Elasticity of horizontal rectus muscles in children with esotropia and exotropia
In-vivo shear-wave elastography study

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ABSTRACT

Purpose: To get quantitative data about elasticity of the lateral and the medial rectus muscles by using shear wave elastography and to compare the data obtained from children with strabismus and age-matched controls.

Materials and Methods: This cross-sectional study involved 106 eyes from 53 subjects. Group 1 included subjects with accommodative refractive esotropia (n=19), Group 2 included subjects with convergence insufficiency-type exotropia (n=16) and age-matched controls (n=18). Ophthalmologic examination and shear wave elastography were performed to all participants. The mean stiffness values of the medial and the lateral rectus muscles were obtained. The datas compared between groups. Also, any correlation between muscle stiffness and age, gender, muscle diameter, deviation angle and near point of convergence was investigated.

Results: The mean age of all subjects was 9.5 years (range 4-18 years). The mean stiffness value of the medial rectus muscles was 6.6±2.2 kPa in Group 1, 8.9±3.5 kPa in Group 2 and 9.4±3.4 kPa in control eyes. Statistically significant lower rigidity (higher elasticity) was found in the medial rectus muscles in Group 1. The mean stifness value of the lateral rectus muscles was 7.3±3.2 kPa in Group 1, 7.8±2.4 kPa in Group 2 and 9.1±2.9 kPa in controls. No significant difference was found between groups. The deviation angle showed a significant correlation with the mean stiffness values of the medial and lateral rectus muscles.

Conclusions: Medial rectus muscles may have greater elasticity in children with accommodative esotropia compared children with convergence insuffiency and healthy controls. Future studies are needed to establish normative data.

Keywords: convergence insufficiency, medial rectus muscle, lateral rectus muscle, shear wave elastography, stiffness

INTRODUCTION

Shear-wave elastography (SWE) is an ultrasonographic imaging modality which displays the elastic properties of tissues and calculates tissue stiffness.[1-2] The history of elastography dates back to the early 1980s; the name of the method was coined by Ophir et al. in 1991.[3] Although SWE is being used with increasing frequency across medical departments, in ophthalmology, the limited published studies reported data about corneal stiffness, peripapillary structures in patients with glaucoma and optic nerve stiffness in idiopathic intracranial hypertension. [4-8]

In the literature, there are two studies that revealed the stiffness of extraocular muscles. [9-10] Those studies conducted in patients with thyroid-associated orbitopathy and healthy controls. The aim of the present study was to determine the elasticity properties of the lateral and medial rectus muscles in children with accommodative esotropia and convergence insuffiency-type exotropia and to compare these parameters between patients and controls. To the best of our knowledge, the use of SWE to evaluate elasticity or stiffness of the horizontal rectus muscles in children with esotropia and exotropia has not been studied previously.

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MATERIALS AND METHODS

This study was conducted in the Bakırköy Dr. Sadi Konuk Training and Research Hospital, Istanbul, between December 2019 and December 2021. The study was approved by the ethics committee of Bakırköy Dr. Sadi Konuk Training and Research Hospital and adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from all patients. The study included 19 children with accommodative esotropia (Group 1), 16 children with exotropia of the convergence insufficiency type (Group 2), and 18 healthy controls, totaling106 eyes.

All subjects were recruited randomly from patients who had been followed up at least 1 year in our pediatric ophthalmology department. A comprehensive ophthalmological examination, including eye movements, deviation angle (prism diopter) and near point of convergence (NPC) was recorded. Patients who had any limitations of eye gaze, had undergone any ocular surgery or had a neuromuscular disorder were not inclueded.

A week after, an experienced radiologist in SWE who was blind to the clinical information of the subjects, performed elastographic evaluations under standard conditions (D.B). All examinations were performed with a Toshiba Applio 500 ultrasound machine (Toshiba, Japan) equipped with a 7.5-10 MHz linear transducer probe. The method of transpalpebral examination (via closed eyelids) was used on all patients in a supine position. The probe was placed perpendicular to the corneal limbus, the control signal of the probe in the direction toward the cornea.[11] Using this method, each horizontal rectus muscle is displayed longitudinally. The elasticity of the medial and lateral rectus muscles was measured outside of the tendon area which has physiologically higher echogenicity, to avoid distorted interpretation of the results. Each of the muscle was always measured in the primary position of the globe and perpendicular to the axis of the muscle. An adjustable rectangular electronic box (region of interest), which was automatically provided by the system software, was placed on the elastogram screen. The electronic box displayed the tissue stiffness in kilopascals (kPa) in real-time using a chromatic scale (spectrum from blue to red) indicating low to high shear modulus (Figure 1). At the same time, the diameter of the muscle, corresponding to its thickness, was measured.

SPSS (Statistical Package for the Social Sciences) 23 was used for data analysis. Data were expressed as the mean ± standard deviation. The distribution of groups was analyzed using the Kolmogorov-Smirnov test. An independent *t*-test was used to analyze the normally distributed data. The Mann-Whitney *U*-test was carried out to evaluate abnormally distrubuted data. The Spearman correlation test was applied to evaluate the relationship between SWE values and age, gender, deviation angle, muscle diameter and NPC. A P value of < 0.05 was considered statisfically significant.

RESULTS

A total of 106 eyes from 53 children were included in this study. The mean age of all subjects was 9.5 (range 4-18 years). Group 1 included patients with esotropia (n=19), Group 2 included patients with exotropia (n=16) and Group 3 included healthy subjects (n=18). The demographical and clinical characteristics of the subjects are summarized in Table 1.

The mean stiffness value of the medial rectus muscles was 6.6±2.2 kPa in Group 1, 8.9±3.5 kPa in Group 2 and 9.4±3.4 kPa in the control eyes. Lower rigidity (higher elasticity) was found in the medial rectus muscles in patients with esotropia when compared with patients with exotropia and controls. This difference was found significant statistically (P= 0.02 and P=0.01 respectively) (Table 2)

The mean stifness value of the lateral rectus muscles was 7.3±3.2 kPa in Group 1, 7.8±2.4 kPa in Group 2 and 9.1±2.9 kPa in controls. When Group 1 and Group 2 were compared, no significant difference was found (P=0.5). The difference between Group 2 and controls was also not significant (P= 0.4) (Table 2).

The mean diameter of the lateral and medial rectus muscles are shown in Table 2. No significant differences were found between groups.

In correlation analysis, the mean stiffness values of the medial and lateral rectus muscles showed a significant correlation with the deviation angle (P=0.03, P=0.04, respectively). No significant correlation was found between muscle stiffness and age, gender or muscle diameter . We also evaluated the correlation between NPC and muscle stiffness, but no significant relationship was found (Table 3).

Table 1. *Demographic and Clinical Parameters of Groups*

	Group 1 (n=19)	Group 2 (n=16)	Control (n= 18)
Age (years) (mean±SD) (range)	8.5 ±4.0 (4-18)	8.1±3.8 (4-17)	12.1 ±3.0 (7-17)
Gender male female	9 10	8 8	9 9
Deviation angle (PD) (mean±SD) (range)	11.8 ±6.4 (4-25)	14.5 ±6.1 (6-30)	0
NPC(cm) (mean±SD)(range)	7.4± 1.3	19.3 ±4.8	8.16 ± 1.2

(SD, standard deviation PD, prism diopter; NPC, near point of convergence)

Table 2. *SWE findings of the lateral and the medial rectus muscles of groups*

	Group 1 (n=19)	Group 2 (n=16)	Control (n=18)	Group 1 vs. Group 2	*P* Group 1 vs. Control	Group 2 vs. control
Medial rectus SWE (kPa) (Mean ± SD)	6.6 ± 2.2	8.9 ± 3.5	9.4 ± 3.4	0.02*	0.01*	0.53
Lateral rectus SWE (kPa) (Mean ± SD)	7.3 ± 3.2	7.8 ± 2.4	9.1 ± 2.9	0.51	0.12	0.43
Medial rectus diameter (mm) (Mean ± SD)	2.3 ±0.4	2.4 ± 0.5	2.3 ±0.4	0.79	0.65	0.52
Lateral rectus diameter (mm) (Mean ± SD)	2.5 ± 0.6	2.6 ± 0.6	2.4 ± 0.5	0.58	0.43	0.18

(SWE, shear wave elastography value; kPa, kilopascal; SD, standard deviation)
*Mann Whitney *U*-test; Student *t*-test

Table 3. *Correlation analysis between muscle stiffness values and patient's age, gender, deviation angle, muscle diameter and NPC*

	age	gender	deviation	Dia of MR	Dia of LR	NPC (cm)
Lateral rectus SWE P N	 0.27 106	 0.58 106	 0.04* 106	 -	 0.24 106	 0.12 106
Medial rectus SWE P N	 0.23 106	 0.96 106	 0.03* 106	 0.46 106	 -	 0.11 106

Dia, diameter; *MR*, medial rectus muscle; *LR*, lateral rectus muscle; *NPC,* near point of convergence; *SWE,* shear wave elastography value
*Spearman Correlation Test

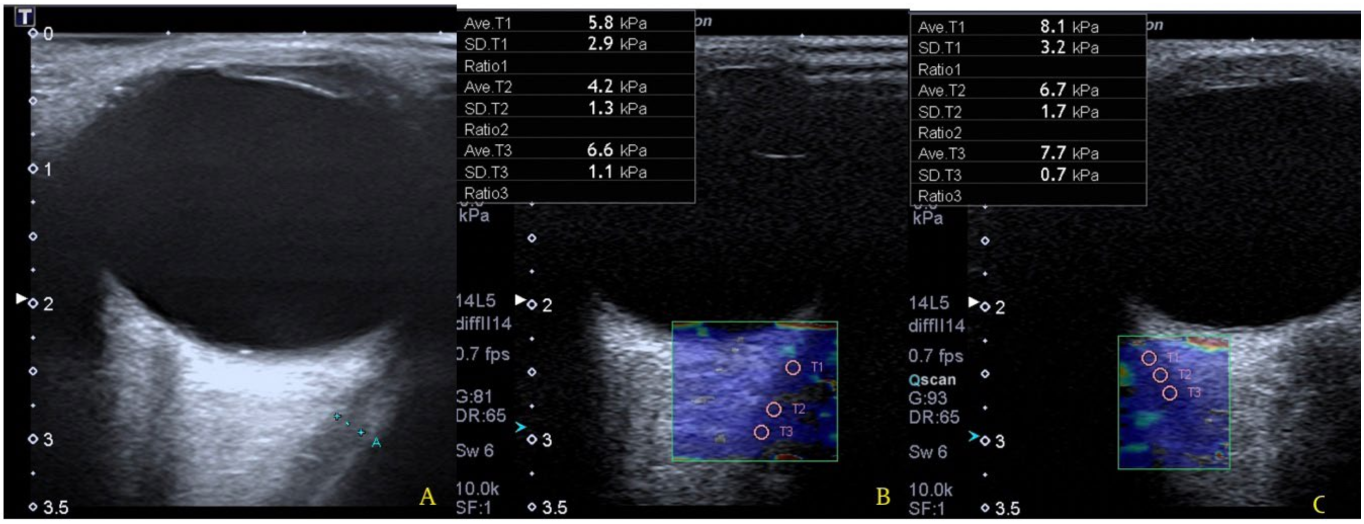

Figure 1. *The image of grayscale sonography and elastogram screen. A, the lateral and medial rectus muscle on grayscale sonography; B, the medial rectus muscle of the right eye on elastogram screen; C, the lateral rectus muscle of the right eye on elastogram screen.*

DISCUSSION

This is the first study that demonstrated extraocular muscles evaluated by SWE in children with strabismus to our knowledge. Quantitative results regarding the stiffness value of the medial and the lateral rectus muscles were obtained in pediatric patients for the first time. The study demonstrated that the medial rectus muscles had lower stiffness values (higher elasticity) in accommodative esotropia patients when compared with those with convergence insuffiency-type exotropia patients.

In a study conducted by Zemanova et al., the mean SWE value of the medial rectus muscle was reported 20.5 ±3.6 kPa and the mean SWE value of the lateral rectus muscle 20.2±1.7 kPa in healthy controls.[9] In our study, we found 9.4±3.4 kPa for the medial rectus and 9.1±2.9 kPa for the lateral rectus in healthy children. Zemanova et al. included the patients aged between 25 and 75 years. We believe that the difference in results depends on the older population in their study, suggesting that younger children may have greater elasticity in the horizontal rectus muscles.

Over-convergence associated with accommodation to overcome a hyperopic refractive error leads to the development of esotropia in children with accommodative esotropia.[9] It is expected that over-convergence may increase the tone of the medial rectus muscle. However, our SWE results obtained showed that the stiffness value of the medial rectus muscle in Group 1 was lower than in Group 2 and the controls. This indicates that children with accommodative esotropia have more elastic (less rigid) medial rectus muscles compared with children with exotropia or no deviation. We suggest that medial rectus elasticity may increase because the muscle is not continuously contracted in accommodative esotropia.

Convergence insufficiency (CI) is characterized by a reduced ability to converge the eyes and maintain binocular fusion while focusing on a near target.[12] Although the exact disease mechanism that causes CI remains unknown, neurological centers controlling convergence eye movements have been identified.[13-15] Any deficiency in these neurological centers may lead to convergence insuffiency. However, it remains unclear whether structural abnormalities of the medial rectus muscles are involved. According to our SWE results, children with CI had stiffness values of the medial rectus muscle similar to those of healthy controls, suggesting no changes in the elastic properties of the medial rectus muscles in CI.

We didn’t find any correlation between age and muscle stiffness values. The reason may be that our study group and control included children of similar ages. Likewise, no correlation was detected between gender and muscle stiffness. However, we found that as the deviation angle increased, the stiffness values of both the medial and lateral rectus muscles also increased. Detorakis et al. reported that medial and lateral rectus muscle stiffness was higher in adduction or abduction compared with the primary position in their study conducted on five patients aged 22-75 years.[10] The correlation between deviation angle and muscle stiffness in our study may be explained by the constant primary position of the globe.

SWE is a convenient and non-painful technique. Although some children in our study group were reluctant to assume the supine position, the absence of pain and the short duration of the procedure prevented any difficulties in its application.

There are several studies in ophthalmology have applied SWE. In an experimental study with rabbits, the authors concluded that corneal tissue exhibited higher stiffness after cross-linking (CXL) and suggesting SWE as an efficient way to monitor the local efficacy of CXL.[7] Dikici et al. demonstrated that patients with glaucoma had higher stiffness values in the peripapillary region compared with healthy controls.[8] Another study showed that patients with idiopathic intracranial hypertension had higher stiffness values of the optic nerve compared with healthy volunteers. [16] To the best of our knowledge, there are no reports on the stifness properties of extraocular muscles in children using SWE, and no previous studies have examined muscle stiffness in patients with strabismus. On the other hand, the lack of prior studies is a limitation of our research, as we couldn't compare our data with existing literature.

A second limitation is that we performed SWE only in the resting position and didn't obtain a stiffness measurements during muscle contraction. Also, the mean age of control group was slightly higher which can be a confounding factor. Nevertheless, we demonstrated for the first time that quantitative measurement of horizontal rectus muscle stiffness is possible in children. The technique was simple, low-cost and also feasible for pediatric patients. It may be preferable in various extraocular movement disorders, especially those that change over time. Future studies are needed to establish normative data and to evaluate its use in different clinical situations.

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