examined. Conventional microscopy is the direct examination of glass slides. Digital pathology is the equivalent in that it's the scanning of the slide and the creation of an electronic image. This in turn enables teleconsultation, collaborative research and the creation of digital teaching collections. Digitisation in no way overcomes the problems of poor tissue preparation or the absence of diagnostic information. A digital image is only as good as the tissue and the imaging process that went into producing it.

3. Artificial Intelligence, Machine Learning and Deep Learning

Artificial intelligence is the broad term for any computing approach that is designed to do things like pattern recognition, classification and prediction.

Machine learning (ML) is a sub-field of AI where algorithms learn from data to identify relationships. In the context of pathology, the model is trained on annotated images of known tissue structures, normal cells and pathological lesions.

Deep learning (DL) is a form of machine learning that uses multi-layered neural networks to identify complex patterns in images. The specific patterns that are detected will of course depend on the training data and can include cellular morphology, tissue architecture and the relationships between various tissue components.

These technologies enable cell counting, tissue classification and lesion detection. Their reliability is contingent upon having representative training data, accurate annotations and independent evaluation. A very sophisticated algorithm is no guarantee of accuracy and its predictions must be read in the context of the biology and clinical situation of the specimen.

4. Advantages of Digital Pathology and AI

4.1 Increased productivity

Digital slides can be retrieved electronically so there's no need to go back to the actual specimen again and again. Image analysis software can be used to help with the repetitive tasks of counting cells, measuring areas of tissue and quantifying staining patterns. These capabilities assist the pathologist in managing their workload and allow them to concentrate on the more diagnostically difficult cases. The actual time saved will of course vary according to the scanning requirements, the performance of the software and how well it integrates into the existing lab workflow.

4.2 Collaboration and telepathology

Digital images allow you to share specimens with specialists at other institutions. They enable second opinions, multidisciplinary discussion and consultation when specialist input is not available locally via telepathology. This is particularly important in vet medicine where access to certain diagnostic subspecialties may be very limited. Successful remote consultation of course is predicated on good image quality, a good internet connection and appropriate data sharing arrangements.

4.3 Veterinary education

Digital slide libraries enable students to go back and re-examine specimens, compare lesions and study the annotated images at their own pace outside of the scheduled practicals. The teacher can point out the key diagnostic features and provide a consistent set of learning materials for students in different locations. Virtual microscopy can of course supplement traditional practical training, although experience with actual slides and the ability to recognise preparation artefacts are still very much required. Virtual microscopy is not a replacement for practical experience. The scanners, the software, the storage

infrastructure, the maintenance and the staff training all have a cost. The financial benefits will differ from institution to institution. Labs should look at the full cost of implementation against the tangible efficiencies gained rather than simply assume that going digital will lead to cost savings.

4.5 Quantitative image analysis

Digital tools can measure tissue areas, quantify staining intensity and identify specific cellular or structural features via defined protocols. They are particularly useful in the research setting where you need to assess a large number of specimens in a consistent manner. Reproducibility doesn't necessarily equate to accuracy. The algorithm could be consistently wrong if it's been designed or trained in the wrong way. Proper validation and expert assessment are still absolutely vital.

5. Applications of Digital Pathology and AI

5.1 Diagnostic pathology

AI assisted systems can detect suspicious areas, classify tissue patterns and quantify features of relevance to diagnosis. They can be used to assist with case prioritisation and to reduce the amount of repetitive manual work. However, diagnosis will usually be a matter of a number of factors including tissue architecture, clinical history and other lab findings. An algorithm developed for one lesion should not be assumed to be of value in distinguishing all the other related diseases.

5.2 Research and experimental pathology

Digital image analysis can be used to improve the measurement of fibrosis, inflammation, necrosis and various cell populations in experimental studies. The automated approach can reduce the amount of repetitive counting and enable easier comparison between groups. For example, Rogers and colleagues (2016) looked at image analysis methods for scoring mouse models of colitis. They showed the potential of automated quantification of CD3 immunolabelling and also pointed out the problems with segmenting H&E-stained sections. That again underlines the importance of assessing whether an analytical method is appropriate for the particular application in hand.

5.3 Predicting molecular characteristics from histological images

Researchers are looking at whether AI can pick up morphological patterns associated with molecular changes. In a 2025 study Puget and colleagues trained deep learning models to predict *c-KIT* exon 11 mutation status in canine mast cell tumours from H&E-stained whole slide images. The dataset comprised 368 tumours and the best reported model achieved 87% accuracy (sensitivity 0.90, specificity 0.83). These results would suggest that routine histological images may contain information relating to specific molecular characteristics. Performance of the model drops off significantly when the staining protocols and scanners are different between the datasets. The results are suggestive but don't prove that AI can replace molecular testing in routine practice. It may be possible to use the images to assess tumour, with necrotic area identification and measurement being a potential application. This would be particularly difficult if the tissue changes are complex. Whilst this has demonstrated the feasibility of automated recognition it has also shown that classification is far from perfect. Such tools may be of use in a quantitative assessment but the vet pathologist will still need to validate and interpret the results.

6. Difficulties and Constraints

6.1 Financial and technical barriers

High-quality scanners, software licences, computing equipment and storage systems are all going to be expensive. Large image files are going to require a good network, a good long term archiving solution and secure backup. The difference between a scanner and a software platform can make sharing images a real pain. The right standards in place with compatible systems will of course go a long way to improving interoperability, but that's no easy thing to achieve without some planning and technical support.

6.2 Staff training and adaptation

Pathologists and lab staff will need training in digital image navigation, scanning quality, annotation and data management. Being familiar with light microscopy in no way equates to being competent in the digital environment. Successful implementation will require practical training and the confidence that the new system will meet the diagnostic requirements.

6.3 AI reliability and validation

AI models can perform badly on specimens that are different to those in their training data. Differences in staining, tissue processing, scanner characteristics and disease populations will all have an impact on the predictions. Models may also be based on iModels may also be based on image patterns which are statistically associated with a diagnosis but which may not represent any biologically meaningful features at all. Independent testing and appropriate reference standards are of

course essential. The algorithm has to be evaluated for the task it is intended to perform, the specimen type and the clinical setting. The false positive and false negative rates must be understood and there need to be procedures in place for dealing with the cases where the prediction is uncertain.

6.4 Data security and specimen limitations

Digital pathology necessitates secure storage and controlled access to the diagnostic images and associated records. Labs will need to put in place procedures covering confidentiality, data sharing and retention. Some specimens (blood smears, cytology, some rapidly processed tissues etc) may require a different imaging approach. You can't assume that a technique will work in all areas of pathology just because it works in routine histology.

7. Future Prospects in Veterinary Medicine

The future of digital pathology is going to be about combining robust imaging systems with analytically sound tools that have been properly validated. Combining histological images with molecular and clinical data has the potential to improve our understanding of disease subtypes and tumour behaviour. More affordable imaging options and shared digital slide libraries could in turn improve access to veterinary education and research. For Indian institutions, collaborative databases being developed by the veterinary colleges and diagnostic labs could be of immense value in the areas of teaching, specialist referral and AI research. Such a scheme would of course require consistent specimen labelling, reliable annotation, appropriate infrastructure and secure data management. A more gradual approach may be the most sensible one: build up digital slide libraries, introduce image analysis tools that are validated for specific applications and then go on to develop more sophisticated AI applications as appropriate datasets and the requisite technical know-how become available. AI will be most useful in the end when it's acting as a tool to augment professional judgement by identifying areas of interest, carrying out the quantitative analysis and pointing out patterns that are worth looking at further.

8. Conclusion

Digital pathology is opening up all sorts of new avenues for tissue assessment, remote consultation, research (quantitative) and veterinary education. AI takes this a stage further with the ability to perform automated analysis and to identify patterns associated with specific pathological and molecular features. Research into canine mast cell tumours, tumour necrosis and digital tumour databases has shown the potential of these technologies. The caveat of course is that there are differences in image quality, training data and lab conditions which all point to the need for careful validation.

The most effective approach is to combine established expertise with reliable digital tools, rather than replace conventional pathology indiscriminately. The future of veterinary pathology lies in making microscopic information more accessible, measurable and useful while retaining the scientific judgement required for correct interpretation.