# Comparison of Smartphone Ophthalmoscopy With Slit-Lamp Biomicroscopy for Grading Vertical Cup-to-Disc Ratio

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**Purpose of the Study:** The purpose of the study was to determine the agreement between smartphone ophthalmoscopy and slit-lamp indirect biomicroscopy when assessing vertical cup-to-disc ratios (VCDRs).

**Materials and Methods:** This was a clinical-based, prospective, comparative instrument study performed in 110 patients with ocular hypertension (OH) or primary open angle glaucoma (POAG). Patients underwent estimation of VCDR by undilated smartphone ophthalmoscopy and slit-lamp biomicroscopy by 2 masked glaucoma specialists.

**Results:** The differences between the mean VCDR estimations obtained by each techniques were not statistically significant. Overall exact agreement between the 2 modalities was found in 21 of 29 eyes (72.4%; simple $\kappa = 0.63$, confidence interval, 0.52-0.73, $P < 0.001$) in POAG patients and in 52 of 78 eyes (66.7%) in OH patients. The optic nerve head was not gradable with smartphone ophthalmoscopy in 1 eye with POAG and in 2 eyes with OH because of media opacities and/or small pupil diameter.

**Conclusions:** Smartphone ophthalmoscopy showed substantial agreement with slit-lamp examination for the estimation of the VCDR. The ubiquitous diffusion of the smartphones, together with their connectivity and portability features, enables an extensive benefit for this technology to be used in glaucoma screening, especially in low-resource settings.

**Key Words:** cup-to-disc ratio, glaucoma, indirect biomicroscopy, smartphone ophthalmoscopy

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Glaucoma is a leading cause of visual impairment and blindness and affects ~60.5 million people worldwide. However, because the disease remains largely asymptomatic as it progresses, researchers estimate that >50% of individuals are unaware of diagnosis until glaucoma reaches advanced stages.[1] Particularly, individuals living in rural or remote areas have limited access to optometrists or ophthalmologists, hence to glaucoma tests. Widespread screening is therefore critical for early diagnosis, treatment, and limiting the incidence of glaucoma-associated blindness.

The pervasive diffusion of smartphones might represent a resource for glaucoma screening, thanks to the recent development of dedicated ophthalmic software and hardware. Indeed, smartphones are capable of accurate and repeatable visual acuity measurements[2] and can be reliably used as ophthalmoscopes with the help of very portable optical devices.[3,4] Certainly, ophthalmoscopic examination of the optic nerve head (ONH) is crucial in the diagnosis and management of glaucomatous patients. Particularly, ophthalmoscopic estimation of the vertical cup-to-disc ratio (VCDR) of the ONH is important in the screening and follow-up of patients with glaucoma,[5] and has been found to correlate with visual field indexes.[6]

The purpose of this study was to validate the efficacy of smartphone ophthalmoscopy to screen for glaucoma in the population. We compared the ability of smartphone ophthalmoscopy with that of undilated retinal biomicroscopy to grade the VCDR of the optic disc.

## MATERIALS AND METHODS

### Study Design

This was a prospective, clinic-based, comparative study of suspicious glaucomatous eyes. This study was conducted in the Ophthalmic Department of Brescia University Hospital, according to the ethical principles of the Declaration of Helsinki. The Institutional Review Board of the "Spedali Civili di Brescia" Hospital approved the study protocol (registered with clinicaltrials.gov, identifier NCT02520674). All study participants provided written informed consent.

Overall, 110 patients with either ocular hypertension or primary open angle glaucoma (POAG) underwent undilated retinal smartphone ophthalmoscopy by a glaucoma specialist (A.R.) followed by undilated retinal biomicroscopy with a slit-lamp by another glaucoma specialist (R.T.) who was masked to the findings of smartphone ophthalmoscopy. Moreover, all participants underwent a thorough ophthalmic study that included a detailed medical history, intraocular pressure measurement, gonioscopy, and visual field testing using the Humphrey Field Analyzer II (Carl Zeiss Meditech, Dublin, CA) 24-2 program with the Swedish Interactive Threshold Algorithm.

Each ophthalmoscopy procedure was reported using a similar form, in which physicians were asked to report the VCDR, and the presence of disc hemorrhages or localized

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wedge-shaped defects of the retinal nerve fibers. Eyes were excluded if they had substantial media opacity or a refractive error outside the range from −10.00 to + 5.00 D. When both eyes were eligible for the study, 1 eye per patient was randomly selected.

## Smartphone Ophthalmoscopy

Smartphone acquisition procedure has been previously described elsewhere.[4] A glaucoma specialist (A.R.) performed an undilated fundus examination with a D-EYE adapter (D-EYE S.r.l., Padova, Italy; http://www.d-eyecare.com) attached to an iPhone 5s (Apple Inc., Cupertino, CA; Fig. 1). The images were captured on the 8 Mpixel camera's sensor. Thus, direct fundus ophthalmoscopy was performed using live images displayed on the smartphone's screen (a video, Supplemental Digital Content 1, http://links.lww.com/IJG/A87 showing a representative acquisition procedure is attached). With undilated pupil, the device captures a field of view of ∼5 to 8 degrees in a single fundus image, according to pupil diameter, at a distance of ∼1 cm from the patient's eye (Fig. 1). The control of the exposure was automatically set by the smartphone; however, if needed, fine adjustments could be done by the operator.

## Undilated Fundus Biomicroscopy

After smartphone ophthalmoscopy, a glaucoma specialist (R.T.), masked to the findings of smartphone ophthalmoscopy, performed an ONH assessment with a slit-lamp indirect biomicroscopy with a 90 D fundus lens. For this study, undilated fundus slit-lamp biomicroscopy was considered the gold standard technique.

## Analysis of Data

The sample size of 110 patients provided a power approaching 0.99 for a standardized effect of size index of 0.98[7] and an α level of 5%.

Descriptive statistics were used to present the demographic and ocular baseline characteristics. To assess the agreement between smartphone and slit-lamp ophthalmoscopy, the κ-statistic was used. Statistical analyses were performed using SPSS software version 20 (SPSS Inc., Chicago, IL).

# RESULTS

Of the 110 patients who underwent smartphone ophthalmoscopy and slit-lamp biomicroscopy, 50 (45.5%) were male and 30 (27.3%) had glaucoma. The mean age of the examined population was 53.5 ± 11.7 years. Patients' characteristics are reported in Table 1. The ONH was not gradable with smartphone ophthalmoscopy in 1 eye with POAG and in 2 eyes with ocular hypertension because of cataract and/or small pupil diameter.

The differences between the mean VCDR estimations obtained by each technique were not statistically significant (Table 2). An exact agreement was found in 21 of 29 eyes (72.4%) in POAG patients and in 52 of 78 eyes (66.7%) in OH patients.

For all graded eyes (107 eyes), simple κ was 0.63 (95% confidence interval, 0.52-0.73; $P < 0.001$), showing a substantial agreement for the grading of VCDR between slit-lamp biomicroscopy and smartphone ophthalmoscopy. In 79.4% of 1-step disagreements, the severity level was higher by smartphone ophthalmoscopy (Fig. 2). The sensitivity and specificity associated with the comparison are reported

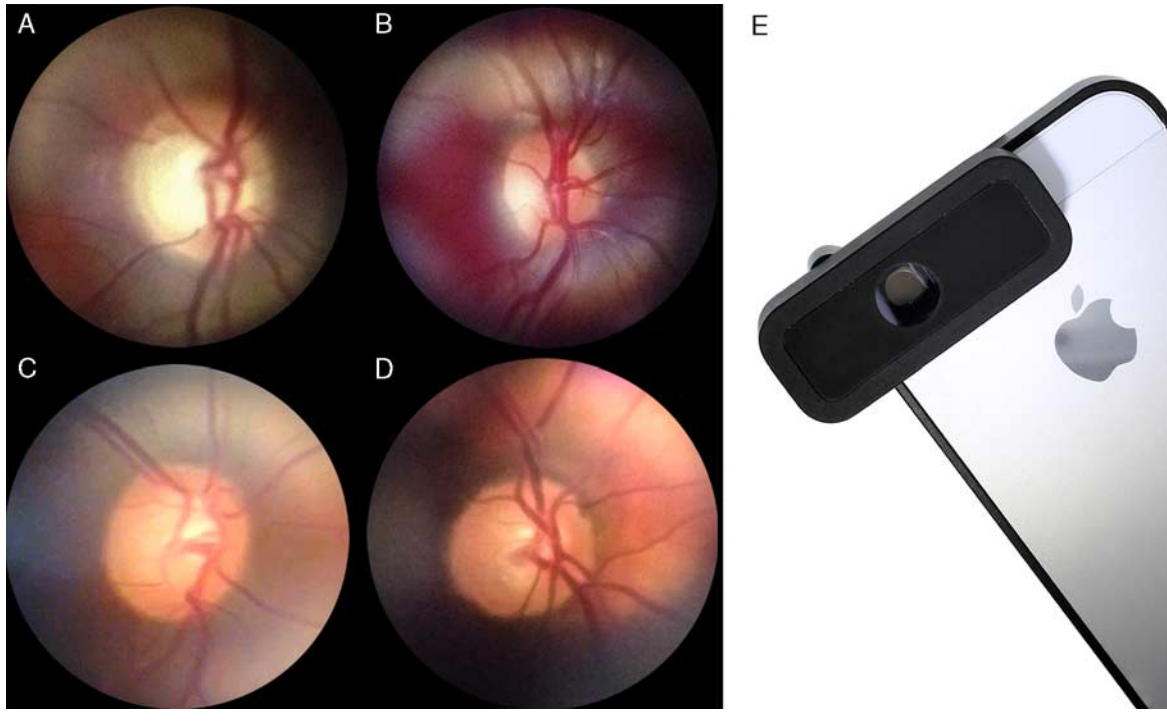


**FIGURE 1.** Representative retinal images of ONH taken with smartphone ophthalmoscopy. A, ONH of a 43-year-old woman graded as 0.6. B, ONH of a 29-year-old man graded as 0.1. C, ONH of a 54-year-old woman graded as 0.6. D, ONH of a 74-year-old man graded as 0.8. E, Depiction of the D-Eye adapter attached to the smartphone used in the study. ONH indicates optic nerve head.

**TABLE 1.** Patients Demographic Characteristics

| | Ocular Hypertension | Glaucoma |
|---|---|---|
| Sex [n (%)] | | |
| Male | 38 (47.5) | 12 (40) |
| Female | 42 (52.5) | 18 (60) |
| Mean ± SD | 50.7 ± 11.4 | 60.9 ± 9.0 |
| Range | 34-74 | 45-74 |
| IOP (mm Hg) | | |
| Mean ± SD | 18.6 ± 2.22 | 16.1 ± 2.03 |
| MD (dB) | | |
| Mean ± SD | −0.74 ± 0.88 | −7.94 ± 5.08 |

IOP indicates intraocular pressure; MD, mean defect.

in Table 3. The reliability showed a very high level of internal consistency, as determined by a Cronbach α of 0.823.

The presence of disc hemorrhages and wedge-shaped defects of the retinal nerve fibers are reported in Table 2.

Mean duration of the smartphone ophthalmoscopy procedure was 12.8 ± 3.2 seconds per eye.

## DISCUSSION

Much enthusiasm surrounds the potential of smartphones as valuable diagnostic instruments in the field of ophthalmology.[4,8] They have been reported to be able to accurately test visual acuity, consistent with published data on the test-retest variability of acuities measured using 5-letter per-line retroilluminated logMAR charts.[2] Moreover, smartphones are able to detect diabetic retinopathy and sight-threatening disease by the means of a condensing lens[9] or attachable optical adapters.[3] This study is the first to compare the use of a smartphone-generated image to more commonly used slit-lamp biomicroscopy to grade the VCDR.

The optical attachment for the smartphone used in this study had a low rate of ungradable images, and the majority of images were at least of acceptable quality, although the age in both groups was relatively young. Our results show that clinical grading of VCDR between the gold standard slit-lamp biomicroscopy and smartphone ophthalmoscopy techniques showed a substantial agreement, according to Landis' and Kock recommendations for unweighted κ interpretations.[10] Compared with biomicroscopy, the smartphone appeared to slightly overestimate the VCDR (Fig. 2): this could be explained with an oversaturation of the displayed image around the cup (much brighter compared with the rim), making it appear larger to the grader. Actually, the lack of stereopsis during the assessment with direct ophthalmoscopy was reported to lead to smaller VCDRs compared with stereoscopic photographs.[11] However, this can be overcome by little movements (voluntary or involuntary) during the dynamic acquisition with the smartphone: they change the perspective of the ONH, highlighting the depth and the shape of the cup (attached video, Supplemental Digital Content 1, http://links.lww.com/IJG/A87) and making the grading easier compared with a still frame.

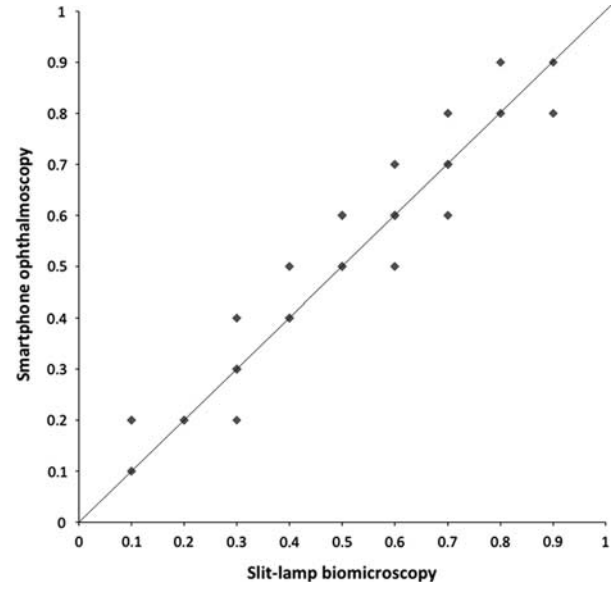


**FIGURE 2.** Plot of the estimated VCDR for slit-lamp biomicroscopy against smartphone ophthalmoscopy. The solid diagonal line represents perfect agreement and data points above the identity line represent overestimation of VCDR by smartphone ophthalmoscopy. VCDR indicates vertical cup-to-disc ratio.

Our results are consistent with previous studies comparing the accuracy of VCDR obtained with direct ophthalmoscope versus undilated fundus biomicroscopy by Watkins et al[12] (substantial agreement) and Theodossiades et al[13] (very good agreement). One of the challenges in

**TABLE 2.** Mean VCDR Estimations and Presence of Disc Hemorrhages or RNFL Wedge Defects in Patients Examined With Slit-Lamp Biomicroscopy and Smartphone Ophthalmoscopy

| | Slit-Lamp | Smartphone | *P* |
|---|---|---|---|
| VCDR in POAG | | | |
| Mean ± SD | 6.8 ± 1.3 | 6.9 ± 1.2 | 0.68 |
| VCDR in OH | | | |
| Mean ± SD | 4.5 ± 1.9 | 4.7 ± 1.9 | 0.50 |
| Total VCDR | | | |
| Mean ± SD | 5.1 ± 2.0 | 5.3 ± 2.0 | 0.50 |
| Disc hemorrhages | | | |
| Glaucoma | 1 | 1 | — |
| OH | 2 | 2 | — |
| RNFL wedge defects | | | |
| Glaucoma | 6 | 6 | — |
| OH | 1 | 2 | — |

OH indicates ocular hypertension; POAG, primary open angle glaucoma; RNFL, retinal nerve fiber layer; VCDR, vertical cup-to-disc ratio.

**TABLE 3.** Sensitivity and Specificity of Comparison Between Slit-Lamp Biomicroscopy and Smartphone Ophthalmoscopy to Grade the VCDR

| VCDR | Sensitivity (95% CI) | Specificity (95% CI) |
|---|---|---|
| 0.1 | 0.38 (0.10-0.74) | 1 (0.95-1) |
| 0.2 | 1 (0.46-1) | 0.94 (0.87-0.98) |
| 0.3 | 0.79 (0.49-0.94) | 1 (0.95-1) |
| 0.4 | 0.78 (0.40-0.96) | 0.98 (0.92-1) |
| 0.5 | 0.47 (0.24-0.71) | 0.96 (0.88-0.99) |
| 0.6 | 0.77 (0.56-0.90) | 0.86 (0.77-0.93) |
| 0.7 | 0.74 (0.49-0.90) | 0.95 (0.88-0.99) |
| 0.8 | 0.67 (0.24-0.94) | 0.95 (0.88-0.98) |
| 0.9 | 0.67 (0.13-0.98) | 0.99 (0.94-1) |

CI indicates confidence interval; VCDR, vertical cup-to-disc ratio.

previously assessed teleglaucoma systems has been the detection of false negatives[14]: in this regard the overestimation of the VCDRs by the smartphone would counter this challenge.

Rather than ideal practice, this study reflects potential screening practice with fast acquisitions in undilated pupils. Although ONH examination is best performed through a dilated pupil (providing better stereoscopic view with biomicroscopy), smartphone ophthalmoscopy is intended to serve as a tool that enables detection of disease in patients with poor access to ophthalmologic care.

The presence of disc hemorrhages and localized wedge-shaped defects was similar between the 2 ophthalmoscopy techniques. Inter alia, the cross-polarization inside the D-EYE adapter improves image detail and contrast, and increased the definition of the nerve fiber layer by reducing its reflectivity (Fig. 3).[4]

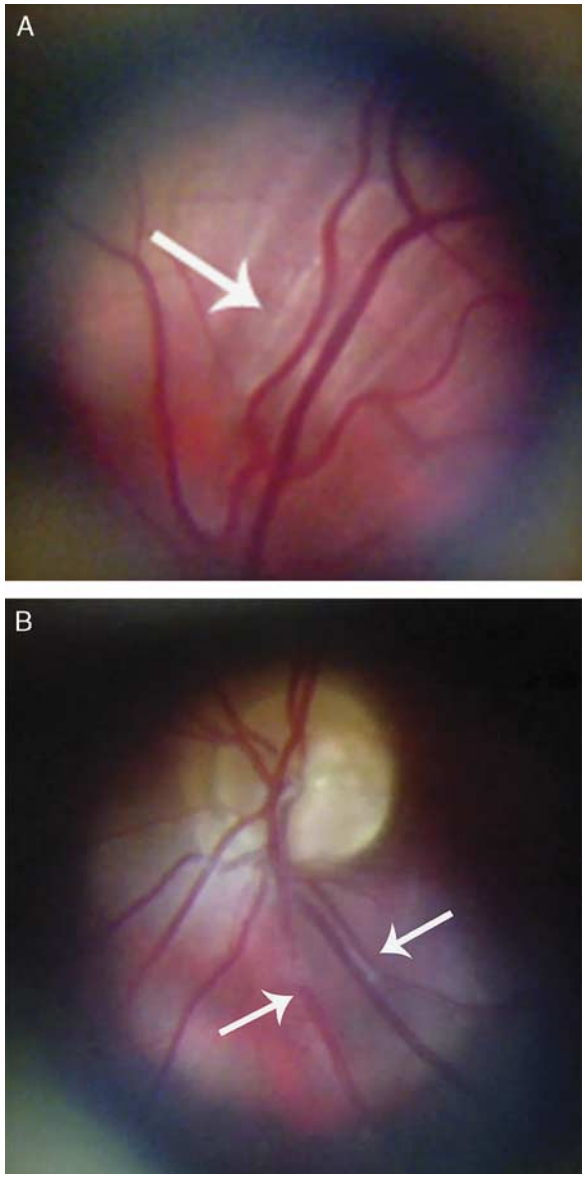


**FIGURE 3.** Cross-polarization inside the D-EYE adapter increased nerve fiber layer definition (A) and wedge-shaped defects (B). White arrows indicate the nerve fiber layer visualisation.

The fast acquisition time per eye ($12.8 \pm 3.2$ s per eye) could make the smartphone ophthalmoscopy a promising tool for glaucoma assessment in community screening programs, even by nonophthalmic personnel exploiting the wireless connectivity of smartphones in a telemedicine scenario.

Indeed, smartphones are arguably the most ubiquitous modern technology: in some developing countries, more people have access to a smartphone than to electricity or even clean water.[15] This extensive diffusion might therefore represent a resource for glaucoma screening, in particular in rural populations like Africans, accounting for the highest prevalence of all POAG cases, often presenting in late stages.[16]

Our study has a few limitations. Firstly, smartphone ophthalmoscopy was executed by a glaucoma specialist and consequently the results we reported cannot be linearly transposed to nonophthalmic personnel. Secondly, we only statistically assessed the VCDR of the ONH for a potential glaucoma screening, while a few other ONH parameters are needed for a thorough glaucoma assessment (ie, cup shape, neuroretinal rim color, vessel path, extent and location of peripapillary atrophy). Thirdly, our results are limited to a relatively young population sample with a limited incidence of cataract.

In conclusion, this study shows a good agreement between smartphone ophthalmoscopy and slit-lamp biomicroscopy when evaluating the VCDR in patients with ocular hypertension and POAG. The pervasive diffusion of smartphones, together with their connectivity and portability features, enables an extensive benefit for this technology to be used in glaucoma screening, especially in low-resource settings. A universal adapter, fitting most smartphone brands, is needed for a widespread screening program.

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