Optimizing Hand-held Spectral Domain Optical Coherence Tomography Imaging for Neonates, Infants, and Children

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PURPOSE. To describe age-related considerations and methods to improve hand-held spectral domain optical coherence tomography (HH-SD OCT) imaging of eyes of neonates, infants, and children.

METHODS. Based on calculated optical parameters for neonatal and infant eyes, individualized SD OCT scan parameters were developed for improved imaging in pediatric eyes. Forty-two subjects from 31 weeks postmenstrual age to 1.5 years were imaged with a portable HH-SD OCT system. Images were analyzed for quality, field of scan, magnification, and potential clinical utility.

RESULTS. The axial length of the premature infant eye increases rapidly in a linear pattern during the neonatal period and slows progressively with age. Refractive error shifts from mild myopia in neonates to mild hyperopia in infants. These factors affect magnification and field of view of optical diagnostic tools applied to the infant eye. When SD OCT parameters were corrected based on age-related optical parameters, SD OCT image quality improved in young infants. The field of scan and ease of operation also improved, and the optic nerve, fovea, and posterior pole were successfully imaged in 74% and 87% of individual eye imaging sessions in the intensive care nursery and clinic, respectively. No adverse events were reported.

CONCLUSIONS. SD OCT in young children and neonates should be customized for the unique optical parameters of the infant eye. This customization, not only improves image quality, but also allows control of the density of the optical sampling directed onto the retina. (Invest Ophthalmol Vis Sci. 2010;51: 2678–2685) DOI:10.1167/iov.s.09-4403

Optical coherence tomography (OCT) is a diagnostic imaging technique that provides cross-sectional images of human retinal morphology in vivo. It has become a standard diagnostic tool for management of vitreoretinal diseases, particularly involving the macula, since it provides information on retinal architecture beyond that obtained by conventional ophthalmic methods.1,2 In older children, OCT has been shown to be more sensitive than clinical examination in the detection of retinal conditions such as edema, subretinal fluid, and retinal thinning.3

With 1.4 million blind children below age 15 worldwide4 and more than 50,000 legally blind children in the United States,5 there is a need to access this technology for use in younger children, particularly since the most common causes of visual impairment are retinal diseases,6 such as retinopathy of prematurity (ROP), ocular albinism, and retinal dystrophies.7,8

A few studies have reported time domain (TD) OCT and spectral domain (SD) OCT imaging in the pediatric population (Table 1). Although numerous publications show the advantage of SD OCT ocular imaging in the adult,22–24 the higher speed of scanning is even more important in young children with limited attention spans and difficulty with sustained fixation, as shown by Chong et al.12 in children with albinism. Scott et al.10 also demonstrated how SD OCT of infant eyes may influence management in cases of shaken-infant syndrome. Chavala et al.9 described preterm retinal structures, schisis, and retinal detachment found on SD OCT, but not on conventional clinical examination in infants with ROP.

In those studies, limiting factors for imaging children were patient motion, poor fixation, patient position, and different optics compared with the adult eye. In this study, we evaluated problems specific to imaging pediatric patients with SD OCT and identified and tested technical corrections to solve these challenges.

METHODS

We used a U.S. Food and Drug Administration–approved portable, noncontact, hand-held SD OCT unit (Bioptigen Inc., Research Triangle Park, NC) consisting of an imaging hand piece connected via a 1.3-m flexible cable to an SD OCT engine mounted on a rolling cart. The SD OCT system has a calibrated knob to adjust the reference arm position with digital readout, as shown in Figure 1A; a manufacturer-supplied calibration factor was used to convert the readout units to optical distance in millimeters. The hand-held probe has a focus correction that can produce a range of ±10 to −12 D (Fig. 1B).

On February 4, 2010, the manufacturer (Bioptigen Inc.) notified us that the retinal scan length settings for this hand-held SD OCT unit were in error; and that each lateral scan setting label on this particular system created a scan that was 68% of the labeled length. Therefore, all scan lengths (both x and y dimensions) recorded off the unit had to be multiplied by the 0.68 correction factor to represent the actual scan lengths. These corrections have been applied, and thus many scan
sizes in this manuscript appear as decimal portions of millimeters (e.g., a 6.8 X 6.8-mm scan).

We reviewed the literature for normative data regarding pediatric optics from 1960 to the present and documented optical changes that occur in the infant eye as a function of age. From this analysis, we identified the problems that potentially affect pediatric imaging and designed reference tables and imaging protocols to image pediatric patients.

We obtained SD OCT imaging in 21 premature infants from the neonatal intensive unit care (NICU) of Duke University Medical Center and 21 outpatient infants from Duke Eye Center. We imaged in parallel with the clinical examination scheduled as part of standard of care, and the subjects were imaged more than once, for a total of 62 subject imaging sessions (113 individual eye sessions) in the NICU and 39 (59 individual eye sessions) outpatient sessions. Imaging was not at all sessions. In the clinic, after obtaining study consent, SD OCT was performed at the time of clinical examination, in a protocol that did not require monitoring of vital signs and allowed up to 30 minutes for the total imaging session.

In both groups, oral 0.5 mL sucrose 24% with pacifier was used to decrease infant stress. The eyelids were usually held open with two fingers of the examiner, although a lid speculum was sometimes used when needed for a stable examination. Artificial tears (Systane; Alcon, Inc., Fort Worth, TX) were used to lubricate the cornea during the examination. To avoid resting the flexible cable on the infant, imaging was always performed with the base of the hand-held scanner and hand-held cord extending over the forehead.

Ease of operation of SD OCT imaging was scored in three areas: ability to (1) obtain an image within 15 seconds (2) orient with the summed voxel projection (SVP); a two dimensional retinal image created by axially summing the OCT volume (see Figs. 3A, 3C, 3E), and (3) image the region of interest (fovea). Time to scan was not measured in less than 1-minute intervals as planned, because the start time was recorded in whole minutes. Captured SD OCT images were viewed with the software on the SD OCT system (NvivoVue 1.2; Biotigten, Inc.). Image quality was considered good if the B-scan image was sharp enough to let the observer differentiate retinal layers and foveal contour (Fig. 2). A field of scan was considered adequate when the B-scan image occupied the full scan, and the SVP image captured part of the optic nerve and an arcade.

**Results**

**Infant Eye Optical Analysis**

The infant eye is unique in many aspects that affect optical imaging: axial length (AXL), refractive error (RE), corneal curvature (CC), and astigmatism. The AXL increases rapidly in the neonatal period growing 0.16 mm per week, according to a linear model (Fig. 3A). This growth slows with age from 2 to 5 years, and to 0.1 mm/year from 5 to 15 years. After age 15, no significant further growth occurs (Fig. 3B).

Gordon and Donzis reported a mean RE of −1.00 ± 0.9 (range, −3.00 to +1.00) D at 30 to 35 weeks of age (PMA), whereas from 36 weeks until the age of 6 years, a
hyperopic state prevails (mean +0.5 ± 0.2 D). Cook et al.27 similarly reported an RE of −2.00 D at 32 weeks and −1.23 at 36 weeks, with a shift to hyperopia (+0.74 to +2.12) by 40 to 52 weeks.

The newborn cornea is generally steeper than the adult cornea, with a mean central corneal power of between 48 and 58.5 D, decreasing to adult values by 3 months.29,33–37 Although the power and axis of infant astigmatism varies in pediatric studies, the newborn eye has greater astigmatism than does the adult eye, but the condition also decreases by 50% in approximately 6 months.34 With retinoscopy, Dobson et al.38,39 reported greater than +1.0 D of against-the-rule astigmatism in 100% of infant eyes under age 6 months, whereas by topography Isenberg et al.34 found a mean astigmatism of 6.0 D (range, 0.2–16.4) that was with the rule in 80% of newborn infant eyes.

These optical properties result in a model infant eye unique from that of the adult. The schematic Gullstrand model eye is used to condense these optical properties into a summary simplified lens estimate that is useful in optimizing systems for viewing or imaging the retina.40 In 1976, Lotmar25 proposed a theoretical model for the eye of newborn infants. We used optical formulas of Gullstrand40 and of Gross and West41 to develop a theoretical eye model for prematurely born neonates using data available in biometric studies of the infant eye (Table 2).27,29 Refractive indices of the media were assumed to be equal to those of the adult eye. Note that the focal length of the premature infant schematic eye is 10.35 mm compared with 11.80 mm for Lotmar’s model newborn infant eye,25 and 17 mm for the adult eye, which is often used as a reference for ocular instrument analysis.42–44 Based on the foregoing analysis, we implemented age-specific considerations in our SD OCT imaging protocol for young children. This included changing the reference arm position, focus, and scan settings based on age (Table 3). For example, in the 32-week PMA infant, each millimeter of presumed scan length would actually be 0.629 mm at the retina in this eye (62.9% of the adult eye). Therefore, performing a 10 mm retinal scan (set for an adult eye) would result in a 6.3 mm retinal scan in this infant eye.

Pediatric SD OCT Image Acquisition

When imaging infant eyes, we found that the operator could readily hold the eyelids open in the awake or sleeping infant and that a speculum was usually not necessary, in part because the OCT scanner does not shine a bright light into the eye, and the subject sees only a faint red line against a black background. Adding artificial tears before imaging provided stable tear film and clearer images. During imaging in the NICU, there was adequate clearance for the SD OCT handpiece within the incubator; therefore, infants were not removed for imaging. Similarly, imaging was possible in one eye each of three infants around continuous positive airway pressure (CPAP) mask systems without removal. We did not need to use oral sucrose in 18% of NICU subjects and 10% of clinic subjects who appeared to be sleeping during imaging. We stopped imaging in two patients (8%) due to an elevation of heart rate above our 20% limit. Follow-up was performed at 1 to 2 hours after imaging for all NICU subjects, and no adverse events were reported in any of the subjects.

Improving Image Quality

To correct the hand-held probe optics for the RE of the subject being imaged, we used the reference table (Table 3) for settings based on age, since RE data were not available for most subjects.27,29 We developed a calibrated RE readout scale applied to the hand-held probe to allow the operator to correct the RE in single-diopter increments (range, −10 to +12 D) (Fig. 1B). This calculation was made with manufacturer-supplied data concerning the objective lens motion required per
diopter of RE correction and the pitch of the objective lens screw mount.

We started imaging premature neonates with the focus set at −1.00 D and term infants at +2.00 D and then adjusted the focus to optimize the image clarity. Changes smaller than 2 D do not produce a discernable improvement in the quality of SD OCT B-scan image; thus, we generally adjusted the focus in 2-D jumps. A properly focused image allows the observer to differentiate retinal layers and small pathologic structures (Fig. 2B).

In less than 10% of cases the RE obtained from Table 3 did not correlate with the best focus used for imaging. As a result of these focus adjustments, 91% of the 113 sessions had adequate image quality.

### Adequate Field of Scan: Correcting OCT Image Vignetting

Imagers achieve two-dimensional scanning of the retina by pivoting the OCT beam in the plane of the patient’s iris. In the smaller infant eye, the OCT scanning pivot location is displaced anteriorly relative to the pupil, and thus the peripheral portion of the image is clipped due to image vignetting by the iris. A pronounced clipping effect loses peripheral information as seen in Figures 4A and 4B. This may be corrected by shortening the OCT reference arm delay such that the pivot point is positioned in the iris plane. The reference arm position is corrected in the SD OCT system as follows:

\[
\Delta \text{in Reference Arm Position in mm} = \Delta \text{in AXL of the Eye in mm} \times n
\]

where, \(n\) is the index of refraction of the vitreous (1.334). The AXL of the pediatric subject may be calculated based on age (reported for our system in Table 3). Commercial OCT systems have a reference arm position pre-established by the manufacturer for a standard adult eye, and this calculated change is with respect to that preset value.

### Table 2. Comparison of Schematic Eye for Adult, Newborn, and Premature Infants

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total eye power, D</td>
<td>58.64</td>
<td>60</td>
<td>84.8</td>
<td>96.54</td>
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<tr>
<td>Eye axial length, mm</td>
<td>24</td>
<td>24.09</td>
<td>17.49</td>
<td>15.1</td>
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<td>Anterior focal length, mm</td>
<td>−17.055</td>
<td>−16.67</td>
<td>−11.8</td>
<td>−10.35</td>
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<tr>
<td>Posterior focal length, mm</td>
<td>22.78</td>
<td>22.27</td>
<td>15.74</td>
<td>13.81</td>
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<tr>
<td>Corneal power, D</td>
<td>43.05 D</td>
<td>43.08</td>
<td>48.9 D</td>
<td>55.25</td>
</tr>
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<td>Corneal curvature radius</td>
<td>7.7</td>
<td>7.8</td>
<td>7.26</td>
<td>6.1</td>
</tr>
<tr>
<td>Lens power, D</td>
<td>19.11</td>
<td>20.83</td>
<td>43.4</td>
<td>43.5</td>
</tr>
<tr>
<td>Refractive error, D</td>
<td>0</td>
<td>+2.8</td>
<td>−1</td>
<td></td>
</tr>
<tr>
<td>Refractive index:</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>Air</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
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<td>Cornea</td>
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<td>1.377</td>
<td>1.377</td>
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<tr>
<td>Aqueous</td>
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<td>1.336</td>
<td>1.336</td>
<td>1.336</td>
</tr>
<tr>
<td>Lens</td>
<td>1.366</td>
<td>1.422</td>
<td>1.45</td>
<td>1.45</td>
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<td>Vitreous</td>
<td>1.336</td>
<td>1.336</td>
<td>1.334</td>
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</table>

### Table 3. Standard Reference Table for Axial Length, Refractive Error, Reference Arm Position, and A-scans per B-scan by Age, with an Example of a 10-mm Adult Scan

#### For a 10-mm (~35 degree) Adult Scan Setting

<table>
<thead>
<tr>
<th>Group Age</th>
<th>Refractive Error D</th>
<th>SD (D)</th>
<th>Axial Length (mm)</th>
<th>SD (mm)</th>
<th>Increase in Reference Arm† (Readout Units)</th>
<th>Scan Length on Retina (mm)</th>
<th>Scan Length on Retina (deg)</th>
<th>Number of A-scans per B-scans‡</th>
<th>Increment A-scans per Each 1 mm of Length</th>
<th>Relative Scan Length to Adult Scan Length (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30–35 wk</td>
<td>−1</td>
<td>0.9</td>
<td>15.1</td>
<td>0.9</td>
<td>97</td>
<td>6.3</td>
<td>22</td>
<td>925</td>
<td>92</td>
<td>63</td>
</tr>
<tr>
<td>35–39 wk</td>
<td>0.3</td>
<td>1.6</td>
<td>16.1</td>
<td>0.6</td>
<td>86</td>
<td>6.7</td>
<td>25</td>
<td>986</td>
<td>99</td>
<td>67</td>
</tr>
<tr>
<td>39–41 wk</td>
<td>0.4</td>
<td>1.5</td>
<td>16.8</td>
<td>0.6</td>
<td>79</td>
<td>7.0</td>
<td>25</td>
<td>1029</td>
<td>103</td>
<td>70</td>
</tr>
<tr>
<td>0–1 mo</td>
<td>0.9</td>
<td>0.9</td>
<td>17.4</td>
<td>0.5</td>
<td>72</td>
<td>7.3</td>
<td>25</td>
<td>1066</td>
<td>107</td>
<td>73</td>
</tr>
<tr>
<td>1–2 mo</td>
<td>0.3</td>
<td>0.6</td>
<td>18.6</td>
<td>0.5</td>
<td>59</td>
<td>7.8</td>
<td>27</td>
<td>1139</td>
<td>114</td>
<td>78</td>
</tr>
<tr>
<td>2–6 mo</td>
<td>0.5</td>
<td>0.6</td>
<td>18.9</td>
<td>0.4</td>
<td>56</td>
<td>7.9</td>
<td>28</td>
<td>1158</td>
<td>116</td>
<td>79</td>
</tr>
<tr>
<td>6–12 mo</td>
<td>0.6</td>
<td>0.2</td>
<td>19.2</td>
<td>0.5</td>
<td>52</td>
<td>8.0</td>
<td>28</td>
<td>1176</td>
<td>118</td>
<td>80</td>
</tr>
<tr>
<td>12–18 mo</td>
<td>0.7</td>
<td>0.6</td>
<td>20.1</td>
<td>0.7</td>
<td>43</td>
<td>8.4</td>
<td>29</td>
<td>1231</td>
<td>123</td>
<td>84</td>
</tr>
<tr>
<td>18 mo–2 y</td>
<td>0.9</td>
<td>1.5</td>
<td>21.3</td>
<td>0.3</td>
<td>30</td>
<td>8.9</td>
<td>31</td>
<td>1305</td>
<td>130</td>
<td>89</td>
</tr>
<tr>
<td>2–3 y</td>
<td>1.1</td>
<td>1.1</td>
<td>21.8</td>
<td>0.1</td>
<td>24</td>
<td>9.1</td>
<td>32</td>
<td>1335</td>
<td>134</td>
<td>91</td>
</tr>
<tr>
<td>3–4 y</td>
<td>0.6</td>
<td>1.8</td>
<td>22.2</td>
<td>0.4</td>
<td>20</td>
<td>9.3</td>
<td>32</td>
<td>1360</td>
<td>136</td>
<td>93</td>
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<tr>
<td>4–5 y</td>
<td>−0.8</td>
<td>0.9</td>
<td>22.3</td>
<td>0.2</td>
<td>19</td>
<td>9.3</td>
<td>33</td>
<td>1366</td>
<td>137</td>
<td>93</td>
</tr>
<tr>
<td>5–9 y</td>
<td>−0.6</td>
<td>1.0</td>
<td>22.7</td>
<td>0.4</td>
<td>14</td>
<td>9.5</td>
<td>33</td>
<td>1390</td>
<td>139</td>
<td>95</td>
</tr>
<tr>
<td>10 y–adult</td>
<td>−0.5</td>
<td>1.5</td>
<td>24.0</td>
<td>0.7</td>
<td>0</td>
<td>10.0</td>
<td>35</td>
<td>1470</td>
<td>147</td>
<td>100</td>
</tr>
<tr>
<td>Axial myopia</td>
<td>26</td>
<td>−22</td>
<td>26</td>
<td>0</td>
<td></td>
<td>10.8</td>
<td>38</td>
<td>1593</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Note that this would apply to an adult scan setting selected from any OCT system.

† A higher number equates with a shorter reference arm length on the system we used. To convert, we used manufacturer data (Bioptigen, Inc., Research Triangle Park, NC) of −10.86 readout units/mm of change in reference arm length. (Note that on the Bioptigen unit used in this study, the 10-mm adult scan appears as a 16-mm scan setting due to a manufacturer labeling error, as explained in Methods.)

‡ Presuming one wants 6.8 μm of separation between A-scans. This would be varied for a different A-scan density.
Per our protocol, we set the calculated reference arm before imaging and check for any OCT clipping. If clipping is observed, we then test the scan response to slight manual lateral movement of the hand-held probe to identify whether the reference arm should be adjusted longer or shorter. When the reference arm is too short, the clipping shadow moves in the same direction as lateral probe movement; when it is too long, the shadow moves in a direction opposite to the probe movement. A proper reference arm position produces a wider field of scanning that allows for better orientation on the retina (Figs. 4C, 4F). Clipping may still occur, even for a perfectly set reference arm position, in large lateral scans.

**Correction for Different Lateral Magnification in the Pediatric Eye**

Variations in the optical system of the eye affect the magnification of retinal images. Sanchez-Cano et al. studied this effect for time-domain OCT images, reporting an inversely proportional relationship between AXL and retinal image size. In infants, because of the very short eye length, this relationship is even more exaggerated. Most OCT system software does not adjust for this. To calculate the correct scan length on the retina (SLOR) for the infant eye, we adapted the following formula:

\[
\text{SLOR} = \frac{\text{Infant Eye AXL}}{\text{Standard Adult AXL}} \times \text{System Scan Length}
\]

For example in Figures 5A and 5B, a 6.8 × 6.8-mm volumetric scan is projected onto the retina of an 8-month-old patient (AXL = 19.2 mm). To correct the lateral dimension:

\[
\text{SLOR} = \frac{19.2 \text{ mm}}{24 \text{ mm}} \times 6.8
\]

\[
\text{SLOR} = 5.4 \text{ mm}
\]

We need to increase the length of the scan to correct for the smaller SLOR in the young infant’s eye. For example, to en-

![Figure 4](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933454/)

**Figure 4.** SD OCT images with (A, B) and without (C–F) vignetting from incorrect reference arm length. (A, B) A 6.8 × 6.8-mm volumetric scan of a 38-week PMA infant obtained without reference arm correction, focus, or scan density correction. After reference arm correction, the 10.9 × 10.9-mm scan of a 35-week (C, D) and of a 47-week (E, F) PMA infant show a decrease in vignetting. The SVP demonstrates the loss of peripheral image in (A) compared with when the reference arm is correct (C, E).

![Figure 5](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933454/)

**Figure 5.** Retinal field of view and magnification with SD OCT in an infant. (A–C) The right eye at 8 months; (C) the projection of the SD OCT imaged area on the retinal camera photograph. (D, G) Additional SD OCT imaging of the same eye at 12 months. Left: the SVP retinal image with a selected B-scan in the middle column (corresponding to the green line in the SVP); (A, B) At high magnification, 6.8 × 6.8-mm scan projecting to 5.4 × 5.4-mm scan length on retina (80% of the adult); (D, E) with moderate magnification and wider field of view, a 10.9 × 10.9-mm scan projecting to 8.7 × 8.7-mm scan length on retina; and (F, G) with an even wider field of view, 13.6 × 13.6-mm volumetric scan projecting to 10.9 × 10.9-mm scan length (38°) on the retina. With SD OCT imaging of a large area, the scan area is limited by the pupil and vignetting occurs as in (F).
compass both macula and optic nerve on SD OCT of this infant’s eye (Figs. 5D–G), the lateral scan length was increased based on the reference table (Table 3). Without correction, measurement of lesions based on presumed mm sweep of the OCT system would be incorrect. The SVP images in Figures 5A, 5D, and 5F show a difference in lateral magnification of the retinal structures on SD OCT depending on the scan length. This difference may not be appreciated in observing the B-scans alone.

Although the American National Standards Institute (ANSI) standards for ophthalmic imaging do allow scanning with denser A-scans per B-scan, we elected to perform pediatric imaging using the same scan density as in the adult. If one does not consider the optics of the infant eye, then scan density will be greater in the infant eye. From the conversion table (Table 3) we could easily preset pediatric scan settings as follows:

\[
\text{A-scans/B-scan} = \frac{(\text{Pediatric AXL mm/24 mm}) \times (\text{Scan Length mm}) \times \text{Selected number of A-scans per mm}}{(1000)}
\]

The 30° SD OCT scan spans 8.57 mm of retina in the adult (3.5° per mm) but only 5.39 mm of retina in the 32-week-old PMA infant (Table 3). The density of A-scans per mm of retina would therefore be higher in the infant retina if not decreased to 63% of the adult number.

Impact of Applying Pediatric-Specific Settings

Using these steps to image pediatric eyes with SD OCT (Fig. 6), we scored the ease of operation in three areas: time to scan, orienting from the retinal SVP image, and ability to image the fovea for the 113 sessions. In the NICU group, we captured an SD OCT image in <1 minute in 51% of sessions, between 1 and 2 minutes in 26%, and >2 minutes in 23%. We captured an average of 6.3 ± 3 scan sets per eye, including rectangular volumetric scans in different areas (100 scans per volume) and linear scans. The total NICU session was 15 minutes per subject; thus, the average time per eye was 8 ± 4 minutes. Four subjects in the NICU group had nasal CPAP apparatus; in these cases, we imaged only one eye because of the difficulty in alignment. In the clinic group, an average of 6 ± 3 scan sets were captured per eye and average imaging time for each eye was 7 ± 5 minutes. Imaging sessions in some children extended over 30 minutes. Nystagmus, poor fixation, and movement accounted for prolonged imaging sessions, more commonly in the older children.

These steps have cut the infant imaging time in half by improving ease of operation of SD OCT imaging. Previously, >3 minutes per scan was necessary, with poorer image quality, compared with under 1.5 minutes with the current protocol. It is important to note that the time reported herein is not scanning time over the retina, but total time spent on an imaging session including time for saving scans, repositioning the subject, instilling artificial tears, and giving oral sucrose.

The operator was generally disoriented when viewing the SVP retinal image, because this was either inverted or rotated and inverted (when scanning at 0° or 90°, respectively). We partially overcame this by creating a reference card and placing labels over the screen to mark the SVP image. To improve orientation, we also used the Biopigen system Free Run mode that creates the SVP image in a continuous real-time scanning mode. In squirming infants, one could save a useful scan after it appeared on the screen. Note that, peripheral imaging with our current techniques is limited (Fig. 5). The field of imaging may extend beyond the posterior pole, depending on eye position; however, unlike fundus photographs, it does not provide a peripheral view.

DISCUSSION

Portable SD OCT imaging can now be used to examine infants and young children, such as those with ROP and those requiring examinations under anesthesia. We modified optical parameters to address age-specific optics of the infant eye and to improve SD OCT imaging of very young infants. Retinal SD OCT imaging was tolerated by NICU infants as performed in this study without adverse events.

The fovea was captured 74% of the time in the 113 NICU sessions. Pronounced Bell’s response during sleep or with eye closure and eye or patient movement were the main reasons for failure. The success rate was 87%, in the 59 clinic sessions, with poor fixation, nystagmus, and patient motion as the major obstacles for obtaining a scan centered on the fovea.
Calculations for ophthalmic beam exposure are based on 17-mm secondary focal length of the 24-mm average AXL adult human eye and do not consider the pediatric eye AXL, even though light exposure safety studies on which ANSI standards are based, were performed in Macaca eyes (AXL, 13.1–19.5 mm), which is comparable to very young children.27–29 Published ocular instrument recommendations45 of a task group of the International Commission on Non-ionizing Radiation Protection46 and an ANSI summary with emphasis on ophthalmic devices44 all reference the adult focal length for calculations of exposure. The anterior focal length of the newborn infant eye was calculated to be 11.8 mm,25 and we calculated it to be 10.35 mm in the premature eye. The optics of the pediatric eye will increase the density of SD OCT A-scans beyond that expected from the standard adult settings. To maintain the same density of scanning for the pediatric eyes as in adult eyes, we recommend decreasing the number of A-scans (focal sites imaged) per B-scan, based on AXL.

In pediatric patients, access to the eye may be limited by infant inattention and movement. Thus, it is critical to optimize scan quality in a short capture time. We have demonstrated the importance of customizing SD OCT imaging settings for the pediatric population. Imagers should consider age and optics of the eye when setting imaging parameters for infants and measuring ocular structures. By detecting critical early retinal changes, a customized approach to SD OCT imaging in children may be a valuable adjunct to clinical examination in predicting infant eyes at high risk of vision loss from ROP and other pediatric retinal disorders. This imaging in neonates, infants, and young children could lead to a better understanding of infant retinal development and pediatric retinal diseases and to improved therapeutic decisions in the future.

References


