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Review Article

Crossing the Andes: Challenges and opportunities for digital pathology in Latin America

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ABSTRACT

The most widely accepted and used type of digital pathology (DP) is whole-slide imaging (WSI). The USFDA granted two WSI system approvals for primary diagnosis, the first in 2017. In Latin America, DP has the potential to reshape healthcare by enhancing diagnostic capabilities through artificial intelligence (AI) and standardizing pathology reports. Yet, we must tackle regulatory hurdles, training, resource availability, and unique challenges to the region. Collectively addressing these hurdles can enable the region to harness DP's advantages—enhancing disease diagnosis, medical research, and healthcare accessibility for its population. Americas Health Foundation assembled a panel of Latin American pathologists who are experts in DP to assess the hurdles to implementing it into pathologists' workflows in the region and provide recommendations for overcoming them. Some key steps recommended include creating a Latin American Society of Digital Pathology to provide continuing education, developing AI models trained on the Latin American population, establishing national regulatory frameworks for protecting the data, and standardizing formats for DP images to ensure that pathologists can collaborate and validate specimens across the various DP platforms.

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Introduction

Digital pathology (DP) is a term that refers to any process of transforming the image of a material (cells, tissues) that would be visualized in a conventional light microscope (i.e., an analog image) into a digital image.[1–3] Scientists began developing virtual microscopes in the 1990s based on satellite imaging technologies.[4] Several modalities of imaging technologies can be called DP (e.g., transmission of static images, robotic static/dynamic telemicroscopy, real-time video telemicroscopy). However, the most widely accepted and used is whole-slide imaging (WSI).[5,6] The USFDA granted two WSI system approvals for primary diagnosis, the first in 2017.[7] Wetzel and Gilbertson define WSI as a fully automated, high-speed device that can image entire slides at high resolution and at a reasonable cost,[8] generating images in three axes and multiple magnifications. The steps are scanning, storing, modifying, and viewing.[9]

In diagnostic terms, studies have shown that WSI is equivalent to traditional microscopy in several materials: biopsies and surgical specimens stained with hematoxylin and eosin (H&E), immunohistochemistry, and special stains.[10–13] DP enhances the ease of sharing for diagnosis, research, teaching, and storage. Improved scanners, optimized systems, quality monitors, and faster networks expand DP's use with higher quality. AI-integrated tools aid extracting information and enhance workflow. Advancing technology enhances objectivity in pathology and aligns with precision medicine's goal of optimal patient-specific diagnosis and treatment.[14,15]

DP also offers an advantage in countries with few pathologists due to large imbalances in pathologist-to-population ratios. For instance, Latin America has 17 pathologists per million people, while North America has 50–65.[16] In Brazil, the biggest country in the region, there are only 3824 pathologists, constituting 0.8% of specialized doctors, equating to 1.79 pathologists per 100,000 residents.[16] To make matters worse, over half (52.8%) live in Southeast Brazil, and about two-thirds (67.4%) in major cities and metro areas. In Colombia,[17] with a population of 44 million, there are approximately 500 general pathologists, challenging optimal patient care. These disparities stem from economic and demographic factors.

Hence, to address the shortage of pathologists, decentralized DP laboratory networks would be an effective solution, providing rural patients with improved access to clinical teams. However, in Latin America, DP platforms are still unevenly distributed, ranging from none to over 10 per country and barely exceeding a hundred across the region.[18] This narrative review aims to assess the current landscape of DP in Latin America and provide recommendations for a wider implementation of this technology in the region.

Methodology

Americas Health Foundation (AHF) assembled a panel of six pathologists who are experts in DP from Brazil and Colombia. On August 28–30, 2023, they had virtual meetings to develop recommendations for implementing DP in Latin America. AHF used PubMed, MEDLINE, and EMBASE to identify the pathologists. All the experts who attended the meeting are named authors of this manuscript.

AHF researched DP in PubMed, MEDLINE, and EMBASE. “Digital pathology,” “telepathology,” and “whole slide imaging,” in combination with “Latin America,” were searched with dates ranging from January 01, 2017 to January 01, 2023. The articles identified were in English, Portuguese, and Spanish. Articles from Latin America were prioritized.

Based on the literature search, AHF developed specific questions to address barriers limiting DP implementation in Latin America and assigned one to each panel member. (Supplemental Table 1) Individual panel members drafted a written response to each question based on the literature review and personal expertise. The entire panel reviewed and edited each narrative during the three-day conference through numerous rounds of discussion until the panel reached - total agreement. An AHF staff member moderated the debate. When the panel disagreed, additional discussions were held until everyone agreed on the paper’s content. All authors reviewed and approved the final manuscript. The recommendations are based on the evidence gathered and expert opinion and all authors approved the final document.

Results and discussion

Digital pathology applications

DP has many uses, being a very versatile tool, either for primary sign-out, remote sub-specialist consulting, or teaching/learning and research (Box 1).[19] DP is an expanding field that includes applications in research, education, intraoperative consultations, and computational pathology.

Research

Research environments can benefit from DP. For example, facilitating communication and sharing images among laboratories in multicenter studies is an obvious benefit. Even within the same institution, different

- Integrate with health care system digital workflows (medical records, imaging, laboratory tests, and molecular data).
- Store slides digitally without quality or identification loss, breakage, and aid record-keeping.
- Quickly access stored material when needed for review or annotation of molecular testing.
- Precisely annotate and measure, including volumetric evaluations.
- Integrate auxiliary tools such as AI.
- Improve quality assurance.

Box 1. Potential benefits in the workflow using digital pathology.

sectors can share images much more easily than physical slides. Besides the ease of access, researchers can annotate and quantify digital images, which are stored and can be analyzed, complemented, and even reviewed by research members. Furthermore, large, digitized databases, such as The Cancer Genome Atlas, are essential sources of information that can be easily accessed for diverse uses, such as comparing and validating experimental data.[20]

Education

The potential use of DP in education is vast. A dynamic analysis of the entire material instead of static photos of parts of it can enrich classes, tumor boards, case discussions, congresses, and symposia. Online databases allow individuals undergoing training, such as medical residency, to learn more dynamically and in a more standardized way, which is especially important in countries with board certifications. In our region, it is particularly useful for teaching at remote centers with live broadcasts of cases and tumor board discussions. Experts can participate in discussions and share their insights without the physical presence in meetings, allowing experts in major centers to reach areas with less resources. The use of DP can also aid in building digital libraries of diseases endemic to our region, improving diagnosis and knowledge of variants and progressions.

Intraoperative consultations

One area that benefits dramatically from DP is the intraoperative (frozen section) examination. Over the past 30 years, researchers have studied the usefulness and feasibility of using DP to improve, or at least equal, the diagnostic accuracy of traditional methods. High concordance rates (aided by the fact that DP allows remote consultation with specialists), reduced analysis time (crucial in the surgical environment), and even final diagnoses were documented.[21–26] Non-robotic systems involving an on-site pathologist transmitting images, robotic systems with remote microscope control by a pathologist, remote WSI, and potential hybrid systems are all viable options.[22,23,26] WSI seems to have the best image quality and handling time performance.[27,28] In Latin America, where access to pathology expertise may be limited, leveraging DP for intraoperative consultations can improve patient care and create a more efficient healthcare system

Computational pathology

Digitized images allow the use of multiple tools to help clinical practice by making specific observer-dependent characteristics more objective and extracting relevant information beyond morphology (e.g., multiomics). An important application is quantifying findings in the image, called pathomic features,[4] such as mitosis figures and proliferative index (e.g., Ki67 immunohistochemical reaction). Counting facilitates the pathologist's work by lowering analysis time and making findings that are relatively subjective evaluations clearer and more objective. Another field of wide use, but which still requires further advances, is identifying genomic features, as AI-based approaches have the potential to identify gene variants from routine histopathology slides.[29] This use is particularly of interest in poor resource areas, for which genomic research is unreachable or not cost-effective. WSI and AI offer the potential for transforming patient care. Digital image processing aids rapid tissue biomarker screening, with AI-assisted algorithms helping pathologists in precise diagnosis using biomarkers and grades, such as *PD-L1* analysis in tumors or Alzheimer's disease progression.[30] In addition, computational pathology may correctly identify molecular alterations using morphological data. An AI algorithm may automate the recognition of imperceptible specific gene variants or translocations.[31] An exciting study developed a convolutional neural network (CNN) capable of predicting the variants of six genes (*KRAS, FAT1, TP53, SETBP1, EGFR,* and *STK11*) in lung adenocarcinomas.[32] There are similar exciting and promising results for detecting microsatellite instability in colonic adenocarcinomas using H&E morphology and AI.[33]

Role of digital pathology

The COVID-19 pandemic was a catalyst for developing and using various technologies that allow remote communication and remote access, including DP. Pathology departments that had started digitizing their workflows benefited from this technology; however, the usual training time was reduced due to the pandemic. Still, it was not a limiting factor in the diagnostic capacity, with no loss of accuracy.[34–36]

DP has gained popularity due to the accessibility of whole-slide scanners, enabling labs to rely on WSI for diagnoses. Benefits include remote work, quicker consultations, and AI utilization. Incorporating digital workflow in analog pathology labs enhances slide quality with thinner standardized sections, improved mounting, and allows for better distribution of the sections on the slides. This boosts diagnosis quality by avoiding scanning issues caused by thick or improperly mounted slides. Poor stain quality, color, and paraffin type also affect scanning. Hence, standardized slides, achieved through routine scanner use, elevate daily workflow quality.

In conclusion, the advantages of incorporating DP into an analog laboratory go beyond the usual benefits of remote working or faster interconsultation. It improves the overall quality of the specimens and workflows. It provides a new array of data that can be easily assessed and analyzed using AI and CNN, with the potential to revolutionize patient care and improve personalized health in the future.

The digital pathology ecosystem

The Digital Pathology Ecosystem (DPE) refers to the comprehensive framework of components, technologies, and processes that generate, view, and manage digital whole-slide images, and integrate these digital assets into the broader healthcare system (Fig. 1).[37] It represents the convergence of hardware, software, data management, and analytical capabilities to renew and enhance pathology practice, improve education and research, and transform the landscape.

Several considerations must be made when a pathology service creates a new workflow or adapts an existing one for DP.[38]

Regarding technology, laboratories must consider four core elements:

1 Scanners
2 Image management systems
3 Laboratory information systems
4 Data center infrastructure

In Latin America, few labs use DP for primary diagnosis, and even fewer use a fully digital workflow. A digital lab positively impacts hospitals and healthcare by enabling quicker diagnoses, cost control, remote collaboration, and informed decision-making for clinicians. The process of setting up a digital lab differs from that of traditional analog labs. This section outlines the necessities for creating a DPE and emphasizes decisions that enhance patient care quality and excellence.

Slide scanners

High-resolution slide scanners capture microscope images of stained tissue. These scanners start the DP process by converting physical slides into digital images. Scanner choice depends on workflow, volume, and use cases like primary diagnosis, research, education, and more. Before adding a scanner to the workflow of a pathology service, the stakeholders within the DPE should ensure that all the elements are interoperable and in accordance with what is needed to run the pathology operation seamlessly (Table 1).

Multiple scanner options exist, varying in capacities and scan times. Throughput, user-friendliness, resolution, integration, and other aspects matter too. Consider continuous loading, optical factors, and adaptability for fluorescence. Insights gleaned from laboratories, conferences, reviews, and experts can help decisions regarding the choice of suitable equipment. Vendor performance, compatibility with existing systems, and integration with laboratory information management systems (LISs) are crucial. This streamlines diagnostic workflow, reduces errors, and enhances efficiency. Table 2 lists the scanners currently available to pathologists in Latin America.

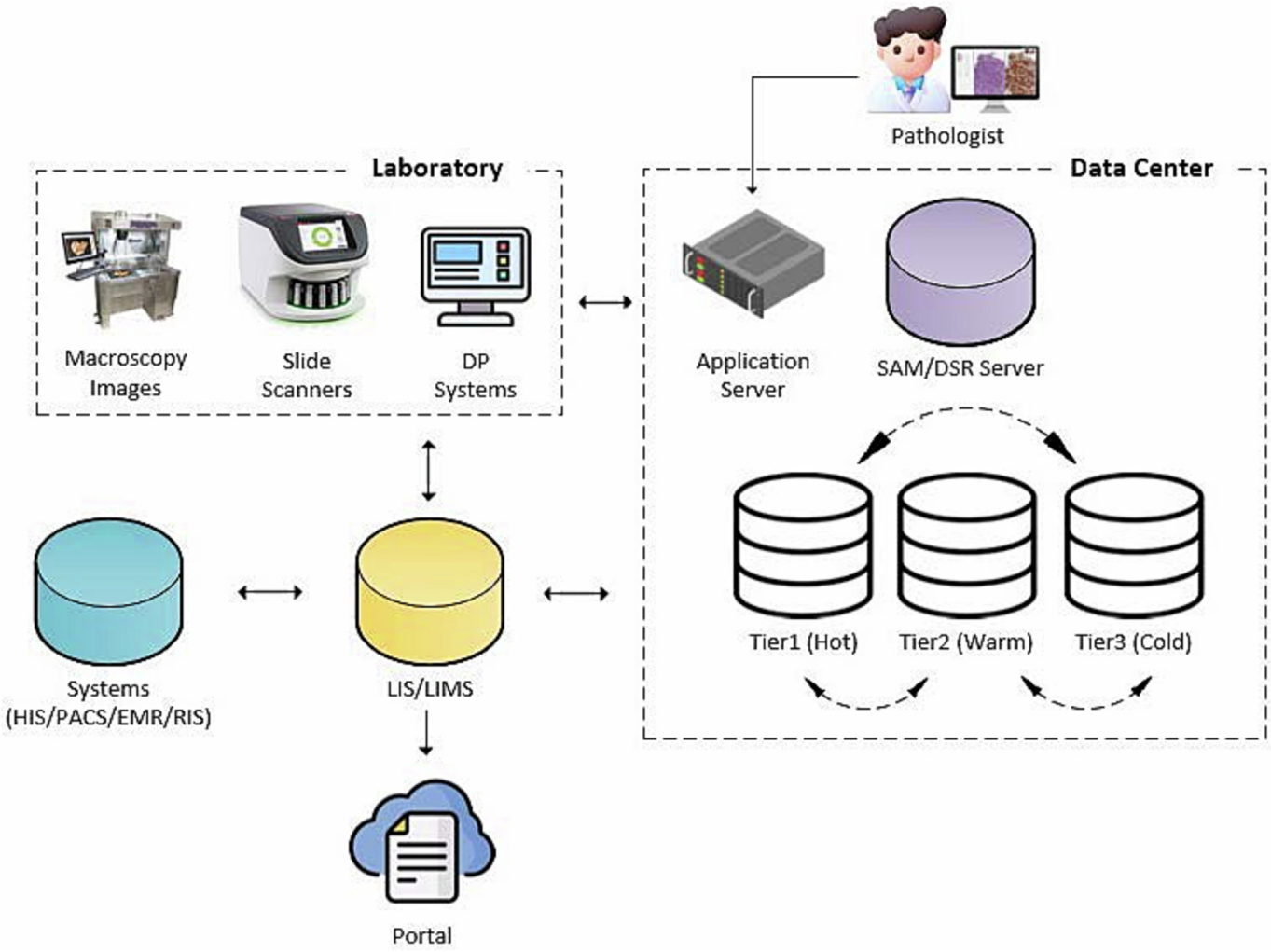

Fig. 1. Information technology infrastructure for digital pathology—may contain the following components: Slide scanner(s), gross macroscopy imaging system, monitors, software (information and DP systems), portal, virtual machine server, and layered storage: Tier 1. High performance (hot). Tier 2. Average performance (warm). Tier 3. Low performance (cold). DP, digital pathology; HIS, hospital information system; PACS, picture archiving and communication system; EMR, electronic medical records; RIS, radiology information system; LIS, laboratory information system; LIMS, laboratory information management system.

Monitors

In the field of DP, choosing the proper digital display is critical to ensure accurate and precise visualization of high-resolution pathology images. Resolution indicates the overall pixel count within the visible screen area, usually presented as a two-dimensional measurement of width by height. Examples of resolutions with their synonyms include 640 × 480 (VGA), 1920 × 1080 (HD), 2048 × 1080 (2K), 2560 × 1440 (WQHD), 3840 × 2160 or 4096 × 2160 (4K), 5120 × 2880 (5K), and 7680 × 4320 (8K). High-resolution monitors (4K or higher) accurately display the fine details in pathology images. They ensure pathologists can zoom in and analyze images without loss of clarity. Color accuracy is important to represent tissue samples precisely, often measured using metrics like Delta E values. Displays that cover a wide color gamut, such as sRGB, Adobe RGB, DCI-P3, or CYMK, are desirable. Calibration capabilities, allowing for precise adjustments of color settings, are essential to ensure consistent and accurate representation over time. Displays with high levels of brightness and contrast ensure that even subtle differences in tissue staining and morphology are apparent and suitable for use in DP. The same features apply to home-based offices. Physicians must have all of these features in mind when mounting their workspace, which should mirror what they have in the hospital.

DICOM (digital imaging and communications in medicine) compatibility is vital for medical imaging, especially in radiology, cardiology, and pathology. DICOM sets the benchmark for representing, storing, and exchanging medical images and associated data. While a file format and communication protocol for pathology in the DICOM framework have been established, their acceptance among vendors and in practice is still pending.[39] Displays with DICOM calibration can accurately exhibit grayscale medical images as intended for diagnosis and provide a more consistent image interpretation by the pathologist. Another essential feature is an anti-glare coating, which helps reduce reflections and glare on the monitor´s surface, which can be distracting and hinder accurate image analysis. Monitors specifically designed for medical imaging are more expensive but

Table 1
Decision criteria for scanner selection.

- Image quality
- Scanner capacity and level of throughput
- Scanning speed
- Resolution and scan modes to adhere to departmental and local regulations
- Systematic quality control of digital slides
- Integration with other departmental devices and software
- Service and parts availability
- Budget

Table 2
Current commercially available high-capacity scanners in Latin America.

Manufacturer	Hamamatsu	3D Histech	Huron	KFBIO	Leica	Motic	Philips	Roche/Ventana
Model	Nanozoomer S360	Panoramic 1000 DX	Tissue Scope iQ	KF-PRO-400	GT450	MoticEasyScan NEW Infinity	IntelliSite Ultra-Fast	DP 600
Imaging mode(s)	Brightfield	Brightfield	Brightfield	Brightfield & Fluorescence	Brightfield	Brightfield	Brightfield	Brightfield
Slide capacity	360 slides	1000 slides	400 standard slides or 200 double-wide slides	400 slides	450 slides (15 racks of 30 slides)	Optionally configured for 60 or 102 slides	300 slides (15 racks of 20 slides)	240 slides (40 trays of 6 slides)
Scan speed	40×: 30 s	40×: 32 s	40×: <60 s	40×: 40 s	40×: 32 s, 15 mm × 15 mm	40×: 60 s	40×: 60 s	40×: <73 s for a 15 mm × 15 mm AOI
Image capture magnification	20× or 40×	20× or 40×	20× or 40×	20× or 40×	20× and/or 40×	10×, 20×, and 40×	40×	20× or 40×
Image capture resolution (μm/pixel)	20×: 0.46 or 40×:0.23	40×: 0.24	40×: 0.20	40×: 0.25	20×: 0.50 or 40×:0.26	40×: 0.13	40×: 0.25	20×: 0.46 or 40×: 0.25
Digital slide format	JPEG	DICOM, MRXS	Big TIFF; DICOM compatible	vsi, JPEG, and TIFF	SVS, TIF and DICOM	DICOM, SVS, and JEPG	RAW, iSyntax	BIF, TIF.DICOM
Multilayer support	Z-stack available	Z-stack and extended focus	Z-stack available	Z-stack available	Z-stack available	Z-stack (Three-dimensional stacking)	No	Z-stack and extended focus
Barcode support	1D, 2D	1D, 2D	1D, 2D		1D, 2D	1D, 2D	1D, 2D	1D, 2D

s, seconds; mm, millimeters; DICOM, Digital imaging and communications in medicine; MRXS, MIRAX-compatible; D, dimensional.

might offer the necessary quality and accuracy and appear to improve the speed of diagnosis.[40–42] Displays suitable for medical and imaging purposes include Barco, BenQ Medical Monitors, Dell Medical Displays, EIZO, LG Medical Displays, and NEC. However, it is essential to consider the budget while balancing the required features. A study has demonstrated that a single monitor and monitors ranging from 13.3 to 42 in. and 1280 × 800 to 3840 × 2160-pixel resolution were appropriate for diagnosis.[35] Studies have demonstrated that commercial off-the-shelf (COTS) monitors do not affect the diagnostic accuracy of breast biopsy specimens.[40–42] Another study showed a substantial agreement of the mitotic counts and *H. pylori* burden assessments between medical-grade and COTS displays.[43] Based on these findings, there is no evidence to demonstrate the necessity or superiority of medical-grade monitors over COTS monitors of equivalent quality.

While a single display has been considered adequate for primary diagnosis, in the panel's experience, having a minimum of two monitors is ideal for more appropriate ergonomics and faster sign-out. These dual monitors can help pathologists examine microscope images, generate reports, access clinical data, and perform other functions more easily. It is preferable to use two monitors of the same size and, if feasible, models.[44] This is important because, even after calibrating, different monitors have varied font sizes and colors.

Ultimately, the choice of monitors in DP should prioritize accurate image representation, color fidelity, and user comfort to facilitate precise diagnosis and collaboration among pathologists. For this reason, pathologists must gain a more thorough understanding of display technology, considering the intricacies of modern monitors, to ensure they possess greater decision-making capability for their upcoming "microscopes."[44]

Other gadgets

In DP, gadgets like workstations and the mouse play a crucial role in enhancing the efficiency and accuracy of image interpretation, analysis, and reporting. DP workstations are specialized computers designed to handle the processing, viewing, analyzing, and managing of DP images. These workstations contain high-performance hardware and software to meet the demanding requirements of image-intensive tasks. A specialized computer mouse is an input device to navigate and interact with DP images and software on the workstation. In DP, precision and ease of use are essential, so the mouse designed for medical imaging often has an ergonomic shape that reduces user burden during extended use, promoting comfort for pathologists.[45,46]

Software

Besides the scanner and monitors or other necessary hardware, specific software is used to manage, view, and manipulate the digital images. Pathology software is moving into its third generation, transitioning from basic viewers to image management systems (IMS) to the latest pathology platforms. The basic viewers emerged from the necessity of the hardware manufacturers to develop image viewers for their scanners. The IMS, a second-generation pathology software, combines viewing functionality with data management and collaboration capabilities. The third generation of software provides a unified hub for people, data, and AI applications.

However, in the current workflow, the most used software are viewers and IMS. The viewer software allows pathologists to view, analyze, and annotate DP images. It provides tools for zooming, panning, measuring, annotating, and comparing images. The IMS is a central platform that stores, organizes, and manages the vast collection of DP images. The available viewers and IMS exhibit significant variability and currently lack any preexisting integration with established LISs or hospital information systems.[47] This oversight fails to account for the intricate nature of the anatomic pathology reporting process, which involves reviewing clinical requests and notes, examining specimens, requesting additional stains or other complementary tests, and creating complete reports.[48]

Acquiring a WSI system does not involve purchasing an off-the-shelf, tested direct integration solution with an LIS. Institutions presently using WSI for primary diagnosis and reporting primarily rely on localized LIS-driven integration. This kind of integration is facilitated through locally developed LIS solutions and involves a resource-intensive and time-consuming procedure if implemented for a commercial LIS. Additionally, it necessitates a mutual agreement between the providers of the LIS and viewers/IMS. Effective integration of the LIS and IMS consolidates all the essential components pathologists require for a thorough diagnosis within a unified and consistent system. This integration affords the pathologist and the diagnostic team an all-encompassing perspective of the patient's case, accessible from anywhere within the healthcare network or worldwide. Accessibility of DP image data and all pertinent data related to the patient is vital within the immediate healthcare facility, across the broader medical network, or anywhere the pathologist is located. Thus, integrating these images with the LIS, an electronic medical record, and other relevant systems guarantees data portability, offering a comprehensive patient file. However, the challenge lies in executing this integration effectively and securely. Interoperability is key to the success of the digital workflow.

Storage

Efficiently storing and managing high-resolution digital images poses unique challenges—local or cloud-based repository choice matters. Local storage suffices for minimal users and non-retained cases. Institutions decide storage requirements based on user needs and policy alignment. Cloud providers offer tiered storage in global data centers, ensuring availability, redundancy, and scalability. Cloud scalability accommodates DP's data volume growth without upfront hardware investments. It aids pathologists in collaborating, remotely accessing data, integrating AI, and complying with healthcare regulations. But there are cloud costs, bandwidth, and control concerns, especially in low- to middle-income countries. Hybrid storage (local and cloud) is a viable strategy. Exploring and understanding storage solutions is vital for unlocking DP's full potential while ensuring data integrity, accessibility, and security.

Telecom

DP uses significant network bandwidth, usually demanding a range of 1–10 gigabits per second, with the potential to accommodate future expansion. Although suboptimal network speeds permit certain DP applications, they may not be conducive to all functions. A study showed that network bandwidth for remote readers, while connected to a virtual private network, ranged from 20 to 849 megabits per second and was adequate for sign-out tasks.[35]

Personnel

In countries where few laboratories have implemented DP in their diagnostic routine, finding employees familiar with both the information technology and laboratory environment is challenging. Finding and hiring technicians skilled in evaluating slide quality and optimizing scanning time is also crucial. In our region, we currently have a lack of specialized trainings or courses, and finding appropriate personnel for implementing emerging technologies is yet an additional and crucial obstacle.

DP workflows

Moving from analog-to-digital workflows will affect many aspects of the pathology laboratory staff's daily work. Within a digital workflow, the referring department creates a unique barcode ID for each sample, and enters it into the LIS. The samples are then grossed, and photo documentation is conducted. Slides are scanned to be visualized and signed out by pathologists or used with advanced algorithms and computer-aided diagnostic techniques (Table 3).

Table 3
Digital pathology laboratory workflow.

Image Workflow in the Laboratory	Description	Picture
Gross section image acquisition	Gross images can be seamlessly integrated into the digital workflow alongside microscope images. This allows for a comprehensive and unified DP report that combines macroscopic and microscopic observations.	
Scanning process	Size of the scan area – typically 15 mm × 15 mm. Resolution – 5× to 40× or higher (×40 is recommended for primary diagnosis). Post-scan compression can significantly reduce the average size of a slide, going from an uncompressed size of 15 GB to an average compressed size of 500 MB. Some scanners can offer z-stacks to create a 3D representation. (Lujan G et al. J Pathol Inform. 2021, 1:17)	
Visualization for primary diagnosis	The display must provide image accuracy, including uniformity correction, which provides a more consistent brightness and color across the entire monitor. Interoperability and integration with common LISs is a very important feature.	
Using AI	AI-powered platform can assists pathologists in diagnosing diseases from digital pathology images. It uses deep learning algorithms to help detect and classify diseases accurately. It's focused on aiding pathologists in their decision-making process.	

DP, digital pathology; AI, artificial intelligence; LIS laboratory information management system.

WSI systems create digital slides that can be assessed by multiple examiners in multiple locations, facilitating remote consultations, streamlining workflows, and reducing the time and financial costs of transferring glass slides between sites, while avoiding material loss. Therefore, DP can benefit several pathology fields, including quality assurance programs, frozen section diagnosis, multidisciplinary team meetings, clinicopathological conferences, expert panel/consensus boards, and education.[39]

A critical technology element is the full-bodied IMS. The IMS must have capabilities to store and manage all digital slides and associated metadata which will go through the scanner. Ideally, the IMS should allow image analysis and scoring results for current reporting and future reviews. Some benchmarking features in an IMS are the capacity for synchronizing image intake, automating metadata import, and the availability of building quality control tools for the DP workflow. Another desirable characteristic is the capacity to integrate with image analysis and homegrown AI applications.[49–52]

Validation

Validating DP integration in clinical practice is critical for identifying concerns and ensuring a seamless transition to lab digitalization. Early adoption and advantages are aided by including technicians and pathologists in the decision-making process. CAP issued guidelines on validating WSI for diagnosis in 2013.[12] CAP recently updated them, using the Grading of Recommendation Assessment, Development, and Evaluation framework, containing three strong recommendations and nine good practice statements (Fig. 2).[6]

The initial strong recommendation is to validate with 60 cases (plus 20 for any routinely used specialized stains), that mirror routine ones. The second recommendation emphasizes at least 95% diagnostic concordance between analog and digital reports, with investigations if it is lower. The third recommendation advises a 2-week washout between digital and glass slide viewing to prevent recall bias.

Strong recommendations

1. Case number for training
    a. The validation process should include a sample set of at least 60 cases for one application or use case that reflects the spectrum and complexity of specimen types and diagnoses likely to be encountered during routine practice; examples include
        i. hematoxylin-eosin-stained sections of fixed tissue
        ii. frozen sections
        iii. hematology
    b. The validation should include another 20 cases to cover additional applications such as immunohistochemistry or other special stains if these applications are relevant to an intended use and were not included in the 60 cases mentioned above
2. The validation study should establish a diagnostic concordance between digital and glass slides for the same observer
    a. If concordance is less than 95%, laboratories should investigate and attempt to remedy the cause
3. Include a washout period of at least 2 weeks between viewing digital and glass slides

Good practice statements

1. All pathology laboratories implementing whole slide imaging (WSI) technology for clinical diagnostic purposes should perform validation studies
2. Validation should be appropriate for and applicable to the intended clinical use and clinical setting of the application in which WSI will be used
    a. Validation of WSI systems should involve specimen preparation types relevant to the intended use (e.g., formalin-fixed, paraffin-embedded tissue, frozen tissue; immunohistochemical stains)
    b. If a new application for WSI is contemplated, and it differs materially from the previously validated use, a separate validation for the new application should be performed
3. The validation study should closely emulate the real-world clinical environment in which the technology will be used
4. The validation study should encompass the entire WSI system
    a. It is not necessary to separately validate each individual component (e.g., computer hardware, monitor, network, scanner) of the system or the individual steps of the digital imaging process
5. Laboratories should have procedures in place to address changes to the WSI system that could impact clinical results (revised from the 2013 guideline)
6. Pathologists adequately trained to use the WSI system must be involved in the validation process
7. The validation process should confirm that all of the material present on a glass slide to be scanned is included in the digital image.
8. Documentation should be maintained, recording
    a. Method
    b. Measurements
    c. Final approval of validation for the WSI system to be used in the anatomic pathology laboratory
9. Pathologists should review cases/slides in a validation set in random order
    a. This applies to both the review modality (i.e., glass slides or digital) and the order in which slides/cases are reviewed within each modality (revised from the 2013 guideline)

Fig. 2. CAP issued recommendations and good practice statements.[6] WSI, whole-slide imaging.

Additionally, there are nine non-evidence-based good practice statements for labs to consider during validation. These practices enhance results and align with real-world scenarios. They include matching apparel, involving the correct number of pathologists, and ensuring all glass slide content is captured in digital images. These practices ensure thorough testing and troubleshooting before clinical use.[9]

Like the CAP recommendations, the United Kingdom's Royal College of Pathologists provides best practice suggestions for DP implementation.[53] It takes a broader approach, focusing on practices for technology integration rather than strict validation criteria. Unlike the American version, it acknowledges varying case volume needs for validation, suggesting a more extended implementation process with ongoing safety vigilance and potential external audits. The UK document delves into scan details, z-stacking, resolution, and ethics. It also addresses risk reduction, advocating glass slide use and supplementary laboratory assays when results are uncertain. The recommendations cover frozen sections, where WSI can substitute for an in-person pathologist, ensuring compliance with conventional histology standards. Recently, several studies of WSI have shown promise for high-accuracy off-site frozen section assessments.[28,54,55]

Official validation guidelines are lacking for cytopathology. A recent systematic review of digital cytology validation found that only a minority of papers adhered to all CAP recommendations. Challenges arise due to the cytological specimens' unique characteristics, which are distinct from surgical specimens.[56] This relates to diverse preparations and the 3D nature of cytological samples, often requiring multiple focus scans (z-stacks). Although using z-stacks has improved results, the technique may seem impractical in a real-world scenario due to time or cost impediments. In this context, modern solutions combining different foci from the same slide into a single image may be a viable alternative.[34] High intra- and inter-personal variability, particularly for atypical cases, further complicates matters. A slight deviation may be considered concordant, especially for indeterminate cases, providing insight for future validation studies.[4,57]

A recently published paper has adapted the CAP guidelines for cytopathology, achieving interesting results without z-stacks. Using up to a one-degree variation as set for concordance, there was a 98.7% agreement between analog and digital diagnoses for all cytological preparations, considered an optimal concordance. When separating per sample type, cytospins and liquid-based cytology (LBC) had a better agreement rate between digital and analog analysis, followed by smears. For LBC cervical samples, the agreement was 99.2%.[56]

In conclusion, when planning the validation of either histological or cytological specimens for implementing DP, one should consider all the necessary steps to ensure the guidelines are followed and all possible amendments are made to ensure a good concordance. The entire team of technicians and pathologists should be familiar with the system. New technologies always bring insecurity and opportunities, and the validation process should serve as a training ground for all endeavors that may show up during the complex and sometimes time-consuming process of digitalizing pathology labs. In Latin America, customized approaches of global standards are needed for a trustworthy process, opening opportunities for local guideline development tailored to our regional DPE priorities.

Specific challenges to the implementation of DP in Latin America

DP is an innovative approach that seeks to standardize pathology reports by digitizing glass slides and allowing analysis by digital means, including telepathology. This enables automated and parameterized counting with the assistance of AI by computational pathology, optimizing human intellectual capacity.[53] However, its application in Latin America faces significant challenges that must be overcome for the tool to realize its potential to revolutionize cancer diagnosis and monitoring, drug development, and enhance the understanding of other diseases. Within the Latin American context, we address some of these difficulties and possible solutions for its successful implementation (Fig. 3).

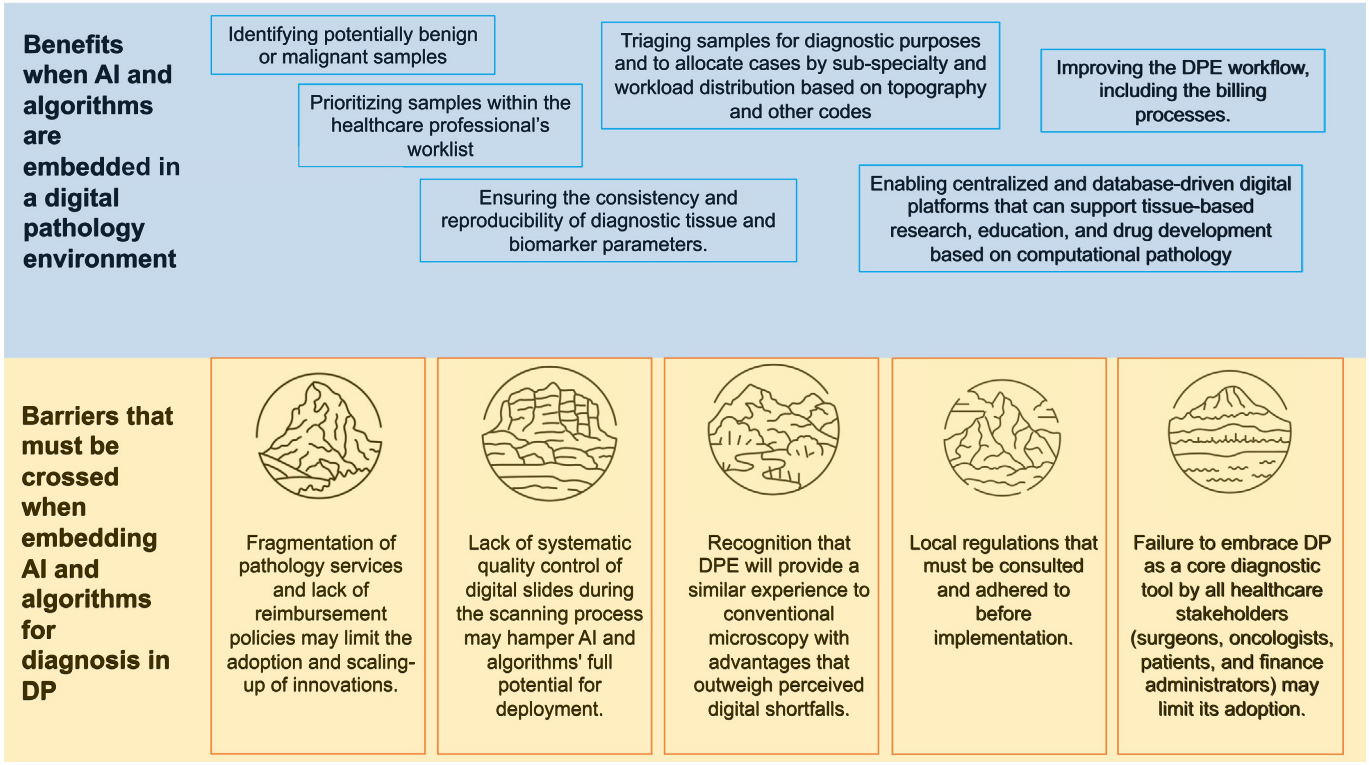

Fig. 3. Hurdles to setting up a digital pathology environment and the benefits of overcoming them. DPE, digital pathology environment; DP, digital pathology.

Our region comprises several nations with varied people, customs, and technical infrastructures. While the challenges faced are similar, it is essential to recognize that some may have a greater impact in particular local contexts. Grouping these difficulties into categories, we can highlight the following: regulatory, training-related, input-related, and others.[18]

Regulatory challenges

Implementing DP in Latin America encounters regulatory obstacles. Each country has its rules and regulations related to health and digitizing medical information. This lack of standardization can delay or hinder adopting DP on a regional scale. Moreover, issues related to patient privacy and digital data security demand a careful approach to ensure the reliability and integrity of digital reports.[58]

In Latin America, there are initiatives to encourage political and regulatory dialogue to facilitate forming regional, subregional, and national strategies for the use of telemedicine and also countries with regulation already well established. However, to our knowledge, only Brazil has a specific regulatory statement for telepathology.[59] The standard establishes that performing DP can only occur if there is appropriate technological support to guarantee the integrity, veracity, confidentiality, privacy, and secrecy of information. This resolution requires that patient information accompany the slides and that it a list of requirements to guarantee the quality of the virtual slides. A potential drawback of this resolution is that it necessitates involving pathologists on both sides of the transmission platform.

Training challenges

The transition to DP requires extensive training for the healthcare professionals involved, especially pathologists. Empowering these specialists to use digital tools effectively, interpret results accurately, and adapt to the new working environment is essential and should be part of their residency training. The absence of specific training programs and the scarcity of DP experts can be significant barriers to widespread adoption.

Input-related challenges

Adopting DP necessitates acquiring suitable equipment and technologies, including high-resolution scanners and systems for image storage and analysis. The availability and cost of these inputs can vary among Latin American countries, making implementation more challenging in some regions. Additionally, the quality of digitized slides and process standardization are crucial factors to consider to ensure result reliability. This represents the "Andes mountain range" of implementationvoluminous, complex obstacles that are difficult to overcome but not impossible.

We can break the challenges at this point down into several pieces:

Preanalytical phase.

- The significant distances that samples must traverse greatly impact their preservation.
- Lack of a macroscopic sampling protocol.
- Specimen collection and handling.
- Fixation and processing.
- Quality of reagents and equipment.

Post-analytical phase.

- Poor-quality inputs lead to suboptimal processing and make slide digitization difficult (sometimes even impossible).

Laboratory support sector.

- Acquiring sufficient infrastructure for implementing DP in a laboratory's routine is financially unattainable for most laboratories in Latin America. The ideal laboratory DPE would host adequate high-capacity scanners (>100 slides per run) for the estimated workload, apart from any additional backup scanners and measures to adapt to analog if needed. Also needed are a dedicated server and virtual space for storing images in a way that allows pathologists to evaluate case, review, and discuss each case with another colleague before signing out.[60] For timely implementation, a comprehensive government policy to incentivize stakeholders is warranted.

Human factors

In addition to the abovementioned aspects, implementing DP in Latin America has further challenges. Cultural factors and resistance to change can affect the acceptance of technology by healthcare professionals and patients. Among professionals, a significant barrier is the fear (which the panel considers unfounded) of AI completely replacing pathologists. A more likely scenario is a synergy between physician judgment and AI, where AI aids tasks like mitosis counting, biomarker estimation, flagging suspicious areas, identifying metastases, and optimizing molecular pathology procedures.

Cost and return on investment

Implementing DP in Latin America involves costs associated with technology adoption, infrastructure development, training, and ongoing maintenance. However, the return on investment (ROI) can be substantial, offering various benefits to healthcare systems in the region, such as significant time savings, increased workflow efficiency, and reduced consultation turnaround times.

In a recent publication, cost is identified as a primary barrier to DP implementation in Latin America, with studies from Europe and North America highlighting the substantial initial investment and maintenance costs.[18] This paper also reports the potential efficiency gains and cost savings from DP. Despite these benefits, experts note challenges, including resource limitations in pathology labs, barriers related to reimbursement negotiations, and concerns about infrastructure readiness in Latin America. However, there is a need for a thorough analysis of attributes and requirements before DP implementation, acknowledging both the potential benefits and existing challenges in the Latin American context.

Conclusion

In Latin America, DP has the potential to reshape health care by enhancing diagnostic capabilities through AI assistance and standardizing pathology reports. Yet, regulatory hurdles, training, resource availability, and unique challenges must be tackled. Collectively addressing these can enable the region to harness DP's advantages, enhancing disease diagnosis, medical research, and healthcare accessibility for its population (Box 2).

Recommendations

1. Promote education and training programs in DP, AI, and computational pathology among residents, pathologists, clinicians, and healthcare administrators.
2. Create a Latin American Society of Digital Pathology to provide continuing education to ensure professionals stay updated with the latest advancements.
3. Promote participation in certification programs to address challenges and ensure quality control in the workflow between pre-analytical and post-analytical phases.
4. Establish national regulatory frameworks that ensure patient data privacy and security of sensitive information.
5. Develop ethical guidelines for the use of AI in DP and form collaborations among academia, healthcare institutions, and industry to develop and validate AI algorithms in Latin American populations.
6. Explore partnerships to provide funding or grants for adopting, implementing, and managing DP and AI to ensure the long-term sustainability of DP networks.
7. Develop AI models trained on datasets encompassing the diversity of Latin American populations and clinical priorities.
8. Standardize formats for DP images and ensure compatibility and validation among different DP platforms.
9. Create DP databases to share pathology images with clinical information for research and educational purposes.

Box 2. Panel recommendations for successfully implementing DP in Latin America.

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Declaration of competing interest

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Appendix A. Supplementary data

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References

1. Mendelsohn ML, Kolman WA, Perry B, Prewitt JM. Morphological analysis of cells and chromosomes by digital computer. Methods Inf Med 1965;4(4):163–167.
2. Mendelsohn ML, Kolman WA, Perry B, Prewitt JM. Computer analysis of cell images. Postgrad Med 1965;38(5):567–573.
3. Weinstein RS, Bloom KJ, Rozek LS. Telepathology and the networking of pathology diagnostic services. Arch Pathol Lab Med 1987;111(7):646–652.
4. Pantanowitz L. Leveraging digital pathology for molecular testing. Cancer Cytopathol 2018;126(12):965–966.
5. Pantanowitz L, Sinard JH, Henricks WH, et al. Validating whole slide imaging for diagnostic purposes in pathology: guideline from the College of American Pathologists Pathology and Laboratory Quality Center. Arch Pathol Lab Med 2013;137(12):1710–1722.
6. Evans AJ, Brown RW, Bui MM, et al. Validating whole slide imaging systems for diagnostic purposes in pathology. Arch Pathol Lab Med 2022;146(4):440–450.
7. FDA. FDA allows marketing of first whole slide imaging system for digital pathology [news release]. Published April 12, 2017. Accessed on August 8, 2023. April 12. Available from: https://www.fda.gov/news-events/press-announcements/fda-allows-marketing-first-whole-slideimaging-system-digital-pathology 2017.
8. Ho J, Parwani AV, Jukic DM, Yagi Y, Anthony L, Gilbertson JR. Use of whole slide imaging in surgical pathology quality assurance: design and pilot validation studies. Hum Pathol 2006;37(3):322–331.
9. Zarella MD, Bowman D, Aeffner F, et al. A practical guide to whole slide imaging: a white paper from the digital pathology association. Arch Pathol Lab Med 2019;143(2):222–234.
10. Mukhopadhyay S, Feldman MD, Abels E, et al. Whole slide imaging versus microscopy for primary diagnosis in surgical pathology: a multicenter blinded randomized noninferiority study of 1992 cases (pivotal study). Am J Surg Pathol 2018;42(1):39–52.
11. Loughrey MB, Kelly PJ, Houghton OP, et al. Digital slide viewing for primary reporting in gastrointestinal pathology: a validation study. Virchows Arch 2015;467(2):137–144.
12. Krishnamurthy S, Mathews K, McClure S, et al. Multi-institutional comparison of whole slide digital imaging and optical microscopy for interpretation of hematoxylin-eosin-stained breast tissue sections. Arch Pathol Lab Med 2013;137(12):1733–1739.
13. Borowsky AD, Glassy EF, Wallace WD, et al. Digital whole slide imaging compared with light microscopy for primary diagnosis in surgical pathology. Arch Pathol Lab Med 2020;144(10):1245–1253.
14. Kiran N, Sapna F, Kiran F, et al. Digital pathology: transforming diagnosis in the digital age. Cureus 2023;15(9), e44620.
15. Berbís MA, McClintock DS, Bychkov A, et al. Computational pathology in 2030: a Delphi study forecasting the role of AI in pathology within the next decade. EBioMedicine 2023;88, 104427.
16. Colangelo M. How AI Can Help Address The Global Shortage of Pathologists. [website]: https://www.linkedin.com/pulse/how-ai-can-help-address-global-shortage-pathologists-colangelo/.
17. Alvarez C, Corredor G, Giraldo D, Romero E. Tele-pathology: a use case in Colombia. 2019 IEEE 16th International Symposium on Biomedical Imaging (ISBI 2019); 2019.8-11 April 2019.
18. García-Rivello H, Cancio A, Monroy AMV, et al. Digital pathology in Latin America. Surg Exp Pathol 2023;6(1):1–9.
19. Pantanowitz L. Digital images and the future of digital pathology. J Pathol Inform 2010:1.
20. National Cancer Institute. Harmonized Cancer Datasets Genomic Data Commons Portal. https://portal.gdc.cancer.gov/. [website]. Accessed on 4 September 2023.
21. Williams BJ, DaCosta P, Goacher E, Treanor D. A systematic analysis of discordant diagnoses in digital pathology compared with light microscopy. Arch Pathol Lab Med 2017;141(12):1712–1718.

22. Horbinski C, Fine JL, Medina-Flores R, Yagi Y, Wiley CA. Telepathology for intraoperative neuropathologic consultations at an academic medical center: a 5-year report. J Neuropathol Exp Neurol 2007;66(8):750–759.
23. Evans AJ, Chetty R, Clarke BA, et al. Primary frozen section diagnosis by robotic microscopy and virtual slide telepathology: the University Health Network experience. Hum Pathol 2009;40(8):1070–1081.
24. Dunn BE, Choi H, Almagro UA, Recla DL, Krupinski EA, Weinstein RS. Routine surgical telepathology in the Department of Veterans Affairs: experience-related improvements in pathologist performance in 2200 cases. Telemed J 1999;5(4):323–337.
25. Dunn BE, Almagro UA, Choi H, Recla DL, Weinstein RS. Use of telepathology for routine surgical pathology review in a test bed in the Department of Veterans Affairs. Telemed J 1997;3(1):1-10.
26. Bashshur RL, Krupinski EA, Weinstein RS, Dunn MR, Bashshur N. The empirical foundations of telepathology: evidence of feasibility and intermediate effects. Telemed J E Health 2017;23(3):155–191.
27. Menter T, Nicolet S, Baumhoer D, Tolnay M, Tzankov A. Intraoperative frozen section consultation by remote whole-slide imaging analysis - validation and comparison to robotic remote microscopy. J Clin Pathol 2020;73(6):350–352.
28. Chang S, Sadimin E, Yao K, et al. Establishment of a whole slide imaging-based frozen section service at a cancer center. J Pathol Inform 2022;13, 100106.
29. Baxi V, Edwards R, Montalto M, Saha S. Digital pathology and artificial intelligence in translational medicine and clinical practice. Mod Pathol 2022;35(1):23–32.
30. Huang Z, Chen L, Lv L, et al. A new AI-assisted scoring system for PD-L1 expression in NSCLC. Comput Methods Programs Biomed 2022;221, 106829.
31. Cifci D, Foersch S, Kather JN. Artificial intelligence to identify genetic alterations in conventional histopathology. J Pathol 2022;257(4):430–444.
32. Coudray N, Ocampo PS, Sakellaropoulos T, et al. Classification and mutation prediction from non-small cell lung cancer histopathology images using deep learning. Nat Med 2018;24(10):1559–1567.
33. Kather JN, Pearson AT, Halama N, et al. Deep learning can predict microsatellite instability directly from histology in gastrointestinal cancer. Nat Med 2019;25(7):1054–1056.
34. Lujan G, Quigley JC, Hartman D, et al. Dissecting the business case for adoption and implementation of digital pathology: a white paper from the digital pathology association. J Pathol Inform 2021;12:17.
35. 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.
36. Giaretto S, Renne SL, Rahal D, et al. Digital pathology during the COVID-19 outbreak in Italy: survey study. J Med Internet Res 2021;23(2), e24266.
37. Lujan GM, Savage J, Shana'ah A, et al. Digital pathology initiatives and experience of a large academic institution during the coronavirus disease 2019 (COVID-19) pandemic. Arch Pathol Lab Med 2021;145(9):1051–1061.
38. Betmouni S. Diagnostic digital pathology implementation: learning from the digital health experience. Digit Health 2021;7.20552076211020240.
39. Pantanowitz L, Sharma A, Carter AB, Kurc T, Sussman A, Saltz J. Twenty years of digital pathology: an overview of the road travelled, what is on the horizon, and the emergence of vendor-neutral archives. J Pathol Inform 2018;9:40.
40. Krupinski EA, Silverstein LD, Hashmi SF, Graham AR, Weinstein RS, Roehrig H. Observer performance using virtual pathology slides: impact of LCD color reproduction accuracy. J Digit Imaging 2012;25(6):738–743.
41. Campbell WS, Talmon GA, Foster KW, Lele SM, Kozel JA, West WW. Sixty-five thousand shades of gray: importance of color in surgical pathology diagnoses. Hum Pathol 2015;46(12):1945–1950.
42. Campbell WS, Hinrichs SH, Lele SM, et al. Whole slide imaging diagnostic concordance with light microscopy for breast needle biopsies. Hum Pathol 2014;45(8):1713–1721.
43. Norgan AP, Suman VJ, Brown CL, Flotte TJ, Mounajjed T. Comparison of a medical-grade monitor vs commercial off-the-shelf display for mitotic figure enumeration and small object (*Helicobacter pylori*) detection. Am J Clin Pathol 2018;149(2):181–185.
44. Abel JT, Ouillette P, Williams CL, et al. Display characteristics and their impact on digital pathology: a current review of pathologists' future "microscope". J Pathol Inform 2020;11:23.
45. Temprana-Salvador J, López-García P, Castellví Vives J, et al. DigiPatICS: digital pathology transformation of the Catalan health institute network of 8 hospitals—planification, implementation, and preliminary results. Diagnostics 2022;12(4):852.
46. Alcaraz Mateos E, Caballero-Alemán F, Albarracín-Ferrer M, et al. Research on devices for handling whole slide images on pathology workstations. an ergonomic outlook. Diagn Pathol 2016;2(1).
47. Alchami F, Iqbal Z, Björkhammer C, et al. Whole slide imaging integration with lab information systems, a study of the requirements, processes and procedures enabling a reporting-based workflow. Pathol Lab Med Int 2023;15:1-11.
48. Amin M, Sharma G, Parwani AV, et al. Integration of digital gross pathology images for enterprise-wide access. J Pathol Inform 2012;3:10.
49. Rashidi HH, Tran NK, Betts EV, Howell LP, Green R. Artificial intelligence and machine learning in pathology: the present landscape of supervised methods. Acad Pathol 2019;6.2374289519873088.
50. Potts SJ. Digital pathology in drug discovery and development: multisite integration. Drug Discov Today 2009;14(19–20):935–941.
51. Metter DM, Colgan TJ, Leung ST, Timmons CF, Park JY. Trends in the US and Canadian pathologist workforces From 2007 to 2017. JAMA Netw Open 2019;2(5), e194337.
52. Hamilton PW, Bankhead P, Wang Y, et al. Digital pathology and image analysis in tissue biomarker research. Methods 2014;70(1):59–73.
53. The Royal College of Pathologists. https://www.rcpath.org/profession/digital-pathology.html. [website]. Accessed 4 September 2023.
54. Kaushal RK, Yadav S, Sahay A, et al. Validation of remote digital pathology based diagnostic reporting of frozen sections from home. J Pathol Inform 2023;14, 100312.
55. Girolami I, Neri S, Eccher A, et al. Frozen section telepathology service: efficiency and benefits of an e-health policy in South Tyrol. Digit Health 2022;8.20552076221116776.
56. Antonini P, Santonicco N, Pantanowitz L, et al. Relevance of the College of American Pathologists guideline for validating whole slide imaging for diagnostic purposes to cytopathology. Cytopathology 2023;34(1):5-14.
57. Pulkkinen J, Huhtala H, Krogerus LA, Hollmén S, Laurila M, Kholová I. Endocervical cytology: inter- and intra-observer variability in conventional pap smears. Acta Cytol 2022;66(3):206–215.
58. Faron A. Cultural Humility, Technology, and Healthcare: Plug and Play. Available from: https://www.plugandplaytechcenter.com/resources/cultural-humility-technology-and-healthcare/ 2019, August 8.
59. Conselho Federal de Medicina. Resolution CFM No. 2.264/2019. sistemas.cfm.org.br/normas/visualizar/resolucoes/BR/2019/2264. [website]. Accessed 29 January 2024.
60. Singh R, Chubb L, Pantanowitz L, Parwani A. Standardization in digital pathology: supplement 145 of the DICOM standards. J Pathol Inform 2011;2:23.