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A semi-quantitative technique to assess excursion of the flexor hallucis longus

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ABSTRACT

Background: Recent research indicates that restriction in excursion of flexor hallucis longus (FHL) contributes to hallux rigidus development. As described in the literature, clinical evaluation of FHL excursion has poor interobserver reliability. A simple, inexpensive, easily used FHL relative excursion measurement device was developed and tested.
Methods: 64 subjects were enrolled with shoe size, height, weight, BMI, and age compared. Using a footplate and series of mechanical wedges, maximum ankle dorsiflexion was measured with the great toe in 15°, 30°, and 45° of dorsiflexion.
Results: Ankle dorsiflexion decrease with progressive hallux dorsiflexion increase was statistically significant with a linear correlation ($r^2 = .814$ $p < .001$) and was not statistically related to shoe size, height, weight, BMI, or age.
Conclusions: This technique provides consistent assessment of the limitation to ankle dorsiflexion incurred by decreased FHL excursion, establishing groundwork for future studies to assess the relationship between diminished FHL excursion and FHL pathology.

1. Introduction

The flexor hallucis longus (FHL) is the primary flexor of the great toe and a primary stabilizer of the forefoot during the push-off phase of gait [1–5]. For a variety of reasons, including overuse and trauma, it can become entrapped at the fibro-osseous tunnel posterior to the ankle [6]. In these cases the restriction to distal excursion can result in clinical symptoms from either local synovitis or altered mechanics of the hallux metatarsophalangeal (MTP) joint [2,3,5,7,8].

Assessing the tightness of the FHL clinically has been described [8] using a technique that attempts to mimic the foot and ankle position at push-off phase during normal gate. This involves manually placing the ankle in maximal dorsiflexion, then holding the 1st metatarsal head so it cannot plantarflex, and then maximally dorsiflexing the 1st MTP joint. It is reported that a "tight" FHL can limit hallux MTP dorsiflexion to less than 20° [8], compared to a normal value estimated to be roughly 75° [9]. While this may be reproducible for that study's investigator, it has not been validated by others.

Whereas previous clinical assessment of decreased FHL excursion was assessed by measuring the limitation of dorsiflexion at the 1st MTP joint, the goal of the current study was to assess decreased ankle dorsiflexion as a function of decreased FHL excursion when the hallux was placed at predetermined degrees of dorsiflexion. In doing so, it was hypothesized that a semi-quantitative and repeatable measurement system could be created that could later be used to detect pathologically tight FHL tendons.

2. Methods

After obtaining approval from this institution's ethics committee and informed consent from participants, subjects were recruited from patients without foot pathology being seen in the University of Vermont Medical Center Orthopaedic Specialty Center. All potential subjects were first questioned regarding pre-existing foot ailments, and excluded from the study if they answered in the affirmative. The subjects were specifically screened to exclude anyone with conditions at either hallux or ankle that would limit motion at these joints. The data collected included age, gender, weight, height, and shoe size. Both feet were tested.

The test instrument was a footplate with a horizontal arm, a vertical arm, and a series of wedges that could be placed under the great toe to induce 15°, 30°, or 45° of dorsiflexion at the 1st MTP

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joint (Fig. 1). The starting state was defined with the vertical arm perpendicular to the base plate and aligned with the anterior tibia. The angular relationship between the horizontal and vertical arms was determined by a goniometer (iGaging Electronic Digital Goniometer, San Clemente, CA) connected to both. The goniometer was accurate to +.5°.

For each test run, the subject stood on the footplate and dorsiflexed their ankle as much as is comfortable with the knee flexed (to relax the gastrocnemius muscle) and the heel remaining on the ground. Dorsiflexion of the ankle is generally decreased when the knee is straight compared to when it is bent (the basis of the Silfverskiold test for a tight gastro-soleus complex). In order to limit this as a confounder in the testing, all assessments of ankle dorsiflexion were obtained with the knee bent. The measurement obtained was the maximum ankle dorsiflexion, as measured by the goniometer attached to the footplate. This procedure was then repeated under the control condition (no wedge under the hallux), and for each size of hallux wedge. By using different sized wedges, the FHL was selectively placed under increasing tension.

The moment arm for the 1st MTP was estimated by measuring the distance from the FHL to the center of the 1st MT head on a sagittal MRI slice located in the midline of the 1st MT head in 5 patients without hallux pathology. This data was then used to calculate the change in FHL excursion, with the moment arm of the FHL at the ankle set to 26 mm and the moment arm at the 1st MTP set to 13.6 mm [4,10]. The baseline position for comparison was defined as maximal ankle dorsiflexion with the hallux MTP joint at neutral.

Continuous demographic data (age, BMI, height, weight) were compared based on gender using Student's-t test. Categorical data were assessed using the Chi-square test. Comparisons of ankle dorsiflexion based on hallux dorsiflexion test conditions, gender, BMI, age, and shoe size were made using ANOVA. Right-left comparisons for continuous data were made using the paired Student-t test. Correlation coefficients were computed using the Spearman correlations for categorical data and the Pearson correlation for continuous data. In all instances, 2-sided testing was performed, with a significance level (p-value) set at .05. All statistics were performed using SPSS (version 21.0, IBM Corp., Armonk, New York).

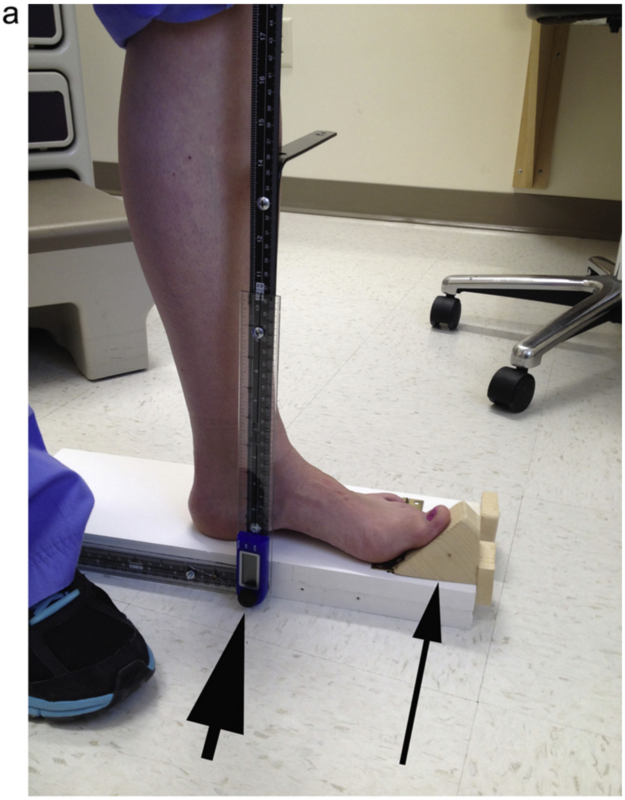
3. Results

A total of 64 subjects were enrolled, encompassing 37 females and 27 males. The mean age was 41.2 years (95% CI 37.7–44.7), which was not significantly different between males and females. The males were statistically taller and heavier than the females, but the BMI was similar for both genders (Table 1). The median shoe size in females was 8 (range 4–11) compared to median male shoe size of 11 (range 9–15) ($p < .001$ by Chi square).

Table 2 shows the data for the decrease in ankle dorsiflexion resulting from forced hallux dorsiflexion using 15°, 30°, and 45° wedges. The results were first assessed for right-left differences by Student t-test, which found no significant differences at any wedge angle used. Therefore the data in Table 2 represents pooled data for left and right feet. Statistically significant decreases in ankle dorsiflexion were noted with progressively increasing hallux dorsiflexion using the aforementioned wedges. Within each wedge angle for the hallux there was no significant difference in decreased ankle dorsiflexion related to shoe size (by ANOVA).

Fig. 2 displays the relationship between hallux dorsiflexion and the subsequent change in ankle dorsiflexion. As the starting point of the hallux MTP becomes more dorsiflexed via increased wedge size, there is decreased ankle dorsiflexion. This relationship is strongly linear, with $r^2 = .814$ ($p < .001$). The progressive decrease in ankle dorsiflexion caused by increased hallux dorsiflexion was

a



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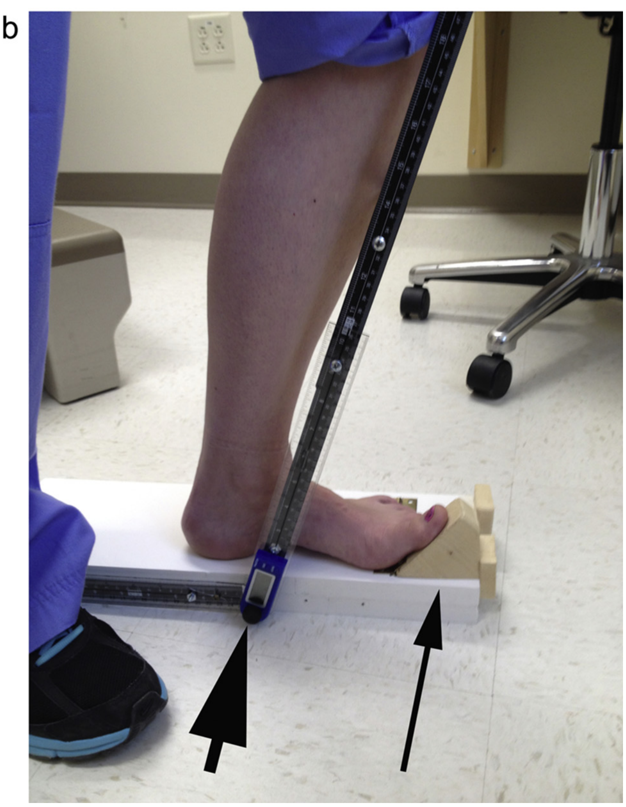

Fig. 1. (A,B)—Photograph of the testing apparatus. The wedge under the hallux is 45°. Alternate wedges can be placed under the toe plate (thin arrow) to establish hallux dorsiflexion at the MTP joint of 0° (no wedge), 15°, 30°, or 45°. The vertical arm is aligned with the anterior tibia, with the starting state defined as the vertical arm perpendicular to the base plate. The angular relationship between the horizontal and vertical arms is determined by the goniometer (thick arrow) that connects to both. The test starts with the leg vertical (A), and goes to maximum ankle dorsiflexion (B).

Table 1
Demographics of study population.

	Female (95% CI)	Male (95% CI)	p-value
Age (yrs)	39.8 (35.4–44.2)	43.1 (37.1–49.1)	.369
Height (m)	1.64 (1.61–1.66)	1.80 (1.78–1.82)	<.001
Weight (kg)	67.1 (63.4–70.8)	87.3 (80.4–94.3)	<.001
BMI (kg/m^2)	25.0 (23.7–26.3)	26.7 (24.9–28.4)	.117

Abbreviations: CI—confidence interval, yrs—years, m—meters, kg—kilograms, m^2—(meter)squared.

not statistically related to shoe size, height, weight, BMI, or age. All of these results were recalculated making adjustments for the fact that the axis of rotation of the goniometer was not at the center of ankle rotation. The alterations in the absolute values were small, with no changes in the significant differences observed.

The mean calculated increased FHL excursion relative to the hallux in neutral position ranged between 2.9 mm and 7.6 mm as the dorsiflexion of the hallux increased.

4. Discussion

The flexor hallucis longus (FHL) is the primary flexor of the great toe. The origin of the FHL is the distal fibula, with the muscle running against the posterior tibia in the deep posterior compartment as it goes distally and medially. It then enters the groove formed by the medial and lateral talar tubercles. This is the upper end of the fibro-osseous tunnel whose floor is the fibrous sheath and the roof is the sustentaculum talus. After it passes under the sustentaculum talus, it courses distally to enter a sheath that is shared with the flexor digitorum. The FHL crosses dorsal to the FDL at the knot of Henry, with the FDL continuing lateral to the FHL. At, or distal to, the knot of Henry, there are one or more tendinous slips that connect the FHL to the FDL (usually the second and third toe slips). The FHL then travels between the sesamoid bones of the forefoot, inserting on the base of the first distal phalanx [11]. It is prone to entrapment at the fibro-osseous tunnel, which limits the ability of the tendon to move distally as the hallux extends [2,3,5]. This limitation becomes relevant during the push-off phase of gate, when both the ankle and the toe are forced into maximum dorsiflexion. Under these conditions there may be pain in the posterior ankle from secondary synovitis or in the hallux from abnormal joint loading associated with decreased range of motion during step off [6,7].

The existing clinical method of assessing the excursion of the FHL [8] is described as maximally dorsiflexing the hallux MTP joint while simultaneously maximally dorsiflexing the ankle and 1st metatarsal, which simulates the position at push-off in the gate cycle. The problem, though, lies in the poor reproducibility and

Table 2
Increased hallux dorsiflexion decreases ankle dorsiflexion.

Hallux dorsiflexion wedge	Mean decreased ankle flexion (deg)	95% confidence interval		p-value*
		Lower	Upper	
15°	1.5	1.2	1.8	<.001
30°	4.1	3.7	4.5	<.001
45°	6.7	6.3	7.2	<.001

* p-value is for comparison to the ankle dorsflexion without a wedge under the hallux.

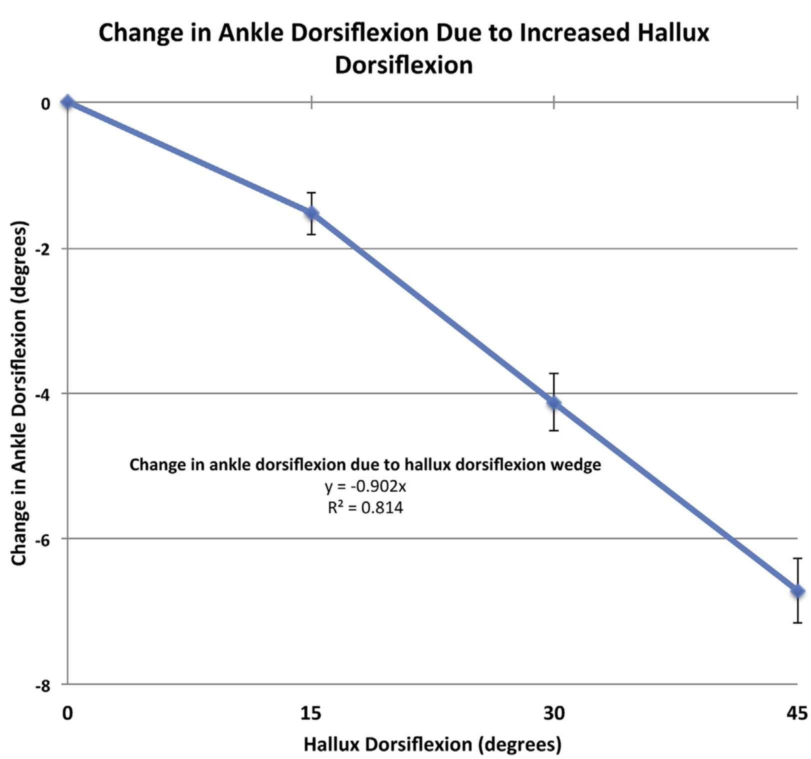

Fig. 2. Linkage between the increased dorsiflexion of the hallux and decreased maximum ankle dorsiflexion. Ankle dorsiflexion was measured as detailed in Methods. Hallux dorsiflexion was set 0°, 15°, 30°, or 45°, using appropriate sized wedges placed under the toe plate. Error bars are 95% confidence intervals. The parameters of the linear regression between ankle and hallux dorsiflexion is shown.

operator dependency of this clinical exam. Furthermore, the reported methods of accurately determining FHL excursion have all involved cadaveric specimens [4,10,12,13], making them unamenable to implementation in the clinical setting.

Using a cadaveric model, Hintermann found a total of 16.9 mm (range 12.1–23.5 mm) of FHL movement when the ankle was ranged between 20° dorsiflexion to 30° plantarflexion [12]. That study did not incorporate hallux dorsiflexion, which would likely increase the total possible FHL excursion. In contrast, Kirane et al. [13]. using a dynamic robot-controlled model that incorporated simultaneous motion at the ankle and hallux during simulated gait, showed that the excursion required for normal ambulation might be considerably less than this maximum.

The calculated change in FHL excursion in the present study ranged from 2.9 mm to 7.6 mm. These small differences in FHL excursion arising from large hallux dorsiflexion movements are consistent with the previous findings that as little as 2 mm of shortening of the FHL (by restricting the distal excursion at the fibro-osseous tunnel) led to significant increases in FHL tension [7]. If large motions of the hallux MTP are associated with small FHL excursions, then small restrictions in FHL excursion would be expected to result in relatively large decreases in hallux MTP dorsiflexion.

5. Limitations of the study

There are two main potential limitations to this study. The first is the possibility of incomplete elimination of test subjects with subtle ankle or hallux disorders that may have altered their motion at these joints. Although every effort was made to restrict the study to patients with normal ankle and hallux mechanics, in the absence of detailed examinations and imaging, it is still possible that a small proportion of patients had a degree of ankle or hallux disorder that was not evident.

Given the variability in the moment arm of the FHL at both the ankle and hallux MTP joint between individuals [4,10], it would be impossible to derive an absolute value for the FHL excursion measured by this technique in a single person in the absence of an MRI. However, the right-left symmetry is strong enough to permit the qualitative comparison of contralateral limbs for the presence of unilaterally limited FHL excursion. Ongoing testing of this methodology is under way involving patients with clinical evidence of restricted FHL excursion (based on the current clinical practice) to determine if the changes seen between patients with and without diminished relative FHL excursion are large enough to be reproducibly detectable.

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Conflict of interest

The authors have no conflicts of interest to disclose.

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