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EDITORIAL

Digital Pathology: Past, Present and Future

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Introduction

Digital pathology has been an important asset in contemporary diagnostic medicine. From telepathology early in the 1960s and 1970s to today's use of artificial intelligence (AI) algorithms, and whole slide imaging (WSI), the speciality has developed significantly. In this editorial, we will explore the immense transformation of digital pathology, its present state, its benefits, its difficulties and how it can influence the future.

The Origins and Past of Digital Pathology—Telepathology to Digital Imaging

The origin of digital pathology goes back to the conceptualisation of telepathology, which benefited pathologists by allowing them to diagnose and consult cases from remote locations using a microscope which included real-time video. This began in the 1960s and 1970s, however, they were limited due to the high expense of specialised equipment, image quality and constrained network speed. Nevertheless, these early interventions created a foundation for digital pathology.

In the 1980s and 1990s, telepathology gained traction within niche applications; despite being mentioned for the first time in English articles in the 1980s (Weinstein, 1986). For instance, remote consultations within isolated areas, as reported by Dunn et al (2009). Although this technology seemed incredibly impressive at the time, it still had its tendencies, such as: low quality/resolution of monitors and cameras, and network issues. Due to these challenges, the technology was not getting much appreciation by pathologists for day-to-day usage, though it was considered useful for very specific situations and research purposes.

In the late 1990s and early 2000s, a major breakthrough occurred due to extreme advancement in computing, including software and hardware development that led to the critical point of innovation in cellular pathology. That was coupled with improved features of computer storage and scanning technology. Whole slide imaging (WSI) has transformed digital pathology as it began the glass slide conversion into improved, higher-resolution digital files. This was a game changer as the entire slide was being scanned by high-resolution scanners at various magnifications, initially at ×20 and later standardised to ×40. That brought a revolution in the advancement of pathology and put cellular pathology into a new digital world. Early pioneers realised the vast potential of whole slide imaging and how it can change the future of digital pathology.

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The Present of Digital Pathology—A Rapidly Growing Field

In recent years, there have been multiple factors which accelerated the growth of digital pathology. Scanning hardware improvements have allowed high-resolution scanning of glass slides possible at high speed. Immense progress in data storage and retrieval has enabled the industry to store and retrieve vast amounts of data effectively.

Validation and Accreditation

A massive milestone has been attained in UK when studies like "Validation of digital pathology imaging for primary histopathological diagnosis" carried out in 2015–2016 (Snead et al, 2016) immediately followed by other studies like all Wales verification and validation of digital pathology for primary diagnosis (Babawale et al, 2021). This led to the development of various guidelines on the use of digital pathology for primary diagnosis by the Royal College of Pathologists, London, Cross et al (2018) and Aslam et al (2020).

However, the digital transition was not slower in the North America and major breakthrough happened when College of American Pathologists (CAP) guidelines were released stipulating how to validate whole slide imaging for diagnostic use, Pantanowitz et al (2013) followed by Food and Drug Administration (FDA) approval (Technical Performance Assessment of Digital Pathology Whole Slide Imaging Devices, 2016). Having the availability of these guidelines improved regular practices and allowed laboratories a ground plan for analysing, testing, and executing efficient digital pathology workflows, getting ready for digital embracement and modernising the laboratories, as it was realised that the digital workflow is not only scanning but a lean and effective pathway throughout the labs. Numerous institutional studies displayed that pathologists could diagnose histopathological cases with high consensus using whole slide imaging rather than the traditional microscope. These validations increased the number of institutions substantially on a global level to adopt digital pathology for primary diagnosis.

Workflow and Efficiency Gains

Digital pathology was able to unlock an optimised workflow as digital platforms integrated seamlessly with Laboratory Information Systems (LIS). Pathologists can access cases remotely, review digital slides in real time and immediately collect data from multiple sources. This improved connectivity has improved diagnosis turnaround time but also encourages multidisciplinary collaboration. For example, boards/multidisciplinary team meetings (MDTs) can discuss cases with the highest quality and resolution images, which are accessible, radiologists, oncologists, and surgeons all at once, regardless of their location.

Economic Considerations

The initial capital expenses can be significant for digital pathology, which covers software, scanners, and infrastructure. There is an enormous amount of evidence indicating that the technology within the pathological world can yield cost

savings over time (Ho et al, 2014). For instance, courier expenses for sending slides between institutions and faster case sign-out times have been reduced. Successful laboratories which have gone "fully digital" have reported gains in increased productivity, very few errors within slide handling, and an efficient workflow.

AI and Machine Learning

Artificial intelligence and machine learning are prepared to redefine the whole diagnostic workflow. Artificial intelligence tools do provide rapid, quantitative assessments that may even surpass a human's work ability in specific tasks. We are already seeing this in the studies carried out on various scales. For example, in Wales, so far more than 6000 prostate patients have been double reported using AI, which significantly improved the diagnostic and prognostic capabilities of reporting pathologists by major contribution towards the quality of the patient diagnostic journey. The algorithm is also used in Wales in Breast and upper gastrointestinal (GI) pathology, with the highest throughput and significant qualitative benefits to the patients, being an additional strong tool to the pathologist. AI in cellular pathology is extremely clever in terms of repetitive tasks like measurement and marking of points of interest, identifying and calculating positive areas such as Ki67, breast markers, mitoses and so on. Algorithms are also used currently by various providers to make sure all slides are being examined and all parts of the slides are being examined.

The Future of Digital Pathology

AI-Driven Morphological Diagnostics

An extremely exciting aspect of digital pathology is the development of artificial intelligence algorithms that can aid in detecting cancer metastasis (Ehteshami Bejnordi et al, 2017), biomarkers and evaluating morphological features. Numerous studies have shown that deep learning algorithms can identify and grade breast and prostate cancer accurately (Heath and Aslam, 2023). Furthermore, detect lymph node metastasis and subtype cancers. These AI tools are incredibly beneficial as they are trained on large sets of labelled images that can speed up certain tasks like cell counting. This can make it easier for pathologists to focus on more complex diagnostic considerations. National and global deployment of digital pathology tools with the background of digital pathology will be a game changer for the speciality and patient diagnostic pathways.

AI-Driven Lab Workflow

Tools are available in research and are being prepared for clinical deployment, which can real-time identify the likelihood of being malignant to triage those cases based on morphology rather than only clinical impression. There are tools in various development which can help the laboratories to identify the appropriate workflow for specific sample from the booking-in area to the morphological assessment to pathologists input and alertness of appropriate slide and slide portions examined and finally helping in the development of AI/human interactive clever reporting tool for each patient (White et al, 2025).

Precision Medicine and Biomarker Analysis

Since oncological treatments increasingly rely on biomarkers, for instance, Programmed Death-Ligand 1 (PD-L1) status in lung cancer or Human Epidermal Growth Factor Receptor 2 (HER2) overexpression in breast cancer, the need for accurate and reproducible pathology readouts becomes paramount. Artificial intelligence algorithms integrated into digital pathology platforms can provide more consistent results. This ensures that patients are receiving the most appropriate, targeted treatments. Pathology labs of the future may offer automated biomarker quantification as a standard service, reducing subjectivity and inter-observer variability. Likewise, using the algorithm, we can answer intriguing questions like why certain patients with the same stage have different clinical outcomes, which can potentially improve our understanding on cancer biology and help us develop new guidelines of adjunct treatment for high-risk patients. The technology is also developing to identify the mutated genes based on the morphology by the algorithm, which potentially saves time and resources to perform expensive genomic testing on a subset of patients.

Remote Consultations and Global Collaboration

Although telepathology is not new, the release of robust digital pathological networks will transform global healthcare collaboration significantly (Retamero et al, 2020). Resource-limited pathologists can upload slides for expert consultations in specialised centres. Also, global archives of digitally scanned images can facilitate research efforts, which will allow large-scale data analysis and more real-world evidence. This significant interconnection can improve public health response and ensure consistent pathology training worldwide. That could potentially support patients from pathologist-deprived nations and help in getting globally improved cancer pathways.

Challenges and Considerations

Although there is a very positive outlook of artificial intelligence on the basis of digital pathology, there are still many challenges remaining. The combination of using AI tools into clinical workflow would require to be validated and oversighted regularly and needs to be supported by appropriate national and global regulations. Also, ensuring data privacy and security are always paramount, when dealing with large-scale collaborations and cloud-based solutions certainly within the time when cybersecurity is extremely challenging to maintain. Moreover, the high expenses of data storage and advanced scanners may continue to create issues for smaller institutions; however, it could potentially help in collaboration and working together. As digital pathology becomes more automated, the question of balancing pathologists' interpretive skills arises with appropriate training to the trainee pathologists. Having a balance between human expertise and automation will be key to benefit from technology without diminishing professional competencies.

Educational Transformation and Workforce Implications

Digital pathology has also transformed medical learning and education. Virtual slides are used in pathology training programs, offering residents consistent exposure to specific cases that might not be available in a single institution. The digital pathology provided significant benefit to the training scheme during the Coronavirus Disease (COVID) period and helped appropriate training to carry on using digital pathology. Likewise, in the UK, almost all of the External Quality Assessment Schemes are digital now, which is helping significantly in teaching and training on interesting and complex cases without the need of expensive and time-consuming slide cutting and postage to each institute. The resource is available for teaching pathologists globally rather than just restricted to the participants as was previously. The trend will continue and expand with artificial intelligence-driven educational tools that can assist trainees in identifying histological features in real time. Programs that integrate digital pathology from the beginning will help the new generation of pathologists to adapt to digital workflows supported by AI quickly.

Furthermore, the implications of digital pathology on the workforce can be profound and a little bit unknown. At hindsight, it may appear that automation may reduce the need for pathologists, but in reality, and small studies so far, it suggests a future collaboration where pathologists will benefit from using AI tools for their diagnostic work, and the cellular pathology will turn into more objective and reproducible science helping the future patients.

Conclusion

The field of digital pathology is moving rapidly from its modest telepathology roots to an evolving artificial intelligence-driven field, with an end-to-end cellular pathology pathway which displays innovative adaptability of the pathology community. Soon, whole slide imaging will continue to be used in laboratories as a routine part of diagnostic workflows, propelled by an abundance of evidence of efficiency, cost-effectiveness and improved patient outcomes, and it is not far from when cellular pathology will be de facto digital cellular pathology.

Although it seems digital pathology is growing in the right path positively, it does still have its issues from regulatory hurdles, data privacy, from infrastructure costs to the need for workforce training. Moving forward, a collaborative mindset among clinicians, pathologists, computer scientists, researchers and policymakers will continue transforming the potential of digital pathology. The future of pathology, it literally is in the digital world.

Key Points

- Digital pathology has rapidly progressed from telepathology beginnings to advanced whole slide imaging (WSI) and powerful artificial intelligence (AI) applications.
- Currently, digital platforms offer significant improvements in diagnostic accuracy, workflow efficiency, remote accessibility, and cost-effectiveness for pathology laboratories.
- The future promises wider adoption of AI-driven diagnostics and biomarker analysis, enhancing precision medicine, global collaboration, and overall patient care.
- Despite these advancements, digital pathology must overcome challenges such as regulatory compliance, infrastructure costs, data security, and workforce training to fully realise its potential.

Availability of Data and Materials

Not applicable.

Author Contributions

SB and MA were responsible for the design of the work, drafting and revision of content. Both authors contributed to the important editorial changes in the manuscript. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

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Conflict of Interest

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References

Aslam M, Barrett P, Gareth Bryson G, Cross S, Snead D, Treanor D, et al. Guidance for remote reporting of digital pathology slides during periods of exceptional service pressure. The Royal College of Pathol-

ogists. 2020. https://www.rcpath.org/static/626ead77-d7dd-42e1-949988e43dc84c97/RCPath-guidance-for-remote-digital-pathology.pdf (Accessed: 11 January 2025)

Babawale M, Gunavardhan A, Walker J, Corfield T, Huey P, Savage A, et al. Verification and Validation of Digital Pathology (Whole Slide Imaging) for Primary Histopathological Diagnosis: All Wales Experience. Journal of Pathology Informatics. 2021; 12: 4. https://doi.org/10.4103/jpi.jpi_55_20

Cross S, Furness P, Igali L, Snead D, Treanor D. Best practice recommendations for implementing digital pathology January 2018. The Royal College of Pathologists. Microsoft Word - Best practice recommendations for implementing digital pathology. 2018. https://www.rcpath.org/static/f465d1b3-797b-4297-b7fedc00b4d77e51/Best-practice-recommendations-for-implementing-digital-pathology.pdf (Accessed: 11 January 2025)

Dunn BE, Choi H, Recla DL, Kerr SE, Wagenman BL. Robotic surgical telepathology between the Iron Mountain and Milwaukee Department of Veterans Affairs Medical Centers: a twelve year experience. Seminars in Diagnostic Pathology. 2009; 26: 187–193. https://doi.org/10.1053/j.semdp.2009.09.007

Ehteshami Bejnordi B, Veta M, Johannes van Diest P, van Ginneken B, Karssemeijer N, Litjens G, et al. Diagnostic Assessment of Deep Learning Algorithms for Detection of Lymph Node Metastases in Women With Breast Cancer. JAMA. 2017; 318: 2199–2210. https://doi.org/10.1001/jama.2017.14585

Heath A, Aslam M. Successful deployment of an Artificial Intelligence solution for primary diagnosis of prostate biopsies in clinical practice. Trillium Pathology. 2023. https://www.trillium.de/en/journals/trillium-pathology/archive/2023/tp-1/2023/pathology-and-ai/successful-deployment-of-an-artificial-intelligence-solution-for-primary-diagnosis-of-prostate-biopsies-in-clinical-practice.html (Accessed: 11 January 2025)

Ho J, Ahlers SM, Stratman C, Aridor O, Pantanowitz L, Fine JL, et al. Can digital pathology result in cost savings? A financial projection for digital pathology implementation at a large integrated health care organization. Journal of Pathology Informatics. 2014; 5: 33. https://doi.org/10.4103/2153-3539.139714

Pantanowitz L, Sinard JH, Henricks WH, Fatheree LA, Carter AB, Contis L, et al. Validating whole slide imaging for diagnostic purposes in pathology: guideline from the College of American Pathologists Pathology and Laboratory Quality Center. Archives of Pathology & Laboratory Medicine. 2013; 137: 1710–1722. https://meridian.allenpress.com/aplm/article/137/12/1710/185974/Validating-Whole-Slide-Imaging-for-Diagnostic (Accessed: 11 January 2025)

Retamero JA, Aneiros-Fernandez J, Del Moral RG. Complete Digital Pathology for Routine Histopathology Diagnosis in a Multicenter Hospital Network. Archives of Pathology & Laboratory Medicine. 2020; 144: 221–228. https://doi.org/10.5858/arpa.2018-0541-OA

Snead DRJ, Tsang YW, Meskiri A, Kimani PK, Crossman R, Rajpoot NM, et al. Validation of digital pathology imaging for primary histopathological diagnosis. Histopathology. 2016; 68: 1063–1072. https://doi.org/10.1111/his.12879

Technical Performance Assessment of Digital Pathology Whole Slide Imaging Devices. Guidance for Industry and Food and Drug Administration Staff. 2016. Available at: https://www.fda.gov/media/90791/download (Accessed: 11 January 2025).

Weinstein RS. Prospects for telepathology. Human Pathology. 1986; 17: 433–434. https://doi.org/10.1016/s0046-8177(86)80028-4

White CD, Chetty R, Weldon J, Morrissey ME, Sykes R, Gîrleanu C, et al. A deep learning approach to case prioritisation of colorectal biopsies. Histopathology. 2025; 86: 373–384. https://doi.org/10.1111/his.15331