Ocular Fundus Photography as an Educational Tool

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Abstract (150 word maximum):

The proficiency of non-ophthalmologists with direct ophthalmoscopy is poor, which has prompted a search for alternative technologies to examine the ocular fundus. Although ocular fundus photography has existed for decades, its use has been traditionally restricted to ophthalmology clinical care settings and textbooks. Recent research has shown a role for nonmydriatic fundus photography in non-ophthalmology settings, encouraging more widespread adoption of fundus photography technology. Recent studies have also affirmed the role of fundus photography as an adjunct or alternative to direct ophthalmoscopy in undergraduate medical education. In this review, we examine the use of ocular fundus photography as an educational tool and suggest future applications for this important technology. Novel applications of fundus photography as an educational tool have the potential to resurrect the dying art of funduscopy.

Introduction

Advances in medical technology have historically been one of the driving forces for innovation in medicine. Although there has been concern over the contribution of medical technology advancements to a decline in clinician examination skills,[1] some advances in technology have enhanced the physical examination. For example, the invention and implementation of the direct ophthalmoscope revolutionized the practice of ophthalmology and neurology by affording the clinician a previously unavailable view of the living ocular fundus.[2] Armed with the knowledge of ocular manifestations of diseases, clinicians using the ophthalmoscope were rewarded with unique information that influenced patient care.

Unfortunately, we have witnessed the slow demise of direct ophthalmoscopy in non-ophthalmologists.[3] Yet, it is not the usefulness of visualization of the ocular fundus that has changed. The posterior pole of the eye harbors useful clues regarding the etiology of a patient's illness in many cases, whether or not an examiner has the time and skill to perform a funduscopic examination. For most non-ophthalmologists, important clinical findings such as papilledema and retinal hemorrhages have been hidden behind a veil of technical difficulty with using a direct ophthalmoscope. Despite adverse patient outcomes in some cases, there has not been sufficient impetus for most non-ophthalmology clinicians to master direct ophthalmoscopy, which has spurred a search for alternative tools to examine the ocular fundus.

With the adoption of computer-based access to radiographic images, laboratory results, and even electronic medical records, there has been a clear recent trend toward an increasingly digital/electronic climate of medical practice. Curriculum design in medical schools has also evolved around the provision of technology, including videotaped lectures, computerized examinations, virtual microscopes, and extensive internet resources to enhance the study of medicine. Ocular fundus photography has taken advantage of advancements in imaging technology to help relieve the technical obstacle of visualizing the ocular fundus and improve the yield of attempts at ocular fundus visualization. Although ocular fundus photography has existed since the 1950s,[4] the continued evolution of the technology has paved the way for the development and refinement of nonmydriatic fundus photography, and even the acquisition of ocular fundus images from hand-held devices.[5,6] On the cusp of a revolution in ocular fundus examination techniques for the non-ophthalmologist, fundus photography offers unique benefits, particularly in emergency departments and primary care settings where obtaining reliable information from a funduscopic examination has been increasingly hindered by difficulty with using a direct ophthalmoscope. As fundus photography becomes more widely adopted in general and emergency practices, there will be an increasing role for fundus photography as an educational tool. In this review, we summarize the history of ocular fundus photography, recent research establishing the efficacy of fundus photography in non-ophthalmology clinical care settings, education and clinical research using fundus photography, and the current and potential future role of fundus photography in medical education.

Fundus Photography in Clinical Practice

Modern nonmydriatic ocular fundus cameras are able to capture high-resolution, wide-angle (30 to 45 degrees) digital images of the posterior pole through an undilated pupil (Figure 1).[4] Photographs can be taken within a matter of minutes by nonphysicians with minimal training and then manipulated on a computer to magnify features of interest.[6] In contrast, the direct ophthalmoscope affords a highly magnified (15x) view of the fundus, but the viewing angle is only about 5 degrees, requiring the examiner to sweep the posterior pole for features of interest and then mentally note their size, location, and other attributes.[3] This is a difficult skill to master and, unsurprisingly, many clinicians perform direct ophthalmoscopy very poorly, if at all.[7,8] There is evidence that even ophthalmologists cannot perform direct ophthalmoscopy well enough to adequately screen for diabetic retinopathy, glaucoma, and hypertensive retinopathy.[9]

For these reasons, among others, ophthalmologists and optometrists have used fundus photography as part of their routine practice for decades. Photographs of the living human fundus were first captured by Jackman and Webster in the late 1800s, and fundus photography became viable for clinical use in the 1950s, with the widespread availability of electronic flash systems and 35 mm cameras.[4] Since then, fundus photography has made essential contributions to ophthalmic patient evaluation, facilitating not only diagnosis, but also documentation and tracking of eye disease progression.[10] Traditionally, fundus images have been captured through a dilated pupil, but the infrared focusing systems used on modern nonmydriatic cameras allow enough physiologic pupillary dilation to capture images of sufficient quality for ophthalmic disease screening.[4] For example, nonmydriatic fundus photography has been used for diabetic retinopathy screening with high accuracy compared to indirect ophthalmoscopy,[11,12] and it has also been studied for the detection of clinically relevant fundus findings in the emergency department.[6,13,14]

The Fundus Photography vs. Ophthalmoscopy Trial Outcomes in the Emergency Department (FOTO-ED) study found that the rate of detection of previously unrecognized fundus abnormalities by emergency physicians increased from 0% to 46% when nonmydriatic fundus photographs were made available to the physicians as an adjunct to direct ophthalmoscopy.[14] Importantly, the emergency physicians did not receive any specific training in fundus photo interpretation, demonstrating that simply removing the technical barrier of direct ophthalmoscopy may improve the detection of fundus abnormalities by non-ophthalmologists. As the trend of improvement in fundus imaging technology continues with commercially available handheld nonmydriatic cameras approaching standard tabletop models in terms of quality and ease-of-use, fundus photography may prove useful in other patient populations, such as the critically ill and patients in remote locations.

Fundus Photography in Medical Education

As evidence mounts for the potential utility of ocular fundus photographs in non-ophthalmology clinical care, the role of ocular fundus photography in medical education has likewise evolved. The systematic use of fundus photographs in medical education beyond the pages of textbooks likely began with the invention of patient simulators for teaching direct ophthalmoscopy. In 1972, Colenbrander described a sophisticated ophthalmoscopy simulator consisting of a mannequin head with optically correct "eyes."[15] The direct ophthalmoscope was used to look through a lens, simulating the cornea, at 35 mm slides of ocular fundus images, acquired with a standard fundus camera. Slides were loaded into the simulator behind the lens and could be moved forward or backward relative to the examiner to simulate emmetropia, myopia, or hyperopia. Changing the slides allowed a variety of fundus abnormalities to be presented. Later, others developed simulators that added features such as eyelids and an adjustable diaphragm that could be set to represent various pupil sizes, but each retained the basic design of the Colenbrander simulator, relying on either a slide or printed photograph to represent the ocular fundus.[16–18] Simpler devices consisting of shallow plastic canisters, similar to film canisters, have also been described; these, too, use printed fundus photographs affixed to the bottom of the canister to represent the fundus, with the ophthalmoscopic view limited by the size of the “pupil” drilled into the canister lid (Figure 2).[19–21]

In 1991, Korenfeld described a direct ophthalmoscopy teaching tool of a rather different design that also used fundus photographs.[22] Instead of restricting practice to a single student, as is necessary with a mannequin, Korenfeld’s approach used a manual occluder to simulate the narrow view afforded by the direct ophthalmoscope on projected fundus images, which could be viewed by many students at once. The occluder was fashioned out of a square meter of dark-colored cardboard with a central, 33 cm diameter aperture cut out of the center. The instructor placed the occluder in front of the projected image and slowly swept the aperture over the fundus landmarks. The goal was to help students develop the ability to create a mental montage of the posterior pole, as is required with direct ophthalmoscopy.

The direct ophthalmoscopy simulator has gained wide use in medical education and the use of these simulators is regularly reported in the medical education and ophthalmology literature.[18,23–26] The early role of fundus photographs in medical education was as an integral part of most ophthalmoscopy simulators, but without an emphasis on any potential stand-alone role for the photographs.[18,23,27] Initially, simulators simply served as a tool for assessing students’ direct ophthalmoscopy skills, but the simulators, and fundus photographs themselves, have more recently been used as tools to teach the ocular fundus examination.[24–26,28] This trend and the use of ocular fundus photography in medical education are summarized in Table 1.

As part of a longitudinal ophthalmology curriculum spanning the second through fourth years of medical school, Mottow-Lippa and colleagues used a custom-built ophthalmoscopy simulator to objectively grade third-year students' direct ophthalmoscopy skills at the end of their core clerkships.[18] A photograph of diabetic macular edema was presented in the simulator's "dilated" right eye (8 mm pupil), and background diabetic retinopathy was shown in the "undilated" left eye (4 mm pupil). Students were told to describe their exam findings using a direct ophthalmoscope and were asked open-ended questions about their clinical management plan based on the findings. Only 32% of students correctly described one or more attributes of at least one of the two fundi; 22% and 20% were unable to describe any fundus features for the dilated and undilated eyes, respectively. The students demonstrated limited proficiency with the ocular fundus examination despite the results of a preclinical ophthalmology skills session held the previous year, during which faculty preceptors rated 72% of the students as proficient in direct ophthalmoscopy. The authors concluded that preceptor ratings did not accurately predict students' future ophthalmoscopy abilities, and that any skills the students acquired in the preclinical years eroded substantially during the core clerkships. The authors later developed and instituted an expanded ophthalmology curriculum at their institution, which included a component embedded within the required third-year family medicine clerkship.[23] Over a total of six hours, a senior ophthalmologist reviewed a fundus examination algorithm introduced during the preclinical years and led case-based didactics. Students were also given practice time on an ophthalmoscopy simulator. Although the mean score on a simulator-based test of ophthalmoscopy skills was 78% at the end of the clerkship, this declined to a mean of

55% on repeat testing at the end of the third year of medical school. The authors concluded that a more intensive ophthalmology curriculum, with reinforcement of ophthalmoscopy skills throughout the core clerkships, would be required for medical students to attain lasting proficiency in direct ophthalmoscopy.

This pair of studies articulated several themes that have provided the foundation for a compelling argument in support of the search for alternatives to the direct ophthalmoscope to examine the ocular fundus: (1) direct ophthalmoscopy requires longitudinal skill reinforcement to attain and maintain proficiency; (2) even diligent efforts by talented and motivated educators have fallen short in reversing the decline in direct ophthalmoscopy skills in medical education; and (3) the technical difficulties of using a direct ophthalmoscope have overshadowed its potential utility.

More recently, ophthalmoscopy simulators have become commercially available. One such product, the EYE Examination Simulator (Kyoto Kagaku Co., Ltd., Tokyo, Japan), which includes one normal and nine abnormal fundus image slides, incorporates ocular fundus photographs as a means of both teaching and assessing direct ophthalmoscopy skills.[25,27] Akaishi and colleagues modified the stock fundus slides to include six 4-digit numbers printed in the vicinity of important fundus landmarks, which participants were asked to find using a direct ophthalmoscope.[27] They concluded that the ability to identify the numbers on simulators with pupils $\leq$ 3.5 mm in diameter correlated with study participants' self-reported cumulative experience with direct ophthalmoscopy.

Fundus photographs have been used to assess direct ophthalmoscopy skills even without the use of a purpose-built ophthalmoscopy simulator. For example, to confirm that students were able to identify the features of a volunteer patient's ocular fundus, they were asked to examine the volunteer using a direct ophthalmoscope and then choose the fundus photograph of the volunteer's eye from among several decoy photographs. In a creative application of this approach, 394 students at two Swedish medical schools had one eye dilated and photographed at the beginning of an ophthalmology clerkship.[29] As part of an end-of-clerkship skills exam, students performed direct ophthalmoscopy on a randomly selected peer without a time limit and selected the photograph of their peer's optic disc among 15 total choices on a computer screen. Over 96% of the students selected the correct photo on the first attempt. In a similar study, 33 fourth-year medical students performed direct ophthalmoscopy on three undilated volunteers at the beginning and end of a one-week ophthalmology clerkship.[30] Each student was asked to select the fundus photograph matching the volunteer's optic disc among four printed photographs. The mean number of photographs students correctly identified increased from 1.4 to 2.4 between the pre- and post-tests ($p<0.004$). A follow-up study at the same institution employed the fundus photographs not only in skill assessment but also in the learning process. Eighty-nine students (in individual cohorts of 8-10) were randomized to have a dilated fundus photograph taken of one eye, after which photographs were printed and distributed among the students.[31] Students were instructed to practice ophthalmoscopy on each other throughout the week until they could identify the person to whom the fundus photograph belonged. Forty-two students, who did not undergo fundus photography, were simply instructed to practice ophthalmoscopy on each other and served as controls. As in the original study, the students were evaluated before and after the clerkship using volunteer patients and fundus photographs in a multiple-choice format. Pre-test scores were similar between the peer fundus photo and control groups, but the performance of the peer photo group was significantly better than that of the control group on the post-test (average of 0.64 out of 2 images correctly identified by controls; average of 1.53 out of 2 correctly identified by those in the peer photo group; $p<0.001$). Interactive photo-matching exercises may enhance student engagement and direct ophthalmoscopy skill acquisition, however, longitudinal reinforcement of these skills remains the most difficult challenge to direct ophthalmoscopy in educational and clinical settings.

One recent study combined photo-based ophthalmoscopy skill assessment with a service-learning project in ophthalmology.[28] Second-year medical students who participated in a pro bono mobile eye clinic received three hours of training from an ophthalmologist, which included the presentation of photographs of glaucomatous optic discs and the opportunity to practice dilated direct ophthalmoscopy on fellow participants with expert supervision. Participants assisted at a mobile eye clinic with high clinical volume the following weekend, with the chance to apply their new skills with live patients. One month later, five participants were randomly selected to perform direct ophthalmoscopy on the dilated eyes of volunteer patients with known, distinctive fundus findings. Five medical students who had completed third-year core clerkships but had not participated in the eye clinic also examined the patients and served as controls. After examining a patient for two minutes, students selected a fundus photograph matching the patient's fundus out of four possible choices or indicated that they did not obtain a view. One year later, at the completion of core clerkships, a second randomly selected group of five eye clinic participants was tested in this manner, and participants' performance was compared to five students of the same level without the service-learning experience. At one month, median ophthalmoscopy scores were 60% for clinic participants (IQR, 40-80%) and 40% (IQR, 20-60%) for control students; at one year, median scores were 100% (IQR, 75-100%) for participants and 0% (IQR, 0-25%) for controls. Although the study suggested a long-term (one year) benefit to an immersion experience in direct ophthalmoscopy without additional interval training, the study included a small number of participants, and there was a potential for bias from the self-selection of more motivated learners among the students who volunteered at the clinic.[32] Others have found a decrease in fundus examination proficiency among medical students without interval skill reinforcement, whether using live volunteers, a direct ophthalmoscopy simulator, or fundus photographs.[18,26]

The majority of medical education studies incorporating fundus photographs has used photographs as a tool to teach direct ophthalmoscopy. Despite the valiant efforts of educators to preserve the skill of direct ophthalmoscopy with the use of simulators and other innovative methods to teach and assess students in their use of direct ophthalmoscopy, both clinical and educational data suggest that these efforts have not yielded the desired results of sustained proficiency with the ophthalmoscope. Recognizing the technical obstacle of the direct ophthalmoscope as a primary contributing factor to the poor yield of dedicated ophthalmoscopy education, recent studies have directly compared stand-alone fundus photography interpretation to direct ophthalmoscopy.

The Teaching Ophthalmoscopy to Medical Students (TOTeMS) study used a prospective, randomized design to compare the accuracy and preferences of medical students learning to examine the ocular fundus using various modalities.[24] First-year medical students were randomized to receive or not receive training on fundus photograph interpretation prior to accuracy assessments. Student preferences for ocular fundus examination with direct ophthalmoscopy on a human volunteer, direct ophthalmoscopy on a simulator (Figure 2), and fundus photographs were assessed. Of 119 medical students, 92 (77%) preferred fundus photography to ophthalmoscopy. Students were also more accurate when interpreting fundus photographs than when performing ophthalmoscopy on simulators, even without further training. Students rated interpreting fundus photographs as easier and less frustrating than direct ophthalmoscopy on humans or simulators. The majority of students (70%) indicated they would prefer to use fundus photographs over direct ophthalmoscopy during clinical rotations.

A 1-year follow-up study (TOTeMS II) with the same cohort of students demonstrated that the students' preference for fundus photographs and increased accuracy when using photographs over direct ophthalmoscopy persisted over time with no additional interval training.[26] Of the 119 students who participated in the original TOTeMS study, 107 (90%) completed the follow-up study and were randomized to fundus examination using either photographs or direct ophthalmoscopy on simulators. Students were again more accurate using photographs for fundus interpretation than using direct ophthalmoscopy on simulators, although both groups performed worse than 1-year prior. The interval performance decline likely reflected a lack of interval skill reinforcement in ocular fundus examination. The students rated interpretation of fundus photographs as easier than direct ophthalmoscopy, and 81 (76%) stated they would prefer using photographs over direct ophthalmoscopy for clinical ocular fundus examinations. The students' self-reported median frequency of performing ophthalmoscopy during general physical examinations over the previous year was <10%. Discomfort with the ophthalmoscopic examination (41/107; 38%) and discouragement by their preceptor (21/107; 20%) were the most common primary reasons for not examining the ocular fundus during a physical examination. The surprising finding of discouragement from preceptors as a primary reason for not performing ophthalmoscopy suggests that substantial barriers to the performance of ophthalmoscopy persist in clinical practice.

Future Directions for Fundus Photography as an Educational Tool

Traditionally, medical students have been expected to own and carry their own direct ophthalmoscope, just as they would a stethoscope or reflex hammer. Yet, in one recent study, only 20% of medical students at one medical school owned a direct ophthalmoscope just prior to graduation.[23] Of those that did not purchase an ophthalmoscope, a perception of unimportance (19%) and that they "didn't use one" (21%) were significant contributing factors. Although mere ownership of an ophthalmoscope does not guarantee proficiency or even its regular use, resistance to ophthalmoscope ownership is likely a manifestation of a larger problem reflecting declining appreciation of ocular fundus findings among both students and teachers. Can innovating new technologies preserve the art of ocular fundus visualization among the rising generation of physicians? By removing the technical difficulty and anxiety associated with use of the direct ophthalmoscope, the answer may be yes.

Fundus photography is well poised to be a potential answer to the dying art of ophthalmoscopy. Although future research is needed to evaluate the proficiency of students, resident physicians in training, and practicing physicians in fundus photograph interpretation, preliminary data suggests a warm reception for fundus photography in medical education.[24,26] Once the obstacle of the direct ophthalmoscope is removed, students and physicians, as well as medical educators, are free to focus on the interpretation of ocular fundus findings. The finding that emergency physicians perform much better in the detection of ocular fundus abnormalities using fundus photographs than with a direct ophthalmoscope, even without additional training in fundus photograph interpretation,[14] suggests the technical barrier of direct ophthalmoscopy may hinder physicians in applying their knowledge of ocular fundus abnormalities. Education aimed at improving proficiency with direct ophthalmoscopy has produced short-term benefits, but obstacles to direct ophthalmoscope usage in practice likely hinder any efforts to maintain a level of acceptable proficiency.[23] Future studies are needed to evaluate the impact of fundus photography on the recognition of normal and abnormal features of the ocular fundus in settings beyond the emergency department – particularly in clinical settings where clinician proficiency with a direct ophthalmoscope has been hindered. Complementary future research in medical education may focus on effective ways to teach the interpretation of ocular fundus findings using fundus photography in a clinical practice setting.

How can medical education and future physicians be prepared for eventual fundus camera use in primary care, emergency department, and neurology outpatient settings? Using fundus photographs to share classic examples of normal and abnormal ocular fundus findings is hardly new, and has been an essential component of ophthalmology education via textbooks for decades. Taking fundus photography to the next level as an educational tool will require creative approaches to improving initial instruction in ocular fundus interpretation, the establishment of a system to encourage longitudinal skill reinforcement throughout medical training, an increase in the prevalence and use of fundus photography in clinical care, and the establishment of a sense of ease and relevance in examining the ocular fundus among practicing physicians.

Even now, fundus photography can be more effectively incorporated into undergraduate medical education. For example, fundus photography could be integrated into problem-based learning curricula, which have increased in popularity in recent years.[33] The use of technology in problem-based medical school curricula has been well received.[33] Problem-based learning focusing on the hypertensive patient, for example, could include fundus photographs with findings of arteriovenous nicking, hypertension-related retinal hemorrhages, and optic disc edema related to hypertension. A discussion of the pathophysiology of these findings in the context of a clinical case and fundus photographs are likely to aid learning and retention by providing an appropriate context for recall. Skills in interpreting ocular fundus findings learned as part of the ophthalmology curriculum in medical school, using either a direct ophthalmoscope or fundus photographs, quickly decay without longer-term longitudinal reinforcement.[23,26] Longitudinal reinforcement of the funduscopic findings of the hypertensive patient could take place during clinical rotations in emergency medicine and ambulatory internal medicine and in other settings where nonmydriatic fundus cameras have been or could be adopted.

Just as the teaching of a systematic approach to reading chest x-rays would be hindered by an intermittent, unreliable, and small view of the radiograph, teaching and using a systematic approach to the ocular fundus examination may have been hindered in the past by a lack of proficiency with the direct ophthalmoscope. To maximize the potential for fundus photography to make a lasting impression in medical education, it will need to be coupled with a simple, systematic approach to examining the ocular fundus as well as an introduction to common and emergent ophthalmic manifestations of disease.

The use of fundus photography in medical education is not limited to its use in clinical care, but will also continue to advance medical education by providing images for medical conferences, didactic presentations, publications, and internet-based educational resources. Fundus photographs are routinely used in ophthalmology didactic presentations, and would be more likely to be incorporated into non-ophthalmology case conferences and presentations if more clinicians were familiar with fundus findings and fundus photography equipment were more readily available outside of the ophthalmology clinic. Indeed, one of the greatest potential benefits of increased availability of ocular fundus photographs in non-ophthalmology clinical care settings would be improved accessibility of the ocular fundus examination, which has the potential to restore the clinical and educational relevance of the ocular fundus examination for both practicing clinicians and students.

Using a fundus photograph in seeking a second opinion from another medical professional also introduces further teaching opportunities, in which the case at hand becomes the teacher. A fundus finding that could not be shown to others could never generate the same teaching opportunities afforded by a recorded image of the ocular fundus. Active learning has long been established as more effective than passive learning, and actively searching for the significance of ocular fundus findings teaches important skills and reinforces retention in a way not possible from reading an answer in a textbook or figure legend.

The nearly universal trend of technological advancements becoming smaller and less expensive has also applied to the evolution of fundus photography. These changes have inspired the development of more portable and convenient solutions for ocular fundus visualization, including the use of smartphone photography and even hand-held nonmydriatic fundus cameras, which are currently being studied.[5] Smartphone photography is already being used in some medical specialties to enhance patient care and education, including dermatology[34] and pathology.[35] Although smartphone ocular fundus photography currently lags behind full-size fundus cameras in photograph quality,[5] the rapidly advancing technology is expected to yield increasingly higher quality images in the future, as good image quality is essential to the clinical usefulness of fundus photographs. The important parameters of image quality and cost of image acquisition are likely to play an important role in the future adoption and applicability of fundus photography technology.

As fundus photography becomes more widely adopted by non-ophthalmology practices, there may also arise a need for continuing medical education (CME) courses specifically designed to instruct clinicians in the art of ocular fundus interpretation. It seems that an increasing number of physicians have been trained in an environment in which ocular fundus examination was rarely a valued part of the physical examination. In these cases, education regarding the utility of the fundus examination will also become an essential part of the didactic instruction.

Conclusions

The future of funduscopy in medical education is bright. Novel ocular fundus examination techniques and technology are being developed and are needed to stimulate renewed interest in this still-relevant component of the physical examination. Recent research has suggested that medical students are more accurate in identifying ocular fundus abnormalities using fundus photographs than when examining an eye simulator with a direct ophthalmoscope.[24,26] These findings are also likely to apply to physicians in non-ophthalmic practices, as they have to emergency department physicians.[14] As fundus photography technology becomes more widely adopted in non-ophthalmology settings, incorporating the technology into medical education will become more natural as well as more important. The potential roles for fundus photography in medical education are varied and future research may help identify the most impactful ways to incorporate fundus photographs into a longitudinal ophthalmology curriculum for undergraduate and post-graduate medical trainees and physicians.

Enthusiastic adoption of fundus photography by students, coupled with increasing quality, availability, and portability of fundus photography technology, has the potential to resurrect the funduscopic art. The most important potential impact of such education programs is the potential to improve clinician competence, patient care, and, ultimately, patient outcomes.

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Figure captions

Figure 1. (A) Typical tabletop nonmydriatic fundus camera and appropriate patient positioning. (B) Nonmydriatic fundus photograph of a normal right eye, showing an example of photograph quality that can be achieved without dilation.

Figure 2. Use of fundus photographs in an ophthalmoscopy simulator. (A) Disassembled (left) and fully assembled (right) plastic canisters for direct ophthalmoscopy training. A printed fundus photograph is affixed to the bottom of each canister; the canister lid, with a “pupil” drilled in the middle, is placed at the mouth of the canister to mimic the limited ophthalmoscopic view available in a real patient. A lens may also be placed beneath the lid to approximate the refractive power of the human cornea and lens. (B) Canisters may be used as part of a mannequin patient simulator, as shown here. (C) A medical student practices direct ophthalmoscopy on the simulator.

Table 1. A summary of recent reports on the use of fundus photography in medical education.

Author	Year	Number	Learners	Goals of FP Use	Description	Conclusions
FPs Used in DO Simulators						
Lippa[18]	2006	96	Third-year medical students	• Assessing DO Skills	Students performed DO on the simulator's "dilated" right eye and "undilated" left eye at the end of their core clerkships; their written fundus descriptions and corresponding clinical management plans were evaluated	Preceptor ratings of preclinical students' DO skills failed to predict their simulator performance at the end of core clerkships
Mottow-Lippa[23]	2009	91	Third-year medical students	• Assessing DO Skills	Same as above, although students practiced and were tested on the ophthalmoscopy simulator during their family medicine clerkship as well; the clerkship also included a didactic component	Training successfully reinforces DO skills, but the

					organized around case studies with correlated FPs viewed in the simulator	skills decay when not habitually practiced
Akaishi[27]	2014	73	Predominantly junior residents and generalist physicians	• Assessing DO Skills	Custom fundus slides were created with numbers printed at various fundus landmarks; participants were given two minutes to perform direct ophthalmoscopy on a simulator eye and record the numbers; participants were tested on “pupil” diameters of 2, 3.5, and 5 mm	Self-reported cumulative experience with DO predicted simulator performance when “pupil” size was $\leq$ 3.5 mm
FPs Used in DO Simulators and FP-Based Multiple-Choice Questions						
Larsen[25]	2014	231	Second-year medical students	Teaching DO	Students electing to participate in a 30-min. session with an ophthalmoscopy simulator were allowed to practice on the simulator with in-person guidance from an ophthalmologist; as students	Simulator exercise increased students’ self-

					practiced, they identified printed FPs corresponding to the fundi	reported ability and confidence with ophthalmoscopy; when surveyed at graduation, students felt the simulator enhanced their physical exam skills throughout the clinical clerkships
FP-Based Multiple-Choice Questions						

Asman[29]	2010	394	Medical students	• Assessing DO Skills	At the beginning of an ophthalmology clerkship, optic disc photographs were taken in one eye of each student; students performed DO on one randomly-chosen peer at the end of the clerkship; students identified the FP depicting their peer's optic disc among 15 total choices on a computer screen	Internet-based software may be used for DO skill assessment
Afshar[30]	2010	33	Fourth-year medical students	• Assessing DO Skills	Students performed DO on three volunteers and identified a FP matching the volunteer's optic disc among four printed FPs; students were re-tested after a one week ophthalmology clerkship	Matching exercise may increase DO skills and be helpful in assessing how well students visualize the optic nerve

Milani[31]	2013	131	Fourth-year medical students	• Teaching DO • Assessing DO Skills	At the beginning of a one-week ophthalmology clerkship, 89 students (in individual cohorts of 8-10) were randomly selected to have a dilated optic disc photo taken in one eye; an additional 42 students served as controls; printed FPs were distributed among the 89 students receiving photography; students practiced DO on each other until they could identify the person to whom the FP belonged; students' DO skills were assessed before and after the rotation	Improvement in DO skills over 1 week using teaching exercise
FP-Based Multiple-Choice Questions and Didactic Slideshow Using FPs						
Byrd[28]	2014	5	Second-year medical students	• Teaching DO • Assessing DO Skills	At one month and one year after a one-day ophthalmology service learning clinic, students had two minutes to examine the dilated eye of a volunteer with a distinctive fundus finding using DO; students identified a FP matching the volunteer’s optic disc among four printed FPs or	Community service projects may enhance short- and long-term DO skills

					indicated that they did not see the fundus; performance was compared to upperclassmen without the service learning experience	
FPs Used in DO Simulators, Didactic Slideshow Using FPs, and Direct Interpretation of FPs						
Kelly[24]	2013	119	First-year medical students	• Teaching and assessing DO skills Teaching and assessing FP interpretation skills	After an introductory lecture and DO practice on volunteers and simulators, students were randomized to receive instruction on interpreting FPs either before or after skill testing; skill testing consisted of identifying abnormal fundus features on simulators using DO and on printed FPs without using DO; student preferences were surveyed	Students were more accurate with and preferred FPs over DO
FPs Used in DO Simulators and Direct Interpretation of FPs						

Mackay[26]	2014	107[a]	Second-year medical students	• Assessing DO skills • Assessing FP interpretation skills	One year after training of the cohort of students assessed by Kelly et al,[24] students' fundus exam skills and preferences were re-evaluated using DO and printed FPs, without interval training	Students were more accurate with and prefered FPs over DO 1 year after initial training, although both groups showed a performance decline over 1 year

Abbreviations: DO, direct ophthalmoscopy; FP, fundus photograph.

[a]Same cohort as Kelly et al.[24]