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Reliability of Thickness Measurements of the Abductor Hallucis Muscle Using the Spring Gauge Technique in Hallux Valgus Subjects: An Ultrasonographic Study

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Purpose: The purpose of this study was to determine the intra- and inter-rater reliability of muscle thickness (MT) measurements of the abductor hallucis (AbdH) in subjects with hallux valgus (HV), using ultrasonography performed at different inward pressures of approximately 0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg, with no pressure control.

Methods: Thirty-two subjects with HV were recruited. The thicknesses of both sides of the AbdH were measured randomly by two different examiners for assessment of the intra- and inter-rater reliability. The measurement values were analyzed using the intra-class correlation coefficient (ICC) with a 95% confidence interval (CI). ICC (2,1) was used to determine the inter-rater reliability of MT measurements of the AbdH, while ICC (3,1) was used to assess the intra-rater reliability.

Results: The results showed higher ICC values for intra-rater reliability compared to inter-rater reliability, and the value for inter-rater reliability with no pressure control (ICC = 0.74 [95%CI = 0.53-0.87]) was smaller compared to pressures of 0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg. Other inward pressures for intra- and inter-rater reliability also showed excellent values (ICC = 0.86-0.96).

Conclusion: The findings showed that maintaining consistent inward pressure is essential for reliable results in measurement of the MT of the AbdH by different examiners in a clinical setting.

Keywords: Reliability, Inward pressure, Abductor hallucis, Hallux valgus, Ultrasonography

INTRODUCTION

The abductor hallucis (AbdH) muscle plays a role in maintaining the alignment of the first metatarsophalangeal joint (1MTPJ).[1] This muscle is located medial to the first metatarsal joint between the medial process of the calcaneal tuberosity and the medial aspect of the proximal phalanx and sesamoid, as an origin and insertion point.[2] As this muscle is located below the transverse axis of the 1MTPJ, the AbdH acts in the plantar flexion and abduction of the 1MTPJ[3], and as a dynamic stabilizer of the longitudinal arch during the late stance and toe-off phases of gait.[4]

Hallux valgus (HV) and pes planus can cause structural and functional disorders of the AbdH.[5] In the 1MTPJ, HV is defined as an abnormal degree of lateral deviation of the great toe with pain.[6] The AbdH in HV patients is rotated inferiorly, with loss of the normal anatomical structures of the 1MTPJ.[7] Structural changes of the AbdH lead to functional disadvantages in this muscle. As a result, the cross-sectional area (CSA) of the AbdH is significantly decreased in individuals with HV.[8] Reduced CSA is closely related to loss of muscle strength.[9]

Since the effective evaluation of the AbdH is an important component in effective rehabilitation for individuals with HV, precise measurements are required in the clinical and research settings.[1] In non-invasive techniques, ultrasonography (US) for measuring the bulk of the AbdH is often involved in the measurement of muscle thickness (MT), as a convenient method for determining the CSA and MT.[1] Although magnetic resonance imaging (MRI) and computed tomography (CT) are widely used to estimate the volume of various muscles,[10] US has been increasingly used to measure MT because of similar advantages to CT or MRI in visualizing muscle tissues.[1] In addition, the valid and reliable measurement tech-

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niques for body tissue evaluation by US have the additional advantages of being time-efficient, inexpensive, and safe.[11]

During MT measurements using US carried out by different examiners, an effort to maintain consistent position, orientation, and inward pressure of the transducer is required to enhance the reliability of the measurement.[12] The HV structure can be miscalculated in US measurement without these essential elements. Previously, various studies have reported that high intra- and inter-rater reliability were established for two different examiners who measured stabilizer muscles, such as the multifidus and longus colli.[13] In addition, US evaluation of AbdH for intra- and inter-rater reliability study was conducted with excellent reliability in asymptomatic subjects.[14] However, the reliability of US may be different according to the measurement region. In addition, no study has evaluated the influence of different inward pressures of the transducer on the AbdH to measure MT in individuals with HV by two different examiners using US. Therefore, the aim of the present study was to determine the intra- and inter-rater reliability of MT measurements for the AbdH, using US with different inward pressures of 0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg, as well as no pressure control, between two different raters. We hypothesized that maintaining consistent inward pressure would result in superior values for intra- and inter-rater reliability at each different inward pressure (0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg), compared to MT measurements with no pressure control.

METHODS

1. Subjects

Sixteen subjects (4 females and 12 males) with HV were included. In addition, the severity of HV was graded using the Manchester Scale as 0 = no deformity, 1 = mild deformity, 2 = moderate deformity and 3 = severe deformity (Table 1).[1] Measurements on both sides for each subject were taken, for a total of 32 AbdHs. The exclusion criteria were as follows: 1) metabolic, neuromuscular, or musculoskeletal disorders, 2) any surgery in the foot region, 3) pain in any region of the foot during testing, and 4) grade 0 in the Manchester Scale. The primary investigator explained all procedures to the subjects before the measurements, and consent was given prior to participation. Before the experiment, the experimental protocols were explained in detail to all of the subjects.

Table 1. General characteristics of the subject (N = 16)

Variable	Mean ± SD
Age (year)	23.42 ± 2.23
Height (cm)	176.72 ± 3.83
Body mass (kg)	69.11 ± 7.14
BMI (kg/m²)ᵃ	22.14 ± 3.15
HV angle (°)	19.94 ± 5.49

2. Instrument

A 7.5 MHz linear US transducer (SonoAce x8, Medison Co., Ltd., Seoul, Korea) was utilized to measure the MT of the AbdH in HV patients. To ensure that the transducer maintained consistent inward pressures of 0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg, a spring gauge (Kirin Co., Ltd., Seoul, Korea) was applied to the region; this was suspended from a fixed perpendicular bar. This measurement equipment had a force-measuring capacity of 0.0 to 10.0 kg, in 0.1 kg increments. The inward pressures were applied perpendicular to the skin surface over the AbdH to ensure precise force generation. The transducer was secured to the end of the spring gauge with Leukotape P non-elastic sports tape (BSN Medical, Hamburg, Germany) to allow both the fixed bar and the spring gauge.

3. Experimental methods

The AbdH of both the left and the right foot were imaged. The subjects were fully relaxed in a sitting position with the legs flexed on a rigid surface. The foot was positioned with the ankle at neutral to 0°. The knee on the non-involved side was supported at approximately 70° of flexion, with the involved side at a comfortable angle of approximately 90° to optimize access to the medial foot (Figure 1). The inward pressure was set at 0 kg in contact with the skin during the application of the transducer in order to precisely apply the four different inward pressures and no pressure control. The subjects' arms were crossed over their chests. The four different inward transducer pressures (0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg), and the

Figure 1. Measurement performed with a handheld ultrasonography transducer and spring gauge.

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measurement without pressure control, were applied using the spring gauge to perform consistent screenings of the AbdH. The transducer was placed transversely on the region anteroinferior to the medial malleolus of the measuring leg. The images captured by US were saved for the calculation of the MT of the AbdH. The angle of the transducer was tilted to position it perpendicular to the muscle fascia of the AbdH. The location of the transducer was marked with a straight line on the skin to control the specific contact area between the surfaces of the transducer and the skin. After these procedures, only the difference in inward pressures was remeasured using the same procedure. The MT was calculated using the values of one measurement for each condition for analysis.

Two experienced examiners, one with six years' experience (examiner 1) and the other with one year's experience (examiner 2), took measurements from both AbdHs of each subject. All measurements were performed on the same day to assess the intra- and inter-rater reliability. To calculate intra-rater reliability, examiner 1 repeated the measurements with 1 hour time interval. To calculate inter-rater reliability, examiner 2 performed the measurement after examiner 1 performed with randomly order. The measurement order of the examiners and the inward pressure settings were randomized. The primary investigator and examiners were blinded to the results of the measurements and the subjects' information. The assistant was involved in recording all of the examiners' results. In order to carry out the experimental procedure, the examiners were familiarized with US, and with the generation of sensitive force with the spring gauge, before performing the actual measurements.

4. Statistical analysis

All statistical analyses were conducted using SPSS (Ver. 18.0, SPSS Inc., Chicago, IL, USA). Intra-class correlation coefficients (ICCs) and a 95% confidence interval (CI) were used. The ICC (3, 1) model was used to estimate the intra-rater reliability, and the ICC (2, 1) model was used to test the inter-rater reliability. We used only one measurement from each image to determine the MT in each condition. The minimal detectable change (MDC) was calculated using the following formula: MDC 95 = 1.96*SEM*. The aim of this procedure was to determine the magnitude of change that would exceed the minimal error of the measurement at a 95% CI. One-way repeated analysis of variance was used to determine differences between AbdH thicknesses according to the different inward pressures (0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg) and no pressure control of the transducer. Values were considered statistically significant at $p < 0.05$.

RESULTS

The ICC for intra-rater reliability was higher than or at least equal to 0.85,

Table 2. Intra-rater reliability of AbdH measurements using ultrasonography with different inward pressures (n = 32 AbdH)

AbdH	Intra-rater reliability			
	ICC (95%CI)	SEM (mm)	MDC (mm)	CV (%)
No control	0.85 (0.71-0.93)	0.21	0.57	23
0.5 kg	0.88 (0.77-0.94)	0.17	0.46	21
1.0 kg	0.91 (0.83-0.96)	0.14	0.38	22
1.5 kg	0.94 (0.88-0.97)	0.11	0.30	22
2.0 kg	0.96 (0.92-0.98)	0.09	0.24	22

AbdH: abductor hallucis, ICC: intra-class correlation coefficients, CI: confidence interval, SEM: Standard error of measurement, MDC: minimal detectable change, CV: coefficient of variance.
$p < 0.05$.

Table 3. Inter-rater reliability of AbdH measurements using ultrasonography with different inward pressures (n = 32 AbdH)

AbdH	Inter-rater reliability			
	ICC (95%CI)	SEM (mm)	MDC (mm)	CV (%)
No control	0.74 (0.53-0.87)	0.23	0.64	21
0.5 kg	0.86 (0.72-0.93)	0.15	0.43	18
1.0 kg	0.91 (0.83-0.96)	0.13	0.36	20
1.5 kg	0.92 (0.85-0.96)	0.11	0.32	20
2.0 kg	0.92 (0.84-0.96)	0.11	0.30	20

AbdH: abductor hallucis, ICC: intra-class correlation coefficients, CI: confidence interval, SEM: Standard error of measurement, MDC: minimal detectable change, CV: coefficient of variance.
$p < 0.05$.

Table 4. Thickness changes of the AbdH muscle (mm) (n = 32 AbdH)

	No control	0.5 (kg)	1.0 (kg)	1.5 (kg)	2.0 (kg)	p value
MT of AbdH	2.16±0.52	2.29±0.50	2.12±0.45	2.00±0.43	1.89±0.42	<0.05

MT: muscle thickness, AbdH: abductor hallucis.

which is an excellent result. In addition, the ICC for intra-rater reliability was higher than that for inter-rater reliability at each different inward pressure. The values for intra- and inter-rater reliability at 0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg are shown in Tables 2 and 3. Lesser values of the coefficient of variance (CV) and the standard error of measurement (SEM) of intra-rater reliability compared with inter-rater reliability are also shown in Tables 2 and 3. In addition, the values for ICC with 95% CI of intra- and inter-rater reliability, including MDC, are presented in the same tables. In the interpretation, ICC values of >0.75 were considered to indicate excellent reliability, 0.40-0.75 indicated fair to good reliability, and 0.00-0.40 indicated poor reliability.[15] A summary description of thickness changes in AbdH measurements is provided in Table 4.

DISCUSSION

This study investigated the intra- and inter-rater reliability of measurements using the US imaging technique for the MT of the AbdH, induced by different inward pressures of approximately 0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg, as well as with no pressure control. We believe that the current study is the first to report a determination of the intra- and inter-rater reliability of US for MT measurements of the AbdH in individuals with HV, based on pressure control of the transducer.

The specific protocols for the measurements with inward pressure control in this study might have contributed to the high intra-rater (ICC = 0.88-0.96) and inter-rater reliability (ICC = 0.86-0.92). The current study indicated that the ICC values for intra-rater and inter-rater reliability inward pressures at 0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg indicated excellent reliability compared to the measurement with no pressure control (ICC = 0.74), thereby supporting our hypothesis.

The high reliability in the current study was influenced by the experimental protocol used to ensure standardization of the measurements using various components. The spring gauge was used to provide consistent inward pressure of the transducer while measuring the MT of the AbdH in response to the different pressures. In addition, the spring gauge was replaced with other spring gauges 6 times, after measurements of 5 subjects, to avoid loss of spring elasticity due to fatigue with extensive use of the spring gauges.[16]

Various studies have reported on MT measurements of the AbdH using US according to different ages[1], different grades of HV severity[8], and different measuring machines.[17] The previous study reported that increased patient age is related to greater reduction of MT and CSA of the AbdH on the side with HV.[1] The HV patients over the age of 65 years showed a significant reduction in AbdH size compared to those younger than 45 years, in accordance with age-related changes in muscles.[1] Another study also reported significant differences in MT and CSA of the AbdH between different severities of HV.[8] However, another study showed that regardless of the type of US machine, the intra-rater reliability for AbdH muscle measurements was excellent.[17] In addition, the previous study performed similarly with present study, US measurement of AbdH muscle for intra- and inter-rater reliability study was conducted with excellent reliability in asymptomatic subjects.[14] In contrast, the present study , the results demonstrated that regardless of the different examiners, the intra- and inter-rater reliability was excellent with maintenance of consistent inward pressure in subjects with HV. However, the inter-rater reliability with no inward pressure control was not excellent.

In previous studies, although the measuring region with inward pressure control was the abdominal muscles, the inward pressure of the transducer was carried out below 6.0 N (approximate 0.6 kg), with excellent reliability.[12] However, excellent intra- and inter-rater reliability were shown even with various inward pressures of 0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg, because attempts to maintain the consistent inward pressures were essential to provide reliable results, especially in measurements by different examiners.

In the present study, although the inward pressures on the skin surface of the AbdH exhibited subtle changes, the MT of the AbdH was slightly decreased according to increased inward pressure of the transducer ($p < 0.05$). The precise measurement of the MT could be affected by the elasticity of the muscles.[12] Thus, the effort to maintain consistent inward pressure using US can be important when measuring MT, not only in the AbdH, but in all muscles. The measurement errors for MT may be misestimated under inconsistent inward pressures of the transducer due to slight MT changes.[12] For this reason, MT measurements using consistent inward pressures can be positively influenced by the equipment, such as a high-density foam cube[18], and a transducer holder.[12]

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Our findings demonstrated that the MT of the AbdH was gradually decreased according to increased inward pressure of the transducer at 0.5 kg, 1.0 kg, 1.5 kg, and 2.0 kg in a manner related to the distortion of the measurement. Therefore, the inward pressure with 0.5 kg for MT measurements of the AbdH can be recommended for minimizing the distortion of measurements. In addition, the inward pressure with no pressure control in this study was approximately 1.0 kg, which was the variable value.

A previous study reported that hands-free transducer holders have practical uses in both clinical and research settings. However, examinations using US transducers can be performed with the handheld technique in a general clinical setting. Thus, the spring gauge described in this study could be used in clinical settings because it has advantages similar to those of the equipment currently used to measure MT with consistent inward pressure.[12,18] Furthermore, the spring gauge in the current study can be used single-handed to simultaneously determine pressure during suspension from stationary objects; moreover, an additional instrument, such as a force plate, is not needed for pressure confirmation. In addition, this equipment has further advantages, such as easy application and cost-effectiveness. These features make it more accessible in the clinical setting when it comes to minimizing possible measurement errors due to inconsistent inward pressures of the transducer while measuring MT.

The current study has several limitations. First, the results cannot be generalized to elderly individuals, and further studies to establish the reliability of MT measurements in older populations are required. Second, the HV was not graded for the US measurements. Further studies to compare possible differences in reliability according to the severity of HV are required.

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