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Quality of non-mydratic digital fundus photography obtained by nurse practitioners in the emergency department: the FOTO-ED study

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Abstract

Objective—Non-mydratic fundus photography by non-ophthalmic trained personnel has recently been shown to be a potential alternative to direct ophthalmoscopy in the emergency department (ED). We evaluated the reliability of a novel quality rating scale and applied this scale to non-mydratic fundus photographs taken during routine ED patient encounters to determine factors associated with diminished photograph quality.

Design—Prospective, cross-sectional

Participants—350 patients enrolled in the Fundus photography vs. Ophthalmoscopy Trials Outcomes in the Emergency Department (FOTO-ED) study were photographed by nurse practitioners after <30 minutes of training followed by supervision.

Methods—Photographs of both eyes were graded for quality on two occasions by two neuro-ophthalmologists. Four regions were independently evaluated for quality: optic disc, macula, superior and inferior vascular arcades. Quality as a function of the number of photographs taken was evaluated by Kaplan-Meier analysis. Mixed effects ordinal logistic regression was used to evaluate for predictors of image quality while accounting for the repeated measures design.

Main Outcome Measure—Overall photographic quality (1–5 scale, 5 best).

Results—We evaluated 1734 photographs. Inter- and intra-observer agreements between neuro-ophthalmologists were very good (weighted kappa:0.84–0.87). Quality of the optic disc area was

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better than those of other retinal areas ($p<0.002$). Kaplan-Meier analysis showed that if a high-quality photograph of an eye was not obtained by the third attempt it was unlikely that one would be obtained at all. A 10 second increase in the inter-photograph interval before a total of forty seconds increased the odds of a one unit higher quality rating by 1.81 times (95%CI: 1.68–1.98), and a ten year increase in age decreased the odds by 0.76 times (95%CI: 0.69–0.85). Black patients had 0.42 times (95%CI: 0.28–0.63) the odds of a one unit higher quality rating compared to whites.

Conclusions—Our 5-point scale is a reliable measure of non-mydriatic photograph quality. The region of interest, interphotograph interval, age, and race are significant predictors of image quality for non-mydriatic photographs taken by nurse practitioners in the ED. Addressing these factors may have a direct impact on the successful implementation of non-mydriatic fundus photography into the ED.

Introduction

Non-mydriatic fundus photography by non-ophthalmic trained personnel has recently been shown to be a potential alternative to direct ophthalmoscopy in the emergency department (ED).^{1,2} Image quality is critical for maximizing the diagnostic capability of fundus photographs, but disease specific scales, such as those developed for diabetic retinopathy or age related diabetic retinopathy, are not applicable to the ED setting where the primary interest is the recognition of a few conditions relevant to the acute medical management of patients. The ED also represents a challenging environment in which to obtain photographs of adequate quality for clinical interpretation. Indeed, patients often present to the ED with acute problems, frequently quite ill. Additionally, in most cases, the ED is a very bright environment with limited ability to dim the lights. Finally, the ED setting is fast-paced with numerous personnel involved in the patient's triage and management. An understanding of the factors that may affect non-mydriatic photographic quality in this real-life clinical setting can provide opportunities for improvements in camera design and personnel training that could lead to improved photograph quality.

Our first objective was to evaluate the reliability of a fundus photograph quality rating scale that would be applicable to photographs taken in the ED setting. Our second objective was to apply this scale to non-mydriatic fundus photographs obtained by nurse practitioners during routine clinical care encounters in the ED to determine factors associated with diminished photograph quality.

Methods

Population

The FOTO-ED study included adult patients presenting to our ED with a chief complaint of headache, acute focal neurological deficit, diastolic blood pressure ≥ 120 mmHg, or acute visual changes.¹ All patients were able to sit up and provide informed written consent. All photographs obtained from patients included in the FOTO-ED study between March 2009 and January 2010 were reviewed. The Emory University IRB approved the study and written informed consent was obtained from all subjects. The study was registered with ClinicalTrials.gov (NCT00873613).

Photographs

Non-stereoscopic non-mydriatic single-field digital fundus photographs of the posterior pole were obtained using the Kowa nonmyd- α -D 5 megapixel fundus camera (Kowa α -D, Torrance, CA). Images were obtained by nurse practitioners during their regular shift in the ED. Training of the fourteen nurse practitioners consisted of written materials, 15–30

minutes of training on the use of the camera, and on-site observation by a member of the study team until the nurse practitioner felt comfortable obtaining photographs on his or her own (usually after about 5–10 patients). Photographs were taken within the ED by using a custom hood over the camera and the patient's head and shoulders to reduce ambient light exposure. Nurse practitioners took photographs between 7 am and 10 pm, seven days a week. Patients who presented to the ED who met the inclusion criteria outside these hours could be included if they were still present in the ED during these hours. The camera was housed at the nursing station for one of the emergency department's subunits. Nurse practitioners were instructed to attempt to obtain two high-quality fundus photographs per eye, and they could take as many photographs as they wished. All the photographs were stored as Joint Photographic Experts Group (JPEG) lossy compression images with resolution of 2528×1936 pixels and compression ratio 1:5.

Analysis of the photographs

All photographs were reviewed independently by two neuro-ophthalmologists (BBB and CL) on 19-inch liquid crystal display monitors (Dell 1907FPV, resolution: 1280×1024 for BB; and HP W1907, resolution: 1440×900 for CL) using custom designed software. The photographs were initially reviewed in the order in which they had been obtained. The reviewers were able to enlarge images and to adjust brightness, contrast, and the gamma of the photographs.

The general quality of each ocular fundus photograph was graded on a five point scale: 1, inadequate for any diagnostic purpose; 2, unable to exclude all emergent findings; 3, only able to exclude emergent findings; 4, not ideal but still able to exclude subtle findings; and 5, ideal quality (Figure 1). Emergent findings were defined as optic disc edema, optic disc pallor, retinal vascular occlusion, intraocular hemorrhages, and grade III/IV hypertensive retinopathy. Examples of subtle findings would include the microaneurysms of background diabetic retinopathy or macular changes of age related macular degeneration. Grade 1 was considered as ungradable. Grade 4 and 5 were considered as high-quality photographs.

The best photograph for each eye was determined using the rating assigned to all photographs by one of the neuro-ophthalmologists during initial review. In the case of a tie, the first image of that eye with the highest quality rating was selected for further analysis. At the time of photography, the nurse practitioners recorded their impression of the quality of the best image taken of each patient's eye using the same five-point scale, but did not assign a rating to specific photographs. For assessments involving the best photographs of each eye, any eye with no photographs was assigned grade 1.

To assess intra-observer variability, a second grading of all patients was performed by the same physician, six months after the first grading, with the patients presented in a random order determined by a computerized pseudorandom sequence.

A regional quality assessment was also performed on the best photograph taken of each eye for a given patient for 4 different regions: the optic disc area, the macula, the superior vascular arcade area, and the inferior vascular arcade area. The quality of each area was assigned a letter (A, B, C) by the following procedure. The reviewer first asked himself, "Do I see the relevant area?" If not, the quality was graded C. If yes, a follow-up question was asked, "Is the quality sufficient to allow me to state with certainty that the relevant area is normal or abnormal?" If not, the quality was graded B. If yes, the quality was graded A (Figure 2).

Statistical Analysis

Statistical analysis was performed by BBB and KPD with R: A language and environment for statistical computing (R Foundation for Statistical Computing, <http://www.R-project.org>; accessed, August 1, 2011) version 2.11.1 and PROC GLIMMIX in SAS (Cary, North Carolina) version 9.2.

Summary statistics of median, mean, and frequency were calculated with complementary measures of variance (e.g, standard deviation, interquartile ranges, ranges). Medians were compared using the Wilcoxon rank sum test. Analysis of variance was used to compare the mean photographic quality across nurse practitioners. Inter-observer and intra-observer agreement were calculated for the general quality assessments using the quadratic (Fleiss-Cohen) weighted kappa statistic. Tabular summaries were prepared and logistic regression was used to estimate the odds ratios and 95% confidence intervals to assess the effect of patient's age and time between each photograph on the quality photographs. A Kaplan-Meier analysis was performed using the index of the photographs of the patient's left eye as the time variable, with failure defined as quality of the photograph 4 or better. McNemar chi square was used to compare the quality of the optic disc region to other regions with Bonferroni correction for the multiple comparisons performed.

Mixed effects ordinal logistic regression modeling was used to study which factors were associated with an increased or decreased photograph quality rating appropriately treated as an ordinal, categorical variable. The factors considered in this multivariate model were the interphotograph interval (see below), race, age, sex, body mass index, mean arterial pressure, and chief complaint as fixed effects and patient and neuro-ophthalmologist rater as random effects. Model convergence, collinearity, interaction (by backwards elimination), and confounding (by a greater than 10% change) were assessed.

The interphotograph interval for a photograph was defined as the time in seconds between that photograph and the preceding one on the same patient. The interphotograph interval was calculated using an automated, electronic time stamp. One patient was excluded because they had only one photograph taken. Because 358 of the 1734 (21%) photographs were the first taken during the patient's session, an interphotograph interval could not be calculated explicitly for these photographs. For the calculation of odds ratios in various categories, these photographs were excluded. For the logistic models, these observations were handled in three ways: (1) excluded as missing observations, (2) replaced with the minimum interphotograph interval for the patient, (3) replaced with the maximum interphotograph interval for the patient. Only the results imputed with the maximum interphotograph interval were reported, because this resulted in the exclusion of fewer observations, was thought to best represent the initial setup and positioning time, and led to longer rather than shorter estimates of best interphotograph interval. The other imputation approaches led to the same general conclusions.

Results

Three hundred and fifty patients with a total of 1734 photographs were enrolled in the study. The median patient age was 44.5 years (interquartile range [IQR]: 31–59). One hundred sixty-eight patients were black (48%), 151 white (43%), and the remainder of other or unknown race. The number of pictures obtained for each patient ranged from 0 to 26, with a median of 4 pictures per patient (IQR: 4–5).

Reliability of the general quality scale: all photographs

The reviewers assigned a high-quality rating (grade 4 or 5) to 37–44% of all 1734 photographs taken by the nurse practitioners. Photographs of no clinical value (grade 1)

represented 25–26% of all photographs taken. The inter-observer agreement between the two neuro-ophthalmologists for the general quality assessment was very good (weighted kappa 0.89 [95% confidence interval (CI): 0.83–0.95].

Reliability of the general quality scale: best photographs for each eye

Two hundred ninety-seven of the 350 patients (85%) had high-quality pictures in at least one eye, and 215 (61%) had high-quality pictures of both eyes, according to at least one reviewer (Table 1). Only 3% (12/350) of the patients had no photographs of diagnostic value according to at least one reviewer. Among these 12 patients, one had no pictures taken because of computer-related difficulties, and 11 patients had all photographs of no diagnostic value obtained by nurse practitioners (grade 1).

The inter-observer agreement between physicians for the best photographs of each patient was very good (weighted kappa 0.84, 95% CI:0.76–0.92). The intra-observer agreement was also very good (weighted kappa 0.87 [95% CI:0.79–0.95]). The inter-observer agreement between the physician and nurse practitioner was moderate (weighted kappa 0.51 [95%CI: 0.43–0.59]) due primarily to overrating of the quality of the photographs by the nurse practitioners.

Factors influencing image quality: univariate analysis

Ocular region—Figure 3 shows the frequency of each quality grade for the four different regions of the best picture of the right eye for each patient (similar results were obtained for the left eye, but are not shown). The reviewer was confident of his ability to evaluate the region as definitely normal or abnormal (grade A) for 64% to 86% of the photographs depending on area. The quality of the optic disc area was consistently better than the 3 other regions ($p<0.002$, Table 2) and the macula was the most difficult region to evaluate. The mean general quality rating of photographs with an “A” rating was 4.3 for the optic disc and 4.6 for the macula. The mean general quality rating of photographs with a “B” rating was 2.5 for the optic disc, and 3.5 for the macula.

Interphotograph interval—There was a non-linear relationship (Figure 4) between the mean quality of images obtained at various interphotograph intervals (i.e., the time in seconds between that photograph and the preceding one on the same patient): the mean quality of images obtained increased rapidly during the first 40 seconds (at 0.30 quality units per 10 seconds) before decreasing more gradually following 40 seconds (at 0.04 quality units per 10 seconds). Waiting at least 30 seconds after obtaining a photograph before obtaining the next photograph improved the odds of obtaining a high-quality photograph compared to waiting a shorter period of time (Table 3). The odds of obtaining a high-quality photograph after waiting 30–90 seconds was 3.8 times (95%CI: 2.6–5.7) that of obtaining a high-quality photograph after waiting less than 15 seconds.

Race—Black race was associated with poorer quality photographs. The mean quality of the best photographs of black patients was 3.6 compared to 3.9 among white patients ($p=0.005$, two-sample heterogeneous variance t-test).

Age—There was a decreasing linear relationship of mean photographic quality by age. Age ≤ 40 years increased the odds that the patients’ average best photograph quality would be high-quality (i.e., 4 or 5) by 2.2 times (95%CI: 1.4–3.4).

Number of photographs—Kaplan-Meier analysis (Figure 5) showed that once two photographs were taken on one eye, over 50% of patients had a high-quality photograph. If a

high-quality photograph was not obtained by the third attempt it was unlikely that one would be obtained at all.

Other factors—Other univariate analyses found no relationship between photographic quality and body mass index, sex, mean arterial pressure, nurse practitioner, or chief complaint.

Factors influencing image quality: multivariate analysis

Mixed effects logistic model development considering most of the factors explored by univariate analysis (see Methods) found that interphotograph interval, age, and race were independent, significant predictors of photograph quality (Table 4). In addition, this analysis did not support significant interaction ($p>0.10$) nor substantial confounding among the factors considered. There was significant variation ($p<0.001$) between baseline patient quality (2.7) and the two neuroophthalmologists (0.06) quality ratings.

The model predicts that a 10 second increase in time before a total of forty seconds has elapsed following the previous photograph increases the odds of a one unit higher quality rating by 1.81 times (95%CI: 1.68–1.98) and decreases it by 0.96 times (95%CI: 0.94–0.98) after a total of 40 seconds has elapsed. A ten-year increase in age decreases the odds of a one unit higher quality rating by 0.76 (95%CI: 0.69–0.85). Black patients had 0.42 times (95%CI 0.28–0.63) the odds of a one unit higher quality rating compared to whites.

Discussion

Fundus photographs have been used in clinical practice to screen for ocular diseases (e.g., age-related macular degeneration and diabetic retinopathy). Additionally, fundus photography serves as a valuable research tool.^{3–10} Most of the quality scales which have been previously used in research are defined by either the detection of subtle, disease-specific features (e.g., microaneurysms in diabetic retinopathy) or the overall image clarity and field of view.^{10–19} However, the ocular fundus abnormalities relevant to patient care in the ED reflect a wide variety of different conditions that tend not to be subtle (e.g., papilledema or grade III or IV hypertensive retinopathy) and which always involve the posterior pole (the only area of the ocular fundus consistently seen on non-mydratic fundus photographs). Thus, we developed a novel 5-point rating scale that reflects the overall image clarity needed within the context of the ED setting. We found that this scale was useful and reproducible as demonstrated by its very good inter-observer and intra-observer agreements (weighted kappa: 0.84–0.87).

Non-mydratic fundus photographs have been reported to be of decreased quality compared to mydratic fundus photographs. The rate of ungradable photographs in prior studies varies from 6 to 36% among those taken without pupillary dilation compared with 2 to 7% of photography performed after pupillary dilation.^{11–21} Variation in the rates of technical failure arise from differences in dark adaptation, equipment, ophthalmologic condition under study, and quality-rating system. Direct comparison of mydratic and non-mydratic fundus photographs in the same patient populations using similar techniques has confirmed that mydriasis does decrease the frequency of technical failure.^{11, 13, 14–18} However, the performance of fundus photography must not disrupt patient flow in the ED where dark adaption and pupillary dilation is not easy to obtain routinely. Moreover, pharmacologic pupillary dilation can mask important changes in a patient's neurological status, and should be avoided. Hence, we specifically chose single-field, non-stereoscopic, non-mydratic digital fundus photography for the FOTO-ED study.

Emergency Department nurse practitioners were able to obtain at least one high-quality fundus photograph using a non-mydratic fundus camera in 85% of patients, and the rate of photographs that were of no clinical value was lower (3%) than that seen in other studies using non-mydratic devices. This low rate of unusable photographs is likely explained by our specific quality scale reflective of ocular findings relevant to the ED. We found that even relatively poor quality fundus photographs were capable of ruling out or detecting ocular findings relevant to acute care that occur in the posterior pole (e.g., note the grade 2 and 3 photographs in Figure 1 where one can rule out papilledema and grade III or IV hypertensive retinopathy without difficulty, even though these photographs are not of adequate quality to appropriately evaluate other ophthalmic diseases such as age-related macular degeneration or diabetic retinopathy). Our regional quality assessment also confirmed that the quality of the area containing the optic disc and first branches of the central retinal vessels was consistently better than the other regions. The quality of this region may be explained by the higher reflectivity of the optic disc and its pericentral location where artifacts tend to be less frequent.

The rate of technical failure is also dependent on the population. In a population of hospitalized persons older than 70 with multiple morbidities, only 51% of the patients were able to have fundus photographs obtained, and the rate of ungradable photographs was 14.5%.⁸ In contrast, among a group of younger (but still >55 years old) and healthier persons, all were able to have non-mydratic fundus photographs obtained and the rate of ungradable photographs was 9.1%.⁸ The authors of this macular degeneration study attributed this difference to the more frequent cataract, higher degree of miosis, and poorer cooperation in the group of older patients.⁸ The ED environment and patient population have not been studied previously from this standpoint. Our population was younger than the patients screened in the macular degeneration study, and this may partially explain why we had such a low rate of ungradable photographs. The relationship of quality to age was reflected in our data, with the odds of high-quality photographs for persons over 40 being 40% lower than those of younger individuals. Additionally, our study excluded patients who were not stable enough to sit at the camera, likely further reducing our rates of technical failure.

Although our quality rating scale is relatively simple, it requires the reviewer to have an appreciation of the image clarity required for adequate clinical diagnosis, rather than a comparison to specific reference images. This may explain why we found the neuro-ophthalmologist's agreement with the nurse practitioners was only moderate (weighted kappa 0.51), with a substantial degree of overrating of quality by the nurse practitioners. This suggests there is an opportunity to obtain better overall photograph quality, thereby improving the clinical utility of the photographs, by additional training of the nurse practitioners or by the development of automated methods of quality assessment to provide point-of-care feedback.

By applying our quality scale to our study population we were able to identify several additional factors for which modifications and additional training could improve the overall quality and process of non-mydratic photography in the ED setting. First, while the relatively young age of our patients may have led to a lower rate of technical failure, our high proportion of black patients (48%), in whom we found a higher risk for poorer quality images, likely increased our frequency of ungradable images. The association of black race with poorer image quality was unsurprising considering that increased retinal pigmentation, expected on average to be higher among black patients compared to white patients, causes decreased reflectance of the ocular fundus.²² Additional education and guidelines for the nurse practitioners about setting the flash level based on race or iris color might reduce our rates of technical failure.

Second, logistic regression analysis showed that when the delay between two photographs is less than 15 seconds, quality suffers, and that the ideal range in which to obtain photographs is in the 30–90 second window. This is likely due to inadequate time for pupillary re-dilation after the first flash. Waiting longer than this window also appeared to be associated with poorer photograph quality, likely due to patient factors such as small pupillary diameter or poor cooperation that required longer re-positioning times of the camera and patient. Finally, three or more attempts to obtain a high-quality photograph on a given eye rarely achieved success. This information will be useful in future studies and clinical settings by providing improved nurse practitioner education about allowing adequate time between photographs and limiting the attempts to no more than 3 per eye unless there was a specific recognized technical failure. Improving the camera's software to include counts and timers might also be helpful.

In conclusion, we have developed a reliable, disease-independent quality rating scale for fundus photography. Using this scale, we found that the quality of non-mydriatic fundus photography obtained by trained nurse practitioners in a clinical ED setting is adequate to assess neuro-ophthalmic emergencies, especially those involving the optic nerve head, and those causing widespread changes in the posterior pole. We also found that the region of interest, interphotograph interval, age, and race are significant, independent predictors of image quality for non-mydriatic photographs taken by nurse practitioners in the ED. Addressing these factors may have a direct impact on the successful implementation of non-mydriatic fundus photography into the ED.

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Figure 1.

Example images for each level of the five-point scale used for general quality assessment: 1) The quality is inadequate for any diagnostic purpose. 2) Graders are unable to exclude all emergent findings. 3) Graders are only able to exclude emergent findings. 4) The quality is not ideal, but graders are able to exclude subtle findings. 5) Ideal quality. Grade 4 and 5 were considered high-quality photographs.

Figure 2. Regional quality assessment. *Upper half:* The four regions that were analyzed for quality independently: (1) the optic disc region, (2) the macular region, (3) the superior vascular arcade region, and (4) the inferior vascular arcade region. *Lower half:* The method by which each region of each photograph was assigned a grade.

Figure 3.

Frequency of each quality grade for the four different regions of the best photograph of the right eye (results similar for the left eye, not shown) for each patient.

Figure 4.

Mean quality of images vs. the midpoint of the interphotograph intervals (circles) within twenty groups of essentially equal sample size (i.e., 20-quantiles or vigintiles with breaks chosen by the interphotograph interval). The best fit piecewise linear regression (dashed line, knot at 40 seconds) is superimposed. This shows a non-linear relationship between how long it took to obtain a photograph and its quality with an apparent inflection point at 40 seconds.

Figure 5. Kaplan-Meier curve showing the proportion of patients who have not yet had a photograph of quality 4 or 5 (i.e., high-quality) in the right eye as a function of number of photographs taken. This figure shows that the chances of obtaining a high-quality photograph rapidly decreased with additional attempts.

Confusion matrix of the two reviewers' agreement regarding the best photograph taken in each eye of each patient

Table 1

		Reviewer #1 Ratings				
		1	2	3	4	5
Reviewer #2 Ratings	1	43	5	-	-	-
	2	11	51	13	6	-
	3	1	25	38	13	-
	4	-	14	67	87	16
	5	-	-	15	77	218

Hyphens represent zero. Weighted kappa 0.84 (95% confidence interval:0.76–0.92)

Table 2

Optic disc vs. other fundus regions based on regional quality assessments showing that the optic disc region is consistently better than other regions

	Disc Better	Disc Same	Disc Worse	McNemar χ^2 , p-value
Macula	99	239	12	<0.0001
Superior Arcade	40	299	11	0.002
Inferior Arcade	60	278	12	<0.0001

Table 3

Quality of images as a function of the time interval between the photographs taken. The highest percentage of highquality images was obtained between 30–90 seconds.

		Quality		
		# non-high-quality (overall rating 1–3)	# high-quality (overall rating 4–5)	% high-quality (overall rating 4–5)
Time (sec)	<15	245	40	14
	15–20	141	59	30
	20–30	213	116	35
	30–90	278	173	38
	>90	68	26	28

Table 4

Final mixed effects ordinal logistic model with significant predictors of a photograph's 5-point quality rating as outcome, accounting for repeated measures on the same patient (multiple photographs each rated by two neuro-ophthalmologists)

Variable	Estimate	Standard Error	t	p
IPI (seconds)	0.06	0.004	14.9	<0.001
(IPI - 40) if IPI > 40 *	-0.06	0.004	-14.3	<0.001
Age (years)	-0.03	0.006	-4.9	<0.001
Race (white race as reference)				
- Black	-0.86	0.20	-4.3	<0.001
- Other	-0.70	0.47	-1.5	0.14
- Unknown	-0.03	0.50	-0.1	0.95

IPI = interphotograph interval, the time in seconds between that photograph and the preceding one on the same patient

* this term accounts for the non-linear effect of interphotograph interval in figure 4