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Is there a correlation between the femoral anteversion angle and the elasticity of the hip muscles in cases of intoeing gait due to increased femoral anteversion angle?

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Abstract

Purpose: One of the common causes of gait disturbance in children is increased femoral anteversion. There are not enough publications in the literature on muscles related to the hip joint in increased femoral anteversion. The aim of this study was to evaluate the relationship between the femoral anteversion angle and hip muscle elasticity in children walking inward, using shear wave elastography (SWE). **Material and methods:** Seventeen children with bilateral increased femoral anteversion angle in computed tomography were prospectively included in this study. Elasticity values of the hip muscles (adductor magnus (adductor), iliopsoas (flexor), gluteus medius (abductor), gluteus maximus (extensor) muscles) were evaluated by ultrasound elastography by two observers. Quantitative measurements of the shear wave velocities were performed using virtual touch tissue imaging quantification. **Results:** There was excellent harmony between the femoral anteversion angle measurements performed by the two observers and a good congruence between the muscle elastography evaluations. While there was a moderate significant correlation between the femoral anteversion angle and the elasticity values of the iliopsoas and adductor magnus muscles, no significant correlation was found with other muscle elasticity measurements. **Conclusion:** Iliopsoas muscle and adductor magnus muscle elasticity are correlated with the femoral anteversion angle. With further studies, we think that physical therapy methods for the elasticity of the muscles associated with the femoral anteversion angle can reduce the complaints of the patients.

Introduction

Intoeing gait is a deformity seen during walks or runs. The causes of intoeing gait have been defined in the literature as metatarsus adductus, internal tibial torsion (ITT), and increased femoral anteversion angle (FAA) in healthy children⁽¹⁾. Metatarsus adductus is a condition where the anterior part of the foot faces inward. ITT is a condition where the tibia is rotated inwards. ITT is the most common cause of this deformity. Increased femoral anteversion is detected by an increase in the femoral anteversion angle. These causes often regress spontaneously in healthy children over time and rarely require surgical intervention⁽¹⁾. Increased FAA refers to the orientation of the femoral neck relative to the femoral condyles. Increased

FAA leads to gait disorders, and can also cause hip dislocation and subluxation⁽²⁻⁴⁾. The FAA decreases from 30–40° in newborns to 10–15° around the age of 8 years⁽⁵⁾.

SWE applies vibrations to the tissues with focused ultrasound waves. Shear wave velocities can be measured from Doppler frequency modulation of simultaneously transmitted ultrasound waves. Young's modulus of elasticity is then measured as a function of shear wave velocity (SWV). As the tissue stiffness rises, the shear wave velocity passing through the tissue also increases⁽⁶⁾. Studies in the literature have shown that SWE and shear modulus measurement values are highly correlated with the strength of a muscle to withstand changes in length when compressed⁽⁷⁾.

The aim of this study was to evaluate the correlation between the FAA and elasticity of the hip muscles in children with intoeing gait due to increased FAA, using SWE.

Material and methods

Study design and population selection

This prospective study was approved by the institutional review board at our hospital. Written informed consent was obtained from the parents.

In this study, a total of 17 children with intoeing gait due to bilateral increased FAA diagnosed by CT were evaluated prospectively. All the children had normal activity of daily living scores. They were normal in growth. They did not have any other abnormalities in gait. The inclusion criteria were as follows: the diagnosis of intoeing gait with increased FAA confirmed by an orthopedist at physical examination and femoral anteversion CT within one month before enrolling in this study. The exclusion criteria were as follows: 1) cerebral palsy; 2) femoral pineal shift; 3) hip dysplasia; 4) hormonal and metabolic diseases (vitamin D-resistant rickets, etc.); 5) history of trauma or lower extremity operation; 6) clinical signs of metatarsus adductus, ITT; 7) injection of botulinum toxin or neurolytic agents; 8) cases receiving physical therapy; 9) polio; 10) neurological disorders (cerebral palsy, agenesis of the corpus callosum, etc.); 11) congenital hip dislocation; 12) syndromes; 13) structural abnormalities (congenital vertebral anomalies, etc.); 14) family history.

All CT were obtained from the picture archiving and communication system (PACS) of our institution. The age range of the patients was 5–8 years (mean of age: 5.41 ± 1.25 years), with the group comprising seven boys and 10 girls.

CT examinations

The CT examinations were performed on a 16-slice scanner (Alexion, Toshiba Medical Systems, Japan). CT was done when the patient was in the supine position with feet first and legs flat on the table. The legs were closed together as much as possible. Two small slabs acquired covered both: 1) hips (from the femoral heads to the lesser trochanters) and 2) knees (from the femoral distal physes to the proximal tibias). The scan parameters were as follows: 5.0 mm section thickness, 5.0 mm intervals, 120-kV voltage, 200- to 300-mA current, and 256×256 matrix. Two radiologists (with six and eight years of experience) examined the CT images for the FAA using a bone algorithm in the axial plane.

FAA measurement on CT

First, the axial view of the femoral neck, where the angle of the femoral neck can be measured best, was selected, and the measurement was performed. The condylar angle was

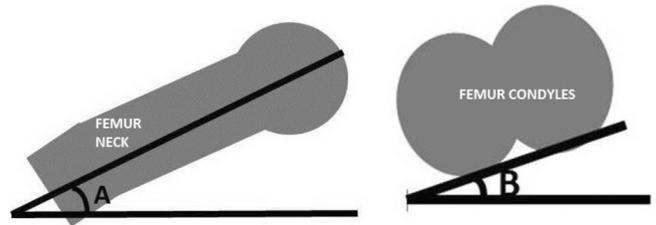


Fig. 1. Definition of femoral anteversion angle measurement on axial CT. **A** is femoral neck horizontal angle. **B** is femoral condyles horizontal angle. $A-B$ = femoral anteversion angle

measured from the back of the femoral condyles. These two angles were summed or subtracted depending on the direction, and the FAA was obtained (Fig. 1)⁽⁸⁾.

SWE measurement

Two radiologists examined all the patients by US elastography. They were blinded to each other's results. The US elastography evaluations were performed using a US system (Acuson S3000; Siemens Medical Solutions, Mountain View, CA, USA) with a linear transducer that enabled scanning with a frequency ranging from 4 to 9 MHz.

US elastography was performed when the patient was in the supine position with feet first and legs flat on the table. The legs were closed together as much as possible for the adductor magnus (adductor) and the iliopsoas (flexor) muscles. The elasticity of the gluteus medius (abductor) and the gluteus maximus (extensor) muscles was measured in the prone position with feet first and legs flat on the table. The legs were closed together as much as possible. The transducer was held in the longitudinal plane to the muscles. Quantitative muscle elasticity was measured by the Virtual Touch tissue quantification software (Siemens Medical Solutions) without pressure to the transducer. The examination was repeated until high-quality data was collected with color-coded quality maps. The high-quality data was frozen and saved. The region of interest (ROI) of the system was set to include the muscle. A rectangular electronic box-shaped region of interest measuring 5×5 mm was used for SWE measurements. Additionally, an SWE scale of 0–10 m/s was chosen. All the scans were repeated at least three times in all the muscles (Fig. 2). The mean value of the elastic modulus inside the rectangular was obtained automatically. The mean SWV values were used for the analysis.

Statistical analysis

Statistical analysis was performed with the SPSS software (version 21.0; IBM Corporation, Armonk, NY, USA). Descriptive statistical data were presented as a mean and standard deviation. According to the Kolmogorov–Smirnov test, all data showed normal distribution. The inter-observer compliance values were expressed using the kappa statistics which were evaluated as follows: $\kappa \geq 0.91$ excellent, $0.90 \geq \kappa \geq 0.71$ good, $0.70 \geq \kappa \geq 0.51$ moderate correlation.

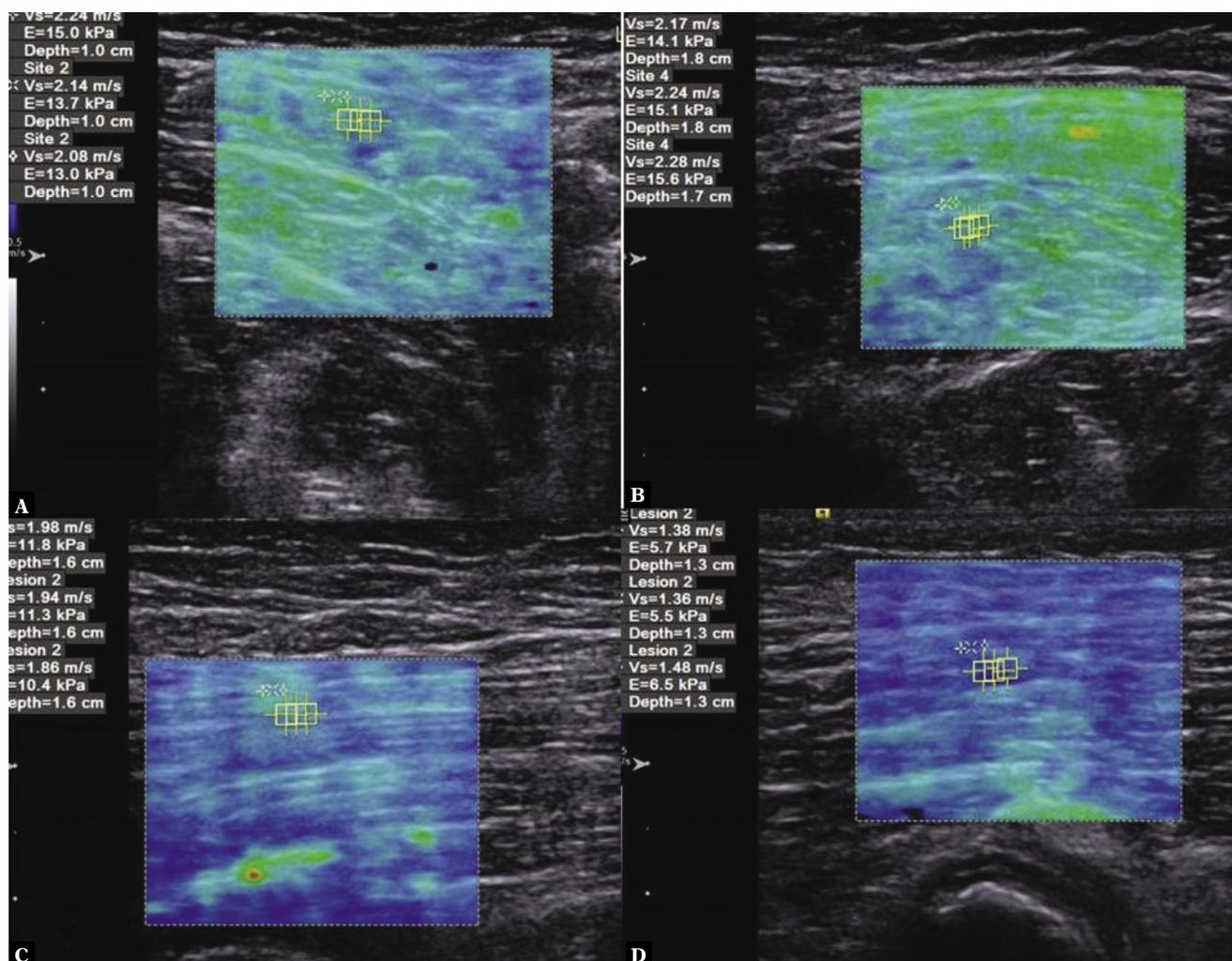


Fig. 2. SWE of a 5-year-old boy with femoral anteversion showing elasticity measurements of the adductor magnus (A), iliopsoas (B), gluteus medius (C), and gluteus maximus (D) muscles

The relationship between the elasticity values obtained in the elastography examination of the muscles and the femoral anteversion angle, as well as the congruence between the observers were analyzed by Pearson's correlation test. The correlation coefficients were evaluated as follows: $r \geq 0.91$ excellent, $0.90 \geq r \geq 0.71$ good, $0.70 \geq r \geq 0.51$ moderate, $0.50 \geq r \geq 0.31$ weak, and $r \leq 0.3$ no correlation. $P < 0.05$ was considered statistically significant in all analyses.

Results

There was an excellent congruence between the femoral anteversion angle measurements performed by the two observers and a good consistency between the muscle elastography evaluations. Iliopsoas, adductor magnus, gluteus maximus, gluteus medius muscles elasticity values and femoral anteversion values are summarized in Tab. 1 for each observer.

The congruence between the measurements performed by the two observers is shown in Tab. 2.

Pearson's correlation analysis performed between the femoral anteversion angle measurements and muscle elastography measurements made by Observer 1 and Observer 2 is shown in Tab. 3. As can be seen, while there was a moderate significant correlation between the FAA measurements and the elasticity values of the iliopsoas and adductor magnus muscles for both observers, there was no similar correlation with other muscle elasticity measurements.

Discussion

The study aimed to evaluate the hip muscles by elastography in patients with intoeing gait due to femoral anteversion.

Femoral anteversion can result from stiff hip muscles due to the position of the fetus in the uterus. It also tends to occur in patient families⁽⁹⁾.

Kong *et al.*, in their study of children aged 4–6 years with recently diagnosed intoeing gait, performed 3D CT at the

Tab. 1. Bilateral iliopsoas, adductor magnus, gluteus maximus, gluteus medius muscles elasticity, and femoral anteversion values for both observers

Patient number	Iliopsoas elasticity				Adductor magnus elasticity				Gluteus maximus elasticity				Gluteus medius elasticity				Femoral anteversion angle			
	Right		Left		Right		Left		Right		Left		Right		Left		Right		Left	
	O1	O2	O1	O2	O1	O2	O1	O2	O1	O2	O1	O2	O1	O2	O1	O2	O1	O2	O1	O2
1	2.04	1.9	2.75	2.6	2.13	2.13	2.79	2.79	2.14	2.2	2.14	2.2	2.13	2.3	2.03	2.2	25	24	28	28
2	3.55	3.4	2.48	2.2	2.76	2.76	2.15	2.15	1.66	1.7	1.86	1.8	2.05	2.2	2.27	2.1	28	29	25	26
3	2.9	3.2	2.37	2	2.99	2.99	2.76	2.76	1.56	1.6	1.51	1.5	2.29	2.1	1.75	1.5	26	26	24	22
4	1.7	2	2.45	2.2	2.02	2.02	2.81	2.81	1.52	1.6	1.53	1.5	2.31	2.5	1.48	1.5	21	21	29	28
5	2.08	2.6	3.84	3.6	2.23	2.23	3.71	3.71	1.38	1.4	1.45	1.4	1.93	1.8	1.67	1.8	20	21	44	41
6	1.78	2	3.36	3.7	3.23	3.23	4.63	4.63	1.92	2	1.72	1.7	1.72	2	2.3	2.5	30	32	44	42
7	1.96	1.7	3.86	4.1	2.02	2.02	3.32	3.92	1.36	1.3	1.52	1.6	1.47	1.6	1.38	1.5	31	33	36	38
8	3.46	3.2	3.06	3.6	4.09	4.76	2.55	2.03	1.47	2	1.46	1.4	1.38	1.4	1.83	1.5	21	22	16	15
9	2.5	2.9	2.48	2.1	2.77	2.14	2.73	2.21	1.4	1.6	1.4	1.4	1.84	1.7	1.59	1.7	37	38	36	37
10	2.66	2.2	3.19	3.9	1.65	1.21	2.23	2.98	1.16	2	1.49	1.5	1.34	1.5	1.36	1.6	26	25	30	32
11	1.88	2.3	3.6	4	2.02	2.97	2.93	2.03	1.41	1.4	1.43	1.4	1.25	1.4	2.08	2.3	33	32	36	38
12	3.61	3.4	3.4	3.9	3.28	3.88	3.07	3.97	2.18	2.2	2.37	2.4	2.54	2.6	2.47	2.6	31	33	30	32
13	2.19	2.5	2.04	2.6	2.58	2.08	2.4	2.98	1.5	1.5	1.75	1.8	2.54	2.4	2.38	2.6	29	27	27	28
14	3.38	3.7	3.35	3.1	3.13	3.97	2.57	2.07	1.22	1.2	1.81	1.8	2.03	2.3	1.27	1.4	38	36	37	35
15	2.66	2.5	4.44	4	2.08	2.98	4.78	4.08	1.63	1.6	1.49	2.2	1.35	1.5	1.21	1.4	30	31	54	51
16	2.39	3	3.72	3.3	1.22	1.92	2.82	2.02	1.63	1.6	1.86	1.8	1.58	1.7	1.61	1.8	30	32	39	37
17	2.35	2	1.32	1.8	2.8	2.08	2.35	2.95	1.98	1.9	2.2	2.3	1.67	2	1.98	1.4	31	32	26	26

O1 – Observer 1; O2 – Observer 2

Tab. 2. Correlation of elasticity values and femoral anteversion angle measurements obtained by muscle elastography inter-observers with kappa statistics

Evaluated measurement	Inter-observer compliance values (κ)
Femoral anteversion angle	0.913
Iliopsoas muscle elastographic elasticity value	0.724
Adductor magnus muscle elastographic elasticity value	0.711
Gluteus maximus muscle elastographic elasticity value	0.674
Gluteus medius muscle elastographic elasticity value	0.681

Tab. 3. Correlation between elasticity values in muscle elastography examination and femoral anteversion angle measurements for each observer

	Observer 1		Observer 2	
	r	p	r	p
Correlation between FAA and iliopsoas muscle elasticity value	0.562	p < 0.05	0.518	p < 0.05
Correlation between FAA and adductor magnus muscle elasticity value	0.566	p < 0.01	0.522	p < 0.01
Correlation between FAA and gluteus maximus muscle elasticity value	-0.093	p > 0.05	-0.014	p > 0.05
Correlation between FAA and gluteus medius muscle elasticity value	-0.259	p > 0.05	-0.012	p > 0.05

time of diagnosis, and reported that a decrease in the FAA was observed for 18 months⁽¹⁰⁾.

In the study of Faulks *et al.*, 95% of the cases were diagnosed as benign intoeing gait and were followed up. The cases in the present study were also benign intoeing gait, and they were planned to be followed up for the FAA⁽¹⁾.

Both in vitro and in vivo studies have demonstrated that the measurement of elastic shear modulus is strongly associated with localized passive muscle tension during stretching⁽¹¹⁾.

Dubois *et al.* observed higher shear modulus values in the muscles involved in knee joint motion and plantar flexion of the foot when stretched compared to rest⁽¹²⁾. Saeki *et al.* found that the shear modulus values of ankle plantar flexion muscles increased with dorsiflexion⁽¹³⁾.

Berrigan *et al.*, in their studies on hamstring muscles, showed that joint and muscle position affected shear modulus values⁽⁷⁾. In their study, Andrade *et al.* found that the maximum dorsiflexion angle of the ankle was affected by the hip angle position, whereas the ankle torque and the passive tension of the gastrocnemius muscle did not change for an equivalent ankle angle⁽¹¹⁾.

In their study, Umehara *et al.* reported that adding hip rotation to the stretching position with hip adduction and extension might have little effect on tensor fascia lata lengthening, and stretching at knee flexion above 90° could effectively lengthen the tensor fascia lata⁽¹⁴⁾.

Gluteal muscle contracture has been linked to a decrease in the hip flexion passive adduction angle and a rise in the mean shear wave velocity in contracture strips in three individuals, as revealed in a study by Guo *et al.*⁽¹⁵⁾. Ogawa *et al.* reported that the hip flexion angle might affect the amount

of muscle elongation in the stretched muscle; however, it remains unclear how the hip joint angle affects the stretching of the adductors⁽¹⁶⁾. Studies in the literature show that conditions affecting joint angle and position can impact muscle tension. From this perspective, it is reasonable to conclude that joint position is affected in the circumstances affecting muscle tension. However, as far as we know, there are not enough elastographic studies on which muscle groups can be influential and/or affected in the FAA.

Analan *et al.* used the hip migration index (MI) on antero-posterior pelvic radiographs to assess hip muscle elasticity. The iliopsoas and adductor magnus muscles were discovered to have a strong connection with the MI. We detected a moderate correlation between the iliopsoas muscle and the adductor magnus muscle in the present study. Analan *et al.* found a weak correlation between the MI and other hip muscles⁽¹⁷⁾. In the present study, we identified a weak correlation between the FAA and other hip muscles.

Previous studies have investigated biomechanical changes during gait in children with genu varum. However, there was no study evaluating biomechanical changes in the hip muscles in the context of increased femoral anteversion angle with intoeing gait in children. In a study by Jafarnezhadgero *et al.*, a corrective training program may contribute to slow joint degeneration, improved mobility and daily living activities in children with genu varum⁽¹⁸⁾. Our study may benefit from a corrective training program for children's increased femoral anteversion angle with intoeing gait.

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Limitations

An important limitation of the study was the small number of participants. As a result, elastography changes throughout patient follow-up could not be examined.

Conclusion

In conclusion, iliopsoas muscle and adductor magnus muscle elasticity values were found to be correlated with the FAA. It might be beneficial to conduct further studies with more extensive patient series in the future. Based on their findings, physical therapy methods effective on the iliopsoas muscle and adductor magnus muscle elasticity can be developed.

Ethical statements

This prospective study was approved by the institutional review board at our hospital. Written informed consent was obtained from the children's parents.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations which might negatively affect the contents of this publication and/or claim authorship rights to this publication.