Received: 5 November 2021 | Accepted: 5 May 2022

DOI: 10.1111/ene.15390

european journal of neurology
the official journal of the european academy of neurology

ORIGINAL ARTICLE

Fundoscopy use in neurology departments and the utility of smartphone photography: a prospective prevalence and crossover diagnostic accuracy study amongst neurology inpatients

George He[1] | Hamish P. Dunn[2,3,4] | Kate E. Ahmad[5] | Eloise Watson[5] | Andrew Henderson[6] | Dominique Tynan[2,7] | John Leaney[2,3] | Andrew J. White[2,3,8] | Alex W. Hewitt[1,9] | Clare L. Fraser[2,10]

[1]University of Melbourne, Melbourne, Vic., Australia

[2]University of Sydney, Faculty of Medicine and Health, Sydney, NSW, Australia

[3]Westmead Hospital, Department of Ophthalmology, Sydney, NSW, Australia

[4]University of New South Wales, Rural Clinical School, Port Macquarie, NSW, Australia

[5]Royal North Shore Hospital, Department of Neurology, Sydney, NSW, Australia

[6]Westmead Hospital, Department of Neurology, Sydney, NSW, Australia

[7]Royal Victorian Eye and Ear Hospital, Melbourne, , Vic., Australia

[8]Centre for Vision Research, Westmead Institute for Medical Research, Sydney, NSW, Australia

[9]Centre for Eye Research, Melbourne, Vic., Australia

[10]Save Sight Institute, Sydney, University of Sydney, Sydney, NSW, Australia

Correspondence
Hamish P. Dunn, University of Sydney, Faculty of Medicine and Health, Sydney, NSW, Australia.
Email: hamish.dunn@sydney.edu.au

Funding information
No funding was provided for the study. Dr Hamish Dunn receives an RTP scholarship from the Australian Government for his PhD research. The non-mydriatic fundus camera was loaned by Welch Allyn/Hill Rom and they provided training support. The smartphone fundoscopy device was loaned by the Western Clinical School, University of Sydney

Abstract

Background and purpose: Although fundoscopy is a crucial part of the neurological examination, it is challenging, under-utilized and unreliably performed. The aim was to determine the prevalence of fundus pathology amongst neurology inpatients and the diagnostic accuracy of current fundoscopy practice compared with systematic screening with smartphone fundoscopy (SF) and portable non-mydriatic fundus photography (NMFP).

Methods: This was a prospective cross-sectional surveillance and diagnostic accuracy study on adult patients admitted under neurology in an Australian hospital. Inpatients were randomized to initial NMFP (RetinaVue 100, Welch Allyn) or SF (D-EYE) followed by a crossover to the alternative modality. Images were graded by neurology doctors, using telemedicine consensus neuro-ophthalmology NMFP grading as the reference standard. Feasibility parameters included ease, comfort and speed.

Results: Of 79 enrolled patients, 14.1% had neurologically relevant pathology (seven, disc pallor; one, hypertensive retinopathy; three, disc swelling). The neurology team performed direct ophthalmoscopy in 6.6% of cases and missed all abnormalities. SF had a

George He and Hamish P. Dunn are co-first authors.

sensitivity of 30%–40% compared with NMFP (45.5%); however, it had a lower rate of screening failure (1% vs. 13%, $p < 0.001$), a shorter examination time (1.10 vs. 2.25 min, $p < 0.001$) and a slightly higher patient comfort rating (9.2 vs. 8/10, $p < 0.001$).

Conclusion: Our study demonstrates a clinically significant prevalence of fundus pathology amongst neurology inpatients which was missed by current fundoscopy practices. Portable NMFP screening appears more accurate than SF, whilst both are diagnostically superior to routine fundoscopic practice, feasible and well tolerated by patients.

KEYWORDS
fundus oculi, neurology, ophthalmoscopy, photography, sensitivity and specificity

INTRODUCTION

Fundoscopy offers a non-invasive glimpse of the brain and vasculature. It is a crucial part of the neurological examination and yet is not reliably performed by non-eye health physicians [1–4]. Neurology inpatients have a particularly increased likelihood of fundus pathology which could affect clinical management [5], yet the prevalence of fundus pathology amongst neurology inpatients remains unclear. Vision- and life-threatening neurological conditions may demonstrate fundal changes without other clinical signs, even with normal magnetic resonance imaging [6]. Whilst direct ophthalmoscopy (DO) is current standard practice, it is challenging, requiring time, practice and patience to master, and is now rarely performed in the clinical setting [3, 7, 8]. Novel technologies such as non-mydriatic cameras (NMFP) and smartphone fundoscopy (SF) have emerged as potential portable alternatives in a ward-based setting [9].

Non-mydriatic fundus photography eliminates the inconvenience of pupil dilation and digital images can be saved into medical records, facilitating review, telemedicine or artificial intelligence diagnostic support [10, 11]. Portable NMFP allows examination of immobile and critically ill patients and is superior to DO in detecting fundus pathology in emergency departments (EDs) [1, 2, 8]. The ubiquitous smartphone can be fitted with fundoscopy lens adapters offering availability, portability and affordability on top of data storage. SF image quality has improved commensurate with advances in smartphone cameras [12]. Consequently SF can improve the accuracy of fundal examinations amongst non-ophthalmologists [12, 13].

In this study the aim was to determine the period prevalence of fundus pathology in neurology inpatients. Additionally, an evaluation of current fundoscopy practices was performed and their diagnostic accuracy was compared with systematic screening using a smartphone or portable non-mydriatic camera.

METHODS

This study adhered to the Declaration of Helsinki and local ethics committee approval was obtained. All participants provided written, informed consent. This trial was prospectively registered with the Australian New Zealand Clinical Trials Registry (ACTRN12620000134921).

Study design and setting

This was a cross-sectional surveillance and diagnostic accuracy study set in Westmead Hospital, a tertiary referral hospital, between 14 February and 14 March 2020. Westmead Hospital currently employs NMFP in the ED [1].

Participants

Consecutive hospital inpatients were eligible for inclusion if they were admitted under the care of neurology or had a neurology consult during business hours (0800–1630). Patients were excluded if they were <16 years or unable to provide informed consent. Participants were identified from electronic hospital records and liaison with the treating team.

Study protocol

Images and videos were obtained without pharmacological mydriasis. The devices used were a commercially available handheld NMFP RetinaVue 100 (Welch Allyn) and an SF device D-EYE (Padova, Italy) attached to an iPhone 6 (Apple Inc.). A medical student researcher who received 1 h of computer-based and face-to-face NMFP and SF training used the interventions by the patient bedside.

Routine care by the neurology team, including whether DO was performed using traditional direct or PanOptic ophthalmoscopy, was observed by the research assistant and any medical note documentation was recorded. After neurology review, participants had both NMFP and SF of both eyes. The order of these interventions was computer randomized during recruitment on REDcap [14]. Randomization was only performed once participants had completed baseline data acquisition to avoid recruitment bias. To minimize diagnostic review bias a minimum 60-min washout time between neurology fundoscopy and screening interventions was mandated, with a minimum 5-min washout between SF and NMFP.

Images and videos centred at the optic disc and macula were obtained in darkened rooms where possible. Patients were asked to rate the comfort of fundus photography on a 10-point sliding bar scale (10 = no discomfort). The number, duration and ease of fundoscopy attempts, potential barriers (e.g., room lights on) and pupil size were recorded.

Images were assessed remotely by a neurologist, a neurology advanced trainee, an ophthalmologist and two fellowship-trained neuro-ophthalmologists with access to clinical information but masked to other interpretations. Images were only provided to the treating neurology team after 3 days unless urgent pathology was detected by telemedicine review. Fundus pathology was defined a priori as optic disc swelling, disc pallor, intraocular haemorrhage, other pathology and anatomical variation. Image quality was graded primarily on adequacy 'to determine with certainty' whether the optic disc and/or macula were normal or abnormal [15]. Graders were additionally asked to judge image quality on a validated 5-point Likert scale [15].

The reference clinical standard for diagnostic testing analyses was assessment of NMFP photographs by two neuro-ophthalmologists with access to clinical data. When NMFP was not possible, consensus grading of SF images was used as the reference standard. Due to limitations imposed by the COVID-19 pandemic, patients with unsuccessful NMFP but successful SF were unable to be reviewed in the clinic. Where any grading disagreement occurred, a consensus arbitration with access to clinical information was held amongst three graders, a neurologist, a general ophthalmologist and a neuro-ophthalmologist.

Outcomes

The primary outcome was the period prevalence of neurologically relevant fundoscopic pathology in patients admitted to hospital under the care of neurology, as detected by a reference standard of consensus assessment of NMFP photographs.

Secondary outcomes included proportions of (1) neurology inpatients and consults who have fundoscopy performed as usual care by their neurology teams; (2) pathology detected by neurology using DO in routine clinical practice; (3) pathology detected by blinded assessment of SF videos. Additionally, fundus imaging feasibility and patient experience parameters were assessed.

Analysis

The study is reported following the Standards for Reporting of Diagnostic Accuracy Studies [16]. Statistical analysis was performed using R Studio (R Foundation for Statistical Computing, http://www.R-project.org). The patient was the unit of analysis for prevalence outcomes whilst each eye was the unit of analysis for diagnostic accuracy outcomes. Means and standard deviations (±SDs) are reported for continuous, normally distributed data, with medians and interquartile ranges (IQRs) reported otherwise. Proportions were calculated with 95% confidence intervals (CIs) by the exact binomial method.

Where NMFP was performed in the ED, patients were included in the primary analysis of fundus pathology prevalence estimates but excluded from secondary outcomes, as NMFP was considered likely to bias DO performance by the treating team. Screening failures with any device, including where no DO was performed, were included in diagnostic accuracy assessments on an intention to screen basis.

Inter-rater agreement was calculated using observed agreement and Cohen's kappa. Agreement for neurologically significant pathology was calculated collating primarily ophthalmic pathologies and anatomical variation as normal, as neurologists would not be expected to detect primarily ophthalmic, chronic conditions without neurological relevance.

Sample size

To determine the specificity of SF compared with NMFP with a 10% width to the 95% CI at 5% α, a cohort of 16 participants would be required based on an estimated specificity of 0.92 from previous studies [17].

RESULTS

Amongst 87 screened patients, 79 (91%) eligible patients were enrolled (Figure 1). Three patients had NMFP in the ED prior to enrolment and were included for prevalence outcomes but excluded from other analyses due to diagnostic review bias. Five patients declined participation. Demographics and presentations are recorded in Table 1. Overall, the portable NMFP captured photographs for 87% (66/76) of screened patients compared with 99% (75/76) of those screened with SF (paired sample t test, $p < 0.001$). Neither NMFP nor SF could be performed for one patient due to difficulty opening their eyes from photophobia and epiphora.

Consensus review found that the period prevalence of neurologically relevant pathology was 11/78 (14.1%; 95% CI 7.3%–23.8%) patients (Table 2). Other chronic but potentially vision-threatening ophthalmic findings were identified in 15/78 (18.9%) patients (Table 3). Thus the total prevalence of ocular pathology was 26/78 (33.3%).

The observed agreement and sensitivities of grading using the different modalities are demonstrated in Table 4. A neurologist graded the NMFP images and both a neurology registrar and an ophthalmologist graded the SF images. Excluding patients who had NMFP in the ED, 5/76 (6.6%) received both DO and NMFP/SF fundoscopic examination. Standard practice by neurologists using or obviating DO had a sensitivity for neurologically significant fundus pathology of 0/11 (0%) and detected 2/75 normal fundi (specificity 2.7%). Final consensus arbitration was required for 14 eyes of 10 (13.2%) patients (Appendix S1).

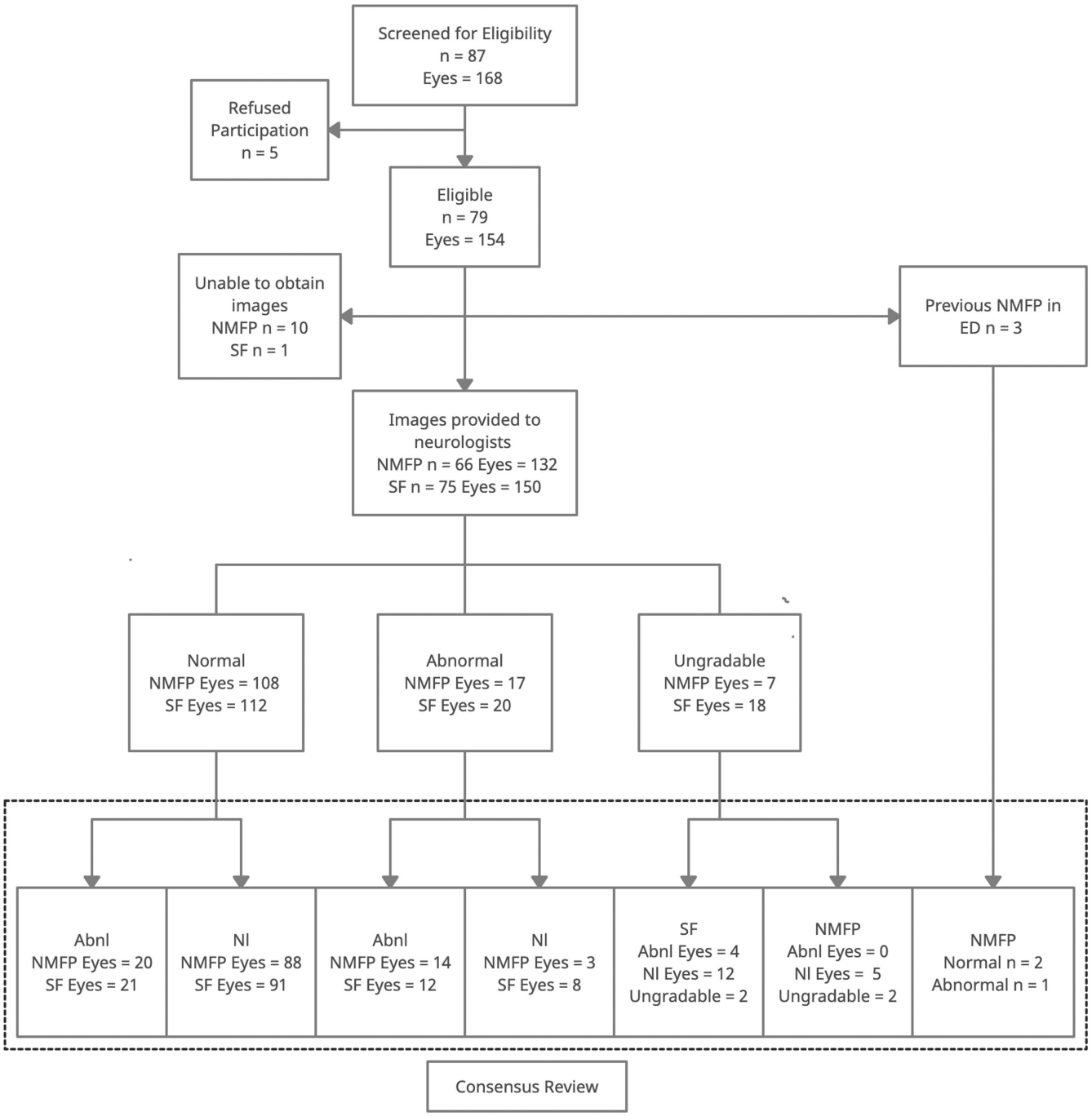

FIGURE 1 Standards for reporting of diagnostic accuracy studies (STARD) flowchart of patients through the prospective study (Abnl, abnormal; Nl, normal)

Image quality was greater for NMFP than for SF, and for the optic disc compared to the macula (Table 4 and Figure 2). A McNemar test showed no systematic difference in graders' certainty of optic disc interpretation with NMFP and SF ($p = 0.066$) (Table 5); however, the certainty of optic disc interpretation was significantly greater than macula certainty for both NMFP ($p = 0.049$) and SF ($p < 0.001$) (Table 3).

A high quality SF video of each eye was selected for analysis. Amongst 76 enrolled patients, images of some clinical value (grade ≥2) were obtained in 130/152 (86%) eyes using NMFP and in 147/152 (97%) eyes using SF videos. 'Overexposure' of NMFP was reported by graders for 15% of patients (10/66) with low quality images. Barriers to ideal imaging were reported in 35 cases (46%), including inability to switch off room lights in 37% and issues of patient compliance or ocular pathology.

A paired sample *t* test demonstrated that the time to capture an image using SF (mean 1.10 min; 95% CI 0.95–1.25) was significantly faster than for NMFP (2.25 min; 95% CI 2.00–2.50) ($p < 0.001$). The average number of image capture attempts per eye was 2.5 using NMFP and 1.7 using SF (paired sample *t* test, $p < 0.001$). Fundus images were rated 'easy/feasible to obtain" for 92.1% of SF images,

TABLE 1 Patient demographics and presentations

Demographics	Number/percentage
Female	38 (48%)
Median age (interquartile range, IQR)	54.5 years (IQR 39.8–69.0)
General neurology inpatients	62 (78.5%)
Neurology day admissions for medication infusions	6 (7.6%)
Consultations requested from other teams	11 (13.9%)
Presentations	
Seizures/epilepsy	16 (20.2%)
Cerebrovascular disease	10 (12.7%)
Multiple sclerosis	5 (6.3%)
Weakness	4 (5.1%)
Headaches	3 (3.8%)
Visual disturbance	2 (2.5%)
Hypertension	2 (2.5%)
Other: alcoholic neuropathy, myasthenia gravis, multiple system atrophy, autonomic neuropathy and viral meningitis etc.	1 (1.2%) each

TABLE 2 Patients with neurologically relevant fundus pathology

Fundus pathology	Number of patients	Neurological/discharge diagnoses
Optic disc pallor	7	Myasthenia gravis, multiple sclerosis (2), transient ischaemic attack, seizures (2), iatrogenic subclavian artery dissection
Hypertensive retinopathy	1	Autonomic neuropathy
Optic disc swelling	3	Cerebral infarct, cavernous sinus soft tissue thickening leading to cranial nerve compression, hypertension related headaches

TABLE 3 Patients with chronic, potentially vision-threatening, ophthalmic conditions detected by review of non-mydriatic fundus photographs

Primarily ophthalmic pathology	Number of patients
Diabetic retinopathy (venous beading, hard exudates)	2
Choroidal naevi	2
Macular drusen	2
Macular atrophy/pigmentary changes	3
Anatomical variation (small crowded disc with anomalous vessel branching (2), inferonasal disc margin elevation, disc tilt)	4
Peripapillary atrophy and myopic changes	2

significantly more than for NMFP (74.9%; paired sample *t* test, $p < 0.001$). The mean rating by patients for comfort during the examination on a 10-point sliding bar scale (10 = very comfortable) was 8 (95% CI 7.55–8.45) for NMFP, significantly lower than for SF at 9.2 (95% CI 8.97–9.43) (repeated measures ANOVA, $N = 76$, $F = 34.87$, $p < 0.001$).

DISCUSSION

A prospective surveillance and randomized crossover diagnostic accuracy study of SF and portable NFMP was conducted, compared with routine DO examination, amongst neurology inpatients. A 14.1% (95% CI 7.3%–23.8%) prevalence of neurologically relevant pathology was detected, yet DO was neglected by the neurology team in 71 of 76 consecutively enrolled inpatients, with a resultant sensitivity of 0% and specificity of 2.7%. It was found that observed agreement with consensus grading was slightly lower for SF than NMFP, and that undilated SF was not clinically useful for macula imaging. Both SF and NMFP were feasible and well tolerated by patients.

Prevalence of fundus pathology

Eleven of 78 enrolled neurology inpatients had neurologically significant pathology including seven optic disc pallor, one hypertensive retinopathy and three with optic disc swelling. These findings are clinically significant; for example, disc pallor in two multiple sclerosis

TABLE 4 Observed agreement and sensitivity of modalities for neurologically relevant pathology

Specialty and modality	Observed agreement vs. consensus	Sensitivity detecting neurological pathology
Neurologist grading NMFP	124/132 (94%) (kappa = 0.53, 95% CI 0.24–0.81)	5/11 (45%)
Ophthalmologist grading SF	139/150 (92%) (kappa = 0.38, 95% CI 0.10–0.67)	4/10 (40%)
Neurology registrar grading SF	136/150 (91%) (kappa = 0.31, 95% CI 0.04–0.58)	3/10 (30%)

Abbreviations: CI, confidence interval; NMFP, non-mydriatic fundus photography; SF, smartphone fundoscopy.

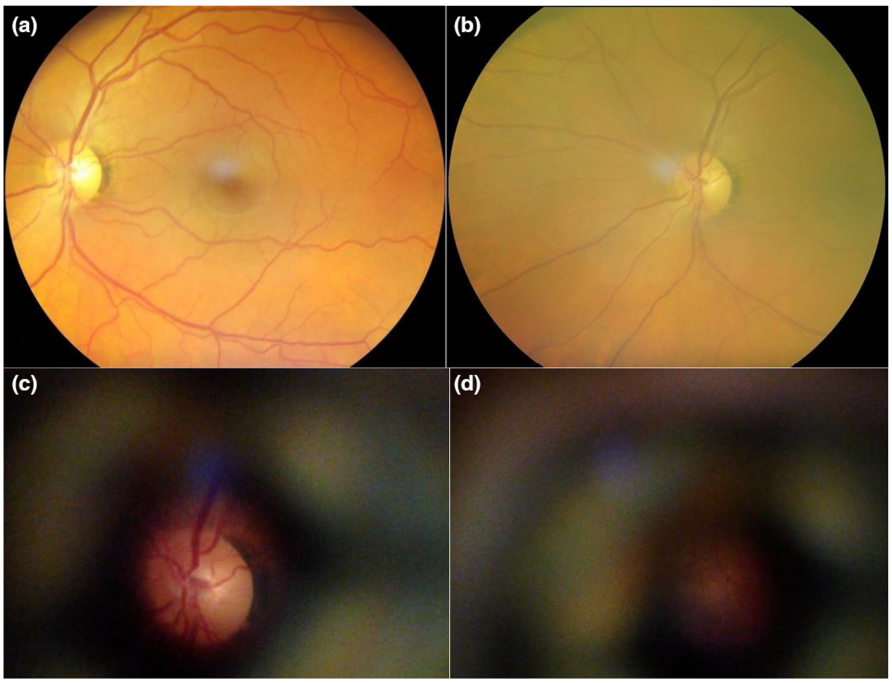

FIGURE 2 Representative fundus images from the left eye of one participant. (a) Macula centred non-mydriatic fundus photograph; (b) optic disc centred non-mydriatic fundus photograph; (c) optic disc centred smartphone fundoscopy video snapshot; (d) macula centred smartphone fundoscopy video snapshot

patients may indicate previous clinical or subclinical optic neuritis, potentially fulfilling criteria for dissemination in time and location which may impact management. In other cases such as myasthenia gravis or iatrogenic subclavian artery dissection, where disc pallor is less likely to be related to the condition, further investigation and correlation with the clinical picture is warranted.

To our knowledge, this is the first prospective study of the prevalence of fundal pathology amongst neurology inpatients. Reported rates of fundal pathology amongst ED presentations warranting fundoscopy range from 10% to 16% in metropolitan and regional settings [1, 2, 8, 15, 18]. A review of the FOTO-ED studies found optic disc swelling in 2.6% of 1408 patients presenting with headache, neurological deficit, hypertension or visual disturbance, and the initial diagnosis was made on the basis of NMFP in 57% of these cases [19]. The clinical importance of fundus findings was demonstrated in a prospective study which found that providing fundus photographs to ED physicians after enforced DO performance changed management for 39% (95% CI 31%–48%) of patients [8]. Furthermore, a 3-year follow-up of 702 FOTO-ED patients found abnormal fundus photographs were associated with an increased rate of all-cause mortality (hazard ratio 4.10; 95% CI 1.5–12.4) and subsequent hospital admission (hazard ratio 2.04; 95% CI 1.5–3.0) [20]. However, not only is it important to detect fundus abnormalities; recognizing a normal retina and optic disc can help avoid unnecessary referrals and investigations [5, 8]. It was found that chronic, potentially vision-threatening pathology was present in 19% of our patients. This is comparable to the rate of incidental detection using NMFP amongst ED presentations [1, 8]. Whilst beyond the usual remit of neurology, detecting preventable vision loss provides additional public health value, supporting the use of NMFP. These findings reveal a clinically significant prevalence of fundus pathology

TABLE 5 Image quality certainty gradings for the optic disc and macula (McNemar test)

	Optic disc 'certain'	Macula 'certain'	Significance
Non-mydriatic fundus photography	96/132	83/132	$p = 0.049$
Smartphone fundoscopy	82/132	0/132	$p < 0.001$
Significance	$p = 0.066$	$p < 0.001$	

amongst neurology inpatients and reinforce the importance of a reliable fundus examination within a standard neurology examination.

Fundoscopy performance rate

It is generally acknowledged that neurologists should be able to assess optic nerve appearances, vascular architecture, the peripapillary retina and macular changes [11, 21]. It was found that fundoscopy was only performed for 6.6% of neurology inpatients and all cases were performed by a registrar. A retrospective review of inpatients with headache, altered mental status or visual disturbance found fundoscopy was documented during examination by neurology in 46%, compared to 13% by internal medicine and 11% by ED physicians [22]. Similarly, the FOTO-ED study found that ED physicians only examined the fundus of 14% of patients even though they knew a trial of fundoscopy was under way [23]. Various barriers limit DO performance, including a lack of confidence in the skill, insufficient time, senior discouragement, lack of equipment and believing the test to be futile [24, 25]. Further, given time constraints, neurologists almost never pharmacologically dilate the pupil and in this context DO, even in the most skilled hands, only gives a limited 5° field of view. A survey of foundation-year doctors in two UK hospitals found <20% were confident identifying papilloedema [26], whilst medical trainees reported fundoscopy to be amongst their least confident examinations [27]. In the light of the limitations of DO, it is disappointing but not surprising that even neurologists omit fundoscopy. Some authors posit the underperformance of fundoscopy as heralding a broader decline in physical examination skills within a health system which sees doctors spending much more time on administrative, computer-related tasks than with their patients [28–30].

Diagnostic accuracy

Routine examination by the neurology team using or omitting DO had a sensitivity of 0%. The sensitivity of telemedicine neurologist review of NMFP was 45% (agreement 94%; kappa 0.53), whilst the sensitivity of telemedicine SF grading by an ophthalmologist was only 40% (agreement 92%, kappa 0.38) and 30% by a neurology registrar (agreement 91%, kappa 0.31). Whilst diagnostic agreement was high, some neurologically relevant pathology was missed using either modality, and discrepancies in categorization of abnormal findings (e.g., optic disc swelling vs. pallor) between initial review and the clinical reference standard probably contributed to weaker correlations. NMFP has been shown to be much more sensitive than DO in diverse settings including amongst medical students, ED physicians and ophthalmologists [5, 8, 25]. Likewise, the accuracy of SF is greater than DO amongst medical students [12, 13]. Telemedicine review of portable NMFP images by four neuro-ophthalmologists for the detection of optic disc oedema in an outpatient setting had a sensitivity of 72%–92% and specificity of 82%–95% compared with slit lamp examination [31].

It was also found that undilated SF was unreliable for macula imaging, with graders reporting uncertainty in all cases. Alongside a reduced field of view (Figure 2), this probably contributed to the low agreement between SF and our reference standard (kappa 0.23–0.33) as it was difficult to see pathology outside of the optic disc which was detected via NMFP.

Most SF devices are designed for use with mydriasis [32], aiming to achieve clinically useful images of the optic disc and macular regions [33]. Cup:disc ratio assessments were reliable without mydriasis using the PanOptic iExaminer SF [34]. SF image quality and assessments of cup:disc ratio and optic disc pallor improve significantly with dilation [35]. Nevertheless, routine dilation of inpatients on a ward round is impractical. Whilst undilated images can be achieved, they are generally of lower quality, and few devices claim to image the retinal periphery adequately [36, 37]. This was significant in our study in that cases of hypertensive retinopathy and optic disc swelling were missed using undilated SF. However, given that the majority of neurologically relevant pathology is located at the disc, and the SF field of view still exceeds that of DO, there is probably still clinical value in utilizing SF devices. The video capability of using SF had the additional benefit of documenting spontaneous venous pulsations to confirm normal intracranial pressure [38].

Interpretation of fundoscopy remains a challenge once an effective fundal view is obtained. However, both SF and NMFP create a digital image which is amenable to diagnostic support from telemedicine collegiate consultation and emerging clinical applications of artificial intelligence [10].

Feasibility

It was found that both SF and NMFP were feasible to employ amongst neurology inpatients; however, SF had a lower rate of screening failure (1% vs. 13%, $p < 0.001$), a shorter examination time (1.10 vs. 2.25 min, $p < 0.001$) and a slightly higher patient comfort rating (9.2 vs. 8/10, $p < 0.001$). Both of these devices are handheld and suit examination at the bedside, even amongst unwell, supine patients. Both are used at arm's length, rather than the 2 cm working distance of DO, with probable reductions in infection transmission, especially during a pandemic [39]. They also allowed images and videos to be obtained in a timely fashion without interruption of patient flow.

Patient-reported comfort outcomes were positive for both NMFP and SF, although SF performed significantly better. This difference in discomfort may be due to the lower intensity light of SF and the technical requirement that the patient need only focus in the distance. With NMFP, the patient must focus on separate fixation targets to obtain macula and optic disc centred images, which may be more confusing for some patients. Using the RetinaVue 100 autofocus setting, NMFP images can be obtained only when alignment is achieved, which probably contributed to the longer examination time compared to SF.

Given the tests were done on hospital wards, room lights could not be switched off for 37% of patients, with resulting pupillary miosis. An additional 9% of patients had other barriers to ideal photograph quality including difficulties complying with examination instructions and obscuring pathology such as cataracts or minimally reactive pupils. Poor NMFP image quality was associated with reported photograph 'overexposure' in 15% of patients which made assessment of disc pallor challenging. These factors led to a 1% failure rate for SF compared to 13% with NMFP. These failure rates compare favourably with a meta-analysis of telemedicine diabetic screening programmes which reported a failure rate of 19% (±10% SD) using tabletop NMFP [40]. Similarly, a pilot study of a portable NMFP achieved successful fundus examination in 93% of 60 neurological emergency presentations compared with 38% using traditional DO [41]. The PanOptic iExaminer SF was shown to be effective in obtaining clinically adequate fundus images amongst 91% of 2–18-year-old children in the ED, but achieved only 16% amongst children 0–2 years old [42]. Likewise, the D-EYE demonstrated good diagnostic agreement with the gold standard amongst a paediatric population [17].

The table-mounted, conventional fundus cameras in most ophthalmology clinics generate high quality images but are large, immobile, expensive devices which require technical expertise to operate [9]. Fundus examination is part of the core business of neurology, but examining inpatients across diverse hospital wards requires more portable, less costly devices which are easier to operate, especially amongst unwell inpatients. Whilst SF image quality remains lower than fundus photography [33], the images obtained by novice examiners approach the quality of the reference standards in more recent studies [12, 43, 44].

The medical student taking photographs and videos in our study had only 1 h of training to use both devices. This suggests fundal images could be obtained easily by junior doctors, clinic nurses or other allied health staff, possibly at the time of obtaining vital signs. NMFP by ED nurse practitioners was feasible after only 30 min of training in diverse settings [1, 23], and junior medical students have found SF easier to use and more useful than DO [44, 45]. Additionally, a study found no difference in image quality when comparing images obtained by a trained ophthalmic photographer (20 years of experience) with non-professional photographers (one with 2 days and one with 1 h of training) [46]. With any new device, there is a user learning curve, although encouragingly for NMFP as opposed to DO it appears that high quality images can be obtained even with limited training and experience. When incorporating new technology and research into public hospital and community settings, significant barriers include cost, compatibility with existing technology and information systems, accessibility, and clinician practice patterns [47, 48]. Smartphone technology has the potential to overcome these barriers, as it can readily be incorporated into existing medical records and directly shared via secure clinical image communication applications for rapid telehealth consultation.

Limitations

The emergence of the COVID-19 pandemic halted this study prior to planned commencement at a second site. Nonetheless a reasonable estimate of the prevalence of neurologically relevant pathology amongst neurology inpatients is provided. Larger prevalence and diagnostic accuracy studies are warranted to determine the generalizability of our findings. Neurology doctors in our study were aware of the trial, potentially inflating the rate of fundoscopy via the Hawthorne effect [49]. Our diagnostic accuracy results are limited by the 13% failure rate of NMFP and the inability to review screening failure patients in clinics due to the pandemic. Future studies could ensure mydriasis is available for patients where non-mydriatic photographs are not achievable, as this improves screening success [50].

Despite our limitations, this study demonstrates that it is possible to obtain clinically useful fundus photographs for neurology inpatients using both NMFP and SF. With continually developing technology, it will be possible to capture better quality images. Further translational studies are required to characterize the cost effectiveness and clinical impact of better fundoscopy technologies and interpretation on outcomes for patients.

CONCLUSION

Our study found a high prevalence of fundus pathology amongst neurology inpatients. This pathology was missed by standard DO techniques. Portable NMFP screening appears more accurate than SF, whilst both are diagnostically superior to routine fundoscopic practice, well tolerated by patients and can feasibly be incorporated into routine neurology inpatient care.

AUTHOR CONTRIBUTIONS

George He: Data curation (lead); formal analysis (lead); investigation (equal); project administration (equal); visualization (lead); writing – original draft (lead); writing – review and editing (equal). **Hamish Dunn:** Conceptualization (lead); formal analysis (equal); investigation (equal); methodology (lead); project administration (lead); resources (lead); supervision (lead); validation (lead); visualization (lead); writing – review and editing (lead). **Kate Ahmad:** Conceptualization (supporting); data curation (supporting); investigation (supporting); methodology (supporting); writing – review and editing (supporting). **Eloise Watson:** Data curation (supporting); investigation (supporting). **Andrew Henderson:** Conceptualization (supporting); data curation (supporting); investigation (supporting); project administration (supporting); resources (supporting); supervision (supporting); writing – review and editing (supporting). **Dominique Tynan:** Writing – review and editing (supporting). **John Leaney:** Data curation (supporting); validation (supporting). **Andrew White:** Conceptualization (supporting); supervision (supporting); writing – review and editing (supporting). **Alex Hewitt:** Supervision (supporting); writing – review and editing (supporting). **Clare Fraser:** Conceptualization (supporting); investigation

(equal); supervision (supporting); validation (equal); writing – review and editing (supporting).

ACKNOWLEDGEMENT

Open access publishing facilitated by The University of Sydney, as part of the Wiley - The University of Sydney agreement via the Council of Australian University Librarians.

CONFLICT OF INTEREST

The Westmead Hospital Department of Ophthalmology has previously received funding for the running of an unrelated clinical trial from Welch Allyn/Hill Rom. The study authors received no personal funding, and Welch Allyn/Hill Rom had no involvement in the study design, analysis or decision to publish.

DATA AVAILABILITY STATEMENT

Non-identifying data are available from the corresponding author on reasonable request. Data have not been placed in a repository due to the risk of re-identification of participants.

ETHICAL APPROVAL

WSLHD Human Research Ethics Committee; 18/01/2019; Ethics approval number AU RED HREC/19/WMEAD/3.

ORCID

George He https://orcid.org/0000-0003-0661-0005
Hamish P. Dunn https://orcid.org/0000-0002-4632-9712
Eloise Watson https://orcid.org/0000-0002-1769-9722
Clare L. Fraser https://orcid.org/0000-0002-0379-7743

REFERENCES

1. Dunn HP, Teo KZ, Smyth JW, et al. Using non-mydriatic fundus photography to detect fundus pathology in Australian metropolitan emergency departments: a prospective prevalence and diagnostic accuracy study. *Emerg Med Australas*. 2020;33(2):302-309. doi:10.1111/1742-6723.13619
2. Bruce BB, Thulasi P, Fraser CL, et al. Diagnostic accuracy and use of nonmydriatic ocular fundus photography by emergency physicians: phase II of the FOTO-ED study. *Ann Emerg Med*. 2013;62(1):28-33.e1.
3. Dalay S, Umar F, Saeed S. Fundoscopy: a reflection upon medical training? *Clin Teach*. 2013;10(2):103-106.
4. Roberts E, Morgan R, King D, Clerkin L. Funduscopy: a forgotten art? *Postgrad Med J*. 1999;75(883):282-284.
5. Biousse V, Bruce BB, Newman NJ. Ophthalmoscopy in the 21st century: the 2017 H. Houston Merritt lecture. *Neurology*. 2018;90(4):167-175.
6. Thulasi P, Fraser CL, Biousse V, Wright DW, Newman NJ, Bruce BB. Nonmydriatic ocular fundus photography among headache patients in an emergency department. *Neurology*. 2013;80(5):432-437.
7. Schulz C, Moore J, Hassan D, Tamsett E, Smith CF. Addressing the 'forgotten art of fundoscopy': evaluation of a novel teaching ophthalmoscope. *Eye*. 2016;30(3):375-384.
8. Dunn HP, Browning SD, Thomson D, et al. Impact on patient management of non-mydriatic fundus photography compared to direct ophthalmoscopy in a regional Australian emergency department. *Emerg Med Australas*. 2021;34(2):186-193. doi:10.1111/1742-6723.13845
9. Panwar N, Huang P, Lee J, et al. Fundus photography in the 21st century—a review of recent technological advances and their implications for worldwide healthcare. *Telemed J E Health*. 2016;22(3):198-208.
10. Milea D, Najjar RP, Zhubo J, et al. Artificial intelligence to detect papilledema from ocular fundus photographs. *N Engl J Med*. 2020;382(18):1687-1695.
11. Rodenbeck SJ, Mackay DD. Examining the ocular fundus in neurology. *Curr Opin Neurol*. 2019;32(1):105-110.
12. Kim Y, Chao DL. Comparison of smartphone ophthalmoscopy vs conventional direct ophthalmoscopy as a teaching tool for medical students: the COSMOS study. *Clin Ophthalmol*. 2019;13:391-401.
13. Dunn HP, Marks S, Teo KZ, Dunn SM, Healey PR, White AJ. eFOCUS 2: a randomised crossover trial of smartphone fundoscopy and direct ophthalmoscopy aiming to improve optic disc interpretation by medical students with e-learning support. *Clin Experiment Ophthalmol*. 2021;49(7):704-713. doi:10.1111/ceo.13977
14. Wright A. REDCap: a tool for the electronic capture of research data. *J Electron Resour Med Libr*. 2016;13(4):197-201.
15. Lamirel C, Bruce BB, Wright DW, Delaney KP, Newman NJ, Biousse V. Quality of nonmydriatic digital fundus photography obtained by nurse practitioners in the emergency department: the FOTO-ED study. *Ophthalmology*. 2012;119(3):617-624.
16. Cohen JF, Korevaar DA, Altman DG, et al. STARD 2015 guidelines for reporting diagnostic accuracy studies: explanation and elaboration. *BMJ Open*. 2016;6(11):e012799.
17. Dickson D, Fouzdar-Jain S, MacDonald C, et al. Comparison study of funduscopic exam of pediatric patients using the D-EYE method and conventional indirect ophthalmoscopic methods. *Open J Ophthal*. 2017;7(3):8.
18. Teismann N, Neilson J, Keenan J. Quality and feasibility of automated digital retinal imaging in the emergency department. *J Emerg Med*. 2019;58(1):18-24. doi:10.1016/j.jemermed.2019.08.034
19. Sachdeva V, Vasseneix C, Hage R, et al. Optic nerve head edema among patients presenting to the emergency department. *Neurology*. 2018;90(5):e373-e379.
20. Bruce BB. Implementation and utility of non-mydriatic fundus photography in the emergency department. 2014. https://search.proquest.com/openview/d4f51a7ec55661c58a821050b14889dd/1?pq-origsite=gscholar&cbl=18750. Accessed October 10, 2021.
21. Kedar S, Digre KB, Biousse V, NANOS curriculum committee. The 2020 update to North American Neuro-Ophthalmology Society's (NANOS) neuro-ophthalmology curriculum. *J Neuroophthalmol*. 2020;40(3):e29-e30.
22. Golombievski E, Doerrler MW, Ruland SD, McCoyd MA, Biller J. Frequency of direct funduscopy upon initial encounters for patients with headaches, altered mental status, and visual changes: a pilot study. *Front Neurol*. 2015;6:233.
23. Bruce BB, Lamirel C, Biousse V, et al. Feasibility of nonmydriatic ocular fundus photography in the emergency department: phase I of the FOTO-ED study. *Acad Emerg Med*. 2011;18(9):928-933.
24. Gupta RR, Lam WC. Medical students' self-confidence in performing direct ophthalmoscopy in clinical training. *Can J Ophthalmol*. 2006;41(2):169-174.
25. Mackay DD, Garza PS, Bruce BB, et al. Teaching ophthalmoscopy to medical students (TOTeMS) II: a one-year retention study. *Am J Ophthalmol*. 2014;157(3):747-748.
26. Nicholl DJ, Yap CP, Cahill V, Appleton J, Willetts E, Sturman S. The TOS study: can we use our patients to help improve clinical assessment? *J R Coll Physicians Edinb*. 2012;42(4):306-310.
27. Wu EH, Fagan MJ, Reinert SE, Diaz JA. Self-confidence in and perceived utility of the physical examination: a comparison of medical students, residents, and faculty internists. *J Gen Intern Med*. 2007;22(12):1725-1730.

28. Block L, Habicht R, Wu AW, et al. In the wake of the 2003 and 2011 duty hours regulations, how do internal medicine interns spend their time? *J Gen Intern Med*. 2013;28(8):1042-1047.
29. Verghese A, Charlton B, Kassirer JP, Ramsey M, Ioannidis JPA. Inadequacies of physical examination as a cause of medical errors and adverse events: a collection of vignettes. *Am J Med*. 2015;128(12):1322-1324.e3.
30. Mackay DD, Garza PS, Bruce BB, Newman NJ, Biousse V. The demise of direct ophthalmoscopy: a modern clinical challenge. *Neurol Clin Pract*. 2015;5(2):150-157.
31. Bursztyn L, Woodward MA, Cornblath WT, et al. Accuracy and reliability of a handheld, nonmydriatic fundus camera for the remote detection of optic disc edema. *Telemed J E Health*. 2018;24(5):344-350.
32. Adam MK, Brady CJ, Flowers AM, et al. Quality and diagnostic utility of mydriatic smartphone photography: the smartphone ophthalmoscopy reliability trial. *Ophthalmic Surg Lasers Imaging Retina*. 2015;46(6):631-637.
33. Wintergerst MWM, Jansen LG, Holz FG, Finger RP. Smartphone-based fundus imaging-where are we now? *Asia Pac J Ophthalmol (Phila)*. 2020;9(4):308-314.
34. LaMonica LC, Bhardwaj MK, Hawley NL, et al. Remote screening for optic nerve cupping using smartphone-based nonmydriatic fundus photography. *Journal of Glaucoma*. 2021;30(1):58-60. doi:10.1097/ijg.0000000000001680
35. Wintergerst MWM, Brinkmann CK, Holz FG, Finger RP. Undilated versus dilated monoscopic smartphone-based fundus photography for optic nerve head evaluation. *Sci Rep*. 2018;8(1):10228.
36. Kim TN, Myers F, Reber C, et al. A smartphone-based tool for rapid, portable, and automated wide-field retinal imaging. *Transl Vis Sci Technol*. 2018;7(5):21.
37. Sharma A, Subramaniam SD, Ramachandran KI, Lakshmikanthan C, Krishna S, Sundaramoorthy SK. Smartphone-based fundus camera device (MII ret cam) and technique with ability to image peripheral retina. *Eur J Ophthalmol*. 2016;26(2):142-144.
38. Jacks AS, Miller NR. Spontaneous retinal venous pulsation: aetiology and significance. *J Neurol Neurosurg Psychiatry*. 2003;74(1):7-9.
39. Lai THT, Tang EWH, Chau SKY, Fung KSC, Li KKW. Stepping up infection control measures in ophthalmology during the novel coronavirus outbreak: an experience from Hong Kong. *Graefes Arch Clin Exp Ophthalmol*. 2020;258(5):1049-1055.
40. Horton MB, Silva PS, Cavallerano JD, Aiello LP. Clinical components of telemedicine programs for diabetic retinopathy. *Curr Diab Rep*. 2016;16(12):129.
41. Alm M, Hautala N, Bloigu R, Huhtakangas J. Comparison of optic disc evaluation methods in neurology emergency patients. *Acta Neurol Scand*. 2019;140(6):449-451.
42. Day LM, Wang SX, Huang CJ. Nonmydriatic fundoscopic imaging using the PanOptic iExaminer system in the pediatric emergency department. *Acad Emerg Med*. 2017;24(5):587-594.
43. Wintergerst MWM, Petrak M, Li JQ, et al. Non-contact smartphone-based fundus imaging compared to conventional fundus imaging: a low-cost alternative for retinopathy of prematurity screening and documentation. *Sci Rep*. 2019;9(1):19711.
44. Mamtora S, Sandinha MT, Ajith A, Song A, Steel DHW. Smart phone ophthalmoscopy: a potential replacement for the direct ophthalmoscope. *Eye*. 2018;32(11):1766-1771.
45. Dunn HP, Kang CJ, Marks S, et al. Perceived usefulness and ease of use of fundoscopy by medical students: a randomised crossover trial of six technologies (eFOCUS 1). *BMC Med Educ*. 2021;21(1):41.
46. Maberley D, Morris A, Hay D, Chang A, Hall L, Mandava N. A comparison of digital retinal image quality among photographers with different levels of training using a non-mydriatic fundus camera. *Ophthalmic Epidemiol*. 2004;11:191-197.
47. Das AV, Mididoddi S, Kammari P, et al. App-based tele ophthalmology: a novel method of rural eye care delivery connecting tertiary eye care center and vision centers in India. *Int J Telemed Appl*. 2019;2019:8107064.
48. Akkara JD, Kuriakose A. Commentary: teleophthalmology and electronic medical records: weighing the pros and cons of unavoidable progress. *Indian J Ophthalmol*. 2020;68(2):367-368.
49. McCambridge J, Witton J, Elbourne DR. Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. *J Clin Epidemiol*. 2014;67(3):267-277.
50. Aptel F, Denis P, Rouberol F, Thivolet C. Screening of diabetic retinopathy: effect of field number and mydriasis on sensitivity and specificity of digital fundus photography. *Diabetes Metab*. 2008;34(3):290-293.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: He G, Dunn HP, Ahmad KE, et al. Fundoscopy use in neurology departments and the utility of smartphone photography: a prospective prevalence and crossover diagnostic accuracy study amongst neurology inpatients. *Eur J Neurol*. 2022;29:2463-2472. doi: 10.1111/ene.15390