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Using a Macro Lens for Anterior Segment Imaging in Rural Panama

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Abstract

Background: *Visual impairment, specifically anterior segment pathology, presents a significant burden of disease in the world.*

Introduction: *Inexpensive tools are necessary to improve eye health of residents in developing countries where care is difficult to access. Our study aimed at determining whether a $5 macro lens attached to a smartphone camera is an effective anterior segment imaging method for screening diseases.*

Materials and Methods: *Fifty four (*n = *54) patients had anterior segment imaging performed by using an Easy Macro lens and an iPhone. Imaging was performed at the Floating Doctors' mobile clinic sites in Panama. Images were sent back and graded by two board-certified ophthalmologists using a modified version of the FOTO-ED scale. Statistical analysis was performed by using a Wilcoxon signed-rank test to compare grades between the two imaging modalities.*

Results: *There was no significant difference in overall clinical utility of images obtained by the iPhone versus Easy Macro lens. The iPhone was significantly superior in imaging of the lens and conjunctiva, whereas the Easy Macro lens was superior in regards to the anterior chamber, iris, and lens.*

Discussion: *The imaging modality that best captures pathology is dependent on what part of the anterior segment is being examined. An imaging protocol with a pair of images, one from a smartphone and one from a macro lens, would have significant clinical utility.*

Conclusion: *Our study demonstrates how minimally trained users can deliver effective eye screening via a telemedicine-based approach in a resource-deprived setting. Future directions would be to develop a telemedicine protocol and determine whether it improves clinically measurable outcomes in patients.*

Keywords: *telemedicine, ophthalmology, technology, teleophthalmology*

Introduction

Visual impairment causes significant emotional and economic burden. In developing countries, where ophthalmologists are scarce and ophthalmological equipment is prohibitively expensive to acquire, visual disability can prevent someone from working and being able to support their family. Ninety percent of the 300 million visually impaired people in the world live in developing nations[1] and up to 75% of blindness in these cases is preventable or reversible. In particular, a significant amount of visual impairment in developing countries can be attributed to anterior segment pathology. Cataracts are the most common cause of blindness worldwide, but their prevalence is significantly higher in lower income regions.[2] The effect of cataracts is compounded by the aging global population, resulting in an increasing number of total cases.[2]

In response to these statistics, significant investigation seeks to reduce the burden of ophthalmological disease in low-income countries. Specifically, there is a growing interest in the potential use of telemedicine to deliver eye care to otherwise inaccessible patient populations. A review of six randomized control trials that used remote devices to screen for eye disease found no difference in the odds of detecting age-related macular degeneration or diabetic retinopathy, but it did find higher odds of patient participation when teleophthalmology was used.[3] Less research exists regarding the use of telemedicine in anterior segment screening. The Veterans Health Administration of the United States operates a diabetic teleretinal screening program that has in a retrospective study been shown to be effective in detecting cataracts (83% sensitivity, 100% specificity).[4] These studies highlight the promise of using telemedicine to

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expand the availability of eye care and reduce the inequitable global burden of eye disease.

This study was conducted in indigenous communities in the province of Bocas del Toro, Panama. For the country of Panama as a whole, 16.1% of adults older than the age of 50 have moderate visual impairment (visual acuity of <20/70) or worse.[5] The main cause of blindness in the country (66.4%) was unoperated cataract.[5] The Bocas del Toro region, in particular, has very limited access to health care due to both geographic and socioeconomic factors. As a result, there is a particularly high burden of eye disease in this area. Floating Doctors is a nonprofit that delivers the majority of the region's health care, but an ophthalmologist is only available for 1 month out of the year. Thus, we developed a study aiming at both testing an inexpensive anterior segment imaging technique and developing a telemedicine protocol for diagnosing eye pathology with the ultimate goal of triaging patients based on the severity of their eye disease.

Smartphones are now a near-ubiquitous tool used by clinicians and are inexpensive relative to the cost of other devices used for ocular photography. The slit lamp is considered to be the conventional gold standard when viewing anterior segment pathology. However, several studies have shown that smart phone-based devices and attachments provide fairly successful detection and documentation of ocular pathology. Ludwig et al. trained seven volunteers for <5 min each to use an iPhone attachment for anterior segment imaging.[6] Using the FOTO-ED scale developed by Bruce et al., the researchers found that three of the seven volunteers had a median image quality of five for their first 100 eyes imaged, and this doubled to six volunteers for the last 100 eyes imaged.[6,7] This demonstrates the ease of use and the high imaging quality that iPhone attachments can provide. Sanguansak et al. conducted a study comparing macro lens attachments with various smartphone imaging modalities. Among all macro lens images acquired, 61% were subjectively rated as acceptable.[8]

Although a variety of mobile applications and imaging devices exist for low-cost eye care, no studies have examined the clinical utility of images obtained by using a macro lens attachment in a global health setting. This study was designed to assess the effectiveness of using the Easy Macro lens (Sommerville, MA), a small magnifying lens held within a rubber band that fits around a smartphone, to image anterior segment pathology. The goal of the study was to assess whether the Easy Macro lens could produce images of acceptable quality such that it could act as a low-cost alternative to conventional ophthalmological equipment, as well as when compared with a smartphone alone. We hypothesized that anterior segment images taken with the Easy Macro lens would be superior to those obtained by using a smartphone camera alone.

Materials and Methods

This study received Institutional Review Board approval from the University of California, Irvine and was conducted in accordance with the Declaration of Helsinki.

This study was conducted by a team of seven medical students in June 2018 in clinics operated by Floating Doctors in the province of Bocas del Toro, Panama. Non-probability consecutive sampling was used, as this was a pilot study. No sample size was calculated, as it was very difficult to estimate ocular morbidity in the Bocas Del Toro area and determine our population size. The main source of background information in regards to ocular pathology was based on anecdotal data from Floating Doctors that cataracts, pterygium, and dry eyes were the most common eye complaints among their patients.

Subjects were recruited in the Floating Doctors general clinic on a sequential basis if they expressed any ocular-related complaints. Potential subjects were considered if they met the inclusion criteria (18+ years of age) and excluded if they were unable to understand the consent. Each consented subject had their visual acuity measured with a Snellen chart and their intraocular pressure measured with a Tono-Pen XL (Reichert Technologies, Depew, NY). Pupillary light reflex was assessed by using the corneal light reflex. An iPhone 5 (Apple, Cupertino, CA) was used for taking anterior segment images. Four images were obtained for each subject, with each eye imaged with the iPhone camera alone and the iPhone camera with an Easy Macro lens attached.

All images were sent to two board-certified ophthalmologists at the University of California, Irvine. The photos were randomized so that photos of the same subject would not appear in sequence. Images were analyzed by using a modified version of the FOTO-ED scale developed by Bruce et al.[7] This is a validated scale used to grade images based on overall diagnostic utility and the ability to visualize individual eye components. The ophthalmologists also noted any pathology that was visible in the images. Statistical analysis was performed by using a Wilcoxon signed-rank test to compare the grades of images obtained with the iPhone camera alone with the grades of images obtained with the Easy Macro lens attached to the iPhone camera.

Results

Fifty-four total patients were enrolled in the study for a total of 216 images. *Table 1* displays FOTO-ED scores assigned to the images, showing the overall quality of the images categorized by imaging modality.

Table 1. FOTO-ED Scores

	IPHONE, *n* (%)	EASY MACRO, *n* (%)
Ideal quality	2 (0.01)	103 (47.69)
Not ideal but still able to exclude subtle findings	38 (17.51)	15 (6.94)
Only able to exclude emergent findings	43 (19.82)	30 (13.89)
Unable to exclude all emergent findings	66 (30.41)	68 (31.48)
Inadequate for any diagnostic purpose	67 (30.88)	0 (0)

Table 2 summarizes the grades given for how well each image captures a certain section of the anterior segment. Of note, <50% of anterior chamber images acquired with the iPhone and Easy Macro had sufficient quality to state with certainty that the area was normal or abnormal.

Table 3 displays the results of the Wilcoxon signed-rank tests, determining which imaging modality was superior for each segment of the eye. Whether the smartphone or the macro lens provided the best image was dependent on the section of the eye being examined. Although there was no significant difference in the FOTO-ED scale overall, the macro lens was better at capturing images of the anterior chamber, iris, and lens. The smartphone was better at visualizing the lids and conjunctiva.

Table 4 lists some of the most common pathologies diagnosed by the ophthalmologists. Cataracts were best observed within the lens of the eye by using the Easy Macro; whereas injection, melanosis, and pinguecula were frequently captured in the conjunctiva by the smartphone. Pterygium was also diagnosed in pictures of the cornea, but neither imaging modality was significantly better for detecting pterygiae.

Discussion

Anterior segment images obtained with a smartphone attachment can detect pathologies in the lens, iris, anterior chamber, cornea, conjunctiva, and lids. Our results are unable to definitively establish whether an iPhone camera alone or with an Easy Macro attached is superior for anterior segment imaging overall. However, the overall image quality as measured by the FOTO-ED score (*Table 1*) achieved with both imaging modalities demonstrates that individuals with minimal training are able to successfully capture images that have significant clinical utility in an underserved setting.

The imaging modality that best captures pathology is dependent on what part of the eye is being examined. One

Table 2. Smartphone Versus Easy Macro Ratings

	LIDS		CONJUNCTIVA		CORNEA		ANTERIOR CHAMBER		IRIS		LENS	
	SMARTPHONE, *n* (%)	MACRO LENS, *n* (%)	SMARTPHONE, *n* (%)	MACRO LENS, *n* (%)	SMARTPHONE, *n* (%)	MACRO LENS, *n* (%)	SMARTPHONE, *n* (%)	MACRO LENS, *n* (%)	SMARTPHONE, *n* (%)	MACRO LENS, *n* (%)	SMARTPHONE, *n* (%)	MACRO LENS, *n* (%)
Quality of the area is sufficient to state with certainty that the area is normal or abnormal	211 (97.69)	144 (66.67)	187 (86.57)	121 (56.02)	185 (85.65)	157 (72.69)	44 (20.37)	100 (46.30)	151 (69.91)	185 (85.65)	73 (33.80)	124 (57.41)
Quality of the area is insufficient to state with certainty that the area is normal or abnormal	5 (2.31)	51 (23.61)	29 (13.43)	92 (42.59)	30 (13.89)	59 (27.31)	44 (20.37)	82 (37.96)	30 (13.89)	23 (10.65)	78 (36.11)	74 (34.26)
Unable to see the relevant area	0 (0)	21 (9.72)	0 (0)	3 (1.39)	1 (0.46)	0 (0)	128 (52.96)	34 (15.74)	35 (16.20)	8 (3.70)	65 (30.09)	18 (8.33)

Table 3. Wilcoxon Signed-Rank Tests

	GRADER A RESULT	GRADER B RESULT	MOST FREQUENT FINDINGS
FOTO-ED	Insignificant ($p > 0.2$)	Macro lens ($p < 0.001$)	None
Lids	Smartphone ($p < 0.001$)	Smartphone ($p < 0.001$)	Dermatochalasis, ptosis
Conjunctiva	Smartphone ($p < 0.001$)	Smartphone ($p < 0.001$)	Injection, melanosis, pinguecula
Cornea	Insignificant ($0.05 < p < 0.10$	Insignificant ($0.05 < p < 0.10$)	Pterygium, arcus
Anterior chamber	Macro lens ($p < 0.001$)	Macro lens ($p < 0.001$)	None
Iris	Macro lens ($0.02 < p < 0.05$)	Macro lens ($p < 0.001$)	None
Lens	Macro lens ($0.01 < p < 0.02$)	Macro lens ($p < 0.001$)	Cataract

possible explanation for the inferior image quality of the lids and conjunctiva of the macro lens involves the larger working distance from the eye. To achieve ideal image sharpness and clarity, the medical students capturing the images were instructed to focus on the iris, allowing most of the anterior segment to come into focus. However, given the 2.5 cm focal length of the Easy Macro lens, the required proximity could often obscure the view of the lids and conjunctiva, either putting them out of focus or completely removing them from the picture frame. Hence, our study indicates that image acquisition from an iPhone camera alone, in addition to an attached Easy Macro lens, could serve best for comprehensively capturing all anterior segment-related pathology.

Our study was conducted in Panama, where the main causes of visual impairment were pterygium and cataracts. Both of these pathologies were frequently captured by the Easy Macro, demonstrating its effectiveness as an imaging method for screening patients. Given that Floating Doctors only has an ophthalmologist available for just 1 month a year, our images were used to effectively screen patients ahead of time. This allowed for the creation of an active list of patients who should receive surgery when a specialist is available, and also triage patients in a resource-limited setting.

Table 4. Most Common Diagnoses

DIAGNOSIS	QUANTITY
Conjunctival injection	64
Dermatochalasis	46
Ocular melanosis	38
Pinguecula	32
Cataract	31
Corneal arcus	28
Pterygium	27

With the availability of smartphones now in developing nations, many parts of an eye exam, including visual acuity, color vision, and refraction, can easily be performed.[6] In addition, secure messaging, high-quality cameras on smartphones, and low-cost macro lenses that are easily utilized allow teleophthalmology to become increasingly accessible.

We believe a telemedicine protocol can be developed by using these inexpensive technologies to provide rapid eye screening to patients in global health settings. Using smartphone camera attachments, images of patients' eyes can be sent through secure messages to certified ophthalmologists anywhere in the world. After being quickly reviewed, patients can be triaged based on how urgently medical intervention is needed. These results can then be relayed back to providers in resource-limited settings for urgent referral to treatment centers, or simply to triage which patients to prioritize for treatment when resources become available (as was the case in this study).

Limitations

There are several limitations of this study. First, we had seven medical students capturing the photographs, with mild inter-user error and inconsistency in image quality. In addition, we did not have an ophthalmologist on site in Panama evaluating patients by using a slit lamp as the gold standard for diagnosing pathologies detected on our images. Lastly, the macro lens cannot fully replace a slit lamp, as observed in *Table 2* where a majority of the images failed to provide a quality image for accurate analysis of pathology in the anterior segment. A slit lamp would be more useful for detecting the depth at which corneal pathology may exist, such as corneal lesions. A future non-inferiority study could help determine whether the smartphone is as sensitive as a portable slit lamp for detecting major pathologies.

Conclusion

In conclusion, our study has shown how a smartphone alone, as well as with a macro lens attachment, can be successfully utilized to obtain high-quality images of the anterior

segment of the eye. Pathology captured by minimally trained users can be easily diagnosed by certified ophthalmologists around the globe, allowing for effective screening of patients in resource-poor settings. Future work should be focused on determining whether a telemedicine protocol actually improves clinically measurable outcomes in the patient population of interest.

Disclosure Statement

No competing financial interests exist.

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