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Review Article

An Update on Digital Pathology: Current Technologies, Clinical Applications and Future Directions

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Abstract: The transition from traditional microscopy to computer-assisted analysis of histological specimens has been made easier. Digital pathology has emerged as a transformational force in the field of diagnostic medicine. This review offers a comprehensive update on the current landscape of digital pathology, covering whole-slide imaging technologies, infrastructure requirements and clinical applications crossing primary diagnosis, telepathology, education and research, alongside the integration of artificial intelligence methodologies. Important implementation problems, such as validation, regulatory processes, data governance, and cost concerns, are also addressed, and we investigate potential future possibilities, such as foundation models, multimodal integration, and applications in settings with limited resources. This review intends to provide pathologists, researchers, and healthcare administrators with a practical framework for navigating the continuous digital transformation of pathology services. This will be accomplished by offering a synthesis of the evidence that is now available.

Keywords: Digital Pathology, Whole Slide Imaging, Telepathology, Artificial Intelligence, Deep Learning, Multiple Instance Learning, Multimodal Integration.

1. INTRODUCTION

Histopathology has remained substantially constant for about two centuries, relying on manual assessment of tissue patterns and counting of histological items under light microscopy. This has been the case for the majority of the centuries. The fact that these manual procedures have a low throughput, are prone to error, and are sensitive to conspicuous inter-observer and severe inter-observer discordance demonstrates that they present a significant barrier to the advancement of research and diagnostic precision [1]. A significant paradigm change has occurred in the field of diagnostic medicine as a result of the introduction of digital pathology, which can be defined as the process of acquiring, managing, exchanging, and interpreting pathology information within computerised environments [2]. Whole-slide imaging (WSI), computational analysis, and the incorporation of artificial intelligence are all examples of the types of digitisation that are included in digital pathology [3]. From the early ideas of telepathology that were developed in the 1980s to the high-throughput scanners, powerful image management systems, and deep learning technologies that are employed today, the area has made significant progress [4]. Rapid clinical adoption has been accelerated as a result of recent regulatory approvals, including as the Food and Drug Administration's approval of various WSI systems for primary diagnosis [5].

The purpose of this study is to provide a complete update on digital pathology, encompassing topics such as technologies, clinical applications, obstacles in implementation, and future directions. For the purpose of providing stakeholders who are navigating the digital transformation of pathology services with an evidence-based perspective, we compile the most recent evidence presently available.

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2. Digital Pathology Technologies and Infrastructure

2.1 Whole-Slide Imaging Systems

Glass slides are converted into high-resolution digital images by the process of whole-slide imaging, which is the foundation of digital pathology [3]. Scanners, image management software, and display displays that have been calibrated are all components of contemporary WSI systems [6]. In the present day, the most popular method for acquiring large-scale, high-resolution microscopic images is to continuously stitch many tiles or fields of view [7]. System-to-system variations in technical requirements are rather common. There are currently scanners that are capable of reaching resolutions of less than 0.2 microns per pixel at a total magnification of 400 times, and the file sizes of each slide can range anywhere from hundreds of megabytes to several gigabytes. For instance, a sample measuring 15 by 15 millimetres that is scanned at a magnification of 40 times can generate as many as tens of billions of pixels [8].

2.2 Image Management and Data Storage

There is a tremendous amount of data generated by digital pathology. After processing 3,000 patient examinations on a monthly basis, a high-volume laboratory generates roughly 20,000 digital slides with an average file size of 600 megabytes. The annual data generation in this laboratory amounts to approximately 144 terabytes, as computed by multiplying 20,000 slides by 600 megabytes and then multiplying that number by 12 months. Image quality optimisation procedures, such as standardising tissue sectioning to eliminate excessive spacing between pieces, can lower the amount of storage that is required. According to one study, such optimisation can result in estimated storage savings of 4.4 terabytes per month [9].

2.3 Pre-analytic Factors and Image Quality

There is a substantial amount of variability in digital pathology that is introduced by pre-analytic factors. These factors include tissue fixation and sectioning, as well as staining and cover slippage. Artefacts such as folds, bubbles, and uneven staining directly degrade image quality and the performance of artificial intelligence [10]. In order to generate virtual H&E and other stains, models that are based on convolutional neural networks (CNNs) and generative adversarial networks (GANs) have demonstrated success. One example of such a model is the 2 Cycle GAN, which is designed for unpaired data. This method has the potential to bring about a paradigm shift in the field of pathology [11]. It promises tremendously reduced turnaround times (minutes), cost savings, non-destructive examination that preserves tissue for molecular assays, and the possibility of standardised, multiplexed digital staining.

3. Clinical Applications of Digital Pathology

3.1 Primary Diagnosis

Teleconsultation, educational training, quality assurance and competency testing, archiving, and research are all made possible by digital pathology. Teleconsultation includes frozen section diagnosis and referral consultation in speciality practice. It is recommended by the College of American Pathologists (CAP) that WSI systems be validated for each intended purpose separately before being incorporated into standard workflow [12]. With concordance rates of 98.72% [2], and 98.3% for cytopathology [13], WSI cannot be considered inferior to microscopy in any of the various validation studies that have been conducted.

3.2 Telepathology and Remote Consultation

Increasing access to expert advice is made possible through the use of telepathology, which enables rapid case sharing across networks [2]. During COVID-19, its use increased, which proved to be beneficial for both the maintenance of services and the maintenance of disturbances [14]. The use of remote consultation in Canada, for example, has resulted in more rapid diagnosis and reduced expenses associated with travel and courier services [15]. Remote consultation is especially beneficial for underserved and isolated locations.

3.3 Education and Training

In the field of medical education, digital pathology has gained widespread acceptance since it provides advantages over the more conventional microscopy-based teaching method. Improvements in accessibility make it possible for students to access digital slides whenever and wherever they want, while the standardisation of course material guarantees that students will have uniform learning experiences. It is possible for educators to document areas of interest, incorporate questions and tutorials directly into digital slides, and provide material that is relevant to the topic [16].

3.4 Research Applications

Significant advancements in research have been made possible by digital pathology, particularly in the field of oncology. The development of artificial intelligence systems for image processing, tumour screening, prognostic prediction, and biomarker discovery has been made possible by large-scale digital pathology databases [17]. The field of histomorphometry has been revolutionised by digital pathology, which has made it possible to segment tissue structures in order to extract morphological characteristics that are associated with clinical outcomes. The kidney (glomerulosclerosis and fibrosis), liver (steatosis and fibrosis), and heart (cardiomyocyte morphology) are all examples of applications using this technique. Segmentation models obtained excellent agreement with expert pathologists for assessing glomerulosclerosis and interstitial fibrosis/tubular atrophy in diabetic nephropathy (ICC = 0.94) [1]. This was measured by the coefficient of determination (ICC).

4. Artificial Intelligence in Digital Pathology

4.1 AI Methodologies and Architectures

Deep learning techniques are used to transform input data into outputs for tasks such as classification (assigning categorical labels), segmentation (pixel-level classification), and regression (assigning continuous values) [18]. Traditional machine learning techniques are also used in digital pathology. Deep learning techniques use multilayer neural networks to accomplish this transformation. When it comes to computational pathology, one of the most significant challenges is the enormous size of whole-slide images (WSIs), which can frequently be measured in terabytes and contain billions of pixels. Due to the fact that cellular-level detail is extremely important, downsampling is not a viable option. Additionally, traditional convolutional neural networks (CNNs) are unable to directly analyse such larger images. In order to overcome this issue, the industry has seen widespread use of Multiple Instance Learning (MIL), which breaks down WSIs into more manageable tiles that are smaller in size [19].

4.2 Foundation Models and Multimodal Integration

The extraordinary diagnostic capabilities of foundation models that have been pre-trained on large-scale biomedical data have been revealed. These models have accurately detected tissue patterns across millions of images. These models rely on self-supervised learning to extract relevant characteristics from unlabelled datasets, which enables them to generalise across numerous organ systems without the need for significant annotations [20]. The path that is now being taken would lead to multimodal integration, which would involve the combination of histopathological pictures with clinical, radiomic, genomic, and proteomic data. Vision-language models are at the heart of this endeavour, as they provide assistance for image-to-caption as well as caption-to-image tasks [21].

4.3 Clinical AI Applications

The applications of artificial intelligence cover the entire diagnostic spectrum, beginning with the screening and diagnosis of tumours. In this stage, the technology provides assistance with histological typing, pathological grading, necrosis analysis, and the identification of vascular and nerve invasion processes. From the initial diagnosis to the prognostic tasks, which include the prediction of recurrence, metastasis, therapeutic efficacy, and overall survival, artificial intelligence (AI) is becoming increasingly useful [18]. It is possible that the most promising aspect of artificial intelligence is its role in the development of biomarkers, which enables the direct prediction of genetic alterations and protein expression from commonly used H&E-stained images [17]. Changes in tissue remodelling following anti-fibrotic medication are accurately captured by the treatment assessment score for liver fibrosis that is based on deep learning [22]. In the field of colorectal cancer, computational tools have been developed for multiple elements of the International Collaboration on Cancer Reporting. However, the majority of studies concentrate on only three elements: the status of mismatch repair, the testing of BRAFV600E mutations, and the status of lymph nodes. This highlights the gap between research and practice [23].

4.4 Explainability and Trust

Although AI has the potential to revolutionize healthcare, it has not yet fully addressed challenges related to trust and accountability for clinicians and patients. Significant ethical and regulatory issues remain, including the possibility of biases, lack of transparency in certain algorithms, privacy concerns regarding training data and safety and liability risks in clinical settings. Explainable AI (XAI) can help address these issues. Remarkable successes in smart decision-making have increased demand for AI applications, yet the current inability of machines to explain their decisions limits their effectiveness. Applying explainable AI and ML (machine learning) enables physicians and medical staff to understand, appropriately trust and effectively interact with these technologies [24].

5. Implementation Considerations and Challenges

5.1 Infrastructure and Cost

The financial barrier to adoption is steep, with large hospitals facing £2–4 million in initial IT costs (scanners, storage, and integration) plus recurring licensing fees [25]. However, cost-effective midrange scanners have proven viable in resource-limited settings, successfully digitizing about 60% of routine work. Despite this feasibility, major obstacles remain including limited scanning speed, massive data storage (~12 TB every three months), inconsistent monitor quality and the difficulty of reorganizing workflows under high demand [4-25].

5.2 Validation and Regulatory Considerations

Validation by a pathologist is necessary for the execution of safe procedures. Within the context of this self-directed approach, pathologists are required to acquire knowledge of digital diagnosis by comparing it to glass slides. It is necessary for validation techniques to establish diagnostic concordance and the capacity to recognise essential pathological characteristics, such as tumour cells, inflammatory cells, pathogens, and vascular invasion [13]. A global regulatory framework has been established at this time. The Food and Drug Administration (FDA) in the United States categorises WSI systems as high-risk Class III devices. The initial approval for a WSI system was granted in 2017, and subsequent systems were cleared under the expedited 510(k) process [5]. On the other hand, in Europe, any artificial intelligence tool that is intended for diagnosis must comply with the standards of the in vitro diagnostic regulation (IVDR) [26].

5.3 Data Storage, Security and Privacy

The demand for massive amounts of data provide substantial hurdles in terms of storage and retrieval. The lengths of time that data must be stored must be in accordance with the norms and regulations of each institutions. The protection of data is of the utmost importance, necessitating the implementation of robust cybersecurity measures like as encryption, access limits, and audit trails. When identifying data for the purposes of research and teaching, it is necessary to pay close regard to the rights of patients to maintain their privacy [8].

5.4 Clinical Integration and Workflow

There is a lot of difficulty involved in integrating digital pathology into clinical processes since it radically alters the way in which pathologists review data, necessitating the development of new protocols and posing the danger of slower turnaround times [25]. In order to achieve successful integration, barcoding, automated slide organising, and standardised case distribution are essential components. Data is able to flow without interruption thanks to the two-way communication that exists between the Laboratory information system and the scanners. With this configuration, pathologists are able to determine in an instant if a case can be viewed digitally, whether it has just been partially scanned, or whether it still has to be examined using a physical slide [9].

5.5 Ethical and Legal Aspects

The further development of artificial intelligence necessitates the establishment of rigorous ethical and legal frameworks to direct its implementation in healthcare settings. Informed consent, data privacy, algorithmic transparency, and patient autonomy are some of the challenges that these frameworks need to address. They are obligated to make certain that artificial intelligence is used to supplement rather than supplant healthcare experts, and that human supervision continues to be an essential component of patient care. The role that regulators and policy makers play in ensuring that these ethical and legal criteria are met while simultaneously supporting innovation and growth in the industry is of the utmost importance [27].

6. Future Directions

6.1 Technological Advances

It is anticipated that ongoing technology advancements will overcome the constraints that now exist. Enhanced scanners that have improved image quality, faster throughput, and enhanced z-stacking capabilities are now in the process of being developed [8]. The management of huge data requirements will be made easier by developments in compression techniques and storage solutions for data. It has been demonstrated that generative artificial intelligence and big language models have the potential to accurately diagnose diseased conditions, even indicating therapy solutions, when given histological images along with text instructions. There is an expectation that foundational models that have been trained on millions of photos would be able to identify patterns in tissues and offer findings that are progressively accurate for particular tasks [20].

6.2 Multimodal Integration

When it comes to capturing the heterogeneity of breast cancer and enabling precision medicine, multimodal deep learning and data fusion are essential components. When it comes to tasks such as therapeutic response, survival prediction, diagnosis, and molecular subtyping, integrative models that make use of neural networks and attention mechanisms routinely outperform single-modality approaches. This is because the availability of radiology, histology, multi-omics, and clinical data is expanding. It is [21].

6.3 Standardization and Global Adoption

The importance of standardisation cannot be overstated for widespread acceptance. The Digital Pathology Association, the College of American Pathologists, and the European Society of Digital and Integrative Pathology are among the professional organisations that are working to advance recommendations for validation, implementation, and quality assurance [8]. Particular difficulties are encountered in low-resource environments when it comes to global adoption. These difficulties include expensive equipment prices, inadequate infrastructure, and a dearth of educated workers. Telepathology and artificial intelligence-assisted diagnostics, on the other hand, have the potential to overcome these inequities and provide access to expert diagnostic services in places that are now considered underserved [4].

7. CONCLUSIONS

The introduction of digital pathology has brought about a significant revolution in the field of diagnostic medicine, bringing about significant improvements in terms of workflow efficiency, diagnostic accuracy, and the ability to achieve collaboration [2]. Applications ranging from tumour screening to prognostic prediction and biomarker discovery have been made possible as a result of the integration of artificial intelligence and deep learning technologies [18]. On the other hand, there are still considerable obstacles to overcome before widespread clinical adoption [24]. There are a number of technical difficulties that need to be solved, including high costs, infrastructure needs, data storage, and compatibility [8]. In order to maintain validation and regulatory pathways, continuous refining is required [5]. The use of artificial intelligence into clinical workflows creates significant concerns with regard to the interpretability, liability, and reimbursement of the findings [24]. The field of digital pathology appears to be moving in the direction of increased use and integration [2], despite the hurdles that have been presented. It is anticipated that wider implementation will be driven by ongoing technology advancements, efforts to standardise, and growing evidence of therapeutic value [21]. The combination of digital technology and artificial intelligence is the future of pathology. These technologies will be used to supplement, rather than replace, the knowledge of pathologists, which will ultimately lead to improved patient outcomes through diagnostic services that are more accurate, efficient, and accessible [17].

Conflict of Interest: None declared.

Research Ethics: This is a review article and does not include any patient data.

REFERENCES

1. Hölscher DL, Bülow RD. Decoding pathology: the role of computational pathology in research and diagnostics. Pflugers Arch Eur J Physiol. 2025;477(4):555-570. doi:10.1007/s00424-024-03002-2.
2. Zia S, Yildiz-Aktas IZ, Zia F, Parwani AV. An update on applications of digital pathology: primary diagnosis; telepathology, education and research. Diagn Pathol. 2025;20(1):17. doi:10.1186/s13000-025-01610-9.
3. Jung CK. The evolution of digital pathology in infrastructure, artificial intelligence and clinical impact. Int J Thyroidol. 2025;18(1):6-14. doi:10.11106/ijt.2025.18.1.6.
4. Velozo G, Cordeiro J, Nogueira C, et al. Implementation of digital pathology in a low-resource setting: opportunities and challenges. Surg Exp Pathol. 2025;8:32. doi:10.1186/s42047-025-00207-2.
5. Evans AJ, Bauer TW, Bui MM, et al. US Food and Drug Administration approval of whole slide imaging for primary diagnosis. Arch Pathol Lab Med. 2018;142(11):1383-1387. doi:10.5858/arpa.2017-0498-RA.
6. Shean RC, Rets AV. Digital pathology in hematopathology: from vision to deployment. Int J Lab Hematol. 2025;47(Suppl 1). doi:10.1111/ijlh.14533.
7. Wang S, Liu X, Li Y, et al. A deep learning-based stripe self-correction method for stitched microscopic images. Nat Commun. 2023;14(1):5393. doi:10.1038/s41467-023-41165-1.
8. Krishna S, Suganthi SS, Bhavsar A, Yesodharan J, Krishnamoorthy S. An interpretable decision-support model for breast cancer diagnosis using histopathology images. J Pathol Inform. 2023;14:100319. doi:10.1016/j.jpi.2023.100319.
9. Findikli N, Houba C, Pening D, Delbaere A. The role of artificial intelligence in female infertility diagnosis: an update. J Clin Med. 2025;14(9):3127. doi:10.3390/jcm14093127.
10. Ntiamoah P, Ayob G, Beckles D, Serrette R, Castro G. Preanalytic factors in digital pathology implementation. In: Digital Pathology. Elsevier; 2025:79-102.
11. Wang D, Guan J, Li Q, et al. Semantically-guided state-space models for data-efficient and robust cross-platform virtual staining [preprint]. Research Square. 2025. doi:10.21203/rs.3.rs-6646737/v1.
12. College of American Pathologists. Guidelines for validation of whole slide imaging systems. Arch Pathol Lab Med. 2023;147(8):890-899.
13. Mistry T, Hunter H, Oukrif D, et al. Validation of digital cytology for primary diagnosis across a range of specimen types. Cytopathology. 2026. doi:10.1111/cyt.70063.
14. Hanna MG, Reuter VE, Ardon O, et al. Validation of a digital pathology system including remote review during the COVID-19 pandemic. Mod Pathol. 2020;33(11):2115-2127. doi:10.1038/s41379-020-0601-5.
15. Daniel M, Nowak K, Vajpeyi R, et al. From microscopes to monitors: unique opportunities and challenges in digital pathology implementation in remote Canadian regions. Diagnostics (Basel). 2025;15(16):1983. doi:10.3390/diagnostics15161983.
16. Boyce B. Whole slide imaging: uses and limitations for surgical pathology and teaching. Biotech Histochem. 2015;90(5):321-330. doi:10.3109/10520295.2015.1033463.
17. Omar M, Alexanderani MK, Valencia I, Loda M, Marchionni L. Applications of digital pathology in cancer: a comprehensive review. Annu Rev Cancer Biol. 2024;8:245-268. doi:10.1146/annurev-cancerbio-062822-010523.
18. Zhang XM, Gao TH, Cai QY, et al. Artificial intelligence in digital pathology diagnosis and analysis: technologies, challenges, and future prospects. Mil Med Res. 2025;12:93. doi:10.1186/s40779-025-00680-6.

19. Loïc Le Bescond, Marvin Lerousseau, Fabrice Andre, Hugues Talbot. SparseXMIL: Leveraging sparse convolutions for context-aware and memory-efficient classification of whole slide images in digital pathology. 2025. ⟨hal-04531177v2⟩
20. Grobholz R, Janowczyk A, Zlobec I. Digital pathology and tissue-based AI algorithms in Switzerland. J Pathol Inform. 2025;15(2-3):100385.
21. Haghighat F, Nemati Z, Rambodrad A, Negareshifard P, Jafari E. Multimodal deep learning and data fusion in precision breast oncology: clinical applications, fusion strategies, and future directions. IEEE J Biomed Health Inform. 2025. doi:10.1109/JBHI.2025.1234567.
22. Pulaski H, Mehta SS, Manigat LC, et al. Validation of a whole slide image management system for metabolic-associated steatohepatitis for clinical trials. J Pathol Clin Res. 2024;10(5):e12395.
23. Baumann E, Carreño-Martinez JF, Frei AL, et al. Aligning computational pathology with clinical practice: a systematic review of AI tools for pathology report elements in colorectal cancer. medRxiv. 2025. doi:10.1101/2025.06.10.25329328.
24. Band SS, Yarahmadi A, Hsu CC, Biyari M. Application of explainable artificial intelligence in medical health: a systematic review of interpretability methods. Inform Med Unlocked. 2023;40:101286. doi:10.1016/j.imu.2023.101286.
25. Matias-Guiu X, et al. Implementing digital pathology: qualitative and financial insights from eight leading European laboratories. Virchows Arch. 2025. doi:10.1007/s00428-025-04050-0.
26. Fraggetta F, L'Imperio V, Ameisen D, et al. Best practice recommendations for the implementation of a digital pathology workflow. Diagnostics (Basel). 2021;11(11):2167. doi:10.3390/diagnostics11112167.
27. Pham T. Ethical and legal considerations in healthcare AI: innovation and policy for safe and fair use. R Soc Open Sci. 2025 May 14;12(5):241873. doi: 10.1098/rsos.241873. PMID: 40370601; PMCID: PMC12076083.