Short Communication

Types and frequency of whole slide imaging scan failures in a clinical high throughput digital pathology scanning laboratory

Ankush U. Patel 1,⁎, Nada Shaker 1, Savannah Erck, David A. Kellough, Erin Palermini, Zaibo Li, Giovanni Lujan, Swati Satturwar, Anil V. Parwani

The Ohio State University Wexner Medical Center Department of Pathology, 450 W 10th Ave, Columbus, OH 43210, USA

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ABSTRACT

Digital workflow transformation continues to sweep throughout a diversity of pathology departments spanning the globe following catalyzation of whole slide imaging (WSI) adoption by the SARS-CoV-2 (COVID-19) pandemic. The utility of WSI for a litany of use cases including primary diagnosis has been emphasized during this period, with WSI scanning devices gaining the approval of healthcare regulatory bodies and practitioners alike for clinical applications following extensive validatory efforts. As successful validation for WSI is predicated upon pathologist diagnostic interpretability of digital images with high glass slide concordance, departmental adoption of WSI is tantamount to the reliability of such images often predicated upon quality assessment notwithstanding image interpretability but extending to quality of practice following WSI adoption. Metrics of importance within this context include failure rates inclusive of different scanning errors that result in poor image quality and the potential such errors may incur upon departmental turnaround time (TAT). We sought to evaluate the impact of WSI implementation through retrospective evaluation of scan failure frequency in archival versus newly prepared slides, types of scanning error, and impact upon TAT following commencement of live WSI operation in May 2017 until the present period within a fully digitized high-volume academic institution. A 1.19% scan failure incidence rate was recorded during this period, with re-scanning requested and successfully executed for 1.19% of cases during the reported period of January 2019 until present. No significant impact upon TAT was deduced, suggesting an outcome which may be encouraging for departments considering digital workflow adoption.

Introduction

Advances wrought from the past 20 years of exponential technological growth have propelled prospects for the digitization of glass slides into reality for that of entire anatomical pathology laboratory workloads.1 Improvements in digital imaging speed, quality, useability, and utility have progressively encouraged the adoption of digitized workflow elements in laboratories spanning the globe, with some departments now documenting encouraging results following full workflow digitization.2-4 Whole slide imaging (WSI) solutions have evolved in tandem with challenges prevailing throughout the modern pathology landscape, e.g., shorter turnaround times, increased report complexity, and diminishing specialist numbers confronted by aging patient demographics with progressively increasing incidences of disease.5

Such issues have steadfastly persisted as a silent undercurrent plaguing many departments, though were fervently exacerbated and exhumed as problems demanding solutions upon inception of the COVID-19 pandemic.5,7 As the pathogen terraformed the global topography of clinical practice, shifting practitioner attitudes favoring WSI adoption for a litany of use cases lay in its wake.5,7 A concurrently dynamic regulatory environment, e.g., US-government sanctioned “enforcement discretion” of CLIA regulations, allowed a restrictive laxity for remote sign out accelerating WSI adoption for primary diagnosis.5,6,11 The US Food and Drug Administration (USFDA) granted clearance for medical marketing of the second WSI scanning system for primary diagnoses in surgical pathology following the Philips IntelliSite Pathology Solution™ in 2017 after affirming diagnostic concordance with glass slides and scanning reproducibility.1,5,12,13 WSI adoption for clinical diagnostics continues to increase,5 primarily for routine surgical pathology with focus in teleconsultation.14-23

Large-scale adoptions catalyzed by the pandemic have spearheaded numerous concordance studies validating WSI for surgical pathology, amassing significant data demonstrating the capacity for WSI to meet and
exceed the capabilities of traditional light microscopy. An increasing number of WSI scanner models now undergo evaluation for USFDA 510(k) clearance and European Union Conformité Européenne (EU CE) mark approval.5,6 Yet, USFDA approval for primary clinical diagnostics in other pathology subspecialties remains to be achieved.1 Despite substantial documentation of WSI employment for a variety of use cases within a diversity of departments, clinical deployment still struggles behind that of digital imaging for radiology, stymied primarily from concerns including WSI quality and its potential impact upon pathology image analysis.24–26

Common image quality errors stemming from digital acquisition of glass slide specimens during the process of WSI scanning include venetian blinding from contaminated objective lens (Figs 1a, 1b), “champagne” bubbling from coverslip errors on frothy mounting media (Fig. 2), slides with dirt (Fig. 3), dust (Fig. 4), mounting media (Fig. 5), and markings (Fig. 6) that have not been appropriately cleaned prior to scanning, clipping from WSI devices (Fig. 7), tissue beyond the coverslip (Fig. 8), and image stitching errors (Fig. 9).

Whole slide images must replicate glass slides with complete accuracy before ubiquitous utilization for routine pathologic diagnosis is realized. As evaluation of WSI device output acts as the singularity from which further workflow transformation may find genesis or remain pendant, a litany of departmental concerns may precipitate from prospective analysis of WSI device acquisition including financial cost benefit, diagnostic utility, and practitioner satisfaction. A diverse array of WSI devices introduced to the market within this recent period have demonstrated the capacity to handle the rigorous of low-to-high volume departments for research, clinical, and educational settings. Features such as continuous or random-access processing facilitate glass slide uploading during the image capture and digitization of others, with improvements in batch-scanning capabilities functioning in tandem to improve laboratory efficiency.1,27 Many WSI devices are now equipped to navigate a slew of slide mediums cast on slides of varying dimensions. WSI scanning cameras and image sensors deliver greater sensitivity, resolution, field-of-view, and frame rates than ever before for optimal capture and digitization of glass slide specimens.

A prospective evaluation of digital deployment as a value driver for departments with specific needs and objectives often prioritizes return-on-investment (ROI) and quality of practice, the latter of which may be analyzed as a function of turnaround time (TAT).

WSI scan failures resulting in image errors and subsequent rescanning efforts are of importance during reassessment of WSI device robustness. Many WSI devices require coverslips for glass slides which may introduce debris, either on the coverslip itself or lodged within the slide upon coverslip casing, interfering with tissue finding and image analysis.5,28 Some glass slides may fail automated scanning and may require reloading for manual scanning. These errors may arise from slide dimensions incompatible with a specific WSI device or broken/damaged glass slides that are loaded into a device yet are not suitable for scanning, e.g., human-errors unrelated to the function of the WSI device itself.29

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**Fig. 1.** (a) Venetian blinding. Captured at 0.25x. (b) Venetian blinding. Captured at 2x; contaminated scanner must be taken offline for inspection while previously scanned slides undergo review for rescanning in a different WSI device.
Fig. 2. Champagne bubbling. Captured at 20x; requires reapplication of coverslip.

Fig. 3. Dirty slide. Captured at 5x; clean slide and rescan.

Fig. 4. Dust on slide. Captured at 10x; clean slide and rescan.
Fig. 5. Mounting media on slide. Captured at 10x; clean slide and rescan.

Fig. 6. Markings on slide. Slide markings causing focus issues.

Fig. 7. Image clipping. Rescan in a different machine or place 3–5 red dots around tissue on rear of slide before rescanning.
error followed by failures due to slide preparation features. The most common machine error was failed ROI followed by skipped tissue error.

**Conclusion**

WSI scan failure is exceedingly uncommon (1.19%) in a facility with experienced slide scanning staff and optimal slide preparations. Rescanning was requested for only 1.19% cases and was feasible in 100% cases.

Scanning of archival versus newly prepared slides did not have an impact on scan failure rates. Recorded scan failures at our institution were not encountered with enough frequency to significantly impact TATs and therefore our results may be of encouragement for similar departments considering transition to digital workflow.

**Declaration of interests**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**References**

1. Kumar N, Gupta R, Gupta S. Whole slide imaging (WSI) in pathology: current perspectives and future directions. J Digit Imaging Aug 2020;33(4):1034-1040. https://doi.org/10.1007/s10278-020-00351-z.
2. Fraggetta F, Garazzo S, Zannoni GF, Pantanowitz L, Rossi ED. Routine digital pathology workflow: the catania experience. J Pathol Inform 2017;8:51. https://doi.org/10.4103/jpi.jpi_58_17.
3. Fraggetta F, Caputo A, Guglielmino R, Pellegrino MG, La Imperia V. Diagnostics (Basel) Oct 16 2021;11(10). https://doi.org/10.3390/diagnostics11010196.
4. Betanera JA, Aneiros-Fernandez J, Del Moral RG. Complete digital pathology for routine histopathology diagnosis in a multicenter hospital network. Arch Pathol Lab Med Feb 2020;144(2):221–228. https://doi.org/10.5858/arpa.2018-0541.OA.
5. Patel A, Balis UGJ, Cheng J, Zaito L, Lujan G, McClintock DS, et al. Contemporary whole slide imaging devices and their applications within the modern pathology department: a

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**Table 1**

Summary of whole slide imaging scan failure types and frequency.

|                     | Archival slides | Primary diagnosis slides | Total life of project |
|---------------------|-----------------|--------------------------|----------------------|
| Tissue skipped errors | 4,392           | 1,841                    | 6,233                |
| ROI<sup>a</sup> errors | 8,030           | 9,512                    | 17,542               |
| Slides dropped       | 1,233           | 271                      | 1,504                |
| Other errors<sup>b</sup> | 894             | 670                      | 1,564                |
| Errors identified on QCC<sup>c</sup> review | 283            | 203                      | 486                  |
| Total errors         | 14,832          | 12,497                   | 27,329               |
| Total slides scanned | 1,244,763       | 1,044,503                | 2,289,266            |
| % Total errors       | 1.19%           | 1.20%                    | 1.19%                |
| Rescan requests      | Data unavailable | 527                      | 527                  |

Key: A – region of interest; B – errors stemming from out of focus, staining faintness, tissue thickness, tissue size, broken slides, and other inciting events; C – quality control.
