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Effects of Age on Strength and Morphology of Toe Flexor Muscles

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Abstract

Study Design: Cross-sectional.

Objective: To compare the strength and size of the toe flexor muscles of older adults relative to their younger counterparts.

Background: Age related muscle atrophy is common in lower limb muscles and we therefore speculated that foot muscles also diminish with age. However, there is a paucity of literature characterizing foot muscle strength and morphology, and any relationship between these two, in older people.

Methods: Seventeen young adults with a normal foot type were matched by gender and BMI to 17 older adults with a normal foot type, from an available sample of 41 young (18-50 years) and 44 older (60+ years) adults. Among the matched groups (n=34), muscle thickness and cross-sectional area (CSA) for five intrinsic and two extrinsic toe flexor muscles were obtained using ultrasound. Toe strength was assessed using a pressure platform. Differences in toe flexor strength and muscle size between the young and older matched groups were determined using ANCOVA (controlling for height). Correlations between strength and size of the toe flexor muscles of the pooled group (n=34) were also calculated.

Results: Toe strength and the thickness and CSA of most foot muscles and were significantly reduced in the older adults (P<0.05). Hallux and toe flexor strength were strongly correlated with the size of the intrinsic muscles toe flexor muscles.

Conclusion: The smaller foot muscles appear to be affected by sarcopenia in older adults. This could contribute to reduced toe flexion force production and affect the ability of older people to walk safely. Interventions aimed at reversing foot muscle atrophy in older people require further investigation.

Keywords: sarcopenia; toe strength; ageing; muscle atrophy; muscle weakness

Introduction

A decline in muscle strength is typically regarded as an inevitable consequence of ageing, with a decline in muscle strength tending to appear around the fifth to sixth decades [24, 11]. Sarcopenia (age-related muscle loss) is now a global phenomenon that is worsening due to our aging population. It is currently estimated that up to 30-57% of older people living in the community have sarcopenia, with a higher incidence reported in older women [4, 11, 25]. Muscle atrophy in older adults has been detected in numerous muscles of the lower limb including the triceps surae muscles [8, 20], and is associated with reduced walking speed and increased risk of disability and falls [12, 25]. Hence, preserving the independence and physical function of the older population should be a primary health priority.

There is a paucity of literature characterising foot muscle morphology and strength in older people. Although often neglected, foot muscles are vital to maintaining physical capability and toe muscle weakness is an independent predictor of falls in older people [17]. By applying pressure to the ground, toes are able to correct for unexpected postural disturbances, help maintain balance and ensure we can walk safely. Correct toe function is thus imperative for performing many important activities of daily living. Investigating age related changes to the foot muscles that perform these vital functions may help us understand mechanisms associated with declining gait and balance control that is common in older people [26]. We hypothesize that muscles within the feet, including those that control the toes, also suffer from atrophy with ageing. Therefore, the purpose of this study was to compare the strength and muscle size of the toe flexor muscles of older adults relative to their younger counterparts. A secondary aim was to determine the correlation between toe flexor strength and size of the toe flexor muscles.

Methods

Fourty-one young adults (18-50 years) and 44 older adults (60+ years) were recruited to participate in the study. The younger adults were recruited from a university student and staff population. Participants were required to be over the age of 18 years and have no lower limb disorders. Older participants were recruited from the community via advertisements. Each older volunteer was required to be aged over 60 years, be independently living, be able to ambulate for at least 10 m unaided, and English speaking. Participants were excluded from the study if they have had foot surgery or toe amputation or a history of neurological disorders. Written informed consent was obtained from participants and their rights were protected throughout the study. Ethics approval was obtained from the University of Salford's Research Ethics Panel (REP10/062).

Each participant had their feet assessed using the Foot Posture Index (FPI; [22)] and the presence of any toe deformities (e.g. hallux valgus, claw/hammer toes) were recorded. The FPI consists of six validated, criterion-based observations of the rearfoot and forefoot of a subject standing in a relaxed position. A FPI of 0-5 is considered normal, with scores less than this (i.e. negative) classified as supinated (high arch) and scores of 6 or more classified as pronated (low arch). Our previous research has found that foot muscle size is altered in a pes planus foot type [2] and people with toe deformites have reduced toe flexor strength[17], therefore particpants with a FPI ≥ 6 or toe deformites were excluded from the analysis. As this was part of a larger study looking at the foot muscles in balance, the preferred balance limb was chosen as the test foot in the older participants. For the younger particpants, if both feet were classified as normal (FPI 0-5), the foot with the lowest score was chosen as the test foot (i.e. most normal), or the right foot if both were equal (the most common test limb in the older particpants).

Toe flexor strength was then quantified using our previously developed reliable (ICC > 0.92) protocol[16, 17]. Each participant stood in even weight-bearing with their test foot on an emed X pressure platform (Novel$_{gmbh}$). During each trial, participants were instructed to push down as hard as possible onto the platform under two conditions: i) using their lesser toes, or ii) using only their hallux. Maximum force (N) under the hallux and lesser toes were calculated and then normalised to body mass (% BW).

The abductor halluces (ABH), flexor hallucis brevis (FHB), flexor digitorum brevis (FDB), quadratus plantae (QP) and abductor digiti minimi (ABDM) muscles in the foot and the flexor digitorum longus (FDL) and flexor hallucis longus (FHL) muscles in the shank were imaged using a Venue 40 musculoskeletal ultrasound system (GE Healthcare, United Kingdom) fitted with either a 5-13 (maximum depth 6 cm) or 8-18 MHz (maximum depth 4 cm) linear transducer. For the flexor digitorum brevis, quadratus plantae, flexor hallucis brevis and abductor digiti minimi muscles, participants lay prone on a plinth with their feet hanging freely. To view the abductor hallucis, flexor digitorum longus and flexor hallucis longus, participants lay supine with their hip externally rotated and knee slightly flexed. Images of the muscles were obtained using a standardized procedure that has been shown to have high intra- and inter-rater reliability [15, 3]. Ultrasound coupling gel was applied over the transducer and skin at each of the measurement sites. To optimize image quality, the transducer was positioned so that the ultrasound beam was aimed perpendicular to the muscle borders. Depth and gain were adjusted to obtain a satisfactory image and then the image was captured when muscles were in a relaxed state. The tester applied minimal pressure to the ultrasound probe in order to reduce deformation of the muscle and surrounding tissues. Three images were taken at each site, removing the probe between each trial. Muscle thickness (mm) and cross-sectional area (mm^2) of each muscle[15] were measured using Image

J software (National Institute for Health, Bethesda, MD, USA) by a researcher blind to participant groups and the three values averaged.

Statistical Analysis

Data was checked for normality using a Kolmogorov-Smirnov test, and all variables were found to be normally distributed. For the young and old comparisons, young adults with normal foot type (FPI 0-5; n=17) were matched by gender and BMI to older adults from with normal foot type and without any toe deformities (n = 17) to form the Young and Old comparison groups. Analysis of Covariance, controlling for height were conducted to determine whether toe flexor strength and muscle size differed between the Young and Old participant groups. Figure 1 depicts the inclusion of the participants in the final analysis.

To determine the strength of association between the muscle size and toe strength, Pearson correlation was performed on the pooled groups (n =34). An alpha of $P < 0.05$ was established for all statistical analyses, which were conducted using SPSS software (IBM SPSS Statistics 21).

Results

Despite being matched for gender, BMI, and foot type and after adjusting for height the older participants displayed significantly reduced flexor strength of both the hallux and lesser toes (see Table 1). This equates to a 38% and 35% reduction in strength of the hallux and lesser toes, respectively. There was also a significant effect of age, after controlling for height, on muscle size whereby the older participant group had reduced thickness and cross-sectional area of the foot muscles (19-45%; $p \leq 0.01$) in all muscles except the abductor hallucis muscle thickness and cross-sectional area and the cross-sectional area of the flexor digitorum muscle (see Table 2).

After combining the young and older groups, hallux flexor strength was shown to be significantly correlated with flexor hallucis brevis cross-sectional area and thickness (r = 0.515-0.606, p < 0.003) but only weakly correlated with flexor hallucis longus thickness (r = 0.372, p = 0.03). Hallux flexor strength was also strongly correlated with quadratus plantar cross-sectional area (r = 0.708, p < 0.001) and thickness (r = 0.544, p < 0.001), but not with flexor hallucis longus cross-sectional area (r = 0.162, p = 0.36). Similarly, lesser toe flexor strength was significantly correlated with flexor digitorum brevis cross-sectional area and thickness (r = 0.369 - 0.501, p < 0.03), but not correlated with flexor digitorum longus cross-sessional area or thickness (r = 0.272-0.283, p = 0.1). Lesser toe flexor strength was also moderately-strongly correlated with quadratus plantar thickness and cross-sectional area (r = 0.52-0.669, p < 0.001), flexor hallucis brevis thickness (r = 0.552, p < 0.001) and abductor digiti minimi cross-sectional area (r = 0.448, p = 0.01).

Discussion

This paper aimed to determine the difference in the size and strength of toe flexor muscles in healthy older people, compared to their younger counterparts with a normal foot type. As hypothesized, sarcopenia appears to affect the smaller foot muscles whereby, after adjusting for height, both the size and strength of the toe flexor muscles were significantly reduced in the older participants. Our finding of a reduction in toe strength of 35-38% is similar to the 29% lower toe strength displayed by older people when performing a maximal reach task [7] and the 27-32% reduction in toe strength in older people reported by Menz et al [14]. With the exception of the abductor hallucis muscle, the thickness and cross-sectional area of the measured foot muscles were reduced by 19-45% in the older participants. Importantly, the difference in size between the younger and older muscles were all greater than the limits of agreement and SEM reported for each of the sites indicating that the differences are unlikely due to measurement error. The scale of these large changes is in agreement with numerous studies that have reported a reduction in muscle size in older people, particularly in the lower limb. For example, the gastrocnemius muscles have been found to be up to 15% thinner in women aged 60 years or older compared to their younger counterparts, and muscle atrophy was detected in men aged 50 or older [8]. Furthermore, the same study reported a significant correlation of **r** = -0.40 between age and gastrocnemius medialis thickness in their 847 male and female participants[8]. Another study assessing the gastrocnemius medialis muscle using CT imaging found that cross-sectional area was reduced by 19.1% in older men (70-81 years) compared to younger men (28-42 years) [20].

Class I sarcopenia has been described as a muscle mass reduction of 1-2 standard deviations below the mean for young adults, and Class II as more than two standard deviations below the average young adult values [11]. In this study, the mean cross-sectional area of the QP, FDL and FHL muscles of the older adults were 1-2 standard deviations below the younger adults, whereas the FHB and ABDM cross-sectional area were at least three standard deviations below the average for the young adults. Similarly, the thickness of the QP, ABDM, FDL muscles were 1-2 standard deviations below the younger participants whereas the FHB, FDB and FHL muscles were more than 2 standard deviations below the younger adults. This further demonstrates the extent of the toe muscle atrophy in older people.

This is the first study to use ultrasound to show an overall reduction in the size of the toe flexor muscles in otherwise healthy older adults. The use of ultrasound to assess sarcopenia has been used less frequently than more well-known approaches however, findings from this study advocate ultrasound to be a useful clinical and research imaging modality for characterizing skeletal muscles and sarcopenia and accord with recently published work in this area [10]. A reduction in the size of the foot muscles may compromise normal foot structure and function and lead to changes in how load is applied to, transferred through and distributed within the structures of the foot. This is supported by data that shows older females, classified as sarcopenic and obese, have increased loading under the midfoot compared to older obese women without sarcopenia [18]. This could be a consequence of altered medial and lateral foot arch kinematics due to a loss of function on the intrinsic foot muscles. It is also possible that a reduction in the size of these foot muscles leads to an imbalance between toe flexor and extensor muscles, and is perhaps the cause the increased prevalence of toe deformities in older people [6, 23]. One study has investigated the association between age and the thickness and cross-sectional area of the abductor hallucis muscle, but in people with hallux valgus deformity [1]. They found a significant reduction in both thickness and cross-sectional area between their oldest age group (65+ years) compared to their youngest age group (20-44 years). Interestingly, this was the only muscle that did not significantly differ between the young and older ages groups in this current study. This difference could be primarily due to the interaction with the deformity, our study excluded people with hallux valgus whereas the Aiyer [1] study only included people with at least mild deformity. Furthermore, when all participants were grouped together, the Aiyer[1] study reported only a weak correlation (r = -0.24) between age and muscle size.

Our study confirms that the strength of the muscles that perform toe flexion is reduced in older people compared to their younger counterparts. This reduction in toe flexor strength is likely to have a profound effect on the ability of older people to walk safely. For example, our previous research has found that a reduction in hallux and lesser toe strength increases the risk of falling, with each 1% BW reduction increasing the risk of falling by 7% [17]. The difference of 6.5% BW in the hallux strength between the young and old cohorts, suggests that the risk of falling could be increased by up to 45% in healthy older people relative to their younger counterparts. The exact cause of the reduction in foot muscle strength with ageing cannot be determined from this study. Numerous factors such as motor unit loss[5], a reduction in physical activity or history of footwear use may contribute to age-related decline.

Although we cannot confirm or refute any of these, it should be noted that the older people in this study were generally mobile, with 5/17 stating that they spend 1-4 hours per day on their feet, 10/17 spending 4-8 hours and 2 participants stating that they spend more than 8 hours per day on their feet.

We found significant positive correlations between the size of the foot muscles and toe flexor strength. Most of the correlation coefficients were in the moderate range of 0.5-0.6. These values are similar to that of Maughan [13] who reported correlation coefficients of 0.51 and 0.59 for the cross-sectional area and strength of the knee extensor muscles for young females and males, respectively. The lack of readily available, valid and reliable instruments to measure toe strength has placed limitations into investigating the function of the toe muscles. Interestingly, toe flexor strength, as measured by the ability to "push down" with the toes, was more strongly correlated with the size of intrinsic foot muscles than the extrinsic toe flexor muscles. This probably reflects that the extrinsic/longer muscles are designed to offer a broader function across a range of joints. Their role as toe flexors could also be affected by the neutral position of the ankle during the test. Little is known about how the strength of the intrinsic foot muscles are affected by foot position, primarily due to our inability to be able to isolate the strength of individual foot muscles, hence the use of ultrasound in this study to measure muscle size. It is acknowledged however, that not all of the muscles would be acting independently, and that the thickness and cross-sectional area measurements are also related variables. However, this test of toe flexor strength may better represent the strength of the intrinsic foot muscles than other dynamometry or grip tests that involve curling the toes, which would require greater involvement of the long flexor muscles that attach to the distal phalanges.

This study is limited by its cross-sectional design whereby the true relationship between age and size of the foot muscles could not be assessed. A longitudinal study design would be required to determine the true rate of atrophy and determinates that accelerate or decelerate the process. Furthermore, the analysis was only conducted on individuals with a normal foot type, without any foot problems, therefore are findings are limited to this population.

Sarcopenia is an independent risk factor for many adverse outcomes, most notably difficulties in activities of daily living, but also falls, and death [4]. Therefore, preventative strategies are required to ensure longevity and quality of life for older people and interventions aimed at reversing foot muscle atrophy in older people warrants further investigation. While exercise generally appears to be effective in increasing muscle strength and improving physical performance in older people, exercise interventions have not consistently shown increased muscle mass in frail, sedentary older adults [4]. Several studies have found that the foot muscles can positively respond to resistance training in younger adults [9], however, exercise interventions targeted specifically at increasing foot muscle strength in older people is yet to be reported. Alternatively, there is emerging evidence to suggest that the toe flexor muscles can respond to training through specialised footwear [21, 19]. Therefore, further efforts into the research and design of functional footwear that can be targeted at restoring foot function in the growing older population should also be investigated.

Conclusion

Our study confirms that the strength of the muscles that perform toe flexion is reduced in older people compared to younger adults. This is the first study to use ultrasound to investigate the size of the toe flexor muscles in otherwise healthy older adults compared to younger adults and sarcopenia appears to affect the smaller foot muscles, even in normal foot types without any foot problems. This could contribute to reduced toe flexion force production and affect the ability of older people to walk safely. Therefore, interventions aimed at reversing foot muscle atrophy in older people are warranted and require further investigation.

Key Points

- Findings: Toe flexor strength is reduced by approximately 35% in older people compared to younger adults. Furthermore, the size of the foot muscles decrease with age, whereby the size of the foot muscles are 19-45% smaller in older people compared to young adults.
- Implications: A reduction in the size and strength of the foot muscles may compromise normal foot structure and function in older people and affect the ability of older people to walk safely.
- Caution: This study utilized a cross-sectional design, therefore the true relationship between age and size of the foot muscles could not be assessed.

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Table 1. Descriptive characteristics (SD) of the Young & Old participant groups. * Indicates a significant difference between the groups ($p \leq 0.02$).

	Young (n = 17)	**Old (n = 17)**
Age (years)	28.8 (8.2)	67.1 (2.9)*
BMI (kg.m^2)	26.0 (4.1)	26.0 (4.0)
Mass (kg)	76.7 (13.2)	70.3 (10.1)
Height (cm)	172.0 (8.9)	164.8 (9.6)*

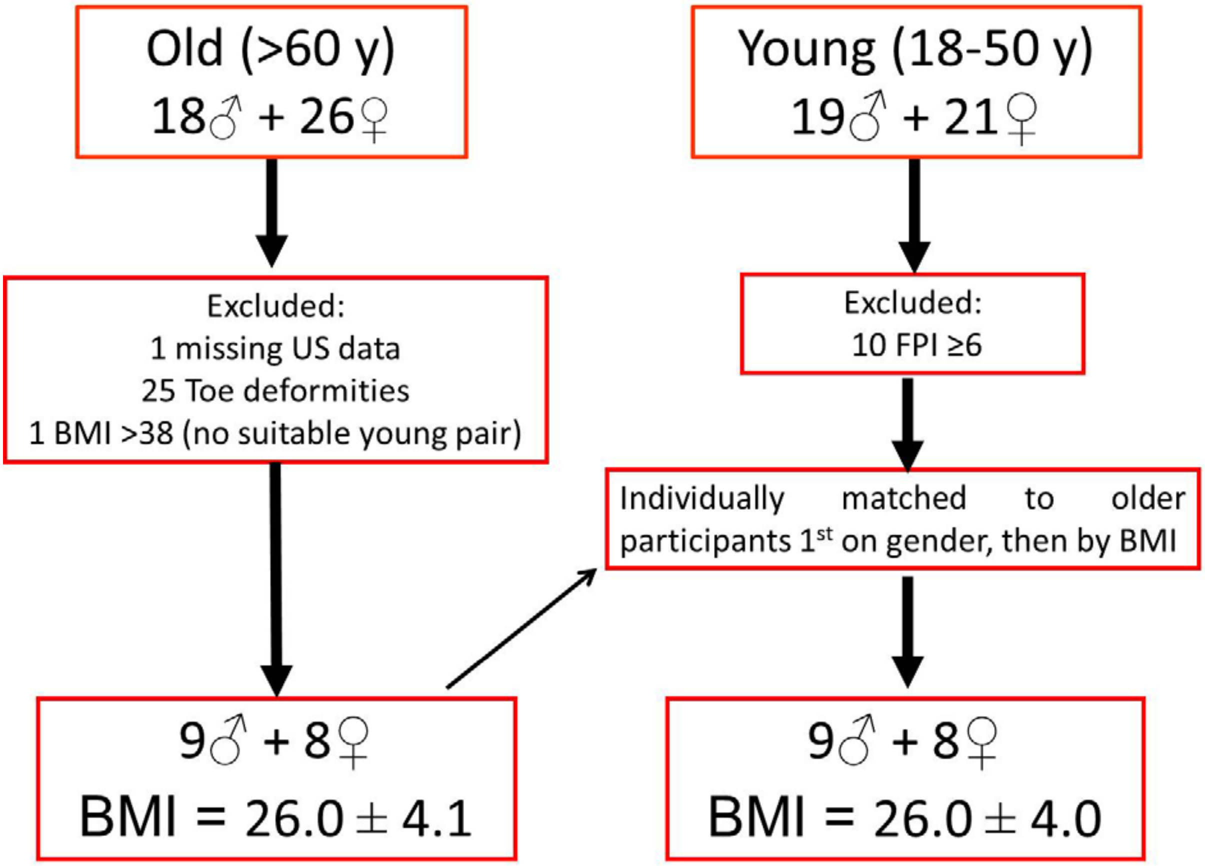
Table 2. Adjusted mean (95% CI) and SEM for the toe strength and muscle size measurements of the Young & Old participant groups. * Indicates a significant difference between the groups ($p \leq 0.05$).

Measure		**Young (n = 17)**	**Old (n = 17)**	**SEM**
Strength	Hallux (% BW)	18.1 (14.8-21.5)	11.0 (7.7-14.4)*	1.9
	Lesser toes (% BW)	11.0 (9.1-12.8)	7.2 (5.3-9.1)*	1.1
ABH	Thickness	12.5 (11.8-13.2)	12.2 (11.5-12.9)	0.19
	CSA	277.3 (257.9-296.8)	265.9 (246.4-285.3)	5.5
FHB	Thickness	15.3 (14.3-16.4)	11.4 (10.2-12.5)*	0.5
	CSA	335.9 (310.3-361.5)	240.3 (212.9-267.7)*	23.3
QP	Thickness	10.3 (9.5-11.1)	7.5 (6.7-8.3)*	0.4
	CSA	202.4 (180.8-224.0)	133.0 (112.1-153.9)*	58.9
ABDM	Thickness	10.8 (9.9-11.6)	8.3 (7.4-9.2)*	0.3
	CSA	218.9 (202.0-235.9)	138.3 (120.7-155.8)*	7.2
FDL	Thickness	19.3 (17.4-21.1)	13.7 (11.8-15.6)*	0.6
	CSA	277.4 (253.2-301.6)	168.5(144.3-192.7)*	19.4
FHL	Thickness	22.3 (20.8-23.7)	12.2 (10.8-13.7)*	0.8
	CSA	353.6 (327.4-379.8)	283.3 (257.1-309.4)*	17.9
FDB	Thickness	10.4 (9.7-11.1)	7.2 (6.5-7.9)*	0.3
	CSA	215.3 (190.5-240.2)	190.1 (166.0-215.7)	5.3

ABH = abductor hallucis; FHB = flexor hallucis brevis; QP = quadratus plantae; ABDM = abductor digiti minimi; FDB = flexor digitorum brevis; FDL = flexor digitorum longus; FHL = flexor hallucis longus.

Legends

FIGURE 1. Flowchart of participants included in the analysis; FPI = Foot posture index


Old (>60 y)
18♂ + 26♀
Young (18-50 y)
19♂ + 21♀
Excluded:
1 missing US data
25 Toe deformities
1 BMI >38 (no suitable young pair)
Excluded:
10 FPI ≥6
Individually matched to older participants 1st on gender, then by BMI
9♂ + 8♀
BMI = 26.0 ± 4.1
9♂ + 8♀
BMI = 26.0 ± 4.0