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Telemedicine for ophthalmic consultation services: use of a portable device and layering information for graders

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Abstract

Introduction—We compared remote, image-based patient consultations to in-person consultations at emergency department and inpatient hospital settings.

Methods—Patients evaluated by the ophthalmic consultation services (gold standard) were imaged over a two-week period. A trained study coordinator took anterior segment photographs (AS) and posterior segment photographs (PS) with a portable camera (PictorPlus, Volk Optical, Cleveland, OH). Ophthalmologists (graders) determined photograph quality, presence of pathology, and their confidence in disease detection. At a separate session, graders reassessed photographs accompanied by a one-sentence summary of demographics and chief complaint (CHx). We computed accuracy and reliability statistics.

Results—We took AS photographs of 24 eyes of 15 patients and PS photographs of 39 eyes of 20 patients. The majority of images were rated as acceptable or excellent in quality (AS: 89–96%; PS: 70–75%). Graders detected AS pathology with 62–81% sensitivity based on photographs, increasing to 87–88% sensitivity with photographs plus CHx. Graders detected PS pathology with 79–86% sensitivity based on a photograph only, increasing to 100% sensitivity with photographs plus CHx.

Discussion—In this pilot study, there is evidence that portable ophthalmic imaging technologies could enable ophthalmologists to remotely evaluate anterior and posterior segment eye diseases with good sensitivity. The ophthalmologist could detect ocular pathology on photographs more accurately if they were provided brief clinical information.

Keywords

Telemedicine; implementation; eye; emergency department; photography

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Introduction

Patients routinely go to the Emergency Department (ED) for their urgent eye needs, and many hospitalized patients require eye care.¹ Ophthalmologists typically practice outside of hospitals and often cannot evaluate patients with eye complaints immediately. A study by Padovani-Claudio et al.² analysed information on 107,568 enrollees who had been seen in the ED for any ocular complaint in a US managed-care network. They found that 8.6% (9237) of those patients were seen for clearly urgent eye diseases (e.g. corneal ulcer, papilledema, retinal vein occlusions). Urgent eye problems could benefit from innovative methods of health care delivery for patients and providers with limited access to ophthalmologists.

In various settings, such as in the United States Army, ophthalmologists have evaluated eye diseases remotely, determined urgency, and triaged patients who required full ophthalmic examinations.³ In a recent study of ED patients presenting with headaches, 8.5% (42/497) had positive findings on retina photography.⁴ These patients had only sporadic retina examinations by ED physicians. Without fundus photographs, ocular pathology, sometimes with neurologic consequences, would have been missed.

We hypothesized that high-quality images could be taken with a portable ophthalmic camera and, when paired with basic patient information, would allow ophthalmologists in off-site locations to accurately triage patients with eye complaints. Portable ophthalmic cameras have been used to screen for diabetic retinopathy and trachoma, but not as a comprehensive screening tool in a hospital-based setting.^{5,6} Remote ophthalmologist graders assessed the presence of ophthalmic disease from photographs taken by a paraprofessional with a portable ophthalmic camera (PictorPlus, Volk, Cleveland, OH). The grader's assessment was compared with the gold standard, a clinical examination.

Methods

Approval of the study was obtained from the University of Michigan Institutional Review Board Committee prior to the study period. Over a two-week period, we performed a study and approached all patients seen on our university-based consult service in the ED (adult and paediatric) or the inpatient hospital setting. We included all patients (a) for whom an ophthalmology consult was obtained and (b) who were able to provide verbal consent. For any subject <18 years old, parental consent was obtained and assent was obtained from the minor. Based on the above criteria, we excluded patients who were on a mechanical ventilator and were not able to provide verbal consent. Patients who did not consent to have photographs taken were also excluded. All patients underwent a full ophthalmic examination by the consulting ophthalmologist – this served as the gold standard examination.

Photograph imaging

The study coordinator, a medical student who had three months of experience with the camera, obtained anterior segment (AS) and posterior segment (PS) photographs with a portable eye camera (PictorPlus, Volk Optical, Cleveland, OH). The camera has 5 megapixel

(1536×1152) resolution. The camera is housed in a casing to block ambient light. The photographer repeated photographs until the highest quality photographs possible were obtained. For the AS, the photographer took seven photographs including: straight gaze, right gaze, left gaze, upgaze, downgaze, eye-lids closed, and cobalt blue LED light. The photographer took AS pictures with the diffuse light illumination attachment for the camera. For the PS, the photographer took a single photograph (45°) of the posterior pole focused on the macula and optic nerve using a non-mydriatic attachment for the camera. The photographer chose to take AS or PS images based on the patient's complaint, and for vague complaints took images of both the AS and PS. In some cases, the patient had difficulty cooperating for photos of all eye positions, which resulted in missing data.

Grader assessment of photographs

Two board-certified ophthalmologists, one with cornea fellowship training (MAW) and the other with glaucoma fellowship training (PANC), served as masked graders for the photographic series. These two graders rated the quality of each series of photographs and determined if ophthalmic pathology was present. Quality was graded as 'not gradable', 'acceptable', or 'excellent'. Ophthalmic pathology was defined as any sign of ophthalmic disease. The graders provided their 'confidence' in their ability to determine the presence of ophthalmic pathology for each photographic series on a Likert scale from 1–10 with 10 representing 'highly confident' and 1 representing 'not confident at all'. At a separate session two months later, graders re-examined the same series of photographs with knowledge of the patient's visual acuity and a one-sentence statement of the patient's age, race, gender, and presenting complaint (CHx) (e.g. a 45-year-old white female with blurred vision). An independent ophthalmologist (SA) abstracted information from the patient's medical record to serve as the gold standard determination of whether or not ocular pathology was present.

Statistical analysis

Statistical analysis was performed using SAS version 9.4 (SAS Institute, Cary, NC). The graders' assessments were compared to each other and to the gold standard clinical exam using kappa (k) statistics with 95% confidence intervals (CI). For confidence measures, we used linearly weighted kappa statistics.⁷ For the purposes of this study, we considered kappa values as weak (0–0.33), moderate (0.34–0.66), or strong (0.67–1.0). For each kappa value, confidence intervals were generated to illustrate the distribution of agreement. The sensitivity and specificity were calculated for the graders compared to the gold standard clinical examination.

Results

Twenty-nine patients consented and were included in the study. Twenty-two additional patients did not participate, including patients who were intubated and thus unable to consent. AS photographs were taken of 24 eyes of 15 patients and PS photographs were taken of 39 eyes of 20 patients (Figures 1 and 2).

Image quality analysis

Of the 138 images of the AS, the two graders rated 3% and 8% of images not gradable, 33% and 23% acceptable, and 63% and 67% excellent (Table 1). Graders had moderate agreement on image quality for AS photos ($k=0.48$, 95% CI=0.34–0.62).

Of the 54 PS images, the graders rated 30% and 15% not gradable, 50% and 65% acceptable, and 20% and 20% excellent. Graders had weak agreement on image quality for PS photos ($k=0.28$, 95% CI=0.06–0.49).

Clinical interpretation of images

Graders had moderate agreement on the presence or absence of AS findings ($k=0.55$, 95% CI=0.19–0.90) (Table 2(a)). Agreement of the graders for AS photographs improved substantially with the addition of visual acuity and a one-line clinical summary ($k=0.89$, 95% CI=0.68–1.00). Graders had moderate agreement on the presence or absence of PS findings ($k=0.54$, 95% CI=0.26–0.82) (Table 2(b)). Agreement of the graders for PS photographs improved with the addition of visual acuity and a one-line clinical summary ($k=0.73$, 95% CI=0.49–0.97).

An independent ophthalmologist determined the presence of eye findings to the gold standard diagnosis recorded in the medical record. Based on the gold standard examination, there were 16 eyes with AS pathology. For AS photographs, agreement with the gold standard improved from 71% to 74% (grader A) and improved from 79% to 83% (grader B) with the addition of clinical history information. Based on the gold standard examination, there were 16 eyes with PS pathology. For PS photographs, agreement with the gold standard improved from 73% to 74% (grader A) and improved from 85% to 89% (grader B) with the addition of clinical history information. The ophthalmologist's sensitivity and specificity parameters are shown in Table 3.

Confidence

Graders' mean confidence in their ability to determine the presence of ocular findings changed from 8.0 to 10.0 (grader A) and 8.4 to 8.8 (grader B) with the addition of clinical information (Online Table). Grader A reported significantly higher confidence ($p<0.01$) with the addition of clinical data, while Grader B's confidence remained stable ($p=0.07$). For PS findings, the graders' mean confidence in their ability to detect pathology changed from 6.9 to 10.0 (grader A) and 8.1 to 7.9 (grader B) with the addition of clinical data. Similar to the confidence in reading the AS photographs, Grader A reported significantly more confidence ($p<0.01$) with the addition of clinical data, while Grader B's confidence remained the same before and after the addition of clinical information ($p=0.82$) (Figure 3(a) and (b)).

Discussion

Primary providers now have access to portable eye imaging tools that can be used to relay digital images to ophthalmologists to aid in obtaining a remote consultation. Improved access to subspecialty care via imaging began with radiology. Remote image analysis allows an evaluation by the physician most qualified to assess the patient's need for care. Although

ophthalmologists are not readily available in hospitals, hospitalized patients should be able to receive high-quality eye care. Imaging is a potential mechanism to expedite an initial evaluation of eye conditions and the referral of triage patients to direct care as needed.

Our study found that sensitivities for evaluation of AS photographs taken with a hand-held, portable ophthalmic camera images were 87–88% when the grader was provided with a brief patient's clinical summary including demographics, vision, and chief complaint. Sensitivity to detect PS pathology (and triage patients to full ophthalmic examinations) was 100% with photographs plus a clinical summary. The British Diabetic Association determined that imaging technologies intended to facilitate remote consultation services must be at least 80% sensitive to be considered as reasonable adjuncts to standard clinical care.⁸ Although low specificity means that some patients will be referred for complete ophthalmic evaluation that may have normal results, this is a safe way to triage patients. Even modest decreases in referrals to eye care providers for patients with healthy eyes would provide cost savings to patients and the health care system.

Our results make intuitive sense that supplemental clinical data aids in diagnostic decision-making. This is consistent with findings in pathology and radiology.^{9,10} In those specialties, clinicians are often separated from the patient and rely on remote clinical data that includes a short clinical history alongside imaging much like that used in the current study.

There were a number of limitations to this pilot study. We tested this camera in two different environments: the emergency department and the inpatient setting. We chose to combine these environments as this was an exploratory study meant to inform future work, and there is a need for improved triage of ophthalmic complaints in both environments. While image quality was fairly good, with 90% of AS photographs and 70% of PS photographs of either acceptable or excellent quality, agreement between graders on photographic quality was moderate at best (kappa range from 0.24 to 0.48). Even though our graders were able to correctly detect pathology when the photograph quality was poor, they had low confidence in their ability to do so (Figure 3(a) and (b)). There is room for improvement in standardizing remote image analysis. Anterior segment images are difficult to capture with only diffuse lighting.¹¹ Our results are consistent with this finding, as graders' sensitivity was higher for PS images than for AS images. In the future, we recommend taking photographs of the entire eye regardless of the suspected type of pathology because a paraprofessional may not have the expertise to assess non-specific eye complaints.

This pilot study was also limited by a small sample size. This affects the generalizability of our results. A sample of all patients presenting to the ED with any eye complaint or headache over a longer period of time would give us a sense of the prevalence of ophthalmic pathology amidst these non-specific complaints, which would then allow us to compute more robust estimates of the positive and negative predictive values of this technology for triaging eye complaints.

Some researchers have evaluated images obtained from smartphone-based cameras.^{5,12} While this technology is promising, there are a number of limitations to it. This technology is just becoming commercially available. In addition, smartphone cameras have embedded

image adjustment software that can limit resolution on near targets, such as the cornea, without additional magnification lenses. Smartphone camera settings can be overridden with special applications. In one pilot study, a magnifying lens and an additional light source was attached to the smartphone to optimize viewing of surface diseases.¹³ These portable devices were used specifically to detect corneal abrasions and trachoma.^{5,13} Other ophthalmology researchers have relied on slit-lamp based imaging, but slit lamps are expensive and require a highly trained person to take pictures.^{12–19} These have been piloted in eye-specific emergency departments and between eye care providers. In one study a general practitioner consulted with an ophthalmologist using a standard slit-lamp video-feed. In our study, we chose to evaluate a dedicated portable ophthalmic camera because it is both commercially available and less expensive than a standard slit-lamp based camera.

In-person evaluation for every eye complaint in the emergency department or inpatient setting is not feasible. Consulting ophthalmologists would be better able to triage the acuity of eye complaints with the addition of ophthalmic images and clinical history information. Portable imaging technologies could provide this source of information if placed in the hands of onsite, trained paraprofessionals. A paraprofessional in the hospital could take the photographs and transmit them to an off-site ophthalmologist for guidance.³ In any new programme, logistical matters, such as ensuring prompt reading of submitted photographs, would have to be addressed. Ocular telemedicine applications have been previously applied in specific settings with robust infrastructure and funding (such as the military). We believe that portable technology can be a cost-effective tool to improve access to high-quality subspecialty care. As quality increases and cost drops for technology, expert evaluation of a person's eye care needs, regardless of location, will become closer to reality.

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Figure 1.

External photograph of a 56-year-old woman presenting to the emergency department with severe eye pain and diplopia. The photograph, using fluorescein and a cobalt blue light, shows evidence of epithelial defect (over a corneal ulcer).

Figure 2. Fundus photograph of a 60-year-old patient hospitalized following a haemorrhagic stroke complaining of worsening vision. A portable camera was used at the bedside. The in-person and remote grading ophthalmologists diagnosed Terson Syndrome.

Figure 3. Confidence grading for Grader A and Grader B based on photo only and photo plus clinical history information for anterior segment (a) and posterior segment (b).

Table 1

Photo quality, rated without clinical history information, N (column %).

	Grader A	Grader B	Total	κ (95% CI)
All anterior segment	138	138	276	0.48 (0.34–0.62)
Excellent	87 (63.0)	93 (67.4)	180 (65.2)	
Acceptable	46 (33.3)	32 (23.2)	78 (28.3)	
Not gradable	4 (2.9)	11 (8.0)	15 (5.4)	
Missing	1 (0.7)	2 (1.4)	3 (1.1)	
All posterior segment	54	54	108	0.28 (0.06–0.49)
Excellent	11 (20.4)	11 (20.4)	22 (20.4)	
Acceptable	27 (50.0)	35 (64.8)	62 (57.4)	
Not gradable	16 (29.6)	8 (14.8)	24 (22.2)	
Missing	0 (0.0)	0 (0.0)	0 (0.0)	

Table 2

(a) Anterior segment pathology and (b) posterior segment pathology, assessed with photo only, and photo with clinical history information, N (column %).

	Grader A	Grader B	κ (95% CI) ^a
(a)			
Photo only	24	24	0.55 (0.19–0.90)
Pathology present	4 (16.7)	8 (33.3)	
Pathology not present	17 (70.8)	12 (50.0)	
Missing	3 (12.5)	4 (16.7)	
Photo with CHx	24	24	0.89 (0.68–1.00)
Pathology present	8 (33.3)	8 (33.3)	
Pathology not present	15 (62.5)	11 (45.8)	
Missing	1 (4.2)	5 (20.8)	
(b)			
Photo only	39	39	0.54 (0.26–0.82)
Pathology present	17 (43.6)	12 (30.8)	
Pathology not present	14 (35.9)	21 (53.8)	
Missing	8 (20.5)	6 (15.4)	
Photo with CHx	39	39	0.73 (0.49–0.97)
Pathology present	23 (59.0)	20 (51.3)	
Pathology not present	9 (23.1)	16 (41.0)	
Missing	7 (17.9)	3 (7.7)	

^a κ calculated for images where both raters provided non-missing values.

Table 3

Comparison with gold standard diagnosis.

	<u>Sensitivity (%)</u>		<u>Specificity (%)</u>	
	Grader A	Grader B	Grader A	Grader B
Anterior segment				
Photo only	61.5	81.3	87.5	75.0
Photo with CHx	86.7	87.5	50.0	75.0
Posterior segment				
Photo only	85.7	78.6	63.2	90.0
Photo with CHx	100.0	100.0	52.6	80.0