

A Compact Smartphone Microscope Adapter for Real-Time Telepathology: Design, Development, and Point-of-Care Applications

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Abstract

Background & Objectives: Smartphone-assisted telepathology offers a cost-effective way to support remote microscopy and teaching. Free-hand imaging through a microscope eyepiece can be unstable and often leads to misalignment or loss of focus. This study aimed to technically validate a compact, modular smartphone microscope adapter for real-time telepathology.

Methods: This prospective cross-sectional validation study took place over six months in a tertiary care pathology department. Researchers evaluated 60 archived slides, including 30 histopathology, 20 hematology, and 10 cytology specimens. Ten participants each assembled the adapter and conducted live transmission sessions on six slides, resulting in 60 sessions. Technical performance was measured using a structured 5-point Likert scale for stability, image resolution, focus quality, color accuracy, and stream stability. User feedback and diagnostic interpretability were also collected.

Results: All 60 sessions finished without any mechanical failures, device detachment, or clamp loosening. The average time for assembly and alignment was 2.4 ± 0.6 minutes. Adapter stability had the highest score (4.72 ± 0.48), followed by image resolution (4.58 ± 0.56), focus quality (4.55 ± 0.59), color fidelity (4.47 ± 0.62), and stream stability (4.41 ± 0.69). The overall composite score was 4.55 ± 0.52 . Images transmitted during the sessions were diagnostically interpretable for all specimen types, and reviewers' diagnoses matched the reference diagnosis in every session.

Interpretation & Conclusions: The adapter showed excellent stability, consistent alignment, easy usability, and provided live image transmission that was suitable for diagnosis in telepathology and teaching.

Keywords: Telepathology; Smartphone microscopy; Digital pathology; Microscope adapter; Point-of-care diagnostics; Real-time imaging.

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Introduction

Telepathology has become increasingly relevant for remote consultation, collaborative diagnosis, and pathology teaching. Advances in smartphone camera technology and internet connectivity have made mobile-based microscopic imaging a practical option in many settings. Smartphone microscopy and smartphone-assisted telepathology have been reported as feasible, low-cost approaches for acquiring, sharing, and remotely reviewing microscopic images [1–3].

A major practical limitation of smartphone-assisted microscopy is the difficulty of maintaining stable and reproducible alignment between the smartphone camera and the microscope eyepiece.

Free-hand imaging is mechanically demanding and often results in motion artefacts, vignetting, focus loss, and inconsistent illumination, particularly during dynamic slide navigation and live transmission [2]. Smartphone microscope adapters have been developed to overcome these limitations by stabilizing the optical interface.

Roy et al. showed that smartphone adapters are inexpensive and easy to use for acquiring digital microscopic [4] images and provide an economically feasible method for sharing pathology photomicrographs. Mondal and Mondal further showed that a low-cost smartphone adapter reduced the time required for image capture and decreased operator effort compared with the free-hand technique [5].

More advanced smartphone-based imaging systems, including smartphone whole-slide imaging platforms, have also been described, although these differ from simple adapter-based live-transmission systems [6]. In addition to telepathology, real-time display of microscopic fields may be useful in medical education, particularly where access to multi-headed microscopes or dedicated digital pathology systems is limited.

In this context, the present study was undertaken to technically validate a compact modular smartphone microscope adapter with emphasis on mechanical

stability, optical alignment, and live-stream performance during real-time telepathology.

Materials and Methods

This prospective cross-sectional technical validation study was conducted over six months in the Department of Pathology, Silchar Medical College and Hospital to assess the performance of a compact modular smartphone microscope adapter fabricated from commercially available components. The adapter consisted of three functional parts: an eyepiece clamp, an adjustable alignment unit, and a smartphone holder compatible with common Android and iPhone devices (Figure 1).



Figure 1: Compact modular smartphone microscope adapter fabricated from commercially available components showing the eyepiece clamp, adjustable alignment unit, ball-head mount, and smartphone holder compatible with routine laboratory microscopes.

Sixty archived diagnostic slides were selected to represent routine pathology practice, including 30 histopathology slides, 20 hematology smears, and 10 cytology preparations. Slides with adequate staining, coverslipping, and morphological preservation were included, while poorly stained or artefact-laden slides were excluded. All selected cases had established final diagnoses in departmental records. As the study used retrospective anonymized material without patient identifiers, a waiver of informed consent was

obtained from the Institutional Ethics Committee. Ten participants from the Department of Pathology, including faculty members and postgraduate trainees familiar with routine microscopy, independently assembled and mounted the adapter on a standard laboratory microscope. Each participant then performed live transmission sessions on six sequential slides, generating 60 sessions in total. This design enabled assessment of initial assembly and alignment, as well as stability during repeated slide transitions (Figure 2).



Figure 2: Sequential workflow of adapter mounting and live telepathology setup showing independent assembly of the modular unit, attachment to the microscope eyepiece, smartphone mounting with optical alignment, and the final ready-to-use live transmission setup.

Slides were examined at 4 \times , 10 \times , 40 \times , and 100 \times oil immersion objectives, according to specimen type and diagnostic requirement. Dynamic stage navigation and focus adjustment were performed to simulate routine microscopic examination. Image viewing and practical screen enlargement during live transmission were assessed on both an iPhone 14 Plus and an Android smartphone. Transition between slides, maintenance of optical centering, and need for readjustment during repeated use were documented.

Technical performance was assessed immediately after each session using a structured 5-point Likert scale, where 1 indicated very poor and 5 indicated excellent performance. The parameters assessed were adapter stability, image resolution, focus quality, colour fidelity, and stream stability. In addition, diagnostic interpretability was assessed by recording whether the transmitted image allowed recognition of the tissue or organ of origin, identification of the underlying pathologic process, evaluation of architectural and cytomorphologic features, and arrival at an interpretation consistent with the established diagnosis. User experience regarding ease of assembly, handling, and preference compared with free-hand smartphone imaging was also recorded. Data were analyzed descriptively. Continuous measurements were reported as mean \pm standard deviation, and the

proportion of ratings scoring ≥ 4 was calculated separately for each parameter. As this was an initial technical validation study, the analysis focused primarily on feasibility, technical performance, user acceptance, and diagnostic interpretability rather than formal diagnostic concordance testing.

Results

Ten participants, including faculty members and postgraduate trainees, independently assembled the smartphone microscope adapter and performed live transmission sessions on six sequential slides each, generating 60 sessions. All sessions were completed successfully, with no mechanical failure, device detachment, clamp loosening, or structural instability observed during the study period.

All participants assembled and mounted the adapter without external assistance. The mean time required for initial assembly and optical alignment was 2.4 ± 0.6 min. After centering, a uniformly illuminated circular field without peripheral vignetting was obtained in all sessions. Once mounted, the adapter remained fixed throughout examination, and no participant required disassembly, reattachment, or major realignment during evaluation of subsequent slides. Following initial installation, slide exchange required no additional structural adjustment and was comparable to routine conventional microscopy.

Optical centering was preserved during sequential slide evaluation.

During dynamic stage navigation and magnification changes, including 100× oil immersion examination, no mechanical drift, clamp re-tightening, or shift in

camera alignment was observed. The adapter maintained consistent axial alignment across all sessions.

Representative microscopic images captured using the adapter are shown in Figure 3A-C.

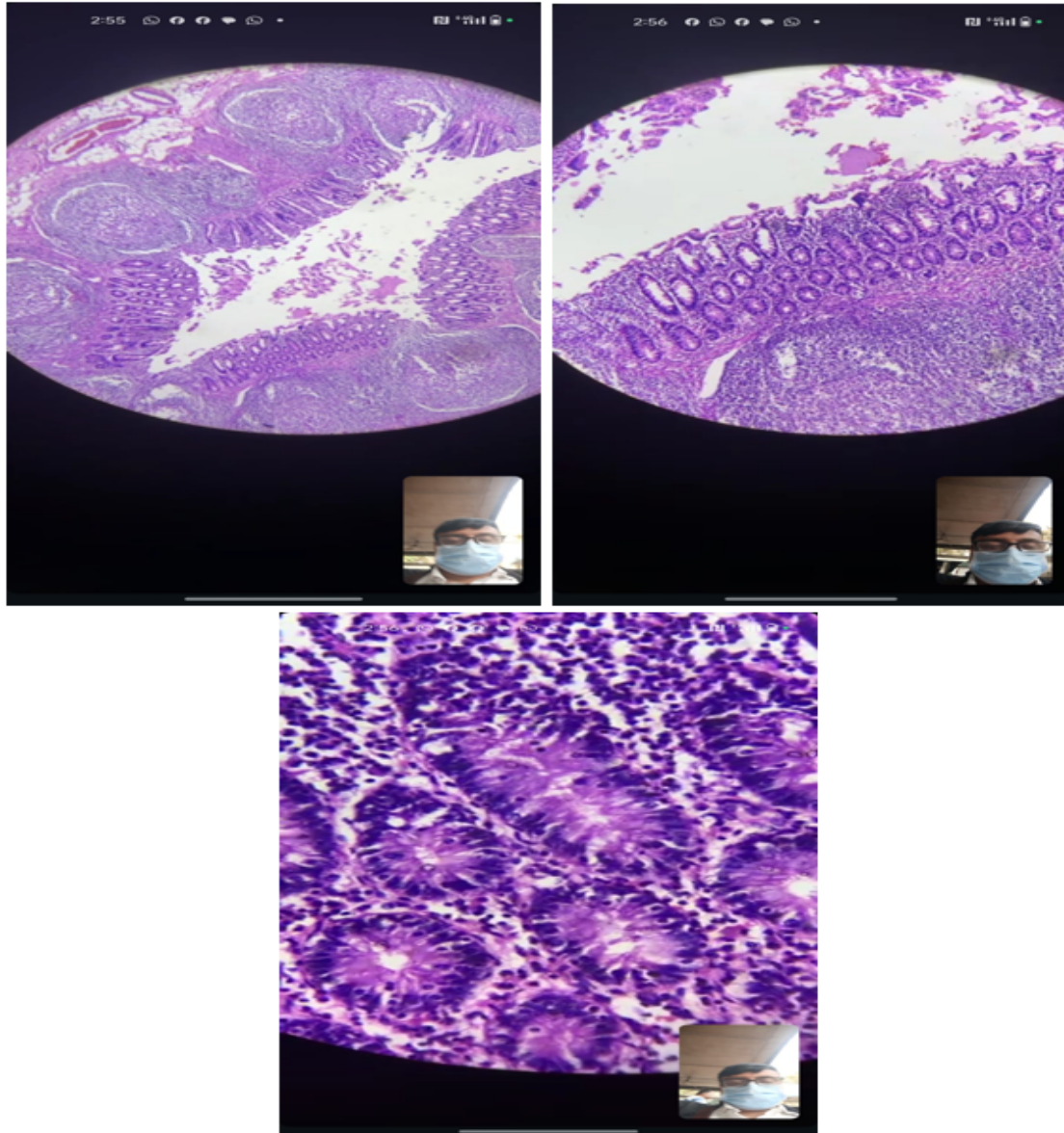


Figure 3A–C: Representative Screenshots captured directly from the smartphone screen during real-time telepathology sessions using the adapter. Figure 3A shows the scanner view used for rapid slide orientation, Figure 3B demonstrates the low-power field for architectural assessment and Figure 3C shows the 40× magnification view highlighting cytomorphologic details and demonstrating preservation of diagnostically relevant microscopic features.

Technical performance scores were high across all domains.

Adapter stability achieved the highest mean score (4.72 ± 0.48), followed by image resolution (4.58 ± 0.56), focus quality (4.55 ± 0.59), color fidelity (4.47 ± 0.62), and stream stability (4.41 ± 0.69). The proportion of sessions scoring at least 4 was 96.7 per

cent for adapter stability, 93.3 per cent for image resolution, 91.7 per cent for focus quality, 88.3 per cent for color fidelity, and 86.7 per cent for stream stability.

No session received a stream stability rating below 3. The composite technical performance score was 4.55 ± 0.52 (Table 1).

Table 1: Technical performance parameter during live transmission (n=60 sessions)

Parameter	Mean \pm SD	Median	% sessions with score \geq 4
Adapter stability	4.72 \pm 0.48	5	96.7
Image resolution	4.58 \pm 0.56	5	93.3
Focus quality	4.55 \pm 0.59	5	91.7
Color fidelity	4.47 \pm 0.62	4	88.3
Stream stability	4.41 \pm 0.69	4	86.7

The transmitted images were diagnostically interpretable across all specimen categories. Reviewers were able to identify the tissue or organ of origin, recognize the underlying pathologic process, assess architectural and cytomorphologic features, and arrive at the correct diagnosis in all evaluated cases. Diagnostic interpretation was generally more straightforward and faster in histopathology specimens, whereas cytology and hematology slides required relatively longer review. Image quality remained satisfactory across both iOS- and Android-based smartphones. On maximal practical zoom during screen review, no appreciable

blurring or loss of diagnostically relevant detail was observed, and relevant microscopic features remained discernible. User feedback was favorable. Eight participants rated assembly as very easy, and nine rated overall handling as easy or very easy. All participants reported reduced physical effort compared with free-hand smartphone positioning, and nine participants preferred adapter-assisted transmission over the free-hand technique. No participant rated the device as difficult to assemble or unstable during use. A still image from a live telepathology session is shown in Figure 4.



Figure 4: Still image captured during a live telepathology session demonstrating real-time display of the microscopic field on the smartphone screen after adapter-assisted alignment.

Discussion

This study shows that a compact modular smartphone microscope adapter can deliver stable and consistent live microscopic images for histopathology, hematology, and cytology samples. Mechanical stability was the device's strongest feature. Once set up, it stayed in place during repeated slide changes, stage movements, magnification adjustments, and even 100 \times oil immersion exams. This matters in practice because free-hand smartphone microscopy often struggles with mechanical instability during real-time use [2]. Image resolution and focus were also rated highly,

showing that the smartphone camera stayed well-centered over the microscope during regular use. Color accuracy was acceptable for all specimen types. Stream stability varied a bit more than the mechanical aspects, which is expected since live transmission quality depends partly on network conditions, not just the device. Still, images remained clear enough to interpret in all sessions, suggesting the adapter works well for telepathology when the internet connection is stable.

A key finding was that the transmitted images were not just technically good, but also clear enough for diagnosis. Reviewers could identify the tissue type,

understand the disease process, assess important features, and make diagnoses that matched the reference results. This process was easier for histopathology slides, while cytology and hematology slides took longer to review, probably because important details were spread out and needed more scanning.

These results align with previous studies on smartphone-based microscopic imaging. Roy et al. showed that smartphone microscope adapters are inexpensive and feasible for acquiring and sharing pathology photomicrographs, although some adjustment is required for optimal focus⁴. Mondal and Mondal similarly reported that a low-cost smartphone adapter reduced image-capture time and operator effort compared with the free-hand technique⁵. More recent work, including the TelePi system, has further reinforced the feasibility of compact smartphone-based platforms for digital microscopy and telepathology¹. Unlike earlier studies focused mainly on static image capture or low-cost photomicrography, the present study specifically evaluated stability during sequential slide transitions, dynamic stage navigation, live-streamed microscopy, and 100× oil immersion use, which more closely reflect real-world teaching and telepathology workflows.

The academic value of the adapter should also be emphasized. Real-time display of microscopic fields may be useful in undergraduate and postgraduate teaching, particularly in centres where multi-headed microscopes or dedicated digital pathology systems are unavailable. Prior literature has highlighted the broader utility of smartphone-based imaging for communication, education, and low-cost digital image sharing^{2,3}. Yu et al. further demonstrated that smartphone-based imaging systems can support more advanced digital pathology workflows, including imaging with both dry and oil objectives⁶. Although the present system is not intended to function as a whole-slide imaging platform, the current results support its role as a simple, portable, and economical option for real-time telepathology and microscopy teaching.

This study has several limitations. It was a single-centre technical validation involving a modest number of users, which may limit generalizability. Performance was assessed under stable internet conditions and may differ in low-bandwidth environments. Although reviewers' interpretations were concordant with the reference diagnosis in the evaluated cases, formal diagnostic concordance analysis with predefined endpoints and blinded

comparison against direct glass-slide review was not undertaken. In addition, the adapter was not compared with commercially available smartphone mounting systems. These issues should be examined in future multicentre studies.

In conclusion, the compact modular smartphone microscope adapter demonstrated excellent mechanical stability, reproducible optical alignment, favourable user acceptance, and diagnostically interpretable live image transmission during telepathology sessions. Its portability, ease of assembly, and compatibility with routine microscopy make it a potentially useful solution for telepathology and teaching, particularly in resource-limited settings.

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