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

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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
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.

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
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 consultants 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).
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 $\geq 2$) 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.
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, \( N = 76, F = 34.87, p < 0.001 \)).
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 0.24–0.81) of patients [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].

![Image](image1.png)

![Image](image2.png)

**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

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

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

Significance: p = 0.066 p < 0.001

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.
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).
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(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.

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