

# Evaluation of Android Smartphones for Telepathology

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## Abstract

**Background:** In the year 2014, Android smartphones accounted for one-third of mobile connections globally but are predicted to increase to two-thirds by 2020. In developing countries, where teleconsultations can benefit health-care providers most, the ratio is even higher. This study compared the use of two Android phones, an 8 megapixel (MP) and a 16 MP phone, for capturing microscopic images. **Method:** The Android phones were used to capture images and videos of a gastrointestinal biopsy teaching set of referred cases from the Armed Forces Institute of Pathology (AFIP). The acquired images and videos were reviewed online by two pathologists for image quality, adequacy for diagnosis, usefulness of video overviews, and confidence in diagnosis, on a 5-point Likert scale. **Results:** The results show higher means in a 5-point Likert scale for the 8 MP versus the 16 MP phone that were statistically significant in adequacy of images (4.0 vs. 3.75) for rendering diagnosis and for agreement with the reference diagnosis (2.33 vs. 2.07). Although the quality of images was found higher in the 16 MP phone (3.8 vs. 3.65), these were not statistically significant. Adding video images of the entire specimen was found to be useful for evaluating the slides (combined mean, 4.0). **Conclusion:** For telepathology and other image dependent practices in developing countries, Android phones could be a useful tool for capturing images.

**Keywords:** Android, developing countries, Likert scale, telepathology

## INTRODUCTION

A study by Groupe Speciale Mobile Association (GSMA) intelligence found that smartphones accounted for one in three mobile connections globally in 2014.<sup>[1]</sup> According to the study, the developing world, which has overtaken the developed world in terms of smartphone connections, accounted for two in every three smartphones in the world. The study also predicted that by 2020, two out of every three mobile connections globally will be smartphones, and four out of every five smartphone connections will come from the developing world.

With advances in photographic (and other) capabilities of smartphones, they are increasingly being considered for use in telemedicine.<sup>[2]</sup> Examples include smartphones used for capturing microscopic images for use in telepathology consultation,<sup>[3,4]</sup> diagnosis of appendicitis,<sup>[5]</sup> stroke diagnosis,<sup>[6]</sup> and ophthalmology.<sup>[7]</sup>

Many of these telemedicine smartphone applications utilize iPhone smartphones. However, according to a forecast report<sup>[8]</sup> from the International Data Corporation, the Android smartphone's share of the smartphone industry has been predicted to grow from 81% in 2015 to 85% in 2020. The report also stated that the biggest volume opportunity

for Android was within the low-cost space. This means that any smartphone-based telemedicine application that targets low-/limited-resource settings should consider using comparatively inexpensive Android smartphones.

This technical note is a continuation of previous work that was done using an iPhone.<sup>[3]</sup> In the previous work, a microscope was fitted with a 3D-printed smartphone adapter and an iPhone 5 smartphone. The smartphone was used to acquire images and videos of glass slides, and these images were submitted to reviewers who were asked to evaluate the quality of the images and videos.

In work described in this technical note, three Android smartphones of varying camera specifications were used. The first was a smartphone with an Android phone OS with a 16 megapixel (MP) camera; the second smartphone was a different Android phone with an 8 MP camera. The third Android

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phone had a 5 MP camera. Results from the 5 MP camera Android phone were discarded because of their poor quality.

## METHODS

The setup comprised a commercially available universal smartphone adapter,<sup>[9]</sup> an Olympus BX41 microscope, ten glass slides, and two Android OS smartphones. The source of the specimens was a well-characterized teaching set of gastrointestinal biopsies from the Division of Gastrointestinal Pathology at the Armed Forces Institute of Pathology (AFIP).

The images were taken with two Android OS smartphones attached to the adapter as shown in Figure 1. The smartphone's position was adjusted until the image on the smartphone's screen was centered and in focus.

The mobile phones used in this study were a Samsung Galaxy S5 and a Google/LG Nexus 5. The Galaxy S5 utilizes a 16 MP camera with a 1/2.6" sensor with a 1.12 mm pixel size and an aperture of f/2.2. The Nexus 5 utilizes an 8 MP camera with a 1/3.2" sensor with a 1.4 mm pixel size and an aperture of f/2.4.

### Data collection

Images were acquired from the smartphone camera at the magnification levels of ×4, ×10, and ×20. Videos of the entire specimens were also acquired at ×4 magnification. The acquired images and videos were uploaded to a website for online review by two pathologists.

Each reviewer completed a web form with questions [Table 1] validated in the earlier study, on image quality, adequacy for diagnosis, usefulness of video overviews, and confidence in diagnosis, in a 5-point Likert scale.<sup>[3]</sup> They were also asked if they had previous telepathology experience in telepathology. Making a diagnosis on the images was optional.

The results were analyzed as ordinal and interval data using similar parametric and nonparametric methods as in the previously reported iPhone study.<sup>[3]</sup> Confidence intervals and tests of significance were calculated using McCallum Layton Stats Calculator available online.<sup>[10]</sup>

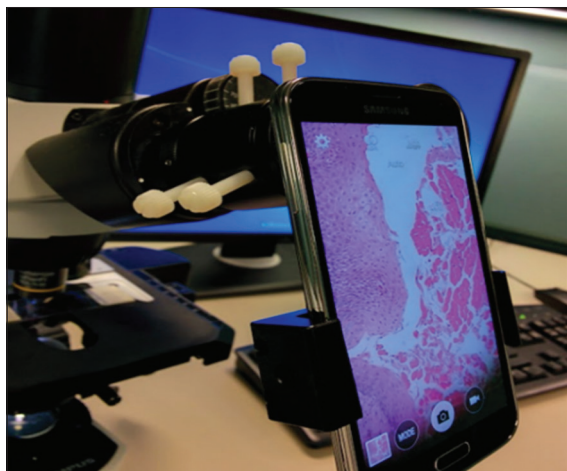


Figure 1: Smartphone attached to a microscope through an adapter

This research was designated as exempt from the Institutional Review Board review by National Institutes of Health Office of Human Subjects Research.

## RESULTS

The mean values and confidence intervals of the forty responses from two pathologists to the evaluation questions are shown in Table 2. All responses are in Likert scale scores. The 8 MP camera seems to be rated higher than the 16 MP camera in quality ( $3.80 \pm 0.34$  vs.  $3.65 \pm 0.29$ ), adequacy for rendering a diagnosis ( $4.0 \pm 0.29$  vs.  $3.75 \pm 0.43$ ), and for agreement with the reference diagnosis ( $2.33 \pm 0.37$  vs.  $2.07 \pm 0.35$ ) although the difference in quality was not statistically significant. In the usefulness of video images, the 16 MP was rated better than the 8 MP camera ( $3.05 \pm 0.52$  vs.  $2.92 \pm 0.33$ , respectively), although this difference was not statistically significant. Although this category was optional, the diagnosis was provided in 33 cases, and agreement with the AFIP diagnosis was statistically more accurate with the 8 MP camera ( $2.33 \pm 0.37$ ) than the 16 MP camera ( $2.07 \pm 0.35$ ). All of the scores were above 3 except for confidence where the combined mean score was 3.

In Table 3, the combined (8 MP and 16 MP cameras) mean Likert scale scores of each of the ten cases in the study are shown. Although providing diagnosis was optional, in only seven cases were the diagnoses missing. The reviewers found four cases (2274, 2390, 2470, and 2507) particularly challenging. These four cases accounted for six of the seven missing diagnosis and the low scores for confidence. Two (intra-dermal nevus in an anal tag and Kaposi sarcoma where the history of HIV was not provided) were the same cases found to be particularly difficult in the earlier study. The two other cases were a desmoplastic tumor of children and Zenker diverticulum.

Likert scale scores (1 = worst, 5 = best) of reviews and their percentages are shown in Table 4. The mode for quality, adequacy, and video was a 4 but was only 3 for confidence. If scores of 3 and above are added together, the total percentages

Table 1: The evaluation questionnaire

Question number	Questions
1	Rate the quality of the images (1 = poor to 5 = diagnostic)
2	In your opinion, are these images adequate for rendering a diagnosis? (1 = no to 5 = yes)
3	How does adding a video overview of the specimen contribute to your confidence in rendering a diagnosis? (1 = it doesn't help at all, to 5 = it helped a lot)
4	What is your diagnosis? (optional)
5	Differential diagnosis, if any (optional)
6	How confident are you of your diagnosis? (1 = not at all confident, to 5 = very confident)
7	I have referred and/or reviewed cases through telepathology previously

**Table 2: Average values and 95% confidence interval values of the responses to the evaluation questions**

	Evaluation questions				
	Quality	Adequacy	Video	Confidence	Diagnosis agreement
Average 16 MP (95% CI)	3.65±0.29	3.75±0.43	4.20±0.44 <sup>#</sup>	3.05±0.52 <sup>*</sup>	2.07±0.35
Average 8 MP (95% CI)	3.80±0.34 <sup>*</sup>	4.00±0.29 <sup>#</sup>	3.75±0.44	2.92±0.33	2.33±0.37 <sup>#</sup>
Average combined (95% CI)	3.73±0.22	3.87±0.26	4.00±0.31	3.00±0.32	2.21±0.25

<sup>\*</sup>Not statistically significant, <sup>#</sup>Statistically significant at the 95% CI. CI: Confidence interval

**Table 3: Average and standard deviation values of the responses for each case**

Case number	Average				
	Mean ± SD (Likert scale) <sup>*</sup>				Agreement with diagnosis, mean ± SD (1-3) <sup>#</sup>
	Quality	Adequacy	Video	Confidence	
2274	3.8±0.5	4.0±0.8	4.8±0.5	3.0±1.0	1.0±0
2333	3.0±1.4	3.8±1.5	3.5±1.7	3.7±1.2	2.3±0.6
2354	3.5±0.6	3.3±1.5	3.3±0.6	3.5±0.6	2.5±0.6
2390	3.8±0.5	4.0±0	4.3±0.5	2.5±1.0	1.7±1.2
2470	3.8±0.5	4.0±0	3.3±2.1	1.7±1.2	1.5±0.7
2483	4.0±0.8	4.0±0.8	3.8±1.3	3.3±1.5	2.5±1.0
2507	3.8±0.5	4.0±0	3.5±0.7	2.7±0.6	1.7±0.6
2511	4.3±0.5	4.5±0.6	4.3±0.5	4.0±0	2.8±0.5
2512	4.3±0.5	3.8±1.0	4.5±0.6	2.3±0.6	2.7±0.6
9632	3.8±0.5	4.0±0.8	4.8±0.5	3.0±1.0	2.8±0.5

<sup>\*</sup>Likert scale scores, 1: Worst, 5: Best, <sup>#</sup>3: Complete agreement, 2: Minor disagreement, 1: Major disagreement. SD: Standard deviation

**Table 4: Likert score chart for all the reviewers' responses**

	Evaluation questions			
	Quality (%)	Adequacy (%)	Video (%)	Confidence (%)
Score=1	1/2.5	1/2.6	1/2.8	3/9.4
Score=2	0/0	1/2.6	3/8.3	5/15.6
Score=3	11/27.5	7/17.9	3/8.3	15/46.9
Score=4	25/62.5	23/59.0	17/47.2	7/21.9
Score=5	3/7.5	7/17.9	12/33.3	2/6.3

A total number of review answers=40. The results are shown as the number of reviewer answers that gave a particular score/percentage

equal to 97.5%, 94.8%, and 88.8% for quality, adequacy, and video, respectively. It was only 74.2% for confidence. Scores were complete for quality but were missing for adequacy (1), video (4), and confidence (8).

## DISCUSSION

The earlier report briefly discussed the shortage of pathologists, especially in low- and middle-income countries leading to delays in diagnosis and possibly an increase in morbidity.<sup>[3]</sup> Recently, whole slide imaging has gained popularity in telepathology, but the limitations of wide implantation remain the same; these limitations include the cost of equipment, maintenance, the challenges of storing, and transmitting large files over the Internet, which may be often slow and unreliable in developing countries.<sup>[11,12]</sup> In these locations, the digitize-and-forward method will likely continue to be the state of the art.

GSMA intelligence maintains a running counter of mobile connections worldwide.<sup>[13]</sup> The counter shows that there are more than 7.7 billion connections, and this number is increasing by the second. This means that there are now more mobile phones than the entire world's population, now estimated at 7.3 billion people by the US Census Bureau.<sup>[14]</sup> Smartphones and other mobile devices will continue to be the window to the world of expertise in telepathology and telemedicine due to the increase in computing power and image capture capability of smartphones with each new model released.

In this study, we used two Android smartphones, the dominant operating system worldwide, an 8 MP and a 16 MP camera smartphones. The results of this study show that the 8 MP camera yielded higher Likert scores in quality (not statistically significant), adequacy of images (statistically significant), and agreement with the reference diagnosis (statistically significant). The 16 MP camera had higher results with assessment for video (statistically significant) and confidence in diagnosis (not statistically significant). These results are paradoxical since it would seem to follow that the higher quality of images translate into greater confidence in their diagnosis, although there were four assessment scores missing in the video assessment and eight scores missing in the confidence scores.

However, the camera's MP count does not seem to be the only determining factor in image quality as this study seems to show. Many experts have examined the "myth" of the high MP count.<sup>[15-18]</sup> Our results suggest that 8 MP is sufficient and

anything higher maybe superfluous. While some parameters gained statistical significance, the mean Likert scores are clustered together tightly enough that the law of diminishing returns is invoked. Other factors that influence image quality include camera sensor and processor, optical quality of the lens, and the medium where the image is viewed (computer monitor vs. print).<sup>[15-18]</sup> We did not study these parameters as we wanted to approximate real-world use where much of this information would not be known by all parties.

As was also seen in the earlier study, the video overviews of the entire specimen were found to be useful. Positive comments included “helps a lot” and “nice video” but there were also comments that higher power video images needed to be taken on the many of the cases, especially to “assess mitosis.” Perhaps, this can be made standard procedure in future teleconsultations.

The images were taken by a nonmedical personnel, so there were many attempts and requests to capture more fields for review. Sometimes, it was difficult to provide direction where they should be taken in the slide. Although not used in this study, a grid template (<https://images.nlm.nih.gov/pathlab/template/>) for small biopsies and larger specimens could be printed and placed under the glass slide [Figure 2] as the first image (orientation slide) sent off the telepathology consultation. If more images are required, the remote pathologist could simply guide the sender to take more pictures from a specific area in the orientation slide.

Although there was difficulty in capturing good quality images initially, this gradually improved with constant practice. Similar challenges will likely be encountered in real world settings but should be overcome with training and practice. Training videos would likely be useful for those who plan to implement this service.

This raises the issue of validation, an important issue for any diagnostic service. The aim of this study was to evaluate Android smartphones as they would be used in the field for

telepathology consultation. As such, in real world conditions, much information about the images (i.e., camera, aperture, and exposure) will likely be unknown to the expert pathologist. We liken this process to consultation of glass slides where staining procedures of the outside laboratory are unknown. The assumption, of course, is that they are the results of a Certified Laboratory Improvement Amendments -certified laboratory. Even so, the quality of stains can vary significantly between laboratories. In those cases where nuclei are too dark for mitoses counting or eosin too pale, the expert pathologist renders no diagnosis and requests additional material. In the proposed setting of our study, we would expect the consultant pathologist to follow a similar response. If the images are unsatisfactory, then either new images or the glass slides themselves would be requested. Similarly, we would assume that viewing conditions for the consultant pathologist would vary depending on the monitor they used. Again, it would be the responsibility of the pathologist to determine adequacy and use a different monitor or setup. That said, anyone wishing to start a telepathology consultation service should refer to the American Telemedicine Association clinical guidelines<sup>[19]</sup> for telepathology as our paper is a preliminary report on specifically using Android smartphones.

We evaluated Android smartphones for suitability for telepathology consultations. Our results seem to show that the images are of adequate quality for diagnosis. Although there was initial difficulty in capturing good images, this was overcome with practice. The communication technologies to send images to referral centers are now available worldwide, and the microscope adapters are available commercially. Microscopes, even monocular types, can be found in many low- and middle-income countries where this technology is most needed. Its generalizability will largely depend on whether pathologists, clinicians, and other health-care providers in remote locations will find the service useful in their practice.

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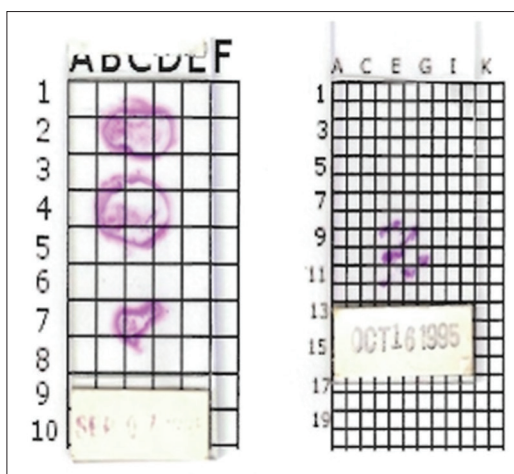
Nil.

### Conflicts of interest

There are no conflicts of interest.

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**Figure 2:** Grid templates for telepathology consultations. Left side for larger specimens and right side for smaller biopsies



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