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Digitalization of pathology in a multicenter setup: A user experience study and comparison of two alternative implementation strategies

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ABSTRACT

Background: Fimlab Laboratories and Turku University Hospital implemented digital pathology simultaneously but with different strategies. At Fimlab, all histological slides were scanned starting from the first go-live date, allowing individual pathologists to determine when to cease the distribution of glass slides. In contrast, Turku initiated slide scanning and screen diagnostics gradually focusing on anatomical subspecialties.
Materials and methods: A voluntary user experience survey was completed by 54 out of 66 pathologists (81.8 %) one year after transitioning to digital diagnostics.
Results: The median utility grade of digital pathology was 9 in both sites (mode 10, mean 8.5, range 1–10). Screen diagnostics was adopted in ≤ 1 month for 75.9 % of the pathologists. The vast majority (86.8 %) of the pathologists signed out 90–100 % of the cases digitally, and most had analyzed over 2000 cases using digital pathology. Digital pathology workflow was considered faster by 62.3 % of respondents whereas 17 % preferred light microscopy. Remote working was reported as convenient by 96.8 % of respondents at Fimlab and 62.5 % at Turku. In the self-assessment questions, 77.8 % of respondents identified as fluent users.
Conclusions: Both strategies led to widespread use of DP in less than 10 months. The median utility of digital transition was excellent and most pathologists adapted to the screen rapidly. After one year, the vast majority of the cases were reported digitally only, which we consider sufficient for workflow gains. Almost no statistical differences were seen after one year of implementation, suggesting both strategies are viable.

1. Background

Digital pathology (DP) started to gain ground two decades ago in niche applications such as teaching, intraoperative sections, glass seminars, and research [1]. At that time, DP was commonly called “virtual microscopy” or “telepathology”. Prior to large-scale adoption in clinical diagnostics, the accuracy and safety of DP needed to be investigated. The first comprehensive validation study, which included over 3000 cases, demonstrated that diagnostics based on whole slide imaging (WSI) were non-inferior to those using light microscopy (LM) [2]. Similar results have since been widely reported across various platforms [3–6]. Meanwhile, advancements in computing power, high-bandwidth networks, and increased storage capacity enabled the first fully digitized clinical pathology laboratories around 2015–2016 [7–9]. The adoption of DP is currently expanding across all continents [10].

Several factors are driving the digitization of clinical pathology. A fully digital workflow is expected to enhance efficiency, reduce turnaround times, facilitate comparisons with archived cases, streamline multidisciplinary meetings, and improve diagnostic quality. These advancements are attributed to improved workflows, easier access to location-independent consultants, and the integration of artificial intelligence (AI) [9,11,12]. Although digitization increases the direct hardware and ICT-related costs for pathology departments, it is still expected to yield long-term savings [13–16].

The digitization of pathology is ongoing, but there is limited literature on how end users have experienced the most significant change in pathology diagnostics in decades. Only a few studies [9,17,18] have reported the digital pathology user experience from the perspective of

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pathologists. As an exceptionally positive example, Retamero et al. reported that 100 % of the pathologists were so satisfied with digital diagnostics that none of them wanted to return to using light microscopes [17]. Furthermore, even less has been reported on the impact of different implementation strategies during the digital transition.

In the present study, we report the results from an anonymous user experience survey conducted among 54 pathologists working in five different pathology laboratories in Finland. At the time of this study, these pathologists had 12–18 months of experience in clinical diagnostics using digital pathology. Furthermore, the laboratories shared the same solution provider but chose different strategies for involving end users in DP, allowing us to compare the success of these strategies.

2. Methods

2.1. Data collection

The user experience questionnaire was shared via Google Forms with all pathologists ($n = 66$) working at the pathology laboratories of Hämeenlinna, Lahti, Tampere, Vaasa, and Turku. Pori was excluded because their implementation project started later. The participants were informed that the results of the survey would be published. Participation was voluntary and was considered informed consent. No age or sex-related information was collected to preserve participants' anonymity and to increase the likelihood of receiving the most objective responses possible, reflecting real-life experiences. The survey included both quantitative and qualitative questions: 23 multiple-choice questions about digital pathology user experience, including self-assessments, and two text fields for open-ended feedback (see Appendix A for the full questionnaire). The questionnaire form was open from March 2nd to 21st, 2022.

2.2. Background information

In 2020, Fimlab Laboratories and the ICT company 2M-IT (2M-IT Oy, Helsinki, Finland) jointly announced a public procurement for DP. As a result, the Philips IntelliSite Pathology Solution (PIPS) (Philips, Amsterdam, Netherlands), which includes the Image Management System (IMS) version 3.2, and Ultra Fast Scanners (UFS, resolution 0.25um/pixel), was selected as our end-to-end DP solution for implementation. Altogether, six pathology laboratories in different locations (Hämeenlinna, Lahti, Pori, Tampere, Turku, and Vaasa) were fully digitized, representing the first large-scale implementation of DP in Finland and accounting for one-third of the Finnish histopathology diagnostics. The annual production volumes of histological slides at Fimlab Laboratories (including Hämeenlinna, Lahti, Tampere, and Vaasa), and Turku University Hospital are 400,000 and 160,000, respectively.

2.3. Implemented equipment

2.3.1. Slide scanners and storage

Fimlab adopted centralized scanning for Tampere and nearby satellite laboratories at Hämeenlinna and Lahti. This was enabled by four UFS scanners and two UVS-L60 scanners for double-slides (75 ×50 mm). Vaasa, located more far away on the west coast, had their own scanners, one UFS and one UVS-L60. Turku started with two UFS scanners and one UVS-L60, but by now they have three UFS scanners for improved redundancy. The common image storage system for both institutions was Dell EMC Isilon hosted by 2M-IT and located at Turku.

2.3.2. Workstations and network

At Fimlab, pathologists' standardized workstation for digital pathology consisted of HP RCTO Z2 Tower G5, Windows 10 Pro 64, Intel Core i7 10700, plus a separate graphics card NVIDIA Quadro P2200. In Turku, the pre-existing computer systems continued to be used without modification, and upgrades were deferred until after the research period had ended. Both in Turku and at Fimlab, the workstations were connected to hospital network using Ethernet network interface card with a theoretical maximum capacity of 1000/1000 Mb/s (download/upload).

2.3.3. Diagnostic screens and panning tools

Both institutions purchased similar screens to all their pathologists to ensure the diagnostic consistency. At Fimlab, the selection was Lenovo ThinkVision P32p-30 and at Turku Eizo ColorEdge CS2731, both of which fulfilled Philips specifications on diagnostic screens (Brightness $\geq$ 300 Cd/m2; Contrast ratio >1000:1; Color Gamut > 99 % sRGB, Color temperature = D65 or similar; Delta E < 3 or similar; Display technology = IPS). In addition, practically all pathologists also had a second (variable) monitor for LIS and other non-diagnostic purposes. For image viewing, pathologists could select input devices that suited their ergonomic preferences from among the models recommended by Philips, such as 3DConnexion SpaceMouse Compact, Pro or wireless (3DConnexion GmbH, Munich, Germany), together with a regular or vertical mouse and keyboard.

2.4. Workflow modifications

Fimlab initiated 100 % scanning of histological slides in August 2021. During the run-in period, double workflow was implemented, allowing for screen diagnostics while still distributing glass slides. The adoption of screen diagnostics began on a voluntary basis, enabling individual pathologists to choose when to forgo glass slides. Eventually, the number of DP-only users reached a critical majority, prompting the decision to discontinue the double workflow. A fully paperless and slideless system for case distribution was subsequently and successfully established. Meanwhile, in Turku, the transition to digital diagnostics was implemented gradually in two-week sequences, organized around several teams of different pathological subspecialties. Whole slide imaging was gradually initiated alongside the teams (Fig. 1). During this transition, the former analogue case distribution, based on assessing cases to individual pathologists (push), was changed to digital team based case distribution (pull).

2.5. Laboratory training

Both institutions carefully prepared to adapt the laboratory to a digital workflow. Based on previous experiences and reports, it was obvious that the quality of slide preparation was one of the keys to success. In addition to internal teaching sessions, one external audit of the laboratory workflow and a one-hour teaching session on slide preparation, sectioning, and tissue placement were conducted onsite by Algol (local representative of Philips) in both Turku and Tampere. To avoid mechanical problems associated with misplacement of glass coverslips, both institutions adapted film coverslipping (Sakura Prism & Sakura Film at Fimlab, Roche Ventana HE 600 at Turku in partial use).

2.6. Statistical analyses

The distribution of the answers to the multiple-choice questions is reported as is. The correlation and statistical significance between sites with alternative implementation strategies, the number of cases analyzed on the screen, and categories reflecting speed and opinion grades were analyzed using Fisher's exact test and the Mann-Whitney *U* test, with IBM SPSS Statistics version 29 (IBM Corp., Armonk, NY, USA).

3. Results

In total, 54 out of 66 pathologists (81.8 %) completed the survey, representing approximately one-third of all active pathologists in Finland. The survey was conducted about one and half years after starting slide scanning and screen diagnostics, including a run-in period

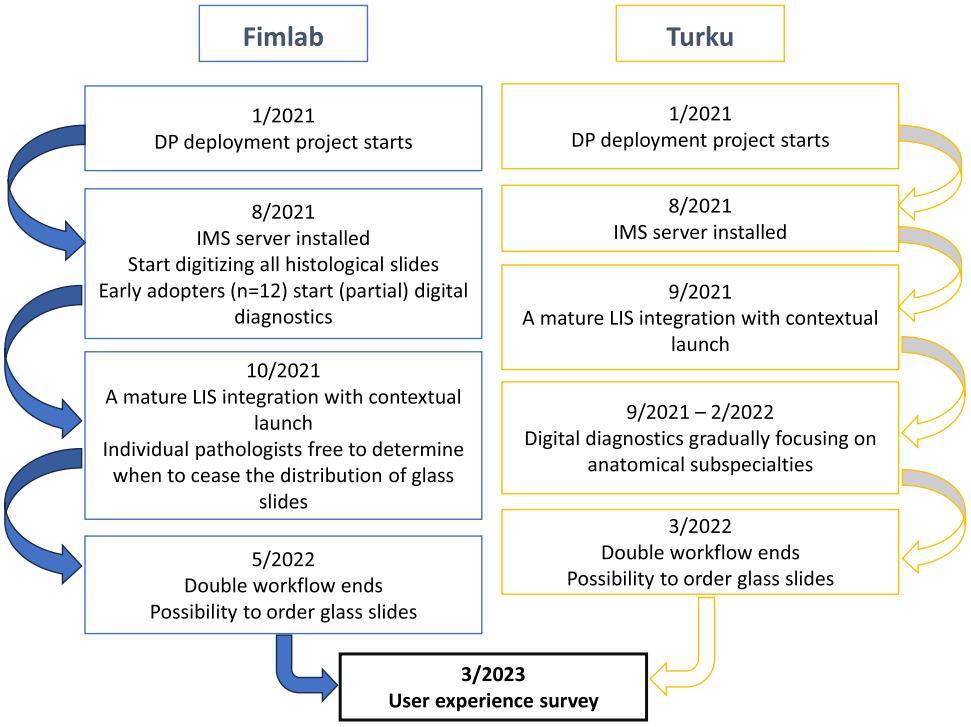

Fig. 1. Deployment flowchart.

of about six months.

3.1. The status of screen diagnostic after one and half years from go-live

As background information, the participants were asked to estimate the number of cases they have reported from the screen, and the percentage they are currently diagnosing from the screen. In both Fimlab and Turku, the vast majority of diagnostics was primarily digital and all pathologists had started screen diagnostics, with most of them having reported more than 2000 cases digitally (55.8 %, mode 2001–5000 cases, Fig. 2.A.). As a comparison, pathologists in public hospitals in Finland usually sign 2000 to 6000 cases per year, depending on their subspecialty. Only a few pathologists primarily used light microscopes anymore. The number of cases analyzed using DP per pathologist was higher at Fimlab ($p = 0.02$). Eighty-seven percent (87 %) of the participants estimated they were analyzing 90–100 % of the cases from screen (Table 1). At Fimlab, two pathologists primarily analyzed cases using LM, with only 10 % of cases utilizing DP, whereas in Turku, one pathologist used DP for half of the cases. The remaining pathologists analyzed at least 70 % of their cases using DP.

3.2. Screen adoption time

Next, we asked the participants to estimate how long it took them to adapt to making diagnostics from a computer screen instead of using LM. In Fimlab 35.3 % and in Turku 15.0 % of the participants felt almost immediately confident in using DP, and in both sites 75.9 % reported the same after one month (Fig. 2.B.). There was no significant difference in the adaptation time between Fimlab and Turku ($p = 0.30$).

3.3. Self-assessment

In self-assessment categories (Fig. 2.C.), there were no statistically significant differences between Fimlab and Turku. However, when comparing self-assessment categories in terms of self-perceived fluency, two statistically significant differences were observed: fluent users at Fimlab reported higher use of annotations and other tools ($p < 0.001$) while knowledge of shortcuts was higher in Turku ($p = 0.03$).

3.4. Digital pathology enhanced the experienced speed of diagnostics

When asked about the viewing speed of diagnostics on a screen versus a light microscope at their workplace, 48.1 % of all pathologists at Fimlab and Turku considered screen diagnostics faster, 24.1 % reported that LM is faster and 18.5 % stated that they were approximately equally fast. The remaining 9.3 % were unable to decide, as it would depend on the case (Fig. 2.D.). No significant difference was observed in the experienced speed of work at the workplace between Fimlab and Turku ($p = 0.82$), nor was there a significant difference between the experienced speed and the number of cases reported using screen diagnostics ($p = 0.55$). However, when comparing the experienced working speed at the workplace to whether one felt fluent user or not, a statistically significant difference was found in favor of fluent users ($p = 0.02$) (Fig. 3B.).

When the participants were asked to assess the overall speed of diagnostics (DP vs. LM), including factors such as slide logistics, retrieval, missing cases, and others, 62.3 % considered DP faster, while 17.0 % preferred LM. The difference between Fimlab and Turku did not reach statistical significance ($p = 0.07$). Not surprisingly, fluent users found that working overall was significantly faster with DP ($p = 0.04$).

3.5. Remote viewing experience satisfaction

Regarding the remote viewing experience from home office, 89.8 % of all respondents were satisfied or highly satisfied with the remote working speed. The overall satisfaction rate was significantly higher at Fimlab (96.8 %) than in Turku 62.5 % ($p = 0.01$). It is noteworthy that only 40 % of respondents from Turku answered this question, compared to a 91 % response rate in Fimlab.

3.6. Utility of digitization

The overall grade for the utility of transitioning to digital pathology averaged 8.5 (median 9, mode 10) on a scale of 1–10, where 1 represents

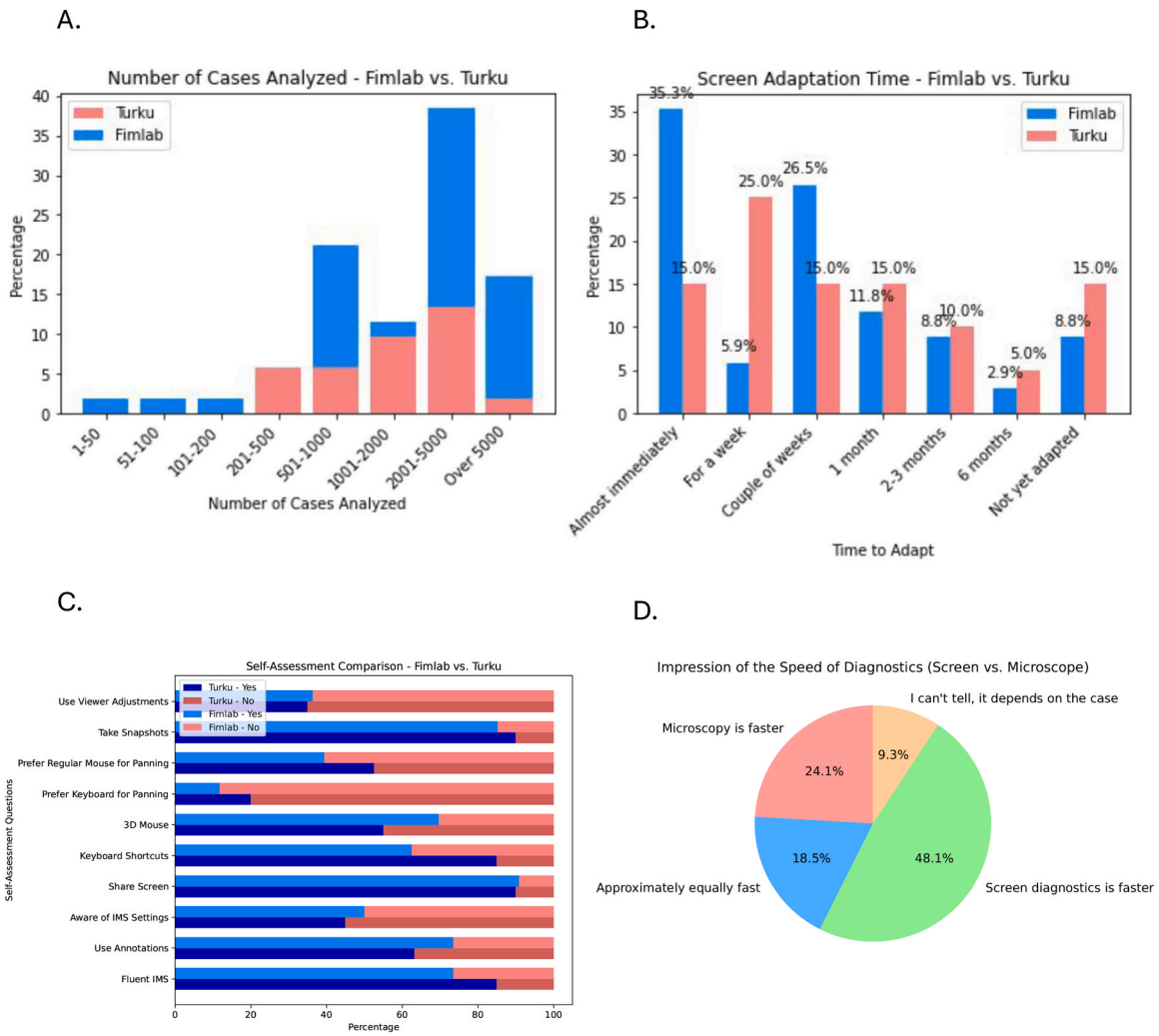

Fig. 2. A. The number of cases analyzed digitally, as estimated by individual pathologists. B. The time required to become comfortable with digital diagnostics. C. Self-assessment as a digital pathologist. D. The respondents' impressions of diagnostic speed: light microscopy compared to screen diagnostics.

Table 1
The estimated percentage of cases reported using DP.

	Fimlab	Turku	All	
% cases	n (%)	n (%)	n (%)	Cumulative %
100	20 (60.6)	9 (45.0)	29 (54.7)	54.7
90	9 (27.3)	8 (40.0)	17 (32.1)	86.8
80	1 (3.0)	1 (5.0)	2 (3.8)	90.6
70	1 (3.0)	1 (5.0)	2 (3.8)	94.3
60	0 (0)	0 (0)	0 (0)	94.3
50	0 (0)	1 (5.0)	1 (1.9)	96.2
40	0 (0)	0 (0)	0 (0)	96.2
30	0 (0)	0 (0)	0 (0)	96.2
20	0 (0)	0 (0)	0 (0)	96.2
10	2 (6.1)	0 (0)	2 (3.8)	100
Total %	100	100	100	

The participants were asked to estimate the percentage of histological cases they currently analyze using DP. At both sites, DP was the most commonly used method for analysis. There was no statistically significant difference between Fimlab and Turku ($p = 0.56$, Fisher's exact test).

the lowest utility and 10 the highest. The means of the grades were 8.6 and 8.2 for Fimlab and Turku, respectively ($p = 0.50$) (Fig. 3A.). We further analyzed whether the self-perceived fluency was associated with an individual's opinion about the utility of the digital transition. The results indicated that fluent users ($n = 42$, 77.8 %) gave significantly better utility grades than non-fluent users ($p = 0.01$) (Fig. 3B.).

3.7. Microscope glass slide retrieval

Glass slides were requested for evaluation due to focus issues or other uncertainties by 7.5 % of the pathologists on a daily basis, 30.2 % on a weekly basis, 35.8 % on a monthly basis, and 26.4 % less frequently than once a month. The only notable difference was observed in the group that requested slides less frequently than once a month: 39.4 % at Fimlab compared to 5.0 % in Turku ($p = 0.01$).

3.8. Qualitative feedback unveiled: Insights and potential impacts

3.8.1. Feedback from respondents rating DP utility 1–5

Seven respondents (13 %), who rated the utility of transitioning to digital pathology between 1 and 5 on a scale of 1–10, were fairly evenly distributed across the different sites. All agreed that microscopy is faster than screen diagnostics. Among them, two reported feeling fluent in using IMS. The number of cases they had viewed varied significantly: three respondents had viewed more than 5000 cases, while the others had viewed between 1000 and 2000. One respondent had adapted to DP within 2–3 months, whereas the others had not yet fully adapted.

In response to an open-ended question about the quality of screen diagnostics, respondents emphasized several challenges. These included the difficulty of detecting Helicobacteria from Giemsa -stained slides, the insufficiency of resolution, and obstacles in assessing the degree of dysplasia or the morphology of individual cells, alongside various

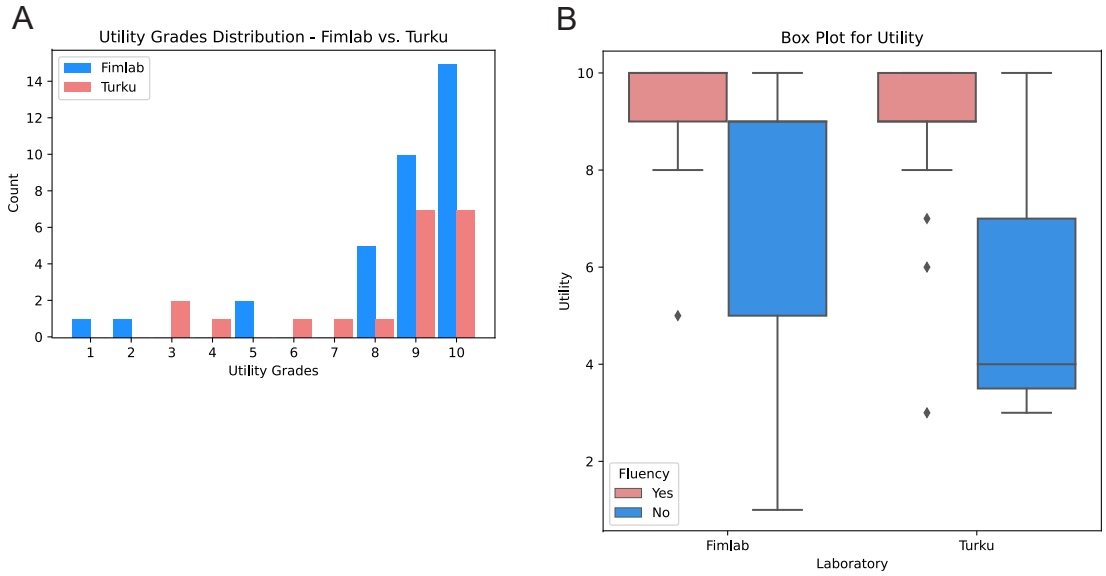

Fig. 3. A. Utility of the digital transition as reported at Fimlab and in Turku. B. Utility compared to self-perceived fluency.

scanning issues. Conversely, they also noted the benefits, such as the ease of consultation. Furthermore, one respondent mentioned that, for basic pathology, the quality of screen diagnostics is fully adequate, in contrast to some subspecialized fields such as hematopathology.

In a section allowing for completely free responses, only three individuals provided feedback. They expressed concerns about a decline in diagnostic quality, the slow pace of work, and the frequent need to retrieve glass slides. One respondent noted that the actual achievements of DP fell short of their initial expectations. On a positive note, the convenience of multidisciplinary meetings was emphasized.

3.8.2. Feedback from respondents rating DP utility 6–10

Of the respondents, 47 (87 %) rated the utility of transitioning to DP between 6 and 10. In their responses to the open-ended question about the quality of screen diagnostics, similar themes emerged as those expressed by the group that assigned ratings between 1 and 5. There was a notable emphasis on challenges related to scanning quality and information technology, as well as difficulties in identifying microbes. Additionally, this group highlighted the benefits of DP, including the ease and precision of measurements, the simplified side-by-side comparison of H&E and IHC slides, and the ability to concurrently review older cases.

Completely open-ended feedback was provided by 12 of these respondents (26 %). Five responses once again highlighted the benefits of the measuring tools, the convenience of multidisciplinary meetings, and DP as a whole. Three responses were entirely negative, criticizing IMS fluency and/or the integration between the laboratory information system (LIS) and IMS. Three responses included both positive and negative perspectives, with content aligning with the points mentioned above.

4. Discussion

Pathology diagnostics have relied on the light microscope for centuries. The very first telepathology applications were introduced in the 1990s for frozen sections [19] and became part of clinical routine in the early 2000s [20], but the low capacity of the networks, storage and computers were still preventing fully digital diagnostics of the entire histological slide production. Therefore, the first fully digital pathology laboratories were not introduced until 2016, making a revolutionary milestone, particularly in terms of workflow.

In Finland, although some pioneers have embraced digital pathology [21], the large-scale digitization of clinical pathology laboratories only began in the 2020 s. This is the first study on user experiences with fully digital pathology in Finland and, to the best of our knowledge, one of the largest in terms of the number of participating pathologists ($n = 54$), representing one-third of all Finnish pathologists. Our results indicate that the digital transition is a positive development in pathology diagnostics in several ways, as reported by the majority of the participants, though a small percentage of pathologists disagree. The utility of digital transition received a median score of 9 (range 1–10, mean 8.5, mode 10), with 62.3 % of participants considering DP (including logistics) faster overall, while 17 % preferred LM. Over 75 % of the pathologists reported becoming familiar with screen diagnostics within one month, regardless of their prior exposure to digital pathology, which is a relatively short time for such a significant change in diagnostics.

IMS's voluntary training sessions were held three times before and twice after the system's implementation. There were even times when training sessions were held weekly. Still, 22.2 % of respondents felt they could not use the system fluently, and 30.2 % felt they could not use annotations and other tools effectively or diversely. However, IMS is the primary tool in DP, and these skills significantly impact the user experience. Clearly, there is a strong need for ongoing education beyond the initial training on how to use the system.

At Fimlab, pathologists who opted to work remotely were provided with 32" 4 K monitors and laptops with powerful GPUs and CPUs. Over 90 % of the pathologists at Fimlab were satisfied with the speed of working remotely from their home offices – a feature that was especially useful during the COVID-19 pandemic and remained beneficial afterward. The importance of sufficient bandwidth for remote internet connections was also emphasized prior to digitization. There are many potential bottlenecks in achieving smooth zooming and panning in DP. At Fimlab, many of these were addressed in advance, which may have contributed to significantly higher satisfaction with remote working compared to Turku at that time.

Over the years, studies have shown that the speed of DP compared to LM varies – being faster in some cases and slower in others [18,22–24]. In this study, approximately half of the pathologists indicated that virtual microscopy is faster than conventional LM, a quarter preferred LM, and the remainder gave ambiguous responses. This variance may reflect differences in attitudes, the number of previous cases analyzed, or the type of specimen material, which can vary among the pathologists in larger centers with greater subspecialization. Technical issues may also affect individual pathologists' experiences, such as the use of a

dedicated GPU instead of an integrated GPU. As early as 2014, it was suggested that DP is as fast as LM for analyzing large cancer resection specimens [25]. Overall, the speed of DP depends on various factors, including system integration, LIS and other ICT specifics, browsing devices, GPU, CPU, and even the cable connecting the screen to the PC, all of which may cause delays. Our perspective is that all potential bottlenecks must be addressed before evaluating the speed of DP, and with a high-performance system, DP can clearly surpass LM in speed.

There are some valid concerns about compliance issues. Most systems designed for fully digital routine diagnostics operate at a resolution of 0.2–0.5 microns per pixel, and with current technologies, no scanner achieves perfect focus [26,27]. The resolution is a compromise between scanning speed, storage size, and diagnostic quality, which, in some cases (e.g., when identifying Helicobacteria or subnuclear details), may be suboptimal. In fact, difficulties with Helicobacteria were the most frequently mentioned issue in the free-text feedback. Gastroscopy specimens may be challenging to cut, resulting in wavy tissues that cause slightly unfocused areas, adding difficulties when using slide scanners. However, when the slides are perfectly focused, a resolution of 0.25 μm/pix should be sufficient to detect Helicobacteria. Despite the special cases that require high nuclear details, pathologists analyze most cases primarily at low magnification without difficulty. At this stage of technological evolution, achieving 100 % digitization remains highly demanding. Therefore, our LIS includes an option to request a rescan or retrieve physical slides when needed.

Several instances of qualitative feedback highlight conflicting user experiences. Initially, some pathologists reported difficulty diagnosing conditions such as prostatic adenocarcinoma from WSI images due to issues with resolution or focus. However, the questionnaire also included an opposing comment: the nucleoli appeared so large that some benign lesions could have been mistaken for cancer. These responses clearly emphasize the need for additional training and education, particularly on technical features such as image adjustments and settings that aid in recognizing more challenging structures. Therefore, it can be concluded that deploying digital pathology represents a significant shift in diagnostic practice and involves a learning curve. Initial concerns are likely to diminish after analyzing a sufficient number of cases on screen, and adoption inevitably takes time.

Some qualitative feedback responses reveal a degree of unmet expectations for digital pathology. One promising aspect, beyond the scope of this study, is the evolving role of AI in this field [28]. The deployment of DP unlocks the potential for AI-based innovations, such as advanced image analysis algorithms capable of detecting patterns imperceptible to the human eye. AI tools are continually improving, providing opportunities to assist pathologists in making more accurate diagnoses, identifying prognostic indicators more quickly, and even predicting patient outcomes with greater reliability. Over time, these tools will become fully integrated into the pathology workflow, delivering the promised improvements and, hopefully, meeting initial user expectations.

Considering the alternative implementation strategies of Fimlab and Turku, after one year of digital diagnostics, there were no statistically significant differences in the vast majority of the responses. Overall, the pathologists at both locations had reported approximately the same number of cases, were equally familiar with the new tools, and expressed similar levels of satisfaction with their new way of working. Since almost no differences were observed after one year of working digitally, both implementation strategies appear to be viable. The statistically significant difference in remote working experience can be attributed to differences in preparation for DP. Fimlab addressed the issue earlier, provided high-quality laptops and diagnostic-grade screens for remote work, and encouraged pathologists to upgrade their home network connections for improved performance.

There are some weaknesses and limitations to the study. First, the survey was completed by 81.8 % of the invited pathologists, which may have introduced bias. Second, we intentionally did not record the participants' age or sex, which could have provided additional insights. However, this was done to protect the anonymity of the respondents, and to encourage as many honest opinions as possible. Furthermore, based on the unenthusiastic feedback from some participants, it seems reasonable to assume that the survey responses were provided confidentially. Third, responses to some questions, such as the number of reported cases or the percentage of reported cases with DP, are estimates rather than precise data retrieved from the LIS. During the double workflow phase, which involves both scanning and the dispatching and distribution of slides, our LIS cannot record whether a case was reported based on WSI or glass slides.

5. Conclusions

The adoption of digital pathology was relatively quick in both Fimlab and Turku. The vast majority (75 %) of the pathologists felt comfortable with screen diagnostics within four weeks. After one year of routine use of DP, about half of the pathologists considered screen diagnostics to be faster, while one in four still believed they were faster using a light microscope. The median overall utility of the digital transition was rated as 9 (average 8.5, mode 10, range from 1 to 10), which was almost surprisingly high. In some cases, the quality of digitization was considered insufficient for diagnostics, a known issue from earlier studies that also relates to the learning curve [2,11,29]. However, digital diagnostics were possible in most cases, which we consider sufficient to enable the benefits of a digital workflow. With few exceptions, there were virtually no significant differences in user experience between Fimlab and Turku, suggesting that various implementation strategies can be successfully employed.

CRediT authorship contribution statement

Mira Valkonen: Writing – review & editing, Visualization, Conceptualization. **Teppo Haapaniemi:** Writing – review & editing. **Paavo Virtanen:** Writing – review & editing. **Pekka Taimen:** Writing – review & editing, Investigation, Data curation. **Pekka Ruusuvuori:** Writing – original draft, Visualization, Supervision. **Minna Peippo:** Writing – review & editing, Project administration, Investigation. **Harry Kujari:** Writing – review & editing, Investigation, Data curation. **Anna Välimäki:** Writing – original draft, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Teemu Tolonen:** Writing – original draft, Supervision, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT-4 in order to improve the readability and language. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Declaration of Competing Interest

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.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prp.2025.156099.

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