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# The influence of aging on the isometric torque sharing patterns among the plantar flexor muscles

LILIAM F. OLIVEIRA, DEBORA VERNEQUE, LUCIANO L. MENEGALDO*

Federal University of Rio de Janeiro, Rio de Janeiro, Brazil.

*Purpose*: Physiological cross-sectional area (PCSA) reduction of the triceps surae (TS) muscles during aging suggests a proportional loss of torque among its components: soleus, medial and lateral gastrocnemii. However, direct measurements of muscle forces in vivo are not feasible. The purpose of this paper was to compare, between older and young women, isometric ankle joint torque sharing patterns among TS muscles and tibialis anterior (TA). *Methods*: An EMG-driven model was used for estimating individual muscle torque contributions to the total plantar flexor torque, during sustained contractions of 10% and 40% of maximum voluntary contraction (MVC). *Results*: Relative individual muscle contributions to the total plantar flexion torque were similar between older and young women groups, for both intensities, increasing from LG, MG to SOL. Muscle strength (muscle torque/body mass) was significantly greater for all TS components in 40% MVC contractions. Increased TA activation was observed in 10% of MVC for older people. *Conclusions*: Despite the reduced maximum isometric torque and muscle strength, the results suggest small variations of ankle muscle synergies during the aging process.

*Key words*: *aging, triceps surae, plantar flexion, EMG-driven model, torque sharing*

## 1. Introduction

Influences of aging on the triceps surae muscles have been described as a reduction of the physiological cross-sectional area (PCSA) [6], of the maximum force and the muscle activation during maximum voluntary contraction (MVC) [7]. Increased Achilles tendon compliance is also observed, which can impair ankle stability [3]. Nagai et al. [8] found higher co-activation among leg muscles in older people during static and dynamic balance tests. They suggest that the compensatory co-activation of the TA is a strategy to overcome the loss of muscle strength and for stiffening the ankle joint.

Regarding muscle architecture, during aging it is possible to observe TS number of fibers reduction, both in series and parallel, possibly decreasing force generation potential [6], Ankle muscles involved in dorsiflexion and plantar flexion are mostly pennate. Such biomechanical characteristic, associated with the neural circuitry that controls the excitation patterns, generate a set of individual muscle torques, which shares the movement demands and produce a determined joint stiffness. Morse et al. [6] reported that the relative TS muscles PCSA proportions do not change with aging, "scaling down harmonically with the decrease in muscle volume and fiber length". From this, they suggest that the torque contributions among them would remain unaltered.

Torque sharing patterns among TS components have been described for young males, based on an EMG-driven model that takes into account individual muscle mechanical characteristics [5], [1]. A crescent order of torque contributions, from LG, MG to SOL has been observed. Antagonist TA torque was small, 2% on average. However, the influence of aging on the TS/TA torque sharing patterns is still an unaddressed problem. Based on the proportional reduction of the cross-sectional areas (CSAs) of the three TS

* Corresponding author: Luciano L. Menegaldo, Av. Horácio Macedo 2030, Cidade Universitária, Prédio do Centro de Tecnologia, COPPE/UFRJ, Bloco H, Sala 327, 21941-914 Rio de Janeiro (RJ), Brazil. Phone: +552139388616, e-mail: lmeneg@ufrj.br
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muscles [6] caused by aging, it is expected that torque sharing distribution does not change. Still, TA activation during plantar flexion torque is likely to be increased.

This study aims to describe the torque sharing patterns among the main muscles that cross the ankle of older people, through a well-validated experimental methodology, using an EMG-driven model implemented in an open-source software [4]. The task consisted in sustaining submaximal isometric plantar flexion with visual feedback of the torque level. A group of older women subjects were studied, and their results compared to a control group of young women adults.

## 2. Material and methods

The cross-sectional study included a group of 11 active women (EG) (74 years ± 5.29) practicing a mild physical activity twice a week. Nine healthy young women (YG) (25.78 years ± 4.06) participated in the control group. All participants signed an informed consent form. The study was approved by the University Hospital (HUCFF/UFRJ) Ethics Committee (Project number 529.392). The experiments were conducted at the Biomechanics Laboratory of the Biomedical Engineering Program at the Federal University of Rio de Janeiro.

Bipolar EMG signals were acquired with an amplifier (OT-USB Bioelettronica, Torino, Italy, 32 channels) with 2000 gain and 2048 Hz sampling frequency. The plantar flexion isometric tasks were performed on an isokinetic dynamometer (Biodex™ System 4 Pro® Medical Systems Inc., USA). Torque signals were acquired from the EMG amplifier auxiliary input and synchronized. SENIAM Project recommendations for bipolar electrodes placement were followed for the SOL, MG, LG and TA muscles. The reference electrode was placed over the contralateral lateral malleolus. The subjects were positioned in the dynamometer seat with the right knee extended and the foot firmly secured by bands to the foot adapter, preventing undesired ankle movements during intense isometric contraction. The lateral malleolus was aligned with the axis of the dynamometer, and the left leg was flexed and free.

Initially, two MVC tests for dorsal and two for plantar flexion of the ankle were performed, for five seconds each, with a rest interval of 60 s. After two minutes rest, the subjects were instructed to perform two submaximal plantar flexion isometric tests. Ankle torque level visual feedback was provided and the subjects were told to keep it as close as possible to a target line on the Biodex screen, equivalent to the subjects' 10% MVC for 50 s. After 60 s rest interval, the test was repeated for 40% MVC. For familiarization, each subject was instructed to perform up to four trials for some seconds. The epoch corresponding to the centered 10-sec of the submaximal tests was considered for analysis, discarding the initial and final transient responses.

The EMG signal processing and the estimation of individual forces and torques of the TS and TA muscles were performed with the open-source software "EMG-Driven Force Estimator" – EMGD-FE [4]. All EMG signals were filtered (band pass from 10 to 500 Hz, Butterworth low pass with 2 Hz cutoff frequency) and normalized by the MVC test. A dynamic Hill-type model is used to estimate the muscle force produced by each muscle, from its EMG signal [5] and individual muscle biomechanical characteristics. The rectified and MVC normalized EMG represents the neural excitation, which is the model input for one muscle. The resulting muscle force was multiplied by the respective moment arm, for torque calculation. The total plantar flexion torque was considered as the sum of the TS component torques minus the TA torque.

Data distribution was verified with the Shapiro–Wilk (SW) test with a significance level of 5% ($P$-value = 0.05). Only the maximum peak torques for plantar flexion and dorsiflexion presented normal distribution ($P > 0.05$). The torque sharing pattern differences among the four muscles, at the two contraction intensities, were verified with the Kruskal–Wallis with Bonferroni post-hoc tests. The Student $t$-test compared the independent variables between groups and the Mann–Whitney test was preferred when normality was not confirmed. Statistical analysis was performed with SPSS, version 20.0 (IBM Corporation, Chicago, USA).

## 3. Results

Maximum plantar flexion torque was lower for the older people accounting for 62.5% of that found in the young group (99.1 ± 19.4 Nm, $P = 0.001$). For the maximum dorsiflexion torque, the older group showed values around 80% compared to the young (26.1 ± 2.9, $P = 0.037$).

The relative muscle torque contribution to the total plantar flexion torque was different among the three components of TS, with a greater contribution from the soleus muscle (Fig. 1). The antagonist (TA) produced small torque values during the plantar flexion. The TS torque sharing pattern was similar between YG and EG, for both contraction intensities ($p > 0.05$).

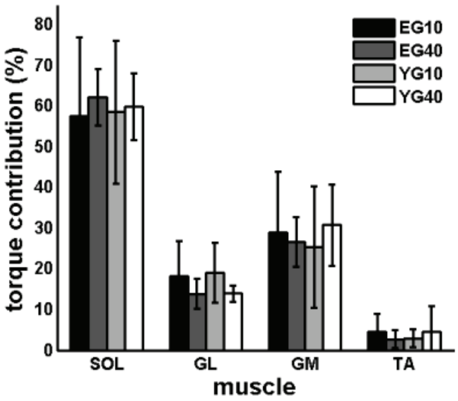


Fig. 1. Average torque sharing patterns ± SD to total ankle torque at 10% MVC and 40% MVC. EG: elderly group, YG: young group, (* = $p < 0.05$)

Table 1. Volunteers' anthropometric data from elderly and young groups: body mass, height and Body Mass Index (BMI)

| | Elderly | | | Young | | |
|---|---|---|---|---|---|---|
| Voluntary Number | Mass (kg) | Height (m) | BMI (kg/m$^2$) | Mass (kg) | Height (m) | BMI |
| 1 | 60 | 1.43 | 29.7 | 53 | 1.61 | 20.4 |
| 2 | 66 | 1.58 | 26.5 | 50 | 1.61 | 19.3 |
| 3 | 48 | 1.44 | 23.4 | 70 | 1.67 | 25.1 |
| 4 | 79 | 1.59 | 31.2 | 60 | 1.67 | 21.5 |
| 5 | 56 | 1.57 | 22.9 | 51 | 1.62 | 19.4 |
| 6 | 72 | 1.64 | 26.8 | 48 | 1.72 | 16.2 |
| 7 | 76 | 1.55 | 31.6 | 51 | 1.6 | 19.9 |
| 8 | 66 | 1.50 | 29.3 | 73 | 1.74 | 24.1 |
| 9 | 75 | 1.61 | 28.9 | 60 | 1.61 | 23.1 |
| 10 | 82 | 1.51 | 36.4 | | | |
| 11 | 72 | 1.61 | 27.8 | | | |
| Mean | 68 | 1.55 | 28.6 | 57 | 1.65 | 21.0 |
| SD | 10 | 0.07 | 3.6 | 9 | 0.05 | 2.6 |
| Min | 48 | 1.43 | 22.9 | 48 | 1.60 | 16.2 |
| Max | 82 | 1.64 | 36.4 | 73 | 1.74 | 25.1 |

SD = standard deviation.

Table 1 shows basic anthropometric parameters (mass, height and body mass index – BMI) in the elderly and young groups. The young group presents greater average height and smaller mass and BMI, as expected. The individual muscle torques normalized by body mass (Nm/kg), for 10% and 40% of MCV torque, are shown in Fig. 2, as a measurement of muscle strength. There can be observed a significant effect of age on the reduction of all triceps surae components strength for 40% MVC. Such differences are not clear for 10% MVC contraction, probably due to the difficulty for the volunteers to precisely control such a reduced level of sustained muscle activity.

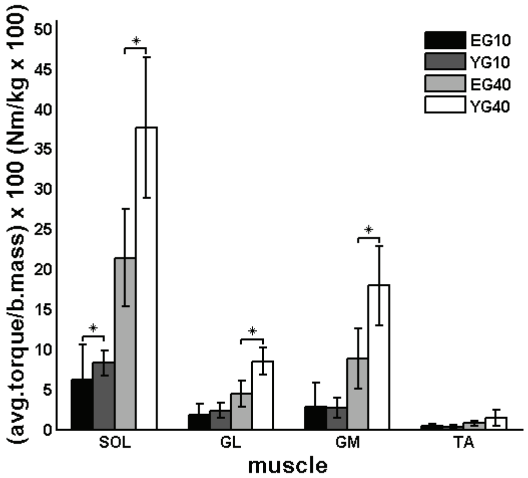


Fig. 2. Average muscle torque normalized by body mass ± SD for each muscle at 10% MVC and 40% MVC. EG: elderly group, YG: young group, (* = $p < 0.05$)

EMG normalized data (Fig. 3) showed significant differences among muscles within each contraction intensity ($P < 0.01$). Compared to YG, the tibialis anterior exhibited higher activation for EG ($P = 0.04$), during the 10% MVC contraction (Fig. 2). This difference was not statistically significant for the 40% MVC contraction, which followed the same pattern of 10% MVC.

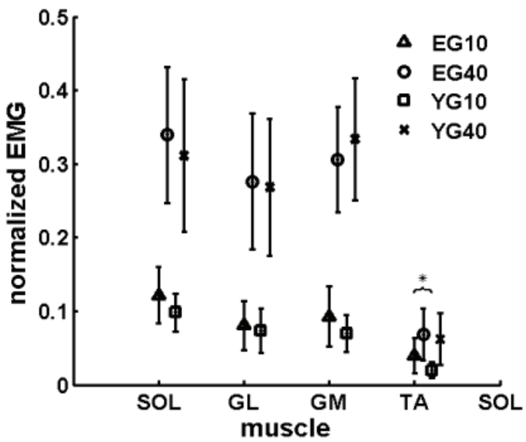


Fig. 3. EMG normalized values ± SD for each muscle at 10% MVC and 40% MVC. EG: elderly group, YG: young group, (* = $p < 0.05$)

# 4. Discussion

The older group average maximum plantar flexor (PF) torque reduction of 37.5%, observed in this study, has also been reported by others for isometric contractions [7], [11]. It is related with the triceps surae PCSA and muscle tension (muscle force/PCSA) reduction in the older subjects [7], because of the loss of sarcomeres in parallel. On the other hand, significant maximum dorsiflexion torque reduction was relatively smaller (around 20%). This finding is in agreement with Lanza et al. [2], but does not match with Simoneau et al. [10]. Such authors observed non-significant maximal dorsiflexors (DF) torque reduction between older and younger. Aside from statistical findings, DF maximum torque seems less sensitive to aging than PF. Both neural and mechanical changes during age can contribute to that. The DF and PF muscles have different sizes, designs and functions. Based on Tracy [11], TA has fewer motor units, but fewer interneurons mediate the corticospinal input, and it seems to present a relative preservation of maximal neuromuscular function of the tibialis anterior with aging compared to soleus muscle. In this case, TA ability to maintain the force generation level during the aging process suggests a minor effect of aging on this muscle.

TS activation patterns, described regarding normalized EMG signals, are similar between the two groups, for both 10 and 40% MVC contraction intensities. This result is in agreement with others [11] who reported a similar rising pattern of muscle activation in sustained contractions, from low to high intensity, for young and older. In the present study, TA activation was greater for the older only during low-intensity contraction (10% MVC). Nagai et al. [8] also found increased TA co-activation during the upright posture of more elderly subjects, which is also a low-intensity effort for the TA. Older subjects TA co-activation during low-intensity plantar flexion has been assigned as a neural control strategy to contribute to joint stiffness [3]. It works as a compensation mechanism for the reduced muscle fibers tension [6] and the increased tendon compliance [3], particularly in the tendon force x deformation curve “toe region”.

Torque sharing patterns of the TS muscles were similar between EG and YG groups, in a crescent order from LG, MG to SOL, similarly to other studies with young subjects [5]. For the sustained isometric effort of 10% of MVC, the average values for torque sharing we found were approximately 56% for SOL, 18% for GL and 26% for GM, with no statistical differences between YG and OG. The torque produced by the antagonist tibialis anterior (TA) was small, around 4% of the total plantar flexion torque value. This distribution did not change in 40% MVC.

These results suggest that the control of force distribution within a muscle group is not affected by aging, despite the reduced absolute and individual muscle strength levels. Possible explanation is the proportional TS muscles loss of PCSA, keeping a constant ratio of each muscular component to the total TS PCSA [6]. Also, according to a recent finding from Reeves et al. [9], the loss of muscle fibers in the older is not fast-twitch selective. Thus, the proportion of type I and II is generally maintained during aging, which confirms our results. Otherwise, the relative contribution of each TS component to the ankle torque sharing pattern would be likely to change, since SOL and gastrocnemii are regarded as tonic and phasic muscles, respectively.

# 5. Conclusion

It is concluded that the torque sharing patterns of the triceps surae muscles of the older group are similar to that presented by the young women during sustained isometric plantar flexion, at low and intermediate levels of torque. This suggests the maintenance of muscle synergies, despite the reduced maximum isometric dorsi and plantar flexion torques.

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