INTRODUCTION

Strabismus has been reported to affect approximately 2% to 5% of the preschool population. Strabismus surgery is often required to correct the ocular misalignment. It can be advantageous in many situations (reoperations, complex strabismus, and unknown previous surgery) to know the location of the extraocular muscles prior to surgery so that an appropriate approach can be better formulated. Many different techniques have been used to image the extraocular rectus muscles, but the ability to accurately image the extraocular rectus muscle insertions may have future implications for the preoperative procedure planning in patients who have had previous surgery.

ABSTRACT

Purpose: To assess the possibility of determining the insertion distance from the limbus of horizontal and vertical extraocular rectus muscles with anterior segment optical coherence tomography (AS-OCT).

Methods: The right eyes of 46 patients underwent AS-OCT. The horizontal and vertical extraocular rectus muscle insertion distances from the limbus were measured in a masked fashion by two pediatric ophthalmologists.

Results: Forty-two lateral rectus, 43 medial rectus, 35 inferior rectus, and 40 superior rectus muscles of the right eyes of 46 patients were included. Insertion to limbus measurements (mean ± SD) were as follows: lateral rectus = mean 6.8 ± 0.7 mm, range = 4.8 to 8.4 mm; medial rectus = mean 5.7 ± 0.8 mm, range = 4.3 to 7.8 mm; inferior rectus = mean 6.0 ± 0.6 mm, range = 4.8 to 7.0 mm; superior rectus = mean 6.8 ± 0.6 mm, range = 5.5 to 8.1 mm. The intraobserver and interobserver correlation coefficients for the insertion to limbus measurements of all four rectus muscles exceeded 0.75 (excellent correlation).

Conclusions: The study showed that AS-OCT is capable of imaging all four of the rectus muscle insertions and measuring the insertion to limbus distance, and is the second AS-OCT study to image the superior and inferior rectus muscle insertions. The insertion to limbus measurements between examiners and on repeat measurements were consistent and reproducible. The ability to accurately image extraocular rectus muscle insertions may have future implications for the preoperative procedure planning in patients who have had previous surgery.

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muscles and their insertions: computed tomography, magnetic resonance imaging (MRI), B-scan ultrasonography, and ultrasound biomicroscopy.\(^2\text{-}^{17}\)

Radhakrishnan et al. first reported the use of anterior segment optical coherence tomography (AS-OCT) to image extraocular rectus muscle insertions.\(^18\) In 2011 and 2014, Liu et al.\(^19\) and Park et al.\(^20\) measured the insertion distances of horizontal extraocular muscles with Visante AS-OCT (Carl-Zeiss Meditec, Dublin, CA). Liu et al. used patients undergoing strabismus surgery and demonstrated strong correlations between intraoperative measurements and preoperative AS-OCT measurements of the distances from insertions of horizontal rectus muscles to the limbus.\(^19\) Park et al. studied the insertions and the distances from insertions to the limbus of horizontal rectus muscles in different positions of gaze and showed that insertion points did not change with different gaze positions.\(^20\) Salcedo-Villanueva et al. imaged the horizontal extraocular muscles and measured the lengths of tendons and thickness of the muscles, conjunctival epithelium, sclera, and Tenon’s capsule.\(^21\) These studies did not measure the superior and inferior rectus muscle insertions and the measurements of the insertions were taken from an arbitrary calculated limbus, from either the anterior chamber angle or scleral spur. The study by Ngo et al. is the only one to date that has imaged the extraocular rectus muscles with AS-OCT in a pediatric population, re-operated muscles, and imaged the vertical rectus muscles.\(^22\)

The goal of the current study was to evaluate the use of the Heidelberg AS-OCT to image extraocular rectus muscle insertions and to expand the use of AS-OCT to also image vertical rectus muscles. We also evaluated the interexaminer and intraexaminer repeatability of horizontal and vertical extraocular rectus muscle insertion distance measurements to the anatomical limbus as imaged by AS-OCT.

**PATIENTS AND METHODS**

The current study included the right eyes of 46 patients without strabismus with ages ranging from 21 to 79 years (mean ± SD: 40.8 ± 17.2 years). Our exclusion criteria included refractive errors greater than -6.00 and +3.00 D, previous strabismus surgeries, myasthenia gravis, thyroid ophthalmopathy, and any other extraocular rectus muscle-related diseases and syndromes. The study had approval from the University at Buffalo Institutional Review Board and conformed to the requirements of the United States Health Insurance Portability and Privacy Act. All patients signed informed consent forms.

Spectralis HRA+OCT with Anterior Segment Module (Heidelberg Engineering, Heidelberg, Germany) was used for the study with a wavelength of 870 nm superluminescent diode laser, transverse resolution of 11 µm, axial resolution of 3.9 µm, penetration depth of 1.9 mm, and a scan width of 16.6 mm. The AS-OCT imaged the lateral rectus, medial rectus, inferior rectus, and superior rectus muscles (Figure 1). The settings on the AS-OCT were IR+OCT, scleral for application/structure, enhanced depth imaging, and multiple scan setting. The ART frames were at 5 and the length of the scan was set to 30° × 3° (7 sections) for horizontal muscles and 30° × 1° (3 sections for vertical muscles). The fixation light on a mobile arm mounted on the AS-OCT was used to have patients look in different gaze positions to image the muscle insertions.

Seven consecutive images were obtained of the horizontal rectus muscle insertions starting from the inferior pole to the superior pole. The lateral rectus muscle insertion was imaged with the patient in abduction and the camera arm rotated temporally. The medial rectus muscle insertion was imaged with the patient in abduction and the camera arm rotated nasally. Three consecutive images were captured of the vertical rectus muscle insertions going nasally to temporally. The superior rectus muscle was imaged with the patient in infraduction and the camera arm rotated superiorly. The inferior rectus muscle was imaged with the patient in supraduction and the camera arm rotated inferiorty. Only 3 images were taken for the vertical rectus muscles versus 7 for the horizontal muscles and their insertions: computed tomography, magnetic resonance imaging (MRI), B-scan ultrasonography, and ultrasound biomicroscopy.\(^2\text{-}^{17}\)

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Seven consecutive images were obtained of the horizontal rectus muscle insertions starting from the inferior pole to the superior pole. The lateral rectus muscle insertion was imaged with the patient in abduction and the camera arm rotated temporally. The medial rectus muscle insertion was imaged with the patient in abduction and the camera arm rotated nasally. Three consecutive images were captured of the vertical rectus muscle insertions going nasally to temporally. The superior rectus muscle was imaged with the patient in infraduction and the camera arm rotated superiorly. The inferior rectus muscle was imaged with the patient in supraduction and the camera arm rotated inferiorty. Only 3 images were taken for the vertical rectus muscles versus 7 for the horizontal
rectus muscles due to the increased difficulty of patients maintaining proper positioning for the vertical muscles. The imaging of all 4 rectus muscles in one patient took approximately 10 minutes. Patients needed to be able to place their chin and forehead against the rests and sustain the desired gaze position for the duration of imaging of each rectus muscle, which took approximately 30 seconds to 1 minute. Of the images acquired, the highest quality image, as determined by the first interpreting pediatric ophthalmologist (MSP), was selected to measure the distance from the limbus to the muscle insertion.

The extraocular rectus muscle insertion to limbus distance was defined as the distance from the most anterior point of insertion of the extraocular rectus muscle to the posterior anatomical limbus. The limbus was marked on a digital external color photograph of the eye taken by the AS-OCT and automatically transferred to the cross-section image using a digital cursor (Figure 2). All images were obtained by a single, experienced ophthalmic photographer.

Measurements were taken using digital calipers integrated in the AS-OCT software by two independent examiners (MSP and JDR) and measurements of the same image repeated at least 1 week apart. To assess the reproducibility of measurements between and within the examiners, we calculated intraobserver correlation coefficients and interobserver correlation coefficients. The statistical analysis was done using SPSS for Windows software (version 2011; SPSS, Inc., Chicago, IL).

**RESULTS**

Forty-two lateral rectus, 43 medial rectus, 35 inferior rectus, and 40 superior rectus muscles of the right eyes of 46 patients were included. All four rectus muscles could not be captured in all 46 patients due to various reasons, including: poor image quality (n = 6), positioning not allowing for the muscle and limbus to be captured in the same image (n = 17), and conjunctival scarring (n = 1). Muscle insertions to limbus measurements are shown in Table 1.

The intraobserver and interobserver correlation coefficients for the four rectus muscles’ insertion distances to limbus measurements all exceeded 0.75, showing an excellent correlation (Table 2).

**DISCUSSION**

Many techniques have been used for imaging extraocular rectus muscles, such as computed tomography, MRI, B-scan ultrasound, and ultrasound...
bimicroscopy. These imaging methods have been used to image the extraocular rectus muscles and detect related diseases, such as tumors, inflammation, trauma, vascular malformation, infections, and Graves’ ophthalmopathy. It is often impractical to use MRI or computed tomography for imaging extraocular rectus muscle insertion points due to cost, time, and resolution. Also, computed tomography and MRI can be difficult to perform in certain patients due to claustrophobia, and the pediatric age group often requires sedation, including general anesthesia. Furthermore, the radiation associated with computed tomography is another hazard that should be considered before imaging. Whereas MRI and computed tomography can show orbital pathology, including the whole length of the muscle, extraocular rectus muscle thickness, the pulleys, and orbital bones, when extraocular rectus muscle insertion points are needed, these can be obtained by a less invasive, less costly, and higher-resolution AS-OCT.

B-scan ultrasound, as shown by Tamburelli et al., can also be used to image extraocular rectus muscles but has limitations, such as poor resolution. Although ultrasound biomicroscopy has better resolution than ultrasonography, it can be a time-consuming and difficult procedure on uncooperative patients, such as the pediatric age group, unless they are sedated. Complications such as corneal abrasions can also be seen after the procedure. In addition, Garcia et al. showed that corneal and scleral images of the B-scan and ultrasound biomicroscopy have poorer quality because of their low resolution compared to OCT.

The Heidelberg AS-OCT uses an 11 µm transverse resolution and 3.9 µm axial resolution, which provides better image resolution compared to computed tomography, MRI, B-scan ultrasonography, or ultrasound biomicroscopy. Additional advantages of the AS-OCT include reduced time, reduced cost, and the ability to perform the study on cooperative pediatric patients while they are awake. Our study also demonstrated good reliability of the measurements for horizontal and vertical muscles both compared between two examiners and close to the generally accepted insertion values. Furthermore, our study showed good reproducibility using the Heidelberg AS-OCT because the same examiner was able to consistently relocate the muscle across time.

However, the Heidelberg AS-OCT is not without limitations. There can be an ambiguous transition from muscle tendon to sclera or Tenon’s capsule, making it difficult to determine the exact point of insertion in cross section. This was the case in 6 of 167 scans. The exact insertion point could be determined in most cases, but if difficult, it could be approximated within a millimeter—a difference that may be clinically insignificant. This limitation may be improved with newer, higher-resolution techniques. Other limitations of AS-OCT include the inability to image the oblique muscles or posterior portions of the extraocular rectus muscles.

The Visante AS-OCT, which was used in the studies conducted by Liu et al., Park et al., and Ngo et al., has an axial resolution of 18 µm and a transverse resolution of 60 µm. Although the Visante AS-OCT has better resolution, further studies need to be conducted to compare the actual extraocular rectus muscle images acquired between Visante and Heidelberg AS-OCT. The Heidelberg AS-OCT has the advantage of a mobile camera arm, which makes imaging acquisition over the extraocular rectus muscles easier while the patient is looking in various positions of gaze. The Heidelberg AS-OCT also has the ability to capture multiple images along the entire width of the insertion, which may be able to identify insertions abnormalities preoperatively or postoperatively (slanted insertions, central sag, and partial tenotomies, among others).

Limitations of the current study include the inability to determine insertion points on a few images due to poor quality. In addition, the patients were all adults without strabismus or previous strabismus surgery. To make imaging the extraocular rectus muscles using Heidelberg AS-OCT more applicable in the clinical realm, further studies need to evaluate its use in the pediatric population, in patients with previous strabismus surgery, and previous extraocular rectus muscle pathology. Intraoperative comparison would also be useful. Images may be more difficult to obtain in the pediatric population and patients may have insertions that are more difficult to identify postoperatively. Ngo et al. were successful in obtaining images in both populations. Our current studies on pediatric patients and reoperated muscles are currently being conducted with promising early results (unpublished data). To date, we have been able to image patients as young as 5 years.

The Heidelberg AS-OCT is capable of imaging all four of the rectus muscle insertions. The study also demonstrated excellent intraexaminer and in-
Further studies on patients with previous surgery, younger patients, and patients in whom we can correlate the AS-OCT findings to intraoperative findings will be useful.

REFERENCES


