INSIGHTS-JOURNAL OF
LIFE AND SOCIAL SCIENCES

INSIGHTS-JLSS
Insights-Journal of Life and Social Sciences

EVOLVING TRENDS IN DIAGNOSTIC PATHOLOGY: FROM CONVENTIONAL MICROSCOPY TO DIGITAL AND AI-ASSISTED SYSTEMS – A NARRATIVE REVIEW

Narrative Review

Aneza Arshad Iqbal[1]*, Muhammad Zahoor[2], Zainab Tasawar[3], Sana Abdullah[4], Seema Shafiq[5], Maryam Raza[6]
[1]D Pharmacy Final Year Student, Ziauddin University, Karachi, Pakistan.
[2]Master in Clinical Laboratory Diagnostic, Department of Pediatric Research Institute, Children's Hospital of Chongqing Medical University, Chongqing, China.
[3]House Officer, PAF Hospital, Islamabad, Pakistan.
[4]MPhil Microbiology Scholar, University of Peshawar, Pakistan.
[5]Assistant Professor, Department of Oral Pathology, Islamic International Dental College and Hospital, Riphah International University, Islamabad, Pakistan.
[6]Senior Registrar, National Institute of Child Health, Karachi, Pakistan.
Corresponding Author: Aneza Arshad Iqbal, D Pharmacy Final Year Student, Ziauddin University, Karachi, Pakistan, aimenarshadiqbal45@gmail.com

Conflict of Interest: None
Grant Support & Financial Support: None
Acknowledgment: The authors would like to acknowledge the valuable contributions of researchers and clinicians whose work in digital pathology and artificial intelligence has informed and inspired this review. No specific funding was received for the preparation of this manuscript.

ABSTRACT

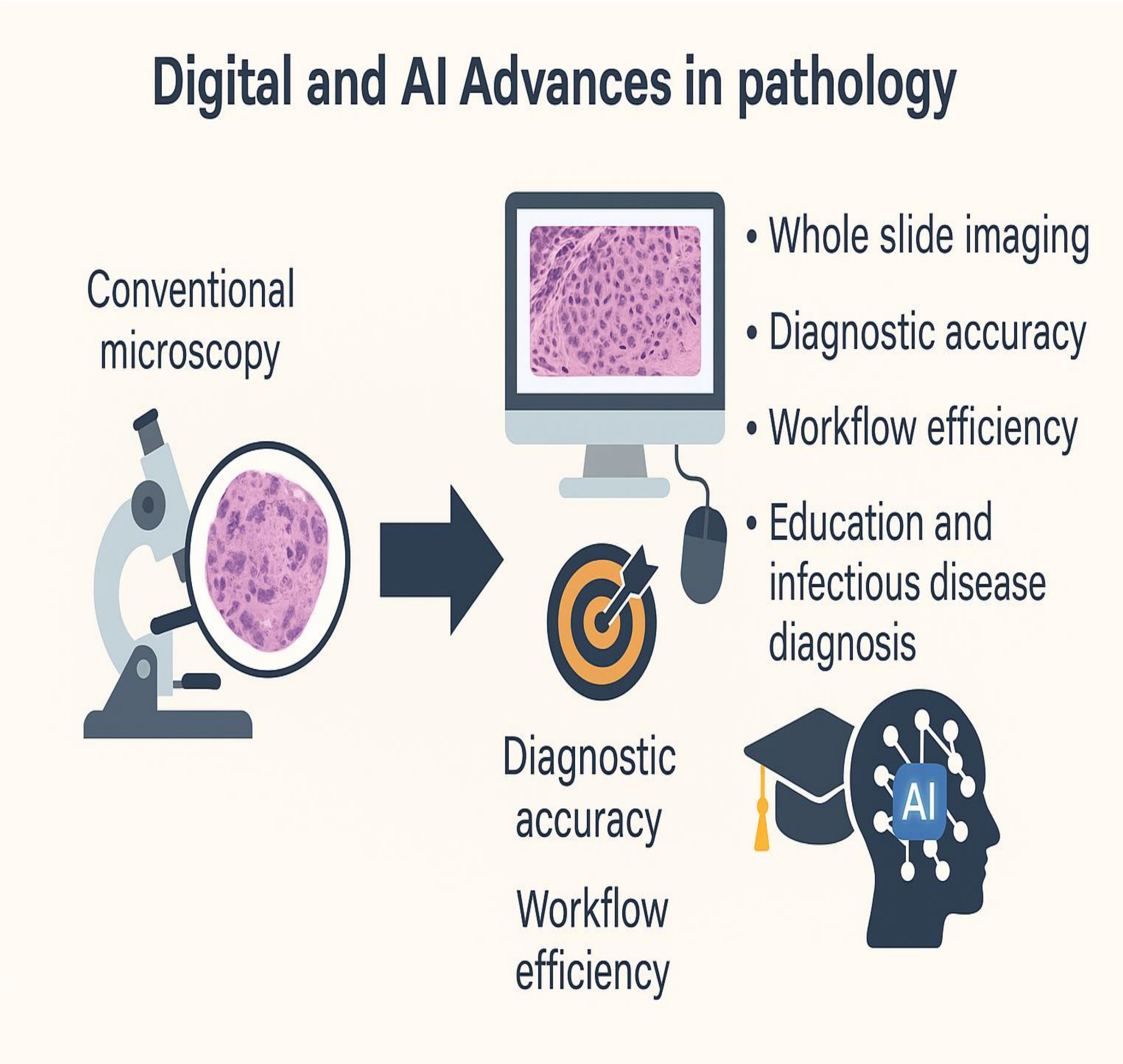
Background: The field of diagnostic pathology is undergoing a paradigm shift from traditional light microscopy toward digitally enhanced and artificial intelligence (AI)-assisted systems. This transition is driven by growing demands for diagnostic accuracy, efficiency, and accessibility amid rising global disease burdens and workforce shortages. Digital pathology and AI applications are increasingly being integrated into clinical, educational, and research settings, presenting both opportunities and challenges for contemporary pathology practice.

Objective: This narrative review aims to explore the evolving landscape of diagnostic pathology, focusing on the transition from conventional microscopy to digital platforms and AI-supported systems. The review highlights current developments, assesses their implications, and identifies gaps in the literature to inform future research and clinical implementation.

Main Discussion Points: Key themes include the adoption of whole slide imaging (WSI), the role of AI in augmenting diagnostic accuracy and workflow efficiency, and the use of digital pathology in education and infectious disease diagnosis. The review also addresses critical limitations in current research, including methodological inconsistencies, limited generalizability, and publication bias. Interoperability issues and the need for standardized guidelines are discussed as major hurdles to widespread adoption.

Conclusion: Digital and AI-assisted pathology systems hold substantial promise for improving diagnostic practice, yet robust clinical validation remains limited. There is a clear need for large-scale, methodologically sound studies to guide evidence-based integration. Strategic implementation and ongoing research are essential to harness the full potential of these innovations in routine pathology.

Keywords: Digital Pathology, Artificial Intelligence, Diagnostic Imaging, Whole Slide Imaging, Histopathology, Narrative Review.


Digital and AI Advances in pathology
Conventional microscopy
• Whole slide imaging
• Diagnostic accuracy
• Workflow efficiency
• Education and infectious disease diagnosis
Diagnostic accuracy
Workflow efficiency
AI

INTRODUCTION

Over the past two decades, the field of diagnostic pathology has witnessed a transformative shift catalyzed by rapid advances in digital imaging, computational technologies, and artificial intelligence (AI). Traditionally reliant on the visual interpretation of stained tissue sections under light microscopy, pathology has served as the gold standard for diagnosing a multitude of diseases, particularly cancers. However, this conventional approach, while time-honored, is not without its limitations—including interobserver variability, labor-intensive workflows, and limited accessibility in remote or resource-constrained environments. In light of these challenges, there is a growing impetus to modernize diagnostic methodologies and integrate more scalable, accurate, and efficient systems (1). This transition is driven not only by technological innovation but also by increasing global demands for more precise and timely diagnoses. Pathology plays a central role in cancer management, and the burden of cancer is rising, with an estimated 19.3 million new cancer cases and almost 10 million cancer deaths worldwide in 2020, according to the Global Cancer Observatory (2). This surge has placed immense pressure on pathology services, particularly as shortages of trained pathologists continue to hamper diagnostic capacity in many regions. Thus, the evolution toward digital and AI-assisted diagnostic platforms presents a pivotal opportunity to alleviate these systemic bottlenecks while maintaining diagnostic rigor (3,4). Recent literature has highlighted the significant strides made in digital pathology, encompassing whole slide imaging (WSI), virtual microscopy, and automated image analysis (5,6). These tools not only allow for the digitization and remote review of pathology slides but also facilitate collaboration, education, and data archiving. More importantly, they form the foundation for integrating AI algorithms capable of identifying subtle histopathological patterns and providing diagnostic support with high sensitivity and specificity. For example, AI-powered platforms have demonstrated near-perfect sensitivity and over 80% specificity in identifying malignant tumors across various organs, enabling accurate tumor subtyping and streamlining the workflow for practicing pathologists (7,8)

Despite the progress, several gaps remain in the current understanding and implementation of these technologies. While numerous studies have explored the technical feasibility and initial clinical outcomes of AI-assisted pathology, comprehensive evaluations of integration barriers, real-world performance metrics, and long-term impacts on diagnostic accuracy and healthcare delivery are still limited (9). Furthermore, concerns about standardization, data privacy, regulatory frameworks, and pathologist training need to be systematically addressed to enable broader adoption. As noted in a recent review, although digital and AI-enhanced multiphoton microscopy show promise for improved diagnostic precision, challenges related to data management, algorithm validation, and clinical deployment persist (10,11) This narrative review aims to chart the evolutionary trajectory from conventional light microscopy to state-of-the-art digital and AI-assisted systems in diagnostic pathology. It explores how digital imaging, automation, and machine learning are reshaping pathology workflows, enhancing diagnostic precision, and potentially redefining the pathologist's role. The scope of this review includes recent peer-reviewed literature from the past five years, with a particular focus on human diagnostic applications. Studies and expert opinions addressing implementation, technical innovations, performance metrics, and clinical outcomes are included to provide a balanced and evidence-informed perspective. By synthesizing available evidence, this review seeks to fill a critical gap in the literature by offering a consolidated understanding of how digital pathology and AI tools are being adopted and optimized in diagnostic practice. The discussion emphasizes both the practical benefits—such as reduced turnaround times, reproducibility, and remote access—and the challenges—such as cost, training, and validation. Ultimately, this review serves not only as a primer for clinicians and researchers but also as a guide for healthcare systems and policymakers aiming to navigate the digital transformation in pathology with informed strategic decisions. In conclusion, as pathology enters a new era of digitalization and intelligence, understanding the full implications of this transition is vital. By documenting both the technological progress and remaining hurdles, this review contributes to a more nuanced and actionable vision of the future of diagnostic pathology.

THEMATIC DISCUSSION

The Emergence of Digital Pathology and Whole Slide Imaging (WSI)

The foundation of the transition from conventional to digital pathology lies in the advent of whole slide imaging (WSI), which allows for the digitization of entire histological slides at diagnostic resolution. Digital platforms have shifted the diagnostic paradigm by enabling remote consultation, enhanced slide sharing, and streamlined data archiving. Multiple studies have demonstrated that WSI can achieve diagnostic accuracy comparable to traditional light microscopy. For instance, when used for dermatopathology training, digital slides yielded higher diagnostic accuracy among residents compared to glass slides, particularly with increasing years of experience (9). Moreover, the use of WSI has shown promise in improving efficiency; a time-based study revealed that diagnosis using digital pathology was significantly faster than using light microscopy for immunohistochemical assessments (10). The ability to synchronize tissue sections on a single platform enhances speed and reduces interpretative fatigue, suggesting an evolving preference for digital modalities among pathologists.

Integration of Artificial Intelligence in Diagnostic Workflows

The integration of artificial intelligence (AI) into digital pathology represents a transformative leap in diagnostic capabilities. AI algorithms have been developed to identify malignant features, quantify biomarkers, and even predict prognosis. AI-assisted diagnostic platforms deployed in real-world settings have demonstrated sensitivity close to 100% and specificity over 80% in identifying malignancies across multiple organ systems including the gastrointestinal tract, lungs, and prostate (11). These systems support digital scanners from multiple vendors and can be embedded into hospital information systems, thus enhancing their practicality and real-time utility. Such integration has facilitated seamless workflows where scanned slides are analyzed automatically, and diagnostic reports are generated within minutes. Despite this progress, concerns remain regarding generalizability of AI models across diverse populations and disease subtypes due to dataset limitations and variability in histological presentation.

AI-Augmented Multiphoton Microscopy and Image Processing

Label-free multiphoton microscopy (MPM), when augmented with AI, has emerged as a promising adjunctive diagnostic tool. Unlike traditional staining, MPM relies on intrinsic optical properties of tissues, offering high-resolution imaging without exogenous dyes. AI further enhances this modality by aiding in image preprocessing, segmentation, and classification. A comprehensive review emphasized how AI-empowered MPM has improved diagnostic accuracy in complex disease contexts by providing detailed microstructural and biochemical data (12). However, the adoption of MPM in routine pathology remains constrained by the high cost of equipment, need for technical expertise, and lack of standardized diagnostic criteria. These factors represent significant barriers to widespread clinical implementation, especially in resource-limited settings.

Applications in Infectious Disease Diagnostics

Digital and AI-based pathology systems have shown significant promise in the diagnosis of infectious diseases, particularly in low-resource regions. A prospective study in the Amazonian region of Peru compared the performance of a conventional Kato-Katz method (KK1.0) and an AI-enhanced version (KK2.0) for detecting soil-transmitted helminths. The AI-based system outperformed the traditional method in sensitivity, especially for *Ascaris lumbricoides*, highlighting its potential in global health applications (13). The findings also underscore the adaptability of AI pathology in epidemiological surveillance and mass screening programs. Nonetheless, challenges in standardizing protocols and ensuring consistent internet connectivity for remote areas must be addressed before broader deployment.

Training and Educational Transformation

One of the most immediate impacts of digital pathology has been in education and training. Medical and dental schools adopting virtual microscopy have reported significant improvements in student engagement, learning efficiency, and diagnostic skills. Digital slides allow for scalable teaching, standardized slide content, and remote learning. Students generally exhibit equal or superior diagnostic performance when using digital microscopy compared to conventional methods, and express a preference for the digital format due to ease of navigation and image quality (14). This digital transition not only modernizes pathology education but also prepares trainees for the increasingly digital diagnostic landscape.

Interoperability and Workflow Efficiency

A key advantage of digital pathology systems is their ability to be integrated into existing hospital information systems, thereby optimizing clinical workflows. In a large-scale deployment, an AI-assisted platform was linked with institutional databases, allowing scanned slides to be accessed, analyzed, and reported directly within the diagnostic interface (15). This integration led to significant improvements in reporting time, diagnostic concordance, and pathologist satisfaction. However, interoperability issues—such as incompatible scanner formats, data storage challenges, and non-uniform labeling—still hinder seamless system-wide adoption. Standardization efforts and vendor-neutral solutions are necessary to achieve full digital integration.

Barriers to Adoption and Ethical Considerations

Despite its clear advantages, digital and AI-assisted pathology faces several adoption barriers. High implementation costs, data storage requirements, resistance from practitioners accustomed to traditional microscopy, and regulatory ambiguity are among the chief challenges. There is also concern regarding algorithmic bias, especially if AI models are trained on non-representative datasets. The lack of explainability in deep learning models can reduce clinical trust, particularly when automated results deviate from human expectations. These concerns necessitate transparent algorithm development, robust validation, and clear guidelines for AI use in clinical diagnostics.

Future Directions and Research Gaps

While initial results are promising, more longitudinal, multi-center studies are needed to assess the long-term impact of AI and digital systems on patient outcomes. Comparative studies evaluating diagnostic concordance between AI-assisted platforms and expert pathologists across diverse disease spectra remain limited. Moreover, the role of digital pathology in precision medicine—such as integrating histopathological data with genomic and proteomic information—remains an underexplored frontier. Expanding research in these domains could redefine the future of diagnostics by enabling more individualized and predictive care strategies.

CRITICAL ANALYSIS AND LIMITATIONS

While the integration of digital and AI-assisted systems in diagnostic pathology has garnered substantial attention and demonstrated early promise, critical appraisal of the existing literature reveals several limitations that must be acknowledged. A notable issue across many studies is the reliance on small sample sizes or single-center investigations, which restricts statistical power and increases susceptibility to random error. For example, studies evaluating AI-based diagnostic tools often involve limited case volumes or are conducted within narrowly defined institutional settings, limiting their capacity to draw robust, generalizable conclusions (16,17). The absence of large-scale, multicenter randomized controlled trials (RCTs) further limits the strength of the evidence base. Without such trials, it remains difficult to determine whether observed benefits result from the interventions themselves or from uncontrolled confounding variables. Methodological heterogeneity and potential bias also compromise the reliability of current findings. Several studies, particularly those examining AI platforms, have lacked blinding of evaluators or independent validation cohorts, which introduces performance and detection biases. For instance, in studies reporting high diagnostic sensitivity for AI-assisted platforms, there is often limited clarity regarding the independence of test datasets from the training data, raising concerns about algorithm overfitting and inflated performance estimates (18,19). Moreover, selection bias is frequently evident, with many investigations conducted on pre-selected cases of well-defined pathologies or within educational contexts, such as academic pathology departments or medical schools (20). These controlled environments may not reflect the full complexity or variability seen in routine clinical practice.

Publication bias represents another limitation, with a notable predominance of studies reporting favorable outcomes. Negative, inconclusive, or neutral findings related to digital or AI-assisted tools are underrepresented, potentially skewing the perceived efficacy of such technologies. This bias may be partly driven by editorial preferences or funding sources interested in promoting technological innovation. Consequently, the evidence base may not adequately reflect the practical challenges or limitations encountered during implementation. Similarly, there is a paucity of longitudinal studies examining long-term outcomes or system performance over time, particularly in relation to diagnostic consistency, adaptability to new data, and user trust among pathologists. Variability in outcome measures across studies further complicates the interpretation and comparison of results. Some investigations emphasize diagnostic accuracy or sensitivity, while others assess workflow efficiency, educational effectiveness, or user preference. The lack of standardized endpoints hampers the ability to synthesize findings coherently and draw unified conclusions about the clinical value of digital pathology systems. For example, while improved speed and accuracy are frequently cited benefits of digital platforms (21), these are often measured using different criteria and time benchmarks, making direct comparisons challenging and potentially misleading.

Generalizability also remains a key concern. Much of the literature is derived from high-resource settings with access to advanced equipment, robust digital infrastructure, and specialized personnel. As such, the applicability of these findings to low-resource or rural environments is limited. AI-based systems, in particular, depend heavily on computational resources, high-quality imaging hardware, and reliable internet connectivity—factors that may not be universally available. Moreover, AI models trained on data from homogenous populations may perform suboptimally when applied to demographically or pathologically diverse cohorts, thus undermining diagnostic equity and reinforcing existing disparities in care delivery (22,23). Taken together, these limitations suggest that while the promise of digital and AI-assisted pathology is compelling, the current body of evidence must be interpreted with caution. Future research must prioritize methodological rigor, greater transparency in reporting, and inclusivity in study populations to ensure the responsible advancement and equitable adoption of these technologies in clinical practice.

IMPLICATIONS AND FUTURE DIRECTIONS

The findings synthesized in this narrative review have important implications for clinical practice, policy development, and the direction of future research in diagnostic pathology. As digital and AI-assisted systems demonstrate comparable or superior performance to conventional microscopy in several diagnostic domains, their integration into daily clinical workflows holds the potential to enhance diagnostic accuracy, improve efficiency, and reduce interobserver variability. In particular, the ability of AI tools to support rapid and reproducible assessments of histopathological features—such as tumor grading and biomarker quantification—could support pathologists in managing increasing diagnostic workloads and improve turnaround times for patient reports, thus contributing to more timely therapeutic interventions (24,25). From a policy perspective, the rapid technological evolution calls for the establishment of standardized clinical guidelines and regulatory frameworks to ensure the safe, effective, and ethical adoption of these tools. Professional organizations and health authorities should consider developing consensus-driven protocols for the validation, implementation, and oversight of AI-based diagnostic systems. These should address algorithm transparency, data security, accountability, and pathways for integration with existing laboratory information systems. Furthermore, policies that promote equitable access to digital infrastructure are essential to prevent technological disparities between high- and low-resource settings. The evidence supporting virtual microscopy in education and training also indicates a need for revising curricula to incorporate digital competency as a core skill for future pathologists (25,26).

Despite promising outcomes, several unanswered questions remain that necessitate further investigation. One pressing gap lies in the generalizability of AI algorithms, particularly when applied across heterogeneous populations or rare disease entities. Additionally, while digital systems have proven effective in narrow domains such as dermatopathology and gastrointestinal malignancies, broader evaluations across complex, multifocal, or subtle pathologies are still limited. Questions regarding how AI tools perform in diagnostically ambiguous cases, their role in second-opinion consults, and how they influence clinical decision-making longitudinally are not yet well understood (23,24). To advance the field meaningfully, future research should prioritize large-scale, prospective, multicenter trials that directly compare conventional and digital or AI-assisted pathology across diverse clinical settings. These studies should be designed with rigorous methodological standards, including appropriate randomization, blinding of evaluators, and long-term follow-up to assess clinical outcomes and cost-effectiveness. In addition, the development of explainable AI models, where decision-making processes can be audited and interpreted by clinicians, may improve trust and facilitate integration into real-world practice. Studies examining user interaction, training adaptation, and human–machine collaboration are also needed to optimize workflow synergy and mitigate the risk of diagnostic over-reliance on automated tools (20,26). Finally, longitudinal studies exploring the impact of digital pathology on patient-centered outcomes—such as time to diagnosis, accuracy in treatment stratification, and survival—are essential. These outcomes will provide more clinically meaningful evidence to inform stakeholders, including clinicians, health administrators, and policymakers, about the tangible benefits of investing in and scaling digital pathology systems. As the field continues to evolve, a collaborative approach involving pathologists, technologists, and regulatory bodies will be crucial in shaping a future where digital and AI-enhanced pathology complements human expertise to deliver more precise, accessible, and efficient patient care.

CONCLUSION

This narrative review highlights the transformative trajectory of diagnostic pathology from traditional light microscopy toward digital and AI-assisted platforms, emphasizing enhanced diagnostic precision, workflow efficiency, and educational utility. Evidence suggests that digital pathology systems—particularly when augmented with artificial intelligence—can match or surpass conventional methods in accuracy and speed, while also supporting remote diagnostics and training. Despite promising results, current literature is largely composed of small-scale or observational studies with methodological limitations, and the absence of large randomized trials limits definitive conclusions. Clinicians are encouraged to integrate digital tools selectively where infrastructure and validation allow, while remaining cautious of algorithmic limitations and variability in performance. For researchers, there is a pressing need for rigorous, multicenter studies that evaluate long-term clinical outcomes, standardize performance metrics, and ensure equitable access across diverse settings. Continued exploration and careful implementation will be essential to realize the full potential of digital and AI-enhanced pathology in routine clinical care.

AUTHOR CONTRIBUTION

Author	Contribution
Aneza Arshad Iqbal*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Muhammad Zahoor	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Zainab Tasawar	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Sana Abdullah	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Seema Shafiq	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Maryam Raza	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

REFERENCES

1. Ahmad Z, Rahim S, Zubair M, Abdul-Ghafar J. Artificial intelligence (AI) in medicine, current applications and future role with special emphasis on its potential and promise in pathology: present and future impact, obstacles including costs and acceptance among pathologists, practical and philosophical considerations. A comprehensive review. Diagn Pathol. 2021;16(1):24.
2. Wang Y, Wen Q, Jin L, Chen W. Artificial Intelligence-Assisted Renal Pathology: Advances and Prospects. J Clin Med. 2022;11(16).
3. Cure-Bolt N, Perez F, Broadfield LA, Levecke B, Hu P, Oleynick J, et al. Artificial intelligence-based digital pathology for the detection and quantification of soil-transmitted helminths eggs. PLoS Negl Trop Dis. 2024;18(9):e0012492.
4. Blackburn J, Alves MJ, Aslan MT, Cevik L, Zhao J, Czeisler CM, et al. Astrocyte regional heterogeneity revealed through machine learning-based glial neuroanatomical assays. J Comp Neurol. 2021;529(10):2464-83.
5. Latonen L, Ruusuvuori P. Building a central repository landmarks a new era for artificial intelligence-assisted digital pathology development in Europe. Eur J Cancer. 2021;150:31-2.
6. Yue M, Zhang J, Wang X, Yan K, Cai L, Tian K, et al. Can AI-assisted microscope facilitate breast HER2 interpretation? A multi-institutional ring study. Virchows Arch. 2021;479(3):443-9.
7. Wong PF, McNeil C, Wang Y, Paparian J, Santori C, Gutierrez M, et al. Clinical-Grade Validation of an Autofluorescence Virtual Staining System With Human Experts and a Deep Learning System for Prostate Cancer. Mod Pathol. 2024;37(11):100573.
8. Salido J, Vallez N, González-López L, Deniz O, Bueno G. Comparison of deep learning models for digital H&E staining from unpaired label-free multispectral microscopy images. Comput Methods Programs Biomed. 2023;235:107528.
9. Neal DE, Johnson EF, Agrawal S, Todd A, Camilleri MJ, Wieland CN. Comparison of Digital Pathology and Light Microscopy Among Dermatology Residents: A Reappraisal Following Practice Changes. Am J Dermatopathol. 2025;47(1):25-9.
10. Abraham TM, Levenson R. Current Landscape of Advanced Imaging Tools for Pathology Diagnostics. Mod Pathol. 2024;37(4):100443.
11. Lu MY, Williamson DFK, Chen TY, Chen RJ, Barbieri M, Mahmood F. Data-efficient and weakly supervised computational pathology on whole-slide images. Nat Biomed Eng. 2021;5(6):555-70.
12. Yamashita R, Long J, Longacre T, Peng L, Berry G, Martin B, et al. Deep learning model for the prediction of microsatellite instability in colorectal cancer: a diagnostic study. Lancet Oncol. 2021;22(1):132-41.
13. Azam AS, Miligy IM, Kimani PK, Maqbool H, Hewitt K, Rajpoot NM, et al. Diagnostic concordance and discordance in digital pathology: a systematic review and meta-analysis. J Clin Pathol. 2021;74(7):448-55.
14. Rocco B, Sarchi L, Assumma S, Cimadamore A, Montironi R, Reggiani Bonetti L, et al. Digital Frozen Sections with Fluorescence Confocal Microscopy During Robot-assisted Radical Prostatectomy: Surgical Technique. Eur Urol. 2021;80(6):724-9.

15. Li X, Kang L, Lo CTK, Tsang VTC, Wong TTW. High-Speed Ultraviolet Photoacoustic Microscopy for Histological Imaging with Virtual-Staining assisted by Deep Learning. J Vis Exp. 2022(182).

16. Zhang Y, Kang L, Wong IHM, Dai W, Li X, Chan RCK, et al. High-Throughput, Label-Free and Slide-Free Histological Imaging by Computational Microscopy and Unsupervised Learning. Adv Sci (Weinh). 2022;9(2):e2102358.

17. Horvath L, Hänselmann S, Mannsperger H, Degenhardt S, Last K, Zimmermann S, et al. Machine-assisted interpretation of auramine stains substantially increases through-put and sensitivity of microscopic tuberculosis diagnosis. Tuberculosis (Edinb). 2020;125:101993.

18. Munck S, Swoger J, Coll-Lladó M, Gritti N, Vande Velde G. Maximizing content across scales: Moving multimodal microscopy and mesoscopy toward molecular imaging. Curr Opin Chem Biol. 2021;63:188-99.

19. Wu Y, Han X, Su Y, Glidewell M, Daniels JS, Liu J, et al. Multiview confocal super-resolution microscopy. Nature. 2021;600(7888):279-84.

20. Fuqua T, Jordan J, Halavatyi A, Tischer C, Richter K, Crocker J. An open-source semi-automated robotics pipeline for embryo immunohistochemistry. Sci Rep. 2021;11(1):10314.

21. Al Sheikhyaqoob D, Oliveira A, Fella M, Laferty D, Niedobitek G. Polarised light scanner for digital pathology. Virchows Arch. 2024.

22. Miao R, Toth R, Zhou Y, Madabhushi A, Janowczyk A. Quick Annotator: an open-source digital pathology based rapid image annotation tool. J Pathol Clin Res. 2021;7(6):542-7.

23. Wang S, Pan J, Zhang X, Li Y, Liu W, Lin R, et al. Towards next-generation diagnostic pathology: AI-empowered label-free multiphoton microscopy. Light Sci Appl. 2024;13(1):254.

24. Rodrigues-Fernandes CI, Speight PM, Khurram SA, Araújo ALD, Perez D, Fonseca FP, et al. The use of digital microscopy as a teaching method for human pathology: a systematic review. Virchows Arch. 2020;477(4):475-86.

25. Yang X, Bai B, Zhang Y, Aydin M, Li Y, Selcuk SY, et al. Virtual birefringence imaging and histological staining of amyloid deposits in label-free tissue using autofluorescence microscopy and deep learning. Nat Commun. 2024;15(1):7978.

26. Jain E, Patel A, Parwani AV, Shafi S, Brar Z, Sharma S, et al. Whole Slide Imaging Technology and Its Applications: Current and Emerging Perspectives. Int J Surg Pathol. 2024;32(3):433-48.

