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ORIGINAL RESEARCH

# Age-Related Reduction of Foot Intrinsic Muscle Function and the Relationship with Postural Stability in Old Adults

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**Introduction:** The risk of falls among the elderly significantly increases, which has become a serious public health concern. Falls can not only lead to serious complications such as fractures and brain injuries but also limit their mobility function, reducing quality of life. Foot intrinsic muscles (FIMs) are an essential part of foot core stability even overall postural stability. This study aimed to investigate the effects of aging on the function of FIMs and to explore the influence of FIMs on postural control in the elderly.

**Materials and Methods:** 56 healthy old participants (60–75 years) and 57 healthy young participants (18–29 years) joined this study. An ergoFet dynamometer was used to determine foot muscle strength (Doming, $T_1$, $T_{23}$ and $T_{2345}$), and ankle muscle strength (plantarflexion and dorsiflexion). The morphology of FIMs and extrinsic foot muscle was determined using a Doppler ultrasound system, whereas the postural stability was assessed through Limits of Stability test. Independent samples *t*-test was used to determine the differences in strength and morphological parameters and Spearman correlation analysis was used to determine whether an association existed between muscle strength and postural stability parameters in the elderly.

**Results:** Compared with young adults, foot muscle strength and ankle muscle strength (Doming, $T_1$, $T_{23}$, $T_{2345}$, dorsiflexion, and plantarflexion, all $p < 0.05$) and the morphology of foot muscles (all $p < 0.05$) were significantly reduced in the elderly. The strength of FIMs and the limit of stability ($r = 0.302–0.424$, all $p < 0.05$) were significantly correlated in the elderly.

**Conclusion:** Compared with young adults, the weakness of strength as well as the morphological decline of the intrinsic and extrinsic foot muscles were found in the elderly. In addition, a correlation was observed between FIM's strength and postural stability in the elderly, suggesting their potential role in posture stability.

**Keywords:** postural stability, aging, foot core system, fall, foot intrinsic muscle, FIMs

## Introduction

Falls are the leading cause of death and injury amongst the elderly globally, second only to traffic accidents.[1,2] Previous studies have reported that falls occur in one-third of the elderly over the age of 65 each year, and up to 80% of those over the age of 80.[3,4] However, in addition to personal sufferings, falls and related injuries represent a serious set of health care problems because they associated with subsequent mobility, disability, hospitalization, family and social burden.[5] For many countries, including China, aging and the increase in fall-related injuries amongst the elderly have become a growing public health problem.[6]

Multiple factors and complication are associated with falls, such as drug utilization, obesity, reduced lower-limb muscle quality and impaired postural control.[7,8] With age, related physiological functions, such as visual, vestibular and motor as well as cognitive functions, in turn affect the ability to stabilize posture, interactively increasing the risk of



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falling.[9–11] Therefore, the factors associated with the decline in postural stabilization in the elderly urgently need to be comprehensively explored to provide a basis for the subsequent establishment of effective intervention strategies.

The foot is the only segment of human body that is in direct contact with the ground during weight-bearing activities and therefore plays an important role in stabilizing the body during standing and walking.[12] As the most distal aspect of lower limb, the foot directly transmits the ground reaction force and distribute the impact forces through the modulation of foot structure, posture and muscle activity.[13,14] There is a growing body of evidence to explore the correlation between foot function and lower limb injuries. For example, the abnormal foot function, such as excessive pronation and dysfunction of the first metatarsophalangeal joint, has been reported associated with decreased foot stability, changing the mechanics of propulsion, and changing load distribution of foot.[15] According to the coupling mechanism among joints of lower limb, these dysfunctions of foot also have been observed to implicate in the development of multiple lower limb injuries, including the plantar fasciitis, stress fracture, patellofemoral pain and anterior cruciate ligament injury.[15,16]

Most previous studies focused on the degradation of postural stability and fall prevention strategies in the elderly, with an emphasis on training the large muscles of the lower extremity, such as the muscles around the ankle and hip.[17] In foot core system,[12] the muscles around the arch and ankle actively changes in their muscle length are one of the key factors in maintaining postural alignment.[18] Before the foot core system was proposed, researchers generally referred to the group of muscles whose muscle origins and terminations were located between the ankle and metatarsophalangeal joints as the toe flexors and suggested the muscular strength of these muscles could serve as one of the most important indicators of muscle strength in the foot.[19] Evidences have suggested a correlation between the toe flexor strength and the body's maximum stabilization range,[20] and its contribution to human postural control and mobility in the elderly.[21] Several cohort studies found toe muscle strength in the elderly is correlated with their risk of falling, and every 1% increase in toe flexor strength corresponded to a 6.7% decrease in the risk of falling.[21,22]

As an important component of the foot active subsystem, foot intrinsic muscles (FIMs), originated and inserted in the plantar bones and aponeurosis,[12] facilitate propulsion and shock absorption during human locomotion, thus supporting the foot functional half dome and foot core stability.[23] In recent years, researchers began to quantify the relationship between FIM strength and human postural stability parameters. Decreased muscle strength of FIMs can lead to foot movement and postural abnormalities, resulting in decreased arch stability, secondary bone structural changes and a possible increased risk of falls.[24,25] Tas et al found that the thickness and cross-sectional area (CSA) of several FIMs (abductor hallucis [AbH], flexor digitorum brevis [FDB] and flexor hallucis brevis [FHB]) were negatively correlated with the stability of unilateral stance postures, whereas the muscle hardness of AbH and FDB were positively correlated with the stability of unilateral stance postures.[26] According to a study by Maeda et al, the thickness of FDB was positively correlated with postural stability, and a regression relationship was found between its muscle hardness and postural dynamic stability.[27]

Compared with healthy adults, the muscle strength and morphology of the foot were significantly decreased in the elderly;[28] however, in previous studies, the foot muscle strength used mostly focused on toe flexor strength, including manual foot muscle strength test, a handheld foot muscle tester, a paper clip test and special tests.[29–31] The above test methods focused on the role of FIMs in producing toe flexion, ignoring the more important essential function of supporting the arch of the foot.[12] In addition to the limitations of the foot muscle strength test, for the elderly, most previous studies investigated the relationship between foot muscle strength and fall risk,[22] mobility,[32] walking speed[33] and functional test,[34] lacking direct evaluation on postural stability.

In summary, exploring the relationship between FIMs and accurate postural stability task may contribute to a more comprehensive understanding of the factors associated with the decline in postural stabilization in the elderly. Therefore, the purpose of this study was to determine the effects of aging on the function of FIMs and to explore the influence of its function on postural control in the elderly.

# Materials and Methods

## Participants

### Sample Size Estimation

In this study, the independent sample *t*-test was utilized as the statistical method. Based on prior research on foot muscle performance in aged and healthy adults,[28] the G*POWER software 3.1 software was used to calculate the sample size for difference between old and young groups for the independent samples *t*-test. With the setting of $\alpha = 0.05$, power $(1-\beta) = 0.95$, and effect size =0.8, the sample size per group was determined to be 42. Considering the inaccuracy of the foot muscle function test, the final setting for each group was 55 participants.

### Inclusion Criteria

1. Elderly people over 60 years of age; (2) Can maintain a standing position; (3) Walk independently without relying on others, a prosthesis or a walker; (4) Normal cognitive function and able to understand the test procedure correctly.

### Exclusion Criteria

1. Abnormal foot structure (toe deformities and hallux valgus); (2) Abnormal foot posture (studies have shown that foot posture affects balance performance,[35] so this study judged by the FPI-6 scale[36]); (3) Diseases associated with postural control such as Parkinson's disease, stroke, psychotropic drug use and peripheral neuropathy; (4) Severe cardiopulmonary system diseases; (5) Lower limb skin injuries; (6) History of trauma to the lower limbs within one year; (7) Diabetes and other conditions with abnormal foot sensation (judged based on vibratory sensory thresholds of the first toe-plantar); (8) History of amputation.

The volunteers were recruited through adverts in various community centres throughout Shanghai, China. The research team (clinicians, physical therapists and exercise specialists) assessed all subjects for participation based on the inclusion and exclusion criteria given above. Participants were those who met the inclusion criteria and were willing to engage in this study, and they were informed the study procedures and signed informed consent in advance. This study was approved by the ethics committee of the Shanghai University of Sport (No.: 102772020RT001), and it was carried out in accordance with the Declaration of Helsinki.

## Measurement and Outcomes

### Foot and Ankle Muscle Strength

Foot and ankle muscle strength testings were divided into three parts: (1) ankle plantarflexion and dorsiflexion; (2) toe flexion muscular strength testing; and (3) doming testing (arching foot maximum strength). The reliability of FIMs strength testing in the elderly has been reported in our previous study.[37] An ergoFet ergometer (Hoggan Health, USA, sampling frequency of 100 Hz) was also employed for the foot and ankle muscle strength testing. Foot and ankle muscle strength testings used in this study have been published in our previous articles for methodological reference.[37,38]

For ankle plantarflexion and dorsiflexion, the participant lied flat on the test bed with self-adhesive tape affixed to the upper chest, pelvis and distal tibia. The tester vocally encouraged the participant to perform ankle plantarflexion and dorsiflexion to the best of his or her ability and sustain it for 2–3 seconds during the formal test. Each trial was performed three times, and adequate rest time was provided between testing to prevent fatigue. Analyses were conducted in the same manner as for toe flexion strength, and the average of the three completed tests was used to calculate ankle plantarflexion and dorsiflexion strength.

In the toe flexion muscle strength testing, the 1st toe flexion strength ($T_1$), the 2nd–3rd toes flexion strength ($T_{23}$) and the 2nd–5th toe flexion strength ($T_{2345}$) needed to be performed unassisted.[39] Referring to previous studies, in this test, the tester fixed a dynamometer to a custom-made wooden frame, which was also fixed to the floor.[39] The participant was seated in a height-adjustable chair with the knee flexed at 90°. The participant's tested foot (dominant side) was placed on the wooden platform with the heel of the foot resting against the other set of panels. To test the strength of the lesser toe flexors, the tester aligned the lesser toe with the dynamometer by adjusting the number of wooden panels at the heel and the position of the participant's foot. The participant was instructed to pull the latch on the dynamometer towards the heel as best he or she could with only his or her lesser toes through the screw clasp. Moreover, the participant was instructed to flex the lesser toe and exert as much force as possible for three seconds and then relax. Three tests needed to be completed, and the average of the results was recorded.

In addition, the 2nd–3rd toe flexion strength ($T_{23}$) and the 2nd–5th toe flexion strength ($T_{2345}$) were determined using a "T"-shaped metal bar instead of a screw buckle. During the test, the participant was instructed to use the 2nd–3rd and 2nd–5th toes to hold the metal tabs attached to the screw clasp and to flex the toes as hard as possible. During the test, if the participant's heel and foot were lifted off the ground, the test was needed to be repeated. Three tests needed to be completed, and the average of the results was recorded. Between all strength tests, sufficient rest time was provided to prevent fatigue.

The doming (arching foot) testing, accomplished by activating the foot muscles to pull the metatarsal heads towards the heel, was effective in shortening foot length without flexion of the foot-metatarsophalangeal joints. This test was performed with the participant's tested foot (dominant side) placed on a custom-made wooden frame with an ergoFet ergometer attached to the crossbar of the frame. The crossbeam can be moved back and forth until the ergometer moved over the dorsal navicular tuberosity of the foot. The tester instructed the participant how to perform the doming in advance to ensure he or she was familiar with the test requirements and to guarantee the accuracy of the test. The main instructions for the doming movement included toes on the ground, sliding the foot backwards towards the heel and elevating the arch of the foot without raising or bending the toes. The participant was required to complete a maximal voluntary contraction movement lasting three seconds and then relax as instructed by the tester. If the participant lifted the toes, the base of the first metatarsal or the heel off the ground, the doming test was considered incorrect, and the test needed to be repeated. Three tests were completed, and the average of the results was recorded.

## Foot and Ankle Muscle Morphology

A portable colour Doppler ultrasound system (Diagnostic Ultrasound System, M7 Super, Mindray, China) with 10 MHz linear broadband array transducer (Model: L14-6s), which can capture foot related muscle images and muscle morphology measurements, was used in this study. The muscle morphology on the dominant side of the participants, including AbH, FDB, QP, FHB, Tibialis Anterior (TA) and Peroneus Longus and Brevis (PER), was captured. To determine the thickness of the muscle, the tester placed the ultrasound probe in the direction of the muscle fibres, and to determine the CSA, the probe was rotated 90° at the thickest part of the muscle. Due to the specificity of the ultrasound testing method, muscle morphology testing was performed by the same tester to ensure the reliability of the test.[27,40] Based on the ultrasound testing protocols of previous studies,[40–42] the ultrasound localization and testing of muscle were summarized. Foot and ankle muscle morphology used in this study have been published in our previous articles for methodological reference.[37,38]

## Postural Stability

The human dynamic posture was traced using the Limits of Stability (LOS) in the NeuroCom Balance Manager System (Version 9.3, Copyright ©1989-2016 Natus Medical Incorporated) to assess postural control in elderly participants. LOS test is a test of autonomic motor function in the NeuroCom Core Assessment that helps quantify a participant's dynamic stability and is widely used in clinical as well as scientific research.[43,44] The balance device uses a 23 cm × 46 cm dual-force plate to measure vertical force with a sampling frequency of 100 Hz.

The test required the participant to stand on the force plate and prestabilize the centre of gravity in the predefined target area. When hearing the bell start signal, the participant must immediately start the body's centre of gravity as far as possible to move directly to the target area to ensure the body's centre of gravity was stable in the target area and maintain the position for 10s. After ringing the end of the signal, the participant adjusted the centre of gravity to return to the centre of the predefined target area. The test participant was required to move in main four directions, namely, forward, backward, dominant side and non-dominant side, and actively move the centre of gravity towards the limit of stability. During the test, the participant kept the body stable without any assistance, did not lose balance and did not take a step. The maximum excursions (MEX), which represents the furthest distance the centre of gravity moved during the trial, was analysed.

## Statistical Methods

Statistical analyses, including the calculation of the mean and SDs for normally distributed continuous variables and the median and interquartile range for not normally distributed continuous variables, were performed by using SPSS statistical software (version 20.0 for Windows; SPSS, Inc., Chicago, IL, USA). The Kolmogorov–Smirnov test was used to evaluate the normality of distribution. The independent samples *t*-test was used to determine whether differences existed between the typical characteristics (age, height and weight) and foot core stability parameters of the two groups (healthy young people versus healthy old people). The chi-square test was used to determine whether a difference existed between the demographic parameters (male-to-female ratio and dominant side) of the two populations.

Spearman correlation analysis was used to determine whether a correlation existed between foot muscle strength and its postural stability parameters in healthy old adults because the data did not conform to a normal distribution, where $0.7 \le |r| < 1$ indicates a strong correlation, $0.3 \le |r| < 0.7$ indicates a moderate correlation and $|r| < 0.3$ indicates a weak correlation. Statistical significance was set at 0.05 for all analyses.

# Results

For this study, two groups of volunteers were recruited: 56 healthy old participants and 57 healthy young participants. There was no significant difference found in demographic data (age, height, weight and BMI) between two groups. In addition, no significant difference was observed between the gender distribution ratio and the dominant side distribution ratio of the two groups of participants, as shown in Table 1.

Table 2 showed that compared with healthy young adults, the foot muscle strength and ankle muscle strength of healthy old adults declined significantly, and the difference was statistically significant (Doming: Mean Difference [MD] = −0.29 N/kg, 95% CI −0.37 to −0.21, t (109) = −7.52, p < 0.001; $T_1$: MD = −0.43 N/kg, 95% CI, −0.56 to −0.30, t (110) = −6.55, p <0.001; $T_{23}$: MD = −0.26 N/kg, 95% CI, −0.35 to −0.17, t (111) = −5.65, p <0.001; $T_{2345}$: MD = −0.37 N/kg, 95% CI, −0.48 to −0.27, t (110) = −7.03, p <0.001; dorsiflexion: MD = −1.27 N/kg, 95% CI, −1.58 to −0.96, t (106) = −8.14, p <0.001; plantarflexion: MD = −0.95 N/kg, 95% CI, −1.82 to −0.08, t (106) = −2.16, p = 0.033).

**Table 1** Demographic Characteristics of Participants in Both Groups

| | Elderly (n = 56) | Young (n = 57) |
|---|---|---|
| Age (years) | 69.0±3.2 | 22.3±3.1 |
| Height (cm) | 160.6±8.2 | 163.3±7.3 |
| Weight (kg) | 62.3±8.9 | 56.2±8.1 |
| BMI (kg/m$^2$) | 24.2±3.5 | 21.0±2.4 |
| Gender (male/female) | 13/43 | 11/46 |
| Dominant side (left/right) | 4/51 | 4/52 |

**Note**: All the data were expressed as means ± SD or ratio.
**Abbreviation**: BM, body mass index.

**Table 2** Difference in Foot Muscle Strength and Ankle Muscle Strength Between Groups

| | Elderly (n = 56) | Young (n = 57) | p-value |
|---|---|---|---|
| Doming (N/kg) | 0.58±0.16 | 0.84±0.28 | <0.001 |
| $T_1$ (N/kg) | 0.67±0.22 | 1.10±0.44 | <0.001 |
| $T_{23}$ (N/kg) | 0.70±0.19 | 0.96±0.29 | <0.001 |
| $T_{2345}$ (N/kg) | 0.77±0.25 | 1.14±0.31 | <0.001 |
| Dorsiflexion (N/kg) | 2.06±0.86 | 3.33±0.75 | <0.001 |
| Plantarflexion (N/kg) | 4.57±1.99 | 5.52±2.54 | 0.033 |

**Note**: All the data were expressed as means ± SD.
**Abbreviations**: $T_1$, the 1st toe flexion strength; $T_{23}$, the 2nd–3rd toes flexion strength; $T_{2345}$, the 2nd–5th toe flexion strength.

**Table 3** Morphological Differences in Foot Muscles and Ankle Muscles Between Groups

| | | Elderly (n = 56) | Young (n = 57) | p-value |
|---|---|---|---|---|
| AbH | Thicknesses (mm)<br>CSA ($cm^2$) | 8.13±1.57<br>1.42±0.38 | 9.44±2.04<br>1.74±0.48 | <0.001<br><0.001 |
| FDB | Thicknesses (mm)<br>CSA ($cm^2$) | 7.63±1.21<br>1.51±0.36 | 8.40±1.36<br>1.72±0.41 | 0.002<br>0.006 |
| QP | Thicknesses (mm)<br>CSA ($cm^2$) | 5.98±1.33<br>0.94±0.31 | 6.87±1.76<br>1.21±0.37 | 0.003<br><0.001 |
| FHB | Thicknesses (mm)<br>CSA ($cm^2$) | 7.65±1.39<br>0.97±0.27 | 9.78±1.88<br>1.55±0.56 | <0.001<br><0.001 |
| PER | Thicknesses (mm)<br>CSA ($cm^2$) | 12.11±2.44<br>2.52±0.61 | 13.68±2.77<br>2.96±0.65 | 0.002<br><0.001 |
| TA | Thicknesses (mm) | 26.17±3.86 | 27.03±4.02 | 0.25 |

**Note**: All the data were expressed as means ± SD.
**Abbreviations**: AbH, adductor hallucis longus; FDB, phalangeal dorsiflexor; QP, plantarflexor; FHB, phalangeal dorsiflexor; PER, peroneus brevis muscle group; TA, tibialis anterior muscle; CSA, cross-sectional area.

The differences in foot and ankle muscle morphology between the two groups of subjects are shown in Table 3. Muscle thicknesses significantly declined in old adults compared with healthy young adults except TA muscle (AbH: MD = −1.32 mm, 95% CI, −1.99 to −0.64, t (111) = −3.86, p <0.001; FDB: MD = −0.77 mm, 95% CI, −1.25 to −0.29, t (111) = −3.20, p = 0.002; QP: MD = −0.89 mm, 95% CI, −1.47 to −0.30, p = 0.003; FHB: MD = −2.13 mm, 95% CI, −2.76 to −1.51, t (109) = −6.80, p <0.001; PER: MD = −1.57 mm, 95% CI, −2.54 to −0.60, t (111) = −3.20, p = 0.002; TA: MD = −0.86 mm, 95% CI, −2.33 to 0.61, t (111) = −1.16, p = 0.25). TA muscle CSA data were lacking in this study due to limitations in the range of ultrasound head acquisition, and CSA parameters for all other muscles were significantly different between the two groups (AbH: MD = −0.32 $cm^2$, 95% CI, −0.48 to −0.16, t (111) = −3.95, p <0.001; FDB: MD = −0.20 $cm^2$, 95% CI, −0.35 to −0.06, t (111) = −2.81, p = 0.006; QP, MD = −0.27 $cm^2$, 95% CI, −0.39 to −0.14, t (111) = −4.16, p <0.001; FHB, MD = −0.58 $cm^2$, 95% CI, −0.74 to −0.41, t (108) = −6.90, p <0.001; PER: MD = −0.44 $cm^2$, 95% CI, −0.67 to −0.20, t (110) = −3.68, p <0.001).

Figure 1 showed the correlation between foot muscle strength (Doming, $T_1$, $T_{23}$ and $T_{2345}$), ankle joint muscle strength (dorsiflexion and plantarflexion) and their postural stability parameters in old adults. The results showed a moderate, statistically significant correlation between doming strength and the maximum shift of the centre of gravity of the body when moving in the anterior, dominant and non-dominant directions in the LOS Test (MEX in anterior test: r = 0.302, p = 0.027; MEX in dominant test: r = 0.424, p = 0.001; MEX in non-dominant test: r = 0.346, p = 0.009; composite MEX: r = 0.344, p = 0.012). In addition, the results showed a moderate, statistically significant correlation between ankle plantarflexor strength and the MEX dominant direction of movement score as well as the composite score (MEX in dominant test: r = 0.319, p = 0.017; MEX in comprehensive test: r = 0.375, p = 0.006).

## Discussion

The purpose of this study was to compare the functional differences of the active subsystem of the foot core system between distinct groups of people and further explore the relationship between the foot muscle function of the elderly and their postural stability. Compared with healthy young adults, the foot muscle strength and ankle muscle strength as well as the foot muscle morphology of the healthy old adults decreased significantly. Doming strength, as the FIMs strength, and ankle plantar flexor muscle strength were moderately correlated with posture stability in old adults.

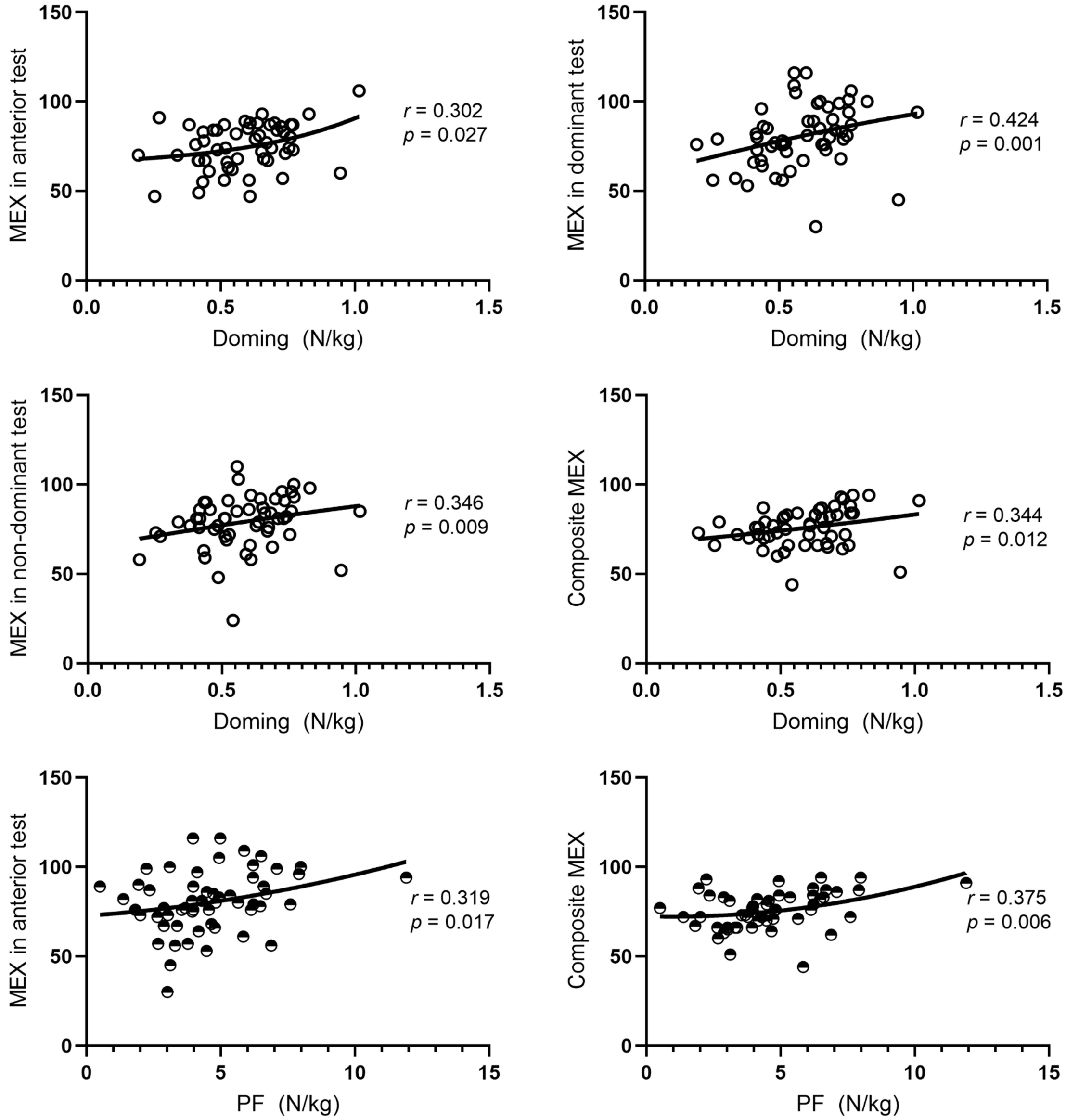


**Figure 1** The correlation between doming strength, ankle plantarflexion muscle strength and the parameter of MEX in LOS test in the elderly.
**Notes**: The LOS test was conducted in four directions. Therefore, the MEX, which represents the furthest distance the centre of gravity moved during the trials, was presented as MEX in anterior test, MEX in dominant test, MEX in non-dominant test, composite MEX: r = 0.344, p = 0.012.
**Abbreviations**: PF, ankle plantarflexor muscle strength; LOS, the Limits of Stability, the maximum excursions (MEX).

## Age Differences in Foot Muscle Strength

In previous studies, the method for evaluating foot muscle strength was toe flexion muscle strength test, which mainly involves the contraction of FIMs (including FDB, QP and AbH) and foot extrinsic muscles (including flexor brevis, flexor longus and flexor digitorum longus).[45] However, with the increase of age, toe flexion strength significantly declined.[20,28,46,47] In the study of Endo et al,[20] the maximum isometric force of the flexion of the first metatarsal joint was measured using a force plate, and age and gender differences were found in the flexion force of the toe. Specifically, compared with the young, the foot muscle strength of the elderly decreased by 28.9%, and the toe flexion muscle strength of men was about 39.1% higher than that of women. Moreover, after standardization based on height and weight, only significant difference was observed in age on the toe flexion force, not in gender.

After foot morphology screening, Mickle et al excluded the influence of foot posture and toe deformity on muscle strength and found the flexion strength of the first metatarsal joint and other toes of the elderly were significantly less than that of the young,[28] which was consistent with the results of our study and Menz et al's.[31] Another Japanese study showed the absolute toe flexion strength and the strength after weight standardization were influenced by age. The strength of men decreased significantly after the age of 50, whereas the strength of women decreased significantly in their 40s to 50s and 60s to 70s.[47] Moreover, Suwa et al compared the effect of aging on toe flexion strength and other muscle strength decline, and the results showed the decline rate of toe flexion muscle strength was significantly greater than that of grip strength and knee extensor strength.[48] Different from previous studies, in addition to the flexion strength of the toes, the doming strength was included in this study, which focused on the FIM's function to support the arch.

## Age Differences in Foot Muscle Morphology

At present, researchers evaluate foot muscle morphology by using various detection technologies, including ultrasound,[40] computed tomography[49] and magnetic resonance imaging.[50] Ultrasound has been widely used in clinical and research fields because of its convenient operation and low cost. The reliability of ultrasound test system to evaluate foot muscle structure has also been verified in many studies.[40,51]

With the advancement of age, the physiological function of the elderly evidently degraded. Mickle et al collected the morphological parameters of the foot muscles by ultrasound. Similar with our results, they found the thickness and CSA of the foot muscles (FDB, QP, abductor digitorum digitorum longus, flexor longus and FDB) of the elderly were smaller than those of the young adults,[28] revealing the existence of foot muscle atrophy in the normal elderly population.

Besides the reduction of muscle volume, the muscle composition of the foot in the old adults also changed. Verhulst et al compared the ultrasonic signal intensity of the foot muscles in participants over 60-years-old and under 60-years-old, and the results showed significant differences in the ultrasonic intensity of ABH.[52] They suspected that with the increase of age, functional muscle fibres were gradually replaced by intramuscular fat and collagen, and this change of muscle composition resulted in the ultrasonic signal. In addition, in the study of Willemse et al, despite no direct comparison of the difference between age and foot muscle morphological parameters, the test error of foot muscle thickness and CSA in the elderly was greater, suggesting age-related muscle mass decreased and intramuscular fat increased.[53] Relevant MR studies also showed the incidence of fatty atrophy of foot muscle increased with age.[54]

## Correlation Between Foot Muscle Function and Postural Stability in the Elderly

Our results showed doming strength and plantar-flexor muscle strength played an important role in maintaining postural stability in the elderly. Previous studies analysed the relationship between toe flexion strength and balance or activity ability of the elderly. For example, Uritani et al collected the toe flexion strength, functional tests of Japanese old adults, and found a significant correlation between toe flexion strength and standing up and walking test time.[34] Other studies with larger sample size also confirmed the association between the toe flexion strength and the balance function and activity ability of the elderly.[21,22]

However, Yamauchi et al collected the toe flexion strength of 55 healthy young participants and the centre of pressure in two-leg and one-leg standing posture task, and their results showed no correlation between toe flexion strength and postural stability in static standing task.[55] In another study for the elderly, Yuki et al reported that for the elderly with pronation and supination foot posture, toe flexion strength was positively correlated with the walking speed and negatively correlated with standing up and walking test time. However, for the elderly with normal foot posture, no correlation existed between toe flexion strength and activity ability.[32] These reasons might explain why no evident correlation between toe flexion strength and postural stability was found in our study. When standing on one leg, the relative height of the arch was negatively correlated with the swing area of the centre of pressure,[56] suggesting the arch, as the core functional dome structure of the foot, adapted to the load by adjusting its shape in daily activities. During the standing posture task, the load to the foot decreased the height of the arch, and the activation of FIM in turn increased to stabilize the foot, thereby improving the posture stability of human body.[57] This reason may be one of the explanations for the correlation between the strength of the arch muscle and the posture stability. In our recent study, similarly for the elderly, the recruitment magnitude of foot muscles significantly increased with the variation in sensory input interference, which suggested their role in postural stability.[58]

## Limitations

Although our study is an important step in determining the age-related reduction of foot muscle function and the relationship with postural stability in the elderly, a mixed-gender sample was used, which might limit the application of our findings to different populations. Moreover, our study included only participants with normal foot posture instead of designing subsystems with pronation, supination and normal foot to determine the effect of age on foot muscle function. Even in the absence of abnormalities in the function of other subsystems, foot muscle strength and morphology continue to show significant decline, similarly with the results of other studies, therefore, we suspect that this decline in muscle function is unavoidable. However, limited studies were designed to explore the function of foot muscle function, the tendency in age-related decline in muscle function are inconclusive, which is one of the limitations of this study. Future studies are needed to determine the interactions amongst these subsystems in human postural stability and the tendency in age-related decline in foot muscle function.

## Conclusion

Compared with young adults, the weakness of FIMs strength and toe flexion strength as well as the morphological decline of the intrinsic and extrinsic foot muscles were found in old adults, indicating the functional decline of foot active subsystem in the elderly. In addition, a correlation was observed between intrinsic foot muscle strength and postural stability in the elderly, suggesting a potential role for FIM in posture stability in the elderly.

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## Disclosure

The authors report no conflicts of interest in this work.

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