Measurement of the Limbus-Insertion Distance in Adult Strabismus Patients with Anterior Segment Optical Coherence Tomography

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PURPOSE. To determine the ability of the anterior segment optical coherence tomography (AS-OCT) in measuring the distance from the corneoscleral limbus to the insertion site of the horizontal extraocular muscles in adult patients with strabismus.

METHODS. A total of 16 strabismus patients were recruited for this study. The limbus-insertion distances of the horizontal rectus muscles were measured with AS-OCT preoperatively and calipers intraoperatively. The intraass correlation coefficient (ICC), Pearson’s correlation coefficients, and Bland-Altman plots were used to evaluate the degree of agreement between the two methods of measurements.

RESULTS. Measurements of the limbus-insertion distances were taken on 37 muscles of the 16 patients: 18 medial rectus (MR) and 19 lateral rectus (LR). The mean limbus-insertion distance of MR and LR measured intraoperatively were 5.32 ± 0.44 mm (range, 4.5–6.1 mm) and 6.58 ± 0.53 mm (range, 5.5–7.5 mm). Comparable results measured with the AS-OCT were 5.72 ± 0.60 mm (range, 4.62–6.82 mm) and 6.80 ± 0.61 mm (range, 5.8–7.86 mm). For MR group and LR group, the values of limbus-insertion distance showed high Pearson’s correlation coefficients (0.729 and 0.786, respectively). With the ICC analysis, excellent agreement was observed for the measurements of LR group (ICC = 0.75). Fair to good agreement was observed for the MR group (ICC = 0.61). Bland-Altman plots also showed good agreement between the two methods of measurements.

CONCLUSIONS. AS-OCT can image the structure of horizontal rectus muscles well and provide good reliability and accuracy in measurement of the limbus-insertion distance. (Invest Ophthalmol Vis Sci. 2011;52:8370–8373) DOI:10.1167/iovs.11-7752

The knowledge of the exact limbus-insertion distance of rectus muscles may benefit the calculation of the surgical amount to be performed in strabismus surgery. However, the insertion is invisible in routine ophthalmic examination such as slit lamp biomicroscopy until surgery. Thus, a preoperative technique that could accurately locate the insertion and evaluate the exact limbus-insertion distance may be useful for improving the surgical plan subsequently needed.

A number of techniques have been tried to image the extraocular muscle (EOM) before strabismus surgery. Computed tomography (CT) scans and high-resolution magnetic resonance imaging (MRI) have been used to define the size and location of the EOM. However, these techniques are unable to define the exact EOM insertion and the distances from the limbus. B scan allows anatomic visualization of the EOM and measurement of limbus-insertion distance, but its accuracy is limited by the relatively low image resolution. Several studies have reported that ultrasound biomicroscopy (UBM) can accurately measure the limbus-insertion distance before strabismus surgery, for both primary surgeries and reoperations. However, due to UBM’s contact feature (placing a cup on the ocular surface), it is difficult to perform on children. Moreover, significant measurement errors are often induced by pressing the eyeball during UBM examination.

The newly developed anterior segment optical coherence tomography (AS-OCT; Visante by Carl Zeiss Meditec, Dublin, CA), wavelength in 1310 nm, generates a two-dimensional high resolution image from a reflected light beam. It has faster scanning (minimizes motion artifact), low scattering, and high penetration into turbid tissue such as sclera, iris, angle, and opaque corneas. Nowadays it is employed more and more often in imaging the anterior segment structures of the eye, specifically in anterior chamber biometry, corneal pachymetry mapping, and angle evaluation. Moreover, AS-OCT evaluation is a noncontact examination, which is particularly suitable for children and postoperative examination.

In this pilot study, we have tried to use AS-OCT to image the horizontal EOM and to measure the limbus-insertion distance. The purpose of this study was to determine the ability and the accuracy of AS-OCT in the measurement of the limbus-insertion distance preoperatively in comparison with intraoperative caliper measurements.

METHODS

Subjects

A total of 16 patients (11 exotropia, 5 esotropia; 13 females, 3 males; age range: 19 to 46 years; mean age ± SD: 28.65 ± 8.89 years) undergoing primary strabismus surgery of their horizontal rectus muscles were recruited for the study. Reoperated patients and patients with vertical misalignment or A and V pattern strabismus were excluded from the study to keep the study group as homogenous as possible. Measurements of the limbus-insertion distance were taken on 37 muscles (18 medial rectus [MR] and 19 lateral rectus [LR]). The eyes of each patient underwent measurements of the limbus-insertion distance on horizontal EOM with AS-OCT preoperatively and calipers intraoperatively. All AS-OCT measurements were performed by one operator,
and all intraoperative measurements were performed by one surgeon. Both examiners were masked to the other’s measurements. Informed consent was obtained from all participants after the procedures used in the study were fully explained. The research complied with the tenets of the Declaration of Helsinki. Ethical approval was obtained from the hospital’s research ethics board.

Preoperative AS-OCT Measurements
Before surgery, an AS-OCT scan of the horizon muscles was done (Visante OCT; Carl Zeiss Meditec). The patients were in sitting position. An extension covered a part of the cornea and the insertion of the EOM was scanned by an axial cross-section. In primary-gaze position, the muscle insertion sites were too posterior in relation to the AS-OCT scanning sector to be displayed. Therefore, guided by a fixation light, the patients were required to make a 15° temporal gaze for the MR muscle scanning and to make a 30° nasal gaze for the LR muscle scanning. Such gaze directions allowed the tendinous insertion to fall in the scanning sector of the AS-OCT, so that the posterior face of the insertion becomes visible on AS-OCT images. To obtain a longitudinal scan of the horizontal rectus muscles allowing for a simultaneous visualization from the limbus up to the muscle belly through its insertion or resection, the scanning plane (0°–180°) was oriented parallel to the long axis of the muscle. Five consecutive scans were taken, and the images were saved.

In the cross-section image, the end of the cleft between EOM and sclera was defined as the insertion site (Fig. 1, left). However, the corneoscleral limbus is difficult to determine in AS-OCT images. In our study, it was located by its relation to the easily identifiable anterior chamber angle. Anatomic studies have reported that the iris root (the anterior chamber angle) lies approximately 1.0 mm posterior to the limbus in the horizontal meridian. With the help of the caliper function in the AS-OCT software, we placed the calipers on the perpendicular projection of iris root on the corneoscleral surface and on the muscle insertion site to measure the angle-insertion distance. The actual value of limbus-insertion distance was adjusted by adding an additional 1.0 mm to the angle-insertion distance. Five consecutive readings were taken, and the mean and SD were calculated.

Intraoperative Direct Measurements
During surgery, the muscle was exposed with a squint hook after a conjunctival incision. After dissection of a muscle from the sclera, the distance from the limbus (gray-white line) to the posterior edge of the insertion of the muscle was measured with Castroviejo calipers at the midpoint of the insertion (Fig. 1, right). Three consecutive readings were taken and then the surgery was completed as planned. The mean and SD were calculated with the three measured values.

Statistical Methods
In the present study, the intraoperative surgical calipers measurement was considered the gold standard because of its direct view and measurement. The Pearson’s correlation coefficients, intraclass correlation coefficient (ICC), and Bland-Altman plots were used in the statistical analysis to compare the AS-OCT measurements to the intraoperative surgical caliper measurements of limbus-insertion distance. The ICC represents the proportion of variance in data explained by between-subject differences; the higher the ICC (maximum value, 1.0), the better the agreement between measures of the same subject. The guidelines for interpretation of the ICC used are as follows: an ICC of < 0.40 indicates poor reproducibility; of 0.40 to 0.75, fair to good reproducibility; and of greater than 0.75, excellent reproducibility. In Bland-Altman analysis, the differences between the two methods are plotted against the average values of the two measurements. According to Bland and Altman, if 95% of the differences are within ±1.96 standard deviations of the mean of the differences, then this denotes good agreements between the two sets of measurements. In addition, a clinically acceptable difference of 1.0 mm between the two measurements was defined as a priori for this study, as 1.0 mm recession or resection of horizontal muscles corrects only 1.5° squint and this accuracy was acceptable for surgical purposes. The statistical analysis was done using commercially-available software (Excel, version 2007; Microsoft, Redmond, WA; and GraphPad Prism version 5.01; Graph Pad Software, San Diego, CA). P < 0.05 was considered statistically significant.

RESULTS
All the examined eyes showed good AS-OCT images on anterior segment structures including cornea, sclera, rectus muscle, anterior chamber angle, and iris (Fig. 1). No abnormal muscle attachments were found. The results of the measurements (mean of repeated measurements ± SD) obtained from the study were reported in Table 1.

Table 2 showed the degree of agreement between the two methods using the Pearson’s correlation coefficient and ICC method. The Pearson’s correlative analysis showed a good level of agreement between the two methods. With the ICC analysis excellent agreement was observed for the measurements of LR group (ICC = 0.75) and the MR + LR group.
Fair to good agreement was observed for the MR group (ICC = 0.61). The Bland-Altman plots (Fig 2) showed that a total of 17 of 18 (94%) and 18 of 19 (95%) AS-OCT-caliper differences, were found in the MR group and LR group respectively, to be within the 95% confidence interval of the mean difference. This is an indication of good agreement between the two methods. The AS-OCT appeared to be overestimating the limbus-insertion distance by 0.40 mm in the MR group and 0.22 mm in the LR group compared with surgical reading. In addition, 92% of the measured values (34 of 37) were within the predefined level (1.0 mm) of agreement between the two methods.

### DISCUSSION

The EOM insertion site is generally treated as a reference point in the calculation of the amount of strabismus surgery. However, the insertion site, particularly that of the medial rectus muscle, varies considerably in some strabismus patients, which may result in inaccuracies in determining the site to which the muscle is to be recessed. The present study offers a novel technique to measure the limbus-insertion distance with AS-OCT, which may help to improve the surgical plan for strabismus patients. This method can potentially be used in reoperation of strabismus cases. Because the prior strabismus surgery may alter the insertion points of the muscles and the surgical undercorrection and overcorrection of horizontal tropia are common problems for strabismus surgery, a careful preoperative evaluation is mandatory for the management of such conditions. However, the information regarding prior surgery is sometimes unavailable. The AS-OCT may help to design a surgical plan for reoperation by localization of the displaced EOM insertion.

It is difficult to identify the limbus in AS-OCT images and we use the anterior chamber angle as an alternative landmark for the measurement of limbus-insertion distance. The anatomic studies have reported that the limbus was approximately 1.0 mm anterior to the anterior chamber angle in the horizontal meridian. Tamburrelli et al. used the anterior chamber angle as a reference for the measurement of limbus-insertion distance with B scan. Because the limbus-angle distance is reduced in hyperopic and immature eyes and their study subjects were mainly hyperopic eyes, they chose 0.9 mm as the limbus-angle distance to be used in the calculation of limbus-insertion distance. As our study subjects were mainly adults with emmetropia or myopia, we chose 1.0 mm as the limbus-angle distance. However, because there is variation in the distance between anterior chamber angle and the limbus, the method we applied here may cause a systematic measurement error.

As we know, there are patients with slanting EOM insertions due to congenital abnormality or previous surgery of slanting muscle insertions for correction of A and V pattern strabismus. The slanting insertions cannot be detected by AS-OCT and other conventional examinations until the operative procedure. In practice, we always perform AS-OCT scanning at the horizontal meridian (0°–180°) approximately pass-

### TABLE 1. Limbus-Insertion Distance of EOM Measured by AS-OCT and Calipers at Surgery

<table>
<thead>
<tr>
<th>Parameter</th>
<th>AS-OCT (mm)</th>
<th>Caliper (mm)</th>
<th>Mean (mm)</th>
<th>Difference (mm)</th>
<th>95% Limits of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial rectus (n = 18)</td>
<td>5.72 ± 0.60</td>
<td>5.32 ± 0.44</td>
<td>5.52 ± 0.56</td>
<td>0.40 ± 0.41</td>
<td>-0.41 to 1.21</td>
</tr>
<tr>
<td>Lateral rectus (n = 19)</td>
<td>6.80 ± 0.61</td>
<td>6.58 ± 0.53</td>
<td>6.69 ± 0.58</td>
<td>0.22 ± 0.38</td>
<td>-0.53 to 0.96</td>
</tr>
<tr>
<td>Total (MR + LR) (n = 37)</td>
<td>6.27 ± 0.81</td>
<td>5.97 ± 0.80</td>
<td>6.12 ± 0.81</td>
<td>0.31 ± 0.40</td>
<td>-0.48 to 1.09</td>
</tr>
</tbody>
</table>

Data are shown as mean ± SD.

### TABLE 2. Level of Agreement between Two Methods by Pearson’s Correlation Coefficient and Intraclass Correlation Coefficient

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Pearson’s Correlation Coefficient</th>
<th>Intraclass Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>P</td>
</tr>
<tr>
<td>Medial rectus (n = 18)</td>
<td>0.729</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lateral rectus (n = 19)</td>
<td>0.786</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Total (MR + LR) (n = 37)</td>
<td>0.875</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

### FIGURE 2. Bland-Altman plots. The differences between AS-OCT measurements and intraoperative readings (AS-OCT reading minus surgical reading) are plotted against the mean of the two distance measurements.
ing through the midpoint of the insertion. Accordingly, we measure the limbus-insertion distance at the midpoint of the insertion with calipers intraoperatively. This strategy ensures the same location for measurement with the two methods even for a muscle with slanted insertion, so long as the muscle lies along the horizontal meridian. However, the horizontal EOM of the A or V pattern strabismus patients sometimes insert sclera above or below the usual positions and the long axis of the muscle is not exactly at the horizontal meridian. 22 For such patients, the AS-OCT scanning plane cannot align to the midpoint of the insertion and measurement errors are inevitable. In addition, one cannot differentiate between normal insertion and abnormal adherence of EOM from the AS-OCT images. These problems should be taken into account for the measurement errors.

In the present study, the statistical analysis demonstrated that the AS-OCT measurement was significantly correlated with the intraoperative measurement by surgical calipers. The LR group showed a better agreement than the MR group, as ICCs and Pearson’s correlation coefficients of the LR group were higher than those of the MR group. This may be due to the different anatomic characteristics between the MR and the LR. As the MR inserts the sclera more anteriorly than LR, an oblique gaze during AS-OCT examination may cause the MR to be more closed to sclera than LR and the insertion sites are more difficult to define in the MR group. Hence, the measurement errors are more common in the MR group.

Our study also showed that there was a trend that the AS-OCT slightly overestimated those measured with calipers at surgery. An important reason is that the insertions of rectus muscles tend to creep toward the limbus when the tendons are disinserted. 20, 25 In addition, the use of a muscle hook to separate the muscle during surgery can result in an anterior displacement of the posterior edge of the insertion. These will cause an underestimation of the limbus-insertion distance measured by calipers. Contrarily, an oblique gaze during AS-OCT examination may cause the muscles close to sclera, which makes the posterior face of the insertion difficult to identify in AS-OCT images and a posterior displaced illusion of the insertion is common. Therefore, a small gaze angle of the examined eye should be required during the AS-OCT examination to reduce the measurement error. As discussed above, the MR tends to be influenced by oblique gaze more easily than the LR. Thus, we usually choose a temporal 15° gaze for MR whereas a nasal 30° gaze for LR in AS-OCT examination. Although the AS-OCT slightly overestimated the limbus-insertion distance measured with calipers at surgery, the difference was not statistically significant.

It should be noted that the statistical analysis of the present study might be disputed due to the relatively imprecise measurement of the surgical calipers. In the measurement of limbus-insertion distance, the AS-OCT can be resolved to the nearest 0.01 mm whereas the caliper can only be resolved to the nearest 0.5 mm. Although the statistical analysis showed a high degree of agreement between the two methods, the validation is somewhat uncompromised by the caliper standard provided here. Therefore, other methods with high precision such as UBM and B scan may further validate the accuracy of AS-OCT in measurement of limbus-insertion distance. Nevertheless, the present study demonstrated that the AS-OCT could provide an unprecedented visualization of the insertion site of the stripe muscle in vivo, and the results supported a reasonable level of concordance between the AS-OCT and intraoperative measurements of limbus-insertion distance. This makes the AS-OCT an ideal instrument for measuring limbus-insertion distance of EOM in vivo. It suggests a potential use of the AS-OCT in the diagnosis of EOM diseases and preoperative evaluation of patients with strabismus.

References