Influence of OCT Signal Strength on Macular, Optic Nerve Head, and Retinal Nerve Fiber Layer Parameters

Chameen Samarawickrama,1 Amy Pai,1 Son C. Huynh,1 George Burlutsky,1 Tien Y. Wong,2,3 and Paul Mitchell1

PURPOSE. To examine the influence of different signal strengths on measurements made with optical coherence tomography (OCT) of macular, optic nerve head, and retinal nerve fiber layer (RNFL) parameters.

METHODS. From 2003 to 2005, 2092 children, mostly aged 12 years, were examined, and macular, optic nerve head, and RNFL parameters were measured by OCT. Multiple fast scans were acquired, and only right eyes were included in the analyses. Signal strength category was determined after averaging individual signal strengths from each scan and classifying scans as providing moderate (average signal strength, 5–7.49), good (average signal strength, 7.5–9.49), and excellent (average signal strength, ≥9.5) image quality. General linear models were used after adjustment for covariates.

RESULTS. Significant differences were observed between measurements obtained at excellent signal strengths compared with those obtained at moderate and good signal strengths for both macular and optic nerve parameters. However, although statistically significant, the magnitude of the differences in macular parameters was very small (~5 μm, or a 2% difference). Differences in optic nerve head parameters were much greater (up to a 32% difference), with larger measurements recorded for most parameters with increasing signal strength category. Significant differences in RNFL parameters with increasing signal strength were not demonstrated.

CONCLUSIONS. Significantly larger macular and optic nerve head OCT measurements were obtained with increasing signal strength measurements, although absolute differences in macular measurements were small and are of questionable clinical importance. The results support the robustness of OCT in providing precise macular imaging. (Invest Ophthalmol Vis Sci. 2010;51:4471–4475) DOI:10.1167/iovs.09-3892

Optical coherence tomography (OCT) is a widely used imaging modality in clinical ophthalmology for assessing retinal and optic disc structure.1,2 Time domain OCT (StratusOCT 3; Carl Zeiss Meditec, Oberkochen, Germany) utilizes partial coherence interferometry technology to obtain optical A-scans of the retina, in which changes in reflectivity are used to define retinal boundaries. With newer versions of OCT, signal strength has replaced signal-to-noise ratio (SNR) as the method of discriminating quality. The signal strength measurement combines SNR with the uniformity of the signal within a scan and is measured on a scale of 1 to 10, where 1 is categorized as poor image quality and 10 as excellent image quality.

Operational guidelines for the StratusOCT recommend signal strengths greater than 5 as an acceptable cutoff for image quality. Although many studies have adhered to this recommendation,3,4 some have used signal strengths of 6,5,6,7,8,9 and even 810 as the minimal inclusion criteria for OCT imagery. To date, there has been no consensus as to the minimum signal strength necessary for a good-quality image. In a recent study, Cheung et al.11 suggested that signal strength may influence the measurement of RNFL thickness. Given this finding, it is critical to determine whether signal strength could also influence the measurement of macular and optic nerve head parameters. If there is a significant effect, standardized guidelines regarding image quality may be needed. Such guidelines would have particular relevance to newer spectral domain OCT technology, which also uses signal strength as the primary mode of discriminating image quality.

In this study, we examine the relationship between signal strength and measurements of macular, optic nerve head, and RNFL parameters in a population-based sample of Australian children most of whom were aged 12 years. We hypothesized that a childhood population would be an ideal one in which to conduct such an evaluation as children have a stable refraction and are free of potentially confounding ocular diseases (e.g., cataract and glaucoma).

METHODS

Study Population

In the Sydney Childhood Eye Study, incorporating the Sydney Myopia Study, childhood eye conditions were examined in a population-based sample of primary and secondary school students in Sydney. The study was approved by the Human Research Ethics Committee, University of Sydney; the Department of Education and Training; and the Catholic Education Office, New South Wales, Australia. The protocol adhered to the tenets of the Declaration of Helsinki.

Detailed study methods have been published.3,12–15 In brief, this study examined year 7 students (median age, 12 years) attending 21 secondary schools across the metropolitan area of Sydney, Australia, from 2003 to 2005. Random cluster sampling was used to select a proportional mix of public and private or religious schools, stratified by socioeconomic status, according to data from the Australian Bureau of Statistics. All year 7 students in these schools were invited to participate. Informed written consent was obtained from at least one parent of each child, coupled with verbal assent from all children.
Examinations were performed on 2353 (75.3%) of 3144 eligible year 7 students during 2004 and 2005.

Questionnaire Data

Parents completed a comprehensive 193-item questionnaire from which each child’s demographic and ocular history data were drawn. Each child’s ethnicity was defined only when both parents had the same ethnic background. Other children whose parents had different ethnicities were considered to have mixed ethnicity.

Examinations

A thorough ocular examination was conducted on all children. Monocular distance visual acuity (VA) was tested at 8 feet (244 cm) using a logarithm of the minimum angle of resolution (logMAR) chart. Presenting VA was assessed without and with spectacle correction, if worn, and recorded as the number of letters read correctly from 0 to 70 (Snellen acuity, <20/200-20/10). The Beaver Dam Eye Study modification of the Early Treatment of Diabetic Retinopathy Study protocol16 was used to perform subjective refraction in children whose presenting VA was <0.02 logMAR units (<54 letters or <20/20). Before cycloplegia, axial length and keratometry were measured with an optical biometer (IOLMaster, Carl Zeiss Meditec, Jena, Germany)12,13 that has a dual-beam partial coherence interferometer with a 780-nm wavelength. The average of five measurements was used in the analyses. Cycloplegia was induced with cyclopentolate 1% and tropicamide 1% (1 drop each), after instillation of amethocaine 1% (1 drop). Autorefraction was performed with an autorefractor (RK-F1; Canon, Tokyo, Japan) approximately 25 minutes after the last drop.

Optical Coherence Tomography

OCT (StratusOCT, software v.4.0.4; Carl Zeiss Meditec) was performed through dilated pupils to obtain cross-sectional measurements of the retina and optic discs. OCT utilizes partial coherence interferometry technology to obtain optical A-scans of the retina. This instrument has an axial resolution of approximately 10 μm17 and has been shown to have good intra- and interobserver reproducibility.1,2

A fast macular thickness mapping protocol was used to image the macular region. This protocol acquires six 6-mm radial lines, consisting of 128 A-scans per line, passing through the foveal center in 1.92 seconds. Optic nerve head parameters were measured using the fast optic disc scanning protocol that acquires a full scan in the same period and consists of six 4-mm-long line scans arranged radially and centered on the optic disc. Each line scan was sampled at 128 points (A-scans), totaling 768 A-scans per optic nerve head. Three optic disc fast scans were performed without making any changes to the scan placement and were averaged before analysis. Average peripapillary RNFL thickness was also measured. The fast RNFL thickness scanning protocol was used, consisting of 256 A-scans along a circular path with a radius of 1.73 mm. The average of three scans was used for analysis.

A single experienced operator performed more than 90% of scans. An internal fixation target was used for all scans, and the location of each scan on the retina was monitored with an infrared-sensitive video camera. The scans were performed assuming standard axial length (24.46 mm) and refraction (0 D) for consistency with usual clinical practice and were accepted only if they were free of artifacts, showed complete cross-sectional images, and had a signal strength of at least 5. Ocular magnification was corrected for this instrument by using the appropriate formulas.18

Statistical Analysis

In the analyses (SAS software, ver. 9.1.3; SAS Institute, Cary, NC), amblyopic eyes and those with significant other disease were excluded, and only right eyes were included. Multiple scans were acquired from each eye, and the means were calculated for each parameter and for signal strength. Eyes with a mean signal strength of 5 to 7.49 were categorized into the moderate signal strength group (repre-
senting signal strengths 5, 6, and 7); mean signal strengths between 7.5 and 9.49 were categorized into the good signal strength group (representing signal strengths 8 and 9); and all mean signal strengths of 9.5 or greater were categorized into the excellent signal strength group (representing signal strength 10). General linear models were then used to examine the relationship between signal strength category and macular, optic nerve head, and RNFL parameters after adjustment for the covariates of age, sex, ethnicity, axial length, and spherical equivalent refraction (sphere + ½ cylinder).

RESULTS

Demographic details of our sample are displayed in Table 1. Australian children in our sample had an average age of 12.7 years and 51.9% were boys. The predominant ethnicity was European Caucasian. Mean axial length (95% confidence interval (CI)) was 23.39 mm (23.35–23.42 mm) and mean spherical equivalent refraction was +0.51 D (0.46–0.56 D).

Table 2 shows that significant differences in macular measurements were observed between images with excellent signal strength and those obtained in the lower signal strength categories. There was a moderate positive association between increasing signal strength and both inner and outer macular thickness (P < 0.01), which was also present for macular thickness in the individual quadrants. The average macular thickness by signal strength category is demonstrated in Figure 1A, where a small but significant increase in measured thickness was observed in the highest signal strength category. We also observed a strong positive association (P < 0.0001) with macular volume (Fig. 1B), where larger volumes were measured in images with higher signal strength. This statistical significance was maintained in almost all parameters after Bonferroni correction (data not shown). It should be noted, however, that the actual differences between images from the three signal strength categories were quite small (maximum difference of 5 μm or 2% difference) and of questionable clinical importance. Table 2 also describes the associations between signal strength category and RNFL parameters. We were able to observe a significantly positive association only for RNFL thickness by signal strength in the temporal quadrant (P = 0.0006).

Table 3 shows that substantial differences (up to 32% differences between categories) in optic nerve head measurements were observed between images with excellent signal strength and images obtained at lower signal strengths. Generally, optic nerve head measurements increased as signal strength increased. This positive association achieved statistical significance (P < 0.05) for all parameters except vertical optic disc diameter and neuroretinal rim area. Figure 2 demonstrates the association between signal strength category and optic disc area (Fig. 2A) and optic cup area (Fig. 2B). Both showed a substantial increase in measured area with higher signal strengths. This finding was significant for both optic cup
Most measured parameters (data not shown). Significance was maintained after Bonferroni correction for

category. Measurements adjusted for age, sex, ethnicity, axial length, and spherical refraction.

**FIGURE 1.**

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**TABLE 2.** Macular and RNFL Parameters by OCT Signal Strength Category

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Moderate (5, 6, 7)</th>
<th>Good (8, 9)</th>
<th>Excellent (10)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central macular thickness, µm</td>
<td>193.58 (192.24–194.92)</td>
<td>193.81 (192.34–195.28)</td>
<td>193.71 (191.06–196.35)</td>
<td>0.07</td>
</tr>
<tr>
<td>Foveal minimum thickness, µm</td>
<td>158.55 (157.10–160.01)</td>
<td>158.71 (157.11–160.31)</td>
<td>157.50 (154.62–169.38)</td>
<td>−0.7</td>
</tr>
<tr>
<td>Macular volume, mm³</td>
<td>6.91 (6.89–6.94)</td>
<td>6.92 (6.89–6.95)</td>
<td>7.03 (6.97–7.08)†</td>
<td>1.7</td>
</tr>
<tr>
<td>Inner macular thickness by quadrant, µm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>273.84 (272.76–274.95)</td>
<td>273.63 (272.44–274.82)</td>
<td>276.97 (274.83–279.11)†</td>
<td>1.1</td>
</tr>
<tr>
<td>Inferior</td>
<td>272.25 (271.18–273.32)</td>
<td>272.63 (271.45–273.80)</td>
<td>276.15 (274.03–278.27)†</td>
<td>1.4</td>
</tr>
<tr>
<td>Temporal</td>
<td>261.20 (260.10–262.30)</td>
<td>261.37 (260.16–262.58)</td>
<td>264.38 (262.21–266.56)†</td>
<td>1.2</td>
</tr>
<tr>
<td>Nasal</td>
<td>272.93 (271.72–274.15)</td>
<td>273.34 (272.00–274.67)</td>
<td>277.51 (274.91–279.71)†</td>
<td>1.6</td>
</tr>
<tr>
<td>Outer macular thickness by quadrant, µm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>241.53 (240.53–242.55)</td>
<td>241.68 (240.58–242.78)</td>
<td>244.68 (242.70–246.60)†</td>
<td>1.3</td>
</tr>
<tr>
<td>Inferior</td>
<td>229.82 (228.80–230.83)</td>
<td>229.69 (228.58–230.81)</td>
<td>234.57 (232.56–236.58)†</td>
<td>2.1</td>
</tr>
<tr>
<td>Temporal</td>
<td>223.78 (222.74–224.83)</td>
<td>224.56 (223.40–225.71)</td>
<td>227.69 (225.62–229.77)†</td>
<td>1.7</td>
</tr>
<tr>
<td>Nasal</td>
<td>257.73 (256.54–258.92)</td>
<td>257.06 (255.76–258.36)</td>
<td>262.83 (260.49–265.18)†</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**Retinal Nerve Fiber Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Moderate (5, 6, 7)</th>
<th>Good (8, 9)</th>
<th>Excellent (10)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RNFL, µm</td>
<td>102.79 (101.94–103.64)</td>
<td>103.84 (103.02–104.65)</td>
<td>104.01 (102.70–105.32)</td>
<td>1.1</td>
</tr>
<tr>
<td>RNFL by quadrant, µm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>129.56 (128.16–130.97)</td>
<td>130.57 (129.23–131.91)</td>
<td>130.48 (128.51–132.65)</td>
<td>0.7</td>
</tr>
<tr>
<td>Inferior</td>
<td>127.60 (126.12–129.07)</td>
<td>129.03 (127.62–130.43)</td>
<td>128.22 (126.94–130.50)</td>
<td>0.5</td>
</tr>
<tr>
<td>Temporal</td>
<td>74.20 (73.20–75.20)</td>
<td>74.65 (73.70–75.60)</td>
<td>77.48 (75.94–79.02)†</td>
<td>4.4</td>
</tr>
<tr>
<td>Nasal</td>
<td>79.77 (78.47–81.06)</td>
<td>81.09 (79.86–82.35)</td>
<td>79.88 (77.87–81.88)</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Data are the mean signal strength (95% CI). Difference (%) is between excellent and moderate categories, as a percentage of the moderate category. Measurements adjusted for age, sex, ethnicity, axial length, and spherical refraction.

* Significant difference, $P < 0.05$, compared with the moderate group.

† Significant difference, $P < 0.05$, compared with the good group.

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**DISCUSSION**

OCT findings from this population-based sample of Australian children free of confounding ocular disease have been reported.3,18–26 In this study, we provide new data showing that retinal OCT measurements obtained at excellent signal strength were significantly larger than measurements obtained at lower (good and moderate) signal strengths, independent of age, sex, ethnicity, axial length, and spherical equivalent refraction. However, the influence of StratusOCT signal strength on measurements in normal subjects has been examined in only one study. Cheung et al.11 performed fast RNFL scans using the StratusOCT in 40 healthy adult subjects at different signal strengths. They altered the focusing knob of the OCT imaging machine to produce at least six scans of each eye at signal strengths 5, 6, 7, 8, 9, and 10, and found that RNFL parameters measured at signal strength 10 were significantly thicker than those obtained at signal strengths <10. In contrast, our results did not show any influence of the various signal strengths on RNFL thickness measurements. Further studies are needed to determine whether signal strength genuinely affects the measured thickness of the RNFL.

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**FIGURE 1.** Influence of signal strength on (A) average macular thickness and (B) macular volume, adjusted for age, sex, ethnicity, axial length, and spherical equivalent refraction.
TABLE 3. Optic Nerve Head Parameters by OCT Signal Strength Category

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Moderate (5, 6, 7) (n = 1029)</th>
<th>Good (8, 9) (n = 877)</th>
<th>Excellent (10) (n = 152)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical disc diameter, mm</td>
<td>1.88 (1.86–1.90)</td>
<td>1.87 (1.85–1.89)</td>
<td>1.88 (1.84–1.93)</td>
<td>0.0</td>
</tr>
<tr>
<td>Vertical cup diameter, mm</td>
<td>0.72 (0.70–0.74)</td>
<td>0.74 (0.71–0.77)</td>
<td>0.81 (0.76–0.87)</td>
<td>12.5</td>
</tr>
<tr>
<td>Vertical cup/disc ratio</td>
<td>0.37 (0.36–0.38)</td>
<td>0.38 (0.37–0.39)</td>
<td>0.41 (0.39–0.44)</td>
<td>10.8</td>
</tr>
<tr>
<td>Horizontal disc diameter, mm</td>
<td>1.59 (1.57–1.60)</td>
<td>1.62 (1.61–1.64)</td>
<td>1.66 (1.63–1.69)</td>
<td>4.4</td>
</tr>
<tr>
<td>Horizontal cup diameter, mm</td>
<td>0.69 (0.67–0.71)</td>
<td>0.72 (0.70–0.75)</td>
<td>0.80 (0.75–0.86)</td>
<td>15.9</td>
</tr>
<tr>
<td>Horizontal cup/disc ratio</td>
<td>0.42 (0.40–0.45)</td>
<td>0.42 (0.41–0.44)</td>
<td>0.46 (0.43–0.49)</td>
<td>9.5</td>
</tr>
<tr>
<td>Disc area, mm²</td>
<td>2.33 (2.30–2.36)</td>
<td>2.34 (2.31–2.38)</td>
<td>2.42 (2.35–2.48)</td>
<td>3.9</td>
</tr>
<tr>
<td>Cup area, mm²</td>
<td>0.47 (0.45–0.49)</td>
<td>0.49 (0.46–0.51)</td>
<td>0.58 (0.53–0.64)</td>
<td>23.4</td>
</tr>
<tr>
<td>Area cup/disc ratio</td>
<td>0.20 (0.19–0.21)</td>
<td>0.21 (0.20–0.22)</td>
<td>0.23 (0.21–0.25)</td>
<td>15.0</td>
</tr>
<tr>
<td>Cup volume, mm³</td>
<td>0.066 (0.061–0.072)</td>
<td>0.067 (0.062–0.075)</td>
<td>0.087 (0.076–0.099)</td>
<td>31.8</td>
</tr>
<tr>
<td>Rim area, mm²</td>
<td>1.86 (1.83–1.89)</td>
<td>1.86 (1.82–1.89)</td>
<td>1.83 (1.76–1.91)</td>
<td>−1.6</td>
</tr>
<tr>
<td>Average nerve width, mm</td>
<td>0.352 (0.328–0.335)</td>
<td>0.350 (0.326–0.335)</td>
<td>0.318 (0.311–0.325)</td>
<td>−4.2</td>
</tr>
</tbody>
</table>

Data are the mean signal strength (95% CI). Difference (%) is between the excellent and moderate categories, as a percentage of the moderate category. Measurements adjusted for age, sex, ethnicity, axial length, and spherical refraction.

* Significant difference, $P < 0.05$, compared with the moderate group.
† Significant difference, $P < 0.05$, compared with the good group.

We demonstrated a positive association of larger measurements with increasing signal strength for optic nerve head parameters measured by StratusOCT. The associations between signal strength and optic nerve head parameters were present for all optic cup parameters (vertical diameter, horizontal diameter, cup area, and volume) and all cup/disc ratios (vertical, horizontal, and area). This finding may stem from the difficulty of differentiating the central retinal vessel trunk from the nerve fiber layer of the neuroretinal rim, resulting in large variability in measurement, with different levels of signal strength. The finding also implies that optic cup measurements are particularly susceptible to changes in image quality and was relevant for the assessment of patients with glaucoma, for whom optic cup measurements are used to monitor disease progression. Clinicians should be aware of these potential differences in optic cup measurements when it is not possible to obtain OCT images with sufficiently high signal strength. Other imaging modalities, such as scanning laser polarimetry (GDx; Carl Zeiss Meditec) and confocal laser scanning tomography (Heidelberg Retinal Tomography [HRT]; Heidelberg Engineering, Heidelberg, Germany) may be preferable or used in conjunction with OCT to improve diagnostic accuracy.

In contrast, the measured differences in macular parameters between signal strength category was very small, with a maximum difference between signal strength categories of less than 3 μm (2% difference). Although statistically significant, these differences are of questionable clinical importance. It can be inferred that time domain OCT is exceptionally adaptable to the measurement of macular parameters, and although signal strength contributes to measurement variability, it has limited clinical importance. This conclusion has significance in the use of the newer spectral domain OCT instruments, which also rely on signal strength to discriminate image quality. Studies have already shown that spectral domain OCT leads to fewer artifacts and results in larger macular retinal thickness measurements than time domain OCT, probably because of detection of a more external outer boundary, such as the retinal pigment epithelium or the intermediate reflective line. Further studies are needed to confirm that signal strength also plays a minimal clinical role in measuring macular parameters with spectral domain OCT and to map the influence of signal strength on optic nerve head and RNFL measurements by using this considerably improved OCT technology.

It is difficult to determine an acceptable signal strength cutoff for image quality. Our findings appear to indicate that signal strength plays a minimal role in measurement variability when measuring macular and RNFL parameters. Thus, any macular or RNFL scan of signal strength 5 or higher could be classified as being of acceptable image quality. However, optic nerve head parameters appear to be influenced by signal strength, so it is recommended that these images be obtained with the maximum possible signal strength to improve accuracy when imaging the optic nerve head with time domain StratusOCT. However, it should be noted that our population is considerably different from that of the typical older patients seen in a clinical setting, so that clinicians should be aware that other potential confounders may exist to alter these associations. Our findings are therefore not directly applicable to
older patients without considering these different confounding factors.

Strengths of our study include its large population-based, random cluster selection sample with high response (75.3%), the use of a validated, objective technique to repeatedly measure optic nerve head, macular, and RNFL parameters and the detailed standardized examination method. In addition, a major strength of our study is the use of a healthy adolescent sample with little burden of adult ocular disease and the statistical correction for important confounders such as axial length and spherical equivalent refraction.

In summary, we found that the measurement of macular parameters is related to OCT image quality, although the differences in measurements were so small they were of questionable clinical importance. In contrast, the measurement of optic nerve head parameters is closely related to the quality of the OCT image, as determined by signal strength category, where larger parameters were measured with increasing signal strength. This result was found to be independent of key potential confounders including axial length and spherical equivalent refraction. Clinicians should take signal strength into consideration, particularly when imaging the optic nerve in glaucoma patients. It appears that StatusOCT provides robust measures when imaging the macula, but when used to image other structures, obtaining the highest signal strength is essential, to minimize measurement variability.

References