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ORIGINAL ARTICLE

Evaluation of iliopsoas tendon using shear wave elastography after open reduction surgery for developmental dysplasia of hip

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ABSTRACT

Objectives: The aim of this study was to investigate the wholeness, thickness, and elastography measurements of the iliopsoas tendon using shear wave elastography who underwent open reduction surgery for unilateral developmental dysplasia of the hip.

Patients and methods: Between January 2011 and December 2016, a total of 15 patients (2 males, 13 females; mean age: 24.6±26.3 months; range, 3 to 98 months) who underwent surgical treatment for unilateral DDH were retrospectively analyzed. In addition to demographic data, clinical findings such as muscle strength, range of motion, and the presence of limping were recorded. Ultrasound elastography was used to examine the thickness, shear wave velocity and elasticity of the iliopsoas tendons.

Results: The mean follow-up was 92.6±30.2 (range, 44 to 120) months. Full range of motion of the hips was observed in all patients. Hip flexor muscles' strength was 5/5 in bilateral. No hip dislocation or limping was not detected in any of the patients. Ultrasound examinations revealed that tenotomized iliopsoas tendons were intact in all patients. The mean muscle thickness was lower in operated sides, indicating no statistically significant difference. The mean velocity and elasticity were statistically significantly higher in the operated sides.

Conclusion: This is the first study using shear wave ultrasonography for iliopsoas tenotomy of the patients underwent open reduction for developmental hip dysplasia. Re-adhesion of the iliopsoas tendons provided wholeness while healing as a more rigid and thinner structure compared to the intact sides.

Keywords: Elastography, hip dysplasia, iliopsoas, tendon healing.

Developmental dysplasia of the hip (DDH) is an orthopedic problem with an incidence of 1.5 to 25 per 1,000 live births.[1] Since it may lead to early hip osteoarthritis when left untreated or when treatment is delayed, DDH is among the preventable causes of disability in childhood, adolescence, and young adulthood.[2-4] Depending on the age of diagnosis, it can be treated with conservative methods such as Pavlic bandages and closed reduction and, sometimes, surgical procedures such as open reduction in advanced ages or pelvic osteotomies. The iliopsoas muscle is among the primary flexors of the hip. The iliopsoas tendon prevents the reduction of the hip joint by obliterating the hip joint capsule from the front (hourglass effect) in DDH. Therefore, the iliopsoas tendon must be tenotomized in all surgical procedures.[1,5] Radiological studies on the status of the iliopsoas tendon after DDH surgery are very limited.[6-8]

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Hip ultrasound (US) is a radiological examination used for DDH screening, particularly in the first three months of life. Elastography, on the other hand, is a low cost, fast, non-invasive US-based application that allows quantitative evaluation of the properties of soft tissues, such as stiffness and flexibility.[9-13] Although there are several different elastography techniques, the most commonly used techniques sonoelastography, real-time elastography and shear wave, also known as real-time elastography. Shear wave elastography (SWE) is an objective method that quantitatively interprets muscle and tendon structures independently from the radiologist.[14]

Patients with DDH who undergo surgical reduction are routinely applied iliopsoas tenotomy, and no repair procedure is performed after tenotomy. Postoperative follow-up is managed only with X-ray and physical examination, and the integrity or function of the iliopsoas is not routinely investigated. There are only three studies in the relevant English literature regarding the postoperative outcomes of iliopsoas, and none of them have used elastography.

In the present study, we aimed to investigate the wholeness, thickness, and elastography measurements of the iliopsoas tendon compared to the unoperated side in patients with DDH undergoing open reduction.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Selçuk University Faculty of Medicine, Department of Orthopedics and Traumatology between January 2011 and December 2016. Patients who had neuromuscular diseases such as cerebral palsy (CP), arthrogryposis, spina bifida, bilateral dislocations, and revision cases were excluded from the study. A total of 15 patients (2 males, 13 females; mean age: 24.6±26.3 months; range, 3 to 98 months) who underwent combined surgical treatment (such as open reduction, open reduction with femoral shortening, open reduction with iliac osteotomy or combination of these procedures) in one session for unilateral DDH were included in the study. In addition to demographic data, clinical findings such as muscle strength, range of motion, and the presence of limping were examined in all patients. Ultrasound elastography was performed by a single radiologist who was experienced in elastography to examine iliopsoas tendons of both sides in all cases.

SWE technique

All elastography measurements were made by the same pediatric radiologist who had over five years of elastography experience. The SWE evaluations were performed using an AplioTM 500 Platinum US device (Canon Medical Systems Co. Ltd., Otawara Tochigi, Japan) and a high-frequency linear probe that was set to small parts preset (frequency range, 5 to 14 MHz). Thickness was measured on the gray scale (Figure 1). Ultrasound examinations were performed with the children laying down calm and motionless. Measurements of the iliopsoas tendon were made in the longitudinal plane on both sides. Tendon stiffness was measured randomly from three different locations and average of these

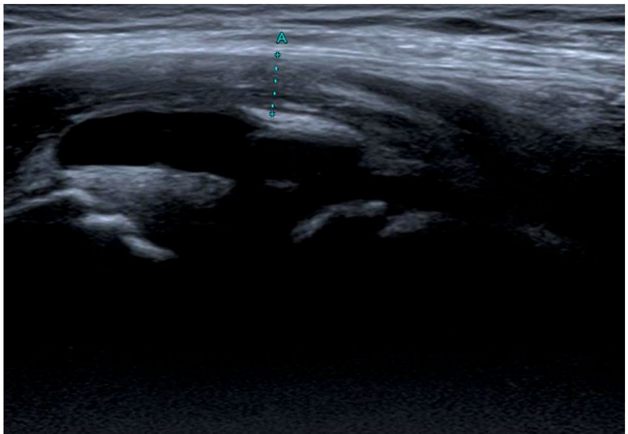

FIGURE 1. Iliopsoas tendon thickness measurement on the gray scale.

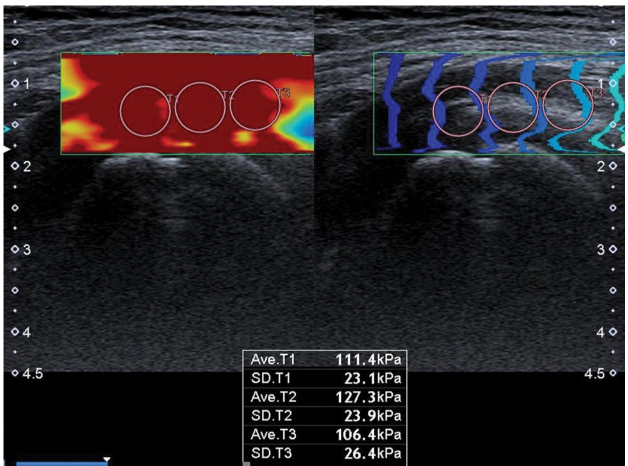

FIGURE 2. An example of shear wave elastography measurement of the Iliopsoas tendon. The 2D-SWE map (left side) and quality mode (right side) are shown. Three valid measurements were taken in two modes (kPa and m/s). Stiffness values are presented in kPa mode.

three measurements was noted (Figure 2). External pressure was not applied to the probe when obtaining the images, and care was taken that the operator's hand was not moving. In split-screen mode, the two-dimensional (2D)-SWE map (left side) and quality mode (right side) were examined. The quality mode, referred to as the propagation mode (arrival time contour), is a mode in which reliable data can be obtained when the lines are parallel and smooth, and the increase in distance between the lines is parallel to the increase in elasticity. The SWE parameters were measured in kilopascal (kPa) for shear wave elasticity (SWe) and meters/second (m/sec) for shear wave velocity (SWv). The elastographic scale was set to 0 to 40 kPa and 0 to 8 m/sec with a real-time propagation map. Three measurements with round-shaped region of interest (ROI) of 5 mm in diameter were obtained from the iliopsoas tendon.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 21.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were presented in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. The data were first subjected to normality analysis with Shapiro-Wilk test, kurtosis and skewness values. To examine the effect of tenotomy on tendon structure, the Student t-test was used to analyze normally distributed parameters and Mann-Whitney U test was used for parameters without normal distribution. A p value of <0.05 was considered statistically significant.

RESULTS

The mean follow-up was 92.6±30.2 (range, 44 to 120) months. Isolated anterior open reduction was performed in six patients, medial open reduction in seven patients, and anterior open reduction and Dega osteotomy was performed in seven patients (Table I).

When the range of motion was evaluated, flexion range was >120°, extension range 0-10°, abduction >45°, adduction >30°, internal rotation >30°, and external rotation >45° in all patients. Muscle strength was evaluated as 5/5 in bilateral lower extremities (Table II). Reduction of the hip was detected in X-ray examinations of all patients. Limping was not observed in any of the patients.

Ultrasound examinations revealed that integrity of the tenotomized iliopsoas tendons was intact in all patients. Evaluation of the iliopsoas muscle showed that mean muscle thickness was 6.16±1.58 mm in the operated side, and 11.8±2.3 mm in the unoperated side. There was a statistically significant difference between the two sides in terms of tendon thickness ($p<0.001$).

TABLE I
Data regarding surgical intervention and follow-up periods of the patients

Case no	Surgical procedure	Age at operation (months)	Age at last follow-up (months)	Follow-up time (months)
1	Anterior OR+ Dega	13	130	117
2	Anterior OR+ Dega	13	135	122
3	Medial OR	10	117	107
4	Anterior OR	15	124	109
5	Anterior OR + Dega	24	134	110
6	Anterior OR	3	49	46
7	Anterior OR	5	54	49
8	Anterior OR	5	64	59
9	Anterior OR+ Dega	20	130	110
10	Anterior OR	14	74	60
11	Medial OR	98	142	44
12	Anterior OR	16	131	115
13	Anterior OR+ Dega	18	124	106
14	Anterior OR+ Dega	51	158	107
15	Anterior OR+ Dega	64	184	120

Anterior OR: Anterior open reduction; Medial OR: Medial open reduction; Dega: Dega osteotomy of ilium.

TABLE II
The clinical results of the operated and non-operated hips of the patients during the last control

Case no	Power of hip flexion muscles		Hip joint flexion degree		Hip joint extansion degree		Hip joint abduction degree		Hip joint adduction degree		Hip joint internal rotation degree		Hip joint external rotation degree		Thickness Mm		SWv m/sec		SWe kPa	
Side	Operated side	Non-operated side	Operated side	Non-operated side	Operated side	Non-operated side	Operated side	Non-operated side	Operated side	Non-operated side	Operated side	Non-operated side	Operated side	Non-operated side	Operated side	Non-operated side	Operated side	Non-operated side	Operated side	Non-operated side
1	5/5	5/5	130	125	5	5	45	50	30	30	45	45	60	45	5.5	13.6	6.72	3.65	145.7	65.4
2	5/5	5/5	135	130	10	0	45	60	30	40	30	60	45	50	5.2	7.8	5.37	3.45	72.3	35.7
3	5/5	5/5	125	125	5	10	60	45	40	40	45	45	50	60	10.2	15.6	5.83	3.38	139.5	65.4
4	5/5	5/5	140	135	0	10	50	50	35	30	40	30	60	75	5.5	11.3	4.97	3.23	115.2	42.5
5	5/5	5/5	135	130	5	5	60	70	30	45	60	45	70	45	5.1	9.2	6.46	3.72	127.6	41.8
6	5/5	5/5	130	125	10	10	55	75	30	30	45	60	45	60	4.6	10.4	6.45	3.43	145.3	64.3
7	5/5	5/5	125	130	5	5	45	60	40	30	70	50	45	60	4.3	9.4	5.87	3.23	112.5	56.8
8	5/5	5/5	140	135	10	0	75	70	35	45	45	40	60	50	3.5	9.7	5.64	3.65	97.4	40.4
9	5/5	5/5	125	140	5	0	60	75	40	45	30	40	60	45	6.2	12.3	7.31	3.47	138.9	55.4
10	5/5	5/5	125	130	5	5	70	60	30	35	65	45	55	45	5.3	9.4	5.37	3.13	121.3	53.2
11	5/5	5/5	125	125	5	0	60	45	30	40	55	45	70	60	6.1	15.5	6.91	3.73	129.4	63.1
12	5/5	5/5	130	125	10	0	50	50	30	35	45	60	75	45	5.3	11.6	5.58	4.23	97.3	63.3
13	5/5	5/5	130	120	5	0	60	60	40	30	30	60	55	60	6.2	9.4	7.34	4.23	123.4	73.4
14	5/5	5/5	135	130	0	5	75	75	35	30	75	45	45	45	7.5	14.1	6.64	3.82	145.5	63.4
15	5/5	5/5	125	135	10	10	70	60	35	35	60	45	60	50	6.3	11.5	5.67	3.21	123.5	54.3

TABLE III
Mean elastography results of the patients

	Operated side	Intact side	
Parameter/side	Mean±SD	Mean±SD	*p*
Thickness (mm)	6.16±1.58	11.8±2.3	<0.001
m/sec	6.09±0.72	3.58±0.33	<0.001
kPa	122.9±18.6	57.5±10.44	<0.001

SD: Standard deviation; m/sec: Meters/second; kPa: Kilopascal.

According to SWE examinations, the mean velocity value was measured as 6.09±0.72 m/sec for the operated side and 3.58±0.33 m/sec for the unoperated side; the difference between the two sides was statistically significant (p<0.001). As for elasticity values, the operated side was mean 122.9±18.6 kPa, and the unoperated side was 57.5±10.44 kPa. Similarly, there was a significant difference between the two sides (p<0.001) (Table III).

DISCUSSION

Open reduction is a standard surgical procedure applied in children with DDH who cannot be treated with conservative methods or cannot be managed with closed reduction. Although various surgical approaches such as medial and anterior approaches are used, tenotomy of the iliopsoas tendon, which prevents the reduction of the hip joint, is routinely applied in all of them. Studies on iliopsoas muscle strength and hip flexion after tenotomy are very limited. There are only three publications in the pediatric literature so far, and all of these studies were conducted using magnetic resonance imaging (MRI).[6-8] In addition, one study only had six cases.[8] This is the first US study to evaluate iliopsoas tendons in patients who underwent surgical treatment for unilateral DDH. It is also the first study in the English literature to measure the stiffness of muscles. In this study, the iliopsoas tendon was examined with US elastography in patients who underwent open reduction due to DDH, and it was found that tenotomized iliopsoas tendons were intact in all cases in mid-term follow up, but that the tendons were stiffer and had a thinner structure.

Shear wave velocities can be measured from Doppler frequency modulation of simultaneously transmitted US waves. Since the speed of sound in the tissue is related to the degree of hardness of said tissue, quantitative measurement of stiffness can be made. With the shear wave velocity measurement method, the measurement units used in elastography are obtained shear wave velocity (m/sec). As the tissue stiffness increases, the shear wave velocity propagating in it increases as well. During the recovery period after tenotomy surgery, the tendon becomes stiffer than normal due to fibrosis. Accordingly, mean velocity values increase. Thus, more objective information can be obtained with numerical data about the stiffness and elasticity values of the tendon.

Clinically, it would provide useful information about tendon elasticity, particularly in infants whose tendon examination is difficult. The limitation of hip joint range of motion is important. In particular, after removing the spica cast or during the brace treatment, flexion of the hip joint can be diminished. One of the reasons of this situation can be the problematic events in hip flexor muscles or femoral nerve injury. Therefore, measuring the shear wave velocities and checking the congruity of the tendons is possible by shear wave elastography examination objectively.

Intervention to the iliopsoas is necessary in the surgical treatment of DDH. Although it has been reported that fractional lengthening can be performed, the widely accepted approach is psoas tenotomy. Tenotomy of the psoas tendon not only eliminates a structure that prevents reduction on the capsule but also prevents the development of avascular necrosis and re-dislocation after reduction.[15] Data about the tenotomy of the on the outcomes of the iliopsoas tendon tenotomy are rather is limited. The first publication in the literature was by Basset et al.[8] in 1999. In their study, the structure of the psoas muscle was evaluated with MRI and it was reported that patients who underwent tenotomy developed atrophy of the psoas muscle in the long-term. Only six patients were included in that study, in which three underwent anteromedial and the other three underwent anterolateral open reduction, and they were compared. However, a statistical analysis could not be made due to the low number of cases.

Furthermore, the cross-sectional areas of the hip flexor muscles were measured after psoas tenotomy. There was no evaluation of the muscles of the hip region with gait analysis or isokinetic dynamometer of whether the iliopsoas tendon reattached to the lesser trochanter or its continuity.

In the first of two studies performed in the same clinic, the thickness and adhesion localization of the psoas tendon were evaluated using MRI.[7] Among 22 patients included in the study, the adhesion rate of the psoas tendon to the lesser trochanter was reported as 32%. Furthermore, other muscles around the hip region, except for the sartorius, developed atrophy. In the continuation of this study, isokinetic muscle strength was examined in the same patients.[6] A significant decrease in isokinetic muscle strength, as well as atrophy in tenotomized muscles was observed, particularly in tendons that did not adhere to their original locations, and adhesion of the tendon to the lesser trochanter preserved muscle strength.

In all three of these studies, only the thicknesses of the muscles were measured with MRI, and their atrophy conditions were not evaluated.[6-8] Although functionality of the muscles was assessed with isokinetic muscle strength testing, both studies yielded different results when the hip flexor muscles were evaluated. While one study only observed atrophy in the psoas muscle.[7] Another study observed atrophy in all flexor muscles.[6] In that study, radiological examination was performed with US. As it is possible to make a dynamic examination with US, wholeness of the muscle or tendon can be visualized without interruption. In addition, elastography measurements can be made, and these measurements are presented objectively. This study is not only the first US study on this subject, but also the first to make objective measurements of the states of the muscles.

All patients included in this study underwent complete tenotomy at the lesser trochanter level. Isolated psoas tendon lengthening proximal to the inguinal ligament was not applied to any of the patients. According to the US examinations, the integrity of the iliopsoas tendon and its more rigid and thinner structure was objectively observed in all patients. We believe that this explains why there was no difference in muscles movements compared to the intact side or why no limping was observed in the clinical examinations of the patients.

Changes in tendon or muscle structure after tenotomy has been examined in various studies. Histological changes have been studied in animal models. The MRI and US studies have been conducted to study human muscles.[16,17] Studies on the hip muscles and the iliopsoas muscle have particularly included CP patients. Animal studies have shown alterations in the organization of muscle fibers and various enzyme factors in the first week after tenotomy.[18-21] In a study by Zhang et al.,[22] serial postoperative SWE measurements of the tendon were positively correlated with tendon functions over time and became more rigid as they healed, in patients with Achilles tendon rupture who underwent surgical treatment. Similarly, in this study, higher kvp and m/sec values were demonstrated during healing by preserving the functions of the iliopsoas tendon. This finding indicates that SWE can provide information regarding biomechanical changes during the healing process of the tendon. Future studies with more cases and different tendon pathologies would clarify this situation.

Hip US is the main radiological imaging technique before six months of age. Not only the diagnosis but also the follow-up of the patients are commonly done by hip US.[23,24] Shear wave elastography is a noninvasive technique that has gained widespread use in recent years, with the awareness of its superiority in illuminating the structure of soft tissues. Many soft tissues such as tendons, muscles, and fascia in the human body have begun to be examined with this technique.[13,25,26] Many studies have examined structural changes in skeletal muscle using the elastography technique, particularly hip muscles in patients with CP. Vola et al.[14] found that the soleus muscle was more rigid in patients with CP. There are many studies demonstrating that the muscle structure is more rigid in patients with CP.[27,28] This difference confirms the validity of excluding children undergoing operation due to neuromuscular hip dislocation.

Nonetheless, this study has several limitations. One of the main limitations is the number of cases. Only 15 patients were included in the study, and while this number can be considered sufficient compared to previous publications, a higher number of cases would strengthen the results. Another limitation is the lack of its prospective design. Furthermore, lack of gait analysis and isokinetic muscle strength testing could also be considered among the limitations of this study. However, the fact that elastography evaluation was made for the first time with US in DDH surgery adds value to this study.

In conclusion, by using grey scale US and SWE methods, re-adhesion of the iliopsoas tendon to the lesser trochanter provided integrity while healing as a more rigid and thinner structure compared to the non-tenotomized tendons. Shear wave elastography can be used to evaluate changes in the iliopsoas tendon due to healing following tenotomy as a non-invasive diagnostic method, providing quantitative data in its differentiation from the intact tendon. Thus, potential problems that may arise due to tenotomy can be identified more clearly and objectively during the follow up of these patients. Further prospective studies involving more patients are warranted to gain more understanding of this subject.

Ethics Committee Approval: The study protocol was approved by the Selçuk University Faculty of Medicine Ethics Committee (no: 2021/53). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: The informed consents forms were obtained from the parents of the participating patients.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea concept: B.K.A.; Design: S.Ç.; Supervision: H.Ş.; Data collection: S.Ç., M.Ö.; Analysis: S.S., M.S.D.; Literature review: B.K.A., M.S.D.; Article writing: B.K.A., S.Ç., M.S.D.; Critical review: H.Ş., S.S.

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