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Predictors of Photographic Quality with a Handheld Non-Mydriatic Fundus Camera used for Screening of Vision Threatening Diabetic Retinopathy

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Abstract

Purpose—To analyze predictors of image quality for a handheld non-mydriatic camera used for screening of vision threatening diabetic retinopathy.

Methods—An ophthalmic photographer at an Aravind Eye Hospital obtained non- mydriatic and mydriatic fundus images using the Smartscope camera (Optomed, Finland) and Topcon tabletop fundus camera (Topcon, Japan) from 3 fields on 275 eyes of 155 participants over 13 months. Two fellowship-trained retina specialists graded images. Repeated measures logistic regression assessed predictors of the main outcome measure - gradability of fundus images.

Results—Of 2,475 images, 76.2% of Smartscope non-mydriatic images, 90.1% of Smartscope mydriatic images, and 92.0% of Topcon mydriatic images were gradable. Eyes with vitreous hemorrhage (VH) (OR = 0.24, $p<0.0001$) and advanced cataract (OR = 0.08, $p<0.0001$) had decreased odds of image gradability. Excluding eyes with cataract or VH, non-mydriatic macular image gradability improved from 68.4% in the first set of 55 eyes to 94.6% in the final set of 55 eyes.

Conclusion—With sufficient training, para-professional healthcare staff can obtain high-quality images with a portable non-mydriatic fundus camera, particularly in patients with clear lenses and clear ocular media.

Keywords

Diabetic retinopathy; image quality; screening; telemedicine

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INTRODUCTION

Diabetic retinopathy is a leading cause of severe visual loss worldwide whose prevalence is increasing.[1,2] Approximately 30 million individuals currently have vision- threatening diabetic retinopathy (VTDR),[2] and the global burden of diabetic retinopathy (DR) and resulting visual loss is expected to continue rising.[1]

Severe visual loss from DR can be prevented with timely screening, detection, and treatment.[3,4] Yet, only one-third to one-half of adults with diabetes in many high- income countries receive yearly eye examinations, leaving substantial numbers at risk.[5–7] Those who do not receive eye examinations have been shown to be poor, young, and lack access to eye care.[5]

Remote digital retinal imaging via telemedicine provides a mechanism to extend eye care services to underserved populations.[8] Recent studies have demonstrated that portable or semi-portable tabletop devices may be used to improve diabetic retinopathy screening rates in community settings.[9–11]

The present study focuses on a hand-held, non-mydriatic camera (Smartscope, Optomed, Oulu, Finland), used for screening of vision threatening diabetic retinopathy. Given the potential in-field utility of handheld non-mydriatic devices over tabletop cameras, whose benefits include increased portability, decreased cost, and not requiring pharmacological dilation, the present study compares the performance of a paraprofessional using a handheld non-mydriatic device with mydriatic handheld and tabletop imaging. We report image quality with each camera as well as predictors of image quality, including photographer experience, imaging field, and ocular media status. Our study also provides insight into the feasibility of training a paraprofessional to take high-quality fundus images in a lower-resource setting (Aravind Eye Hospital, Pondicherry, India).

METHODS

This study was approved by the Institutional Ethics Committee at the Aravind Eye Hospital and the Institutional Review Board at the University of Michigan. Informed consent was obtained from all participants. The study was performed according to the ICH-GCP guidelines and fulfilled the tenets of the Declaration of Helsinki.

Enrollment

Participants over 21 years of age were recruited over 13 months from a convenience sample of diabetics and healthy controls from retina and comprehensive ophthalmology clinics at the Aravind Eye Hospital (Pondicherry, India). Patients were excluded if the retina specialist could not visualize the fundus on examination or if they had previously undergone vitreoretinal surgery and/or laser photocoagulation.

Imaging

A single, trained ophthalmic photographer took all images. Prior to commencing this study, the photographer obtained consent to train with the Smartscope on 75 patients (150 eyes) before a retina specialist determined him able to obtain gradable images. The photographer took three images per eye: 1) posterior pole centered on the macula corresponding to Early Treatment Diabetic Retinopathy Study (ETDRS) photo area 1; 2) nasal field, corresponding to ETDRS photo area 2; and 3) superotemporal field, corresponding to ETDRS photo area 4.[12,13] Images were repeated as necessary until the photographer was satisfied with the image quality. Study participants underwent 45° non-mydriatic fundus photography with the Smartscope followed by mydriatic Smartscope and mydriatic tabletop fundus camera (Topcon TRC–50DX, Tokyo, Japan) photography. Images were stored as Joint Photographic Experts Groups (JPEG) files after removing patient identifiers. All images from the Smartscope were transmitted and stored in their native state with JPEG 100 quality (1280 x 960 pixels); Topcon images were approximately 4200x 2800 pixels post-transmission.

Clinical examination

Study participants underwent a clinical examination including best-corrected visual acuity (BCVA) and dilated fundus examination by a single retina specialist. Patients' age, gender, diabetic status, and duration of diabetes were recorded. The specialist identified media opacities and assessed for mild, moderate, or severe non-proliferative diabetic retinopathy (NPDR); proliferative diabetic retinopathy (PDR); and/or clinically significant macular edema (CSME) according to the National Health Service (NHS) guidelines.[14,15] VTDR was defined according to the NHS definition as severe NPDR or worse and/or the presence of diabetic macular edema.[14–16] Cataracts were defined according to Lens Opacities Classification System (LOCS) III grading.[17] Eyes with nuclear sclerosis/opalescence grade ≥3 (NS/NO3) and/or cortical cataract ≥C4 and/or posterior subcapsular cataract ≥P4 were categorized as advanced cataracts.

Remote interpretation of fundus images

Fundus images were graded by two masked retina specialists. Reading stations followed NHS quality guidelines, which recommend a screen size of at least 17 inches diagonally.[18] The retina specialists received batches containing approximately 400 randomly selected images from any three imaging modalities. Photographs from the same patient taken with different cameras were not included in the same batch to minimize bias from seeing potentially higher quality images of the same fundus. The retina specialists graded each field (macular, superotemporal, nasal) according to predefined quality criteria of excellent, acceptable, and ungradable **(eFigure 1 - available online)**. These quality standards were based on guidelines set forth by the NHS to distinguish between adequate and inadequate images.[19] The two retinal specialists that took part in this study agreed upon additional standards to further distinguish between excellent and acceptable images for those images that were defined as adequate by NHS guidelines.

Statistical analysis

Inter-grader reliability for image quality (excellent, acceptable, or ungradable) was assessed between pairs of graders with weighted kappa statistics. Agreement was stratified by photographic modality (non-mydriatic Smartscope, mydriatic Smartscope, Topcon), and field of view (macular, superotemporal, nasal).

Image gradability was defined by aggregating scores from both graders. Images were scored as gradable only if they received a quality score of "excellent" or "acceptable" by both graders. Images were scored as ungradable if at least one grader gave a quality score of "ungradable."

Repeated measures logistic regression was used to predict the probability of an image being gradable. This model accounted for correlations between photos from the same eye and photos from different eyes of the same subject using generalized estimating equation (GEE) methods.[20] Variables investigated included age, sex, logMAR BCVA, DM duration, photographic modality, field of view, lens status, DR stage, and presence/absence of vitreous hemorrhage. We tested for interactions with photographic modality. We used the best subset method to identify the multivariable model containing the largest number of statistically significant independent predictors when compared to closely competing models.

To assess whether photographer experience had an effect on gradability in non-mydriatic Smartscope fundus images, the gradability of images was analyzed over time. Images were ordered chronologically and divided into quintiles for analysis. Quintiles were chosen as a compromise between capturing monthly variation in image gradability, which was not accurately depicted with a continuous effect of time, and the necessity of keeping sample size large enough for statistical analysis. Locally weighted scatterplot smoothing (LOESS) regression was used to construct curves for image gradability over time.[21,22] Multivariate logistic regression models with GEE were built to investigate the effect of quintile on probability of non-mydriatic Smartscope fundus image gradability, after adjusting for covariates found to significantly impact gradability in the larger model investigating all modalities. Statistical analysis was performed with SAS software, version 9.4 (SAS Institute, Cary, NC) and R statistical software, version 3.2.4 (R Core Team, Vienna, Austria). Statistical significance was defined as p-value < 0.05.

RESULTS

Demographics

Overall, 275 eyes from 155 subjects were included in the study. Thirty five eyes were not included because all three fields of view were not obtained for each imaging modality according to the study protocol. Subjects were on average 55.7± 9.1 years old and 64% were male (n=99). Ninety-four eyes (34.2%) came from healthy controls, 11 eyes (4.0%) from patients with type 1 DM, and 170 eyes (61.8%) from patients with type 2 DM. Mean logMAR BCVA was 0.27±0.41 (approximately 20/40 Snellen equivalent). Approximately half of the subjects (52%) had logMAR BCVA = 0 (20/20 Snellen equivalent). Among eyes with cataracts (n=100), 29 (29.0%) had advanced cataracts and the remainder had early cataracts. Fifteen eyes (5.5%) had vitreous hemorrhages.

Image gradability

2475 photos were taken on 275 eyes, including 3 fields from each modality. 628 of 825 total non-mydriatic images (76.1%) were gradable, compared with 90.1% for mydriatic images (n=743/825), and 92% for the Topcon images (n=759/825). Dilation improved image gradability with the handheld Smartscope by 14%. Of 628 gradable non-mydriatic images, 215 (34.2%) were macular images, 197 (31.2%) were superotemporal images, and 217 (34.5%) were nasal images. All three fields were gradable in 170 (61.8%) of eyes. Among non-mydriatic images, 21.8% of macular images, 28.4% of superotemporal images, and 21.1% of nasal images were ungradable.

An investigation of inter-grader reliability for image quality revealed moderate-to-good agreement between pairs of graders, with weighted kappa values ranging from 0.64 (95% CI=0.57–0.72) to 0.71 (95% CI=0.65–0.78) for images acquired with the non-mydriatic Smartscope, 0.59 (95% CI 0.50–0.68)–0.66 (95% CI 0.56–0.72) for the mydriatic Smartscope, and 0.70 (95% CI 0.62–0.78)–0.81 (95% 0.74–0.88) for the mydriatic Topcon (Table 1).

Effect of Experience on Image Gradability

Image gradability for the non-mydriatic Smartscope was: 78.8% (n=130/165) in quintile 1, 70.9% (n=117/165) in quintile 2, 67.9% (n=112/165) in quintile 3, 78.1% (n=129/165) in quintile 4, and 86.7% (n=143/165) in quintile 5, over all fields of view.

LOESS curves for image gradability demonstrated an increase in gradable images over time for the macular field among eyes with no cataract or media opacity (Figure 1a). The curve for nasal and superotemporal field images showed a less clear trend over time, although gradability improved between the second and fifth quintiles (Figure 1b–c). Potential factors diminishing the linearity of nasal and superotemporal image quality over time include increased technical difficulty obtaining the fields compared to the macular field or other external factors unclear to the authors at the time of this analysis.

Multivariate logistic regression models of image gradability for non-mydriatic Smartscope images included main effects for cataract, quintile of experience, and the interaction between cataract and quintile. Models were stratified by field of view. Models excluded images from eyes with vitreous hemorrhage due to the small sample size (n=15) and their being mostly ungradable

For macular images, there was a significant interaction between cataract status and quintile of experience. In eyes without cataract, image gradability increased over time (Figure 2A). Images in the fourth quintile showed significantly increased odds of being gradable compared with images from the first quintile (OR=5.87, 95% confidence interval (CI=1.19–28.90, p=0.0296), and images from the fifth quintile had marginally significant increased odds of being gradable compared with images from the first quintile (OR=7.57, 95% CI=0.96–59.90, p=0.0551). In eyes with cataract, there was no clear trend with respect to image gradability by quintile.

For the superotemporal field, in eyes without cataract, images from the fourth or fifth quintile had a significantly increased odds of being gradable compared with the second quintile (OR=10.12, 95% CI=2.09–48.94, p=0.0040; OR=4.35, 95% CI=1.28–14.75, p=0.0182, respectively, Figure 2B). In eyes with cataract, there was no clear trend for gradability by quintile.

For the nasal field, there was no significant interaction between cataract and quintile (p-value=0.1089, Figure 2C). When a model was run with only main effects for cataract and quintile, there was no significant effect for quintile of time (p-value=0.4798), but the main effect of cataract was significant showing decreased odds of being gradable for images with cataract present vs no cataract (OR=0.33, 95% CI=0.17–0.64, p =0.0012).

Predictors of Image Gradability

Univariate and multivariate repeated measures logistic regression models demonstrated a number of factors associated with obtaining a gradable photograph (Tables 2 & 3). In univariate models (Table 2), older age, worse logMAR BCVA, presence of cataract, and vitreous hemorrhage were associated with significantly decreased odds of image gradability (all p<0.05). The non-mydriatic Smartscope was associated with significantly reduced odds of image gradability compared to Topcon (OR=0.29, 95% CI=0.20–0.41, p<0.0001) or mydriatic Smartscope modalities (OR=0.36, 95% CI=0.26–0.50, p<0.0001). No significant differences were found between Smartscope mydriatic and Topcon mydriatic modalities.

Multivariate modeling revealed significant independent predictors of photo gradability including a main effect of vitreous hemorrhage, and significant interactions between camera modality and cataract status, and between camera modality and image field (Table 3). Presence of vitreous hemorrhage was associated with an 81% reduced odds of photo gradability (OR=0.19, 95% CI=0.09–0.38, p<0.0001). Eyes with cataracts were associated with decreased odds of being gradable compared to eyes without cataracts, regardless of modality (p<0.001 for all comparisons). In eyes without cataract, mydriatic Smartscope images had decreased odds of being gradable when compared to Topcon images (OR=0.36, 95% CI=0.18–0.72, p=0.0037). However, in eyes with cataract, mydriatic Smartscope images did not have decreased gradability compared to Topcon images (p=0.808). Non-mydriatic Smartscope images were associated with decreased odds of being gradable compared to mydriatic Smartscope or Topcon images, regardless of cataract status.

There were significant differences in gradability when investigating the interaction between imaging modality and image field (Table 3). The non-mydriatic Smartscope showed decreased odds of image gradability in all fields compared to mydriatic Smartscope or mydriatic Topcon (p<0.01 for all comparisons). The mydriatic Smartscope showed decreased odds of image gradability compared to Topcon images of the macular field (OR=0.36, 95% CI=0.21–0.63, p=0.0003), but not the nasal or superotemporal fields.

In terms of image field, the non-mydriatic Smartscope nasal and macular field gradabilities were not significantly different from each other (p=0.75), but the superotemporal field was associated with a decreased odds of gradability compared to the macular or nasal field (OR 0.68, 95% CI=0.50–0.92, p=0.0124; OR 0.65, 95% CI=0.48–0.86, p=0.0030, respectively).

Mydriatic Smartscope images had increased odds of gradability for nasal (OR=1.64, 95% CI=1.03–2.62, p=0.0376) and superotemporal (OR=2.16, 95% CI=1.36–3.44, p=0.0011) fields compared to the macular field. Topcon images showed similar gradability regardless of field (p>0.5 for all comparisons).

DISCUSSION

High-quality imaging is essential in store-and-forward telemedicine for diabetic retinopathy screening.[23,24] We evaluated the quality of fundus photographs taken by an ophthalmic photographer with a non-mydriatic, handheld camera to investigate the factors affecting image quality, including patient characteristics and photographer experience over time. Not surprisingly, ocular media opacities (i.e., advanced cataract or vitreous hemorrhage) were associated with a decreased likelihood of obtaining a gradable retinal image. Furthermore, Topcon images were of higher quality than mydriatic Smartscope images, which were of higher quality than non-mydriatic Smartscope images. We also found a significant, positive effect of imaging experience on image gradability in eyes with clear media, especially for the macular field, but not in eyes with cataract or vitreous hemorrhage. Considering eyes with clear lenses and media, our photographer's gradability rate improved from 68.4% in the first set of 55 eyes to 94.6% in the final set of 55 eyes over 13 months of imaging 275 total eyes.

The para-professional taking photographs in this study was a trained ophthalmic photographer and had extensive experience using the portable camera (75 patients) before beginning the study. We might have expected to see no learning curve during the 13-month study period, but this was not the case. These findings suggest that obtaining high-quality fundus images with a handheld camera requires a separate skill set from those needed for taking high-quality, non-portable mydriatic images. If health care workers are to use portable fundus cameras for DR screening, they may need sufficient training and volume of patients to attain and maintain their skill levels. Therefore, it will be important to deploy this new technology only where patient volumes are high enough to facilitate this skill-building process.

As diabetic eye disease is projected to rise over the coming decades,[1] the volume of patients requiring DR screening will continue to increase. Well-trained para-professional staff may prove essential to extending DR screening to patients in all areas, especially traditionally underserved areas. Though DR disproportionately affects underserved populations,[25] the sheer number of diabetic patients precludes ophthalmologists' ability to screen all patients while maintaining their ability to treat eye disease. Using portable non-mydriatic fundus imaging in high volume eye camps or primary care offices globally may improve access to recommended diabetic eye care and decrease DR related blindness as the robust telemedicine DR screening program has done in the United Kingdom.[8,26,27] Furthermore, the knowledge from our study of the patient characteristics that are associated with poor image quality would allow screening services to target highly "imageable" patients, while opting to directly refer all other patients to the ophthalmologist, as patients who are difficult to image often have other referral-warranted pathology present such as cataract or vitreous hemorrhage.

Previous studies assess the performance of non-mydriatic tabletop cameras[12,28–40] and mydriatic smart-phone based fundus imaging systems.[41–44] While these studies demonstrate the validity and utility of a telemedicine platform for DR screening, they either use bulky, expensive, or time consuming (e.g., requiring pupillary dilation) cameras. These camera systems are not reasonable to use in many rural, low-resource settings, where resources, staff, and infrastructure are limited. However, the performance of hand-held non-mydriatic cameras is still evolving. One recent study assessed the use of a hand-held, non-mydriatic smartphone-based camera with a 25° field of view for grading cup to disc ratio to screen for glaucoma.[45] The authors found only moderate reproducibility of optic disc grades for images taken with this portable non-mydriatic camera. In our present study, we demonstrate that with sufficient training and practice, a non-physician health care worker can obtain high quality fundus images with a portable non-mydriatic fundus camera used to screen for vision threatening diabetic retinopathy.

There were limitations to our study design. First, the paraprofessional taking the photographs had prior training in fundus imaging as an ophthalmic photographer. While this skill set facilitated our analysis comparing imaging modalities using a single health care worker, it impaired our ability to predict how untrained paraprofessionals may perform. Second, our study took place in an eye hospital and utilized a convenience sample of patients from the retina and comprehensive clinics. While the use of handheld fundus imaging devices may begin in eye care centers, the goal is to use them in primary care settings or rural outreach settings where there is no ophthalmologist on site for assistance. Furthermore, the sample was recruited from a tertiary care center and the results may not generalize precisely to the population being seen at a primary care clinic where screening will ultimately be focused.

Our study demonstrates that it is possible to obtain high quality images with a non-mydriatic, handheld fundus camera by a paraprofessional with training and moderately extensive practice. Furthermore, it is possible to achieve over 90% gradability of macular and superotemporal images in eyes with clear lenses and media using a non-mydriatic handheld fundus camera. The development of a user-friendly imaging device that can reliably produce high-quality images when used by paraprofessionals with limited training remains a challenge in ophthalmic telemedicine.

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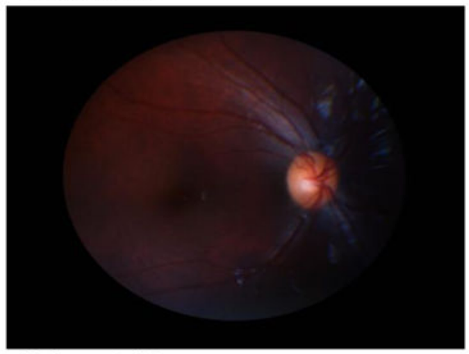
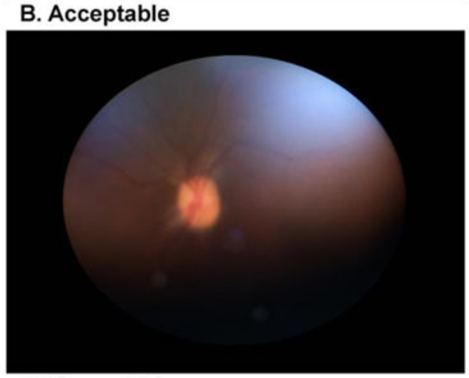
Appendix

A. Excellent



B. Acceptable



C. Ungradable

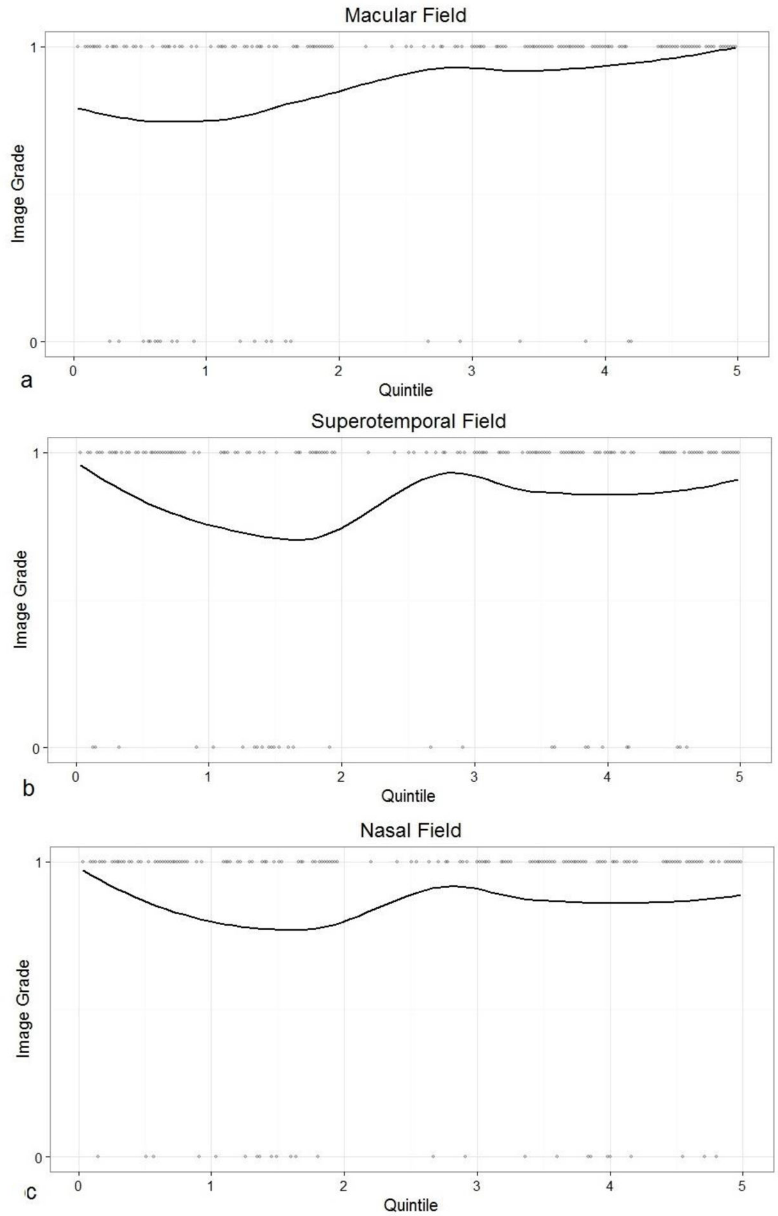


Figure 1.

Scatterplot of image grade by quintile of time, including locally weighted scatterplot smoothing (LOESS) regression line for a. macular field images, b. nasal field images, and c. superotemporal field images. Images were graded as acceptable/excellent quality (1) or non-gradable (0). Quintiles of time each included 55 chronological images.

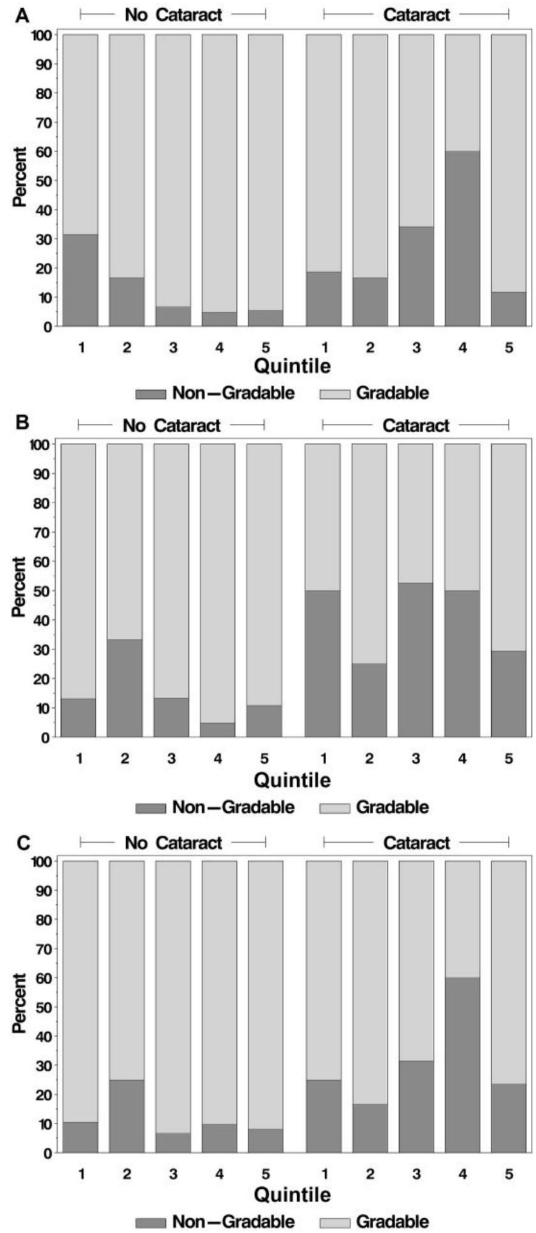


Figure 2.

Stacked barchart displaying the percent of gradable and non-gradable images over quintile of time for the A) macular field, B) superotemporal field, and C) nasal field. Gradability is further stratified by eyes with and without the presence of cataract. Quintiles of time each included 55 chronological images.

Table 1

Grader agreement on image quality, stratified by field and camera modality

	Grader 2 - Quality			
Grader 1–Quality	**Excellent**	**Acceptable**	**Ungradeable**	**Kappa (95% CI)**
Non-mydriatic Smartscope				
Macula				
Excellent	96	11	0	
Acceptable	36	72	14	0.64 (0.57, 0.72)
Ungradable	5	6	35	
ST				
Excellent	94	16	2	
Acceptable	27	60	21	0.68 (0.61, 0.75)
Ungradable	1	5	49	0.71 (0.65, 0.78)
Nasal				
Excellent	115	5	0	
Acceptable	31	66	23	0.71 (0.65, 0.78)
Ungradable	1	1	33	
Mydriatic Smartscope				
Macula				
Excellent	163	4	0	
Acceptable	36	35	5	0.64 (0.56, 0.72)
Ungradable	3	11	18	
ST				
Excellent	178	2	0	
Acceptable	37	38	7	0.66 (0.58, 0.75)
Ungradable	0	2	11	
Nasal				
Excellent	167	6	0	
Acceptable	43	34	10	0.59 (0.50, 0.68)
Ungradable	1	2	12	
Mydriatic Topcon				
Macula				
Excellent	190	6	0	
Acceptable	16	43	6	0.78 (0.71, 0.86)
Ungradable	0	2	12	
ST				
Excellent	187	7	0	
Acceptable	12	46	9	0.81 (0.74, 0.88)
Ungradable	0	0	14	
Nasal				
Excellent	167	20	0	
Acceptable	18	47	8	0.70 (0.62, 0.78)

	Grader 2 - Quality			
Grader 1–Quality	**Excellent**	**Acceptable**	**Ungradeable**	**Kappa (95% CI)**
Ungradable	0	1	14	

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Table 2

Univariate repeated measures logistic regression models* predicting the probability of a photo being gradable (excellent or acceptable) vs ungradable.

Variable	OR	95% CI	P-value
Age (per 5 years)	0.77	(0.65, 0.91)	0.0024
LogMAR (per 0.1 unit)	0.92	(0.88, 0.96)	0.0004
Best-corrected LogMAR	0.92	(0.88, 0.96)	0.0005
Duration Diabetes (per 1 year)	0.99	(0.96, 1.02)	0.5572
Modality			
Smartscope Non-mydriatic (vs Topcon)	0.29	(0.20, 0.41)	<0.0001
Smartscope Mydriatic (vs Topcon)	0.79	(0.59, 1.07)	0.1279
Smartscope Non-mydriatic (vs Smartscope Mydriatic)	0.36	(0.26, 0.50)	<0.0001
Sex (Male vs Female)	0.77	(0.41, 1.43)	0.4032
Lens Status			
Cataract - advanced (vs WnL)	0.08	(0.04, 0.16)	<0.0001
Cataract - early/immature (vs WnL)	0.40	(0.20, 0.79)	0.0089
IOL (vs WnL)	0.56	(0.24, 1.29)	0.1733
Diabetes stage			
Pre-proliferative (vs No/Background Retinopathy)	3.16	(0.59, 16.86)	0.1789
Proliferative (vs No/Background Retinopathy)	0.61	(0.36, 1.05)	0.0752
Vitreous Hemorrhage (Present vs Absent)	0.24	(0.14, 0.42)	<0.0001
Image Field			
Nasal vs Macula	1.12	(0.89, 1.41)	0.3474
Superotemporal vs Macula	0.96	(0.78, 1.19)	0.7279
Nasal vs Superotemporal	1.16	(0.96, 1.40)	0.1146

*Models used generalized estimating equation (GEE) methods to account for the correlation between eyes of a subject; each variable is in a separate model.

OR – odds ratios, CI – confidence interval, logMAR – logarithm of minimum angle of resolution, WnL – within normal limits.

Table 3

Multivariate repeated measures logistic regression model* predicting the probability of a photo being gradable (excellent or acceptable) vs ungradable.

Variable	OR	95% CI	P-value
Vitreous Hemorrhage (Present vs Absent)	0.19	(0.09, 0.38)	<0.0001
Modality by Cataract Interaction (type 3 p-value=0.0220)			
Non-mydriatic Smartscope vs Mydriatic Smartscope within no cataract	0.28	(0.18, 0.44)	<0.0001
Non-mydriatic Smartscope vs Topcon within no cataract	0.10	(0.05, 0.21)	<0.0001
Mydriatic Smartscope vs Topcon within no cataract	0.36	(0.18, 0.72)	0.0037
Non-mydriatic Smartscope vs Mydriatic Smartscope within cataract	0.32	(0.19, 0.55)	<0.0001
Non-mydriatic Smartscope vs Topcon within cataract	0.34	(0.21, 0.56)	<0.0001
Mydriatic Smartscope vs Topcon within cataract	1.05	(0.69, 1.62)	0.8080
Cataract vs No Cataract within Non-mydriatic Smartscope	0.37	(0.21, 0.64)	0.0004
Cataract vs No Cataract within Mydriatic Smartscope	0.32	(0.15, 0.65)	0.0018
Cataract vs No Cataract within Topcon	0.11	(0.04, 0.28)	<0.0001
Modality by Image Field Interaction (type 3 p-value=0.0002)			
Nasal vs Macula within Smartscope Non-mydriatic	1.05	(0.78, 1.41)	0.7523
Superotemporal vs Macula within Smartscope Non-mydriatic	0.68	(0.50, 0.92)	0.0124
Superotemporal vs Nasal within Smartscope Non-mydriatic	0.65	(0.48, 0.86)	0.0030
Nasal vs Macula within Smartscope Mydriatic	1.64	(1.03, 2.62)	0.0376
Superotemporal vs Macula within Smartscope Mydriatic	2.16	(1.36, 3.44)	0.0011
Nasal vs Superotemporal with Smartscope Mydriatic	0.76	(0.54, 1.07)	0.1187
Nasal vs Macula within Topcon	0.83	(0.48, 1.43)	0.5059
Superotemporal vs Macula Topcon	0.83	(0.47, 1.47)	0.5257
Nasal vs Superotemporal with Topcon	1.00	(0.66, 1.52)	1.0000
Smartscope Non-mydriatic vs Topcon within Macula	0.19	(0.10, 0.33)	<0.0001
Smartscope Mydriatic vs Topcon within Macula	0.36	(0.21, 0.63)	0.0003
Smartscope Non-mydriatic vs Smartscope Mydriatic within Macula	0.52	(0.34, 0.78)	0.0015
Smartscope Non-mydriatic vs Topcon within Nasal	0.23	(0.14, 0.40)	<0.0001
Smartscope Mydriatic vs Topcon within Nasal	0.71	(0.43, 1.17)	0.1795
Smartscope Non-mydriatic vs Smartscope Mydriatic within Nasal	0.33	(0.21, 0.53)	<0.0001
Smartscope Non-mydriatic vs Topcon within Superotemporal	0.15	(0.09, 0.26)	<0.0001
Smartscope Mydriatic vs Topcon within Superotemporal	0.93	(0.51, 1.69)	0.8188
Smartscope Non-mydriatic vs Smartscope Mydriatic within Superotemporal	0.16	(0.10, 0.26)	<0.0001

*Model used generalized estimating equation (GEE) methods to account for the correlation between eyes of a subject.

OR – odds ratios, CI – confidence interval, logMAR – logarithm of minimum angle of resolution.