Slow passive stretch and release characteristics of the calf muscles of older women with limited dorsiflexion range of motion

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Abstract

Objective. Examine the slow passive stretch and release characteristics of the calf muscles of older women with limited dorsiflexion range of motion.

Design. A cross-sectional comparative design.

Background. The passive stretch and release characteristics of the calf muscles of older women with limited dorsiflexion range of motion have not been studied.

Methods. Fifteen older women (mean 79 years) with active dorsiflexion ≤10° and 15 younger women (mean 24 years) without limited dorsiflexion were tested. The right ankle was stretched from plantarflexion to maximal dorsiflexion and released into plantarflexion at 5°/s with minimal surface EMG activity in the soleus, gastrocnemius, and tibialis anterior muscles. Length, passive-elastic stiffness and stored passive-elastic energy were examined.

Results. The older women had less maximal passive dorsiflexion, a greater initial stretch angle, and less angular change than the younger women (P < 0.05). The maximal passive resistive force (Newtons) of the stretch phase, and the stored passive-elastic energy (J) during both stretch and release phases were also less (P < 0.001). The older women had greater passive-elastic stiffness at 0° and 5° of dorsiflexion (P < 0.001).

Conclusions. The older women had decreased calf muscle length, extensibility, maximal passive resistive force, stored passive-elastic energy, but greater angle-specific-stiffness at 0 and 5° of passive dorsiflexion.

Relevance

Older women with limited dorsiflexion range of motion have decreased calf muscle length, passive resistive forces and stored passive-elastic energy that may impact static and dynamic standing balance activities. Greater passive-elastic stiffness within their ambulatory dorsiflexion range of motion may partially compensate for the deficits.

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Keywords: Aged; Calf muscles; Passive-elastic stiffness; Passive-elastic energy; Women

1. Introduction

Decreased length of the calf muscles, operationally defined by decreased dorsiflexion (DF) range of motion (RoM) with the knee extended, is associated with normal aging in both men and women (James and Parker, 1989; Vandervoort et al., 1992; Gajdosik et al., 1996, 1999). Changes in the maximal passive resistive force, passive-elastic stiffness, and stored passive-elastic energy may be associated with decreased maximal passive calf muscle length, but these possibilities have not been examined for older people with limited DF RoM. As therapeutic interventions are often used to ameliorate what is perceived as shorter and stiffer calf muscles, knowledge about their passive characteristics for older people with limited DF RoM is important to consider.
Several studies have examined the influence of age on the maximal passive resistive force (reported as passive torque), and on the passive-elastic stiffness of passive ankle DF in relation to a pre-established DF RoM that was common to all subjects, but these studies have yielded conflicting results. Chesworth and Vandervoort (1989) reported no differences in the passive resistive torque or in the passive-elastic stiffness among younger, middle aged and older women at 0°, 5° and 10° of ankle DF. In another study, Vandervoort et al. (1992) reported an increase in the passive resistive torque at 10° of DF with increasing age among six age groups of women from 55 to 85 years of age. Porter et al. (1996, 1997) then reported greater passive resistive torque for older women than for younger women at 10° of DF. The passive resistive torque and the passive-elastic stiffness reported in these studies were within a DF stretch RoM of 10° for all age groups, a RoM considered within the ambulatory functional DF RoM. None of these studies, however, provided information about the maximal passive DF RoM of the women examined, so differences in this important variable could account for the conflicting results. These studies apparently examined older women from the general population. They did not examine the passive characteristics of the calf muscles for older women with limited DF RoM.

In a previous study, Gajdosik et al. (1996) stretched the calf muscles to an end point of stretch that was defined by the subjects’ perceived tolerance, or by marked electromyographic (EMG) activity at the very end of the stretch, or by both. The maximal passive DF angle (maximal muscle length) and the angular change from an initial DF angle to the maximal DF angle (length extensibility) were both decreased for older women compared to the younger women. In a follow-up study with older women, middle aged women and younger women, the calf muscles were also stretched to the subjects’ maximal available DF RoM, and the results supported the proposal that decreased DF RoM in older women was associated with decreased maximal passive resistive torque and decreased average passive-elastic stiffness (Gajdosik et al., 1999). The angle-specific passive-elastic stiffness at 0°, 5°, and 10° of DF, however, did not differ among age groups. Similar to the studies cited earlier, these two studies examined the passive characteristics of the calf muscles of older women from the general population and did not examine the calf muscles of older women with limited DF RoM (Gajdosik et al., 1996, 1999). Accordingly, we were motivated to conduct the present study with a sample of older women with limited DF RoM in order to conduct a comprehensive study of the passive characteristics of their calf muscles. Passive-elastic energy is stored during the stretch of a muscle and partially lost during the passive shortening of a muscle, as demonstrated in the hysteresis loop. Changes in the ability of aged calf muscles to store passive-elastic energy may have functional implications, particularly with regard to falls prevention programmes designed to improve static and dynamic standing balance. Accordingly, we designed the present study to examine the stored passive-elastic energy in addition to the passive characteristics examined previously. The purpose of the study, therefore, was to examine the slow passive stretch and release characteristics of the calf muscles of older women with limited DF RoM compared to younger women without limited DF RoM. We hoped that the results would contribute to a comprehensive understanding of the influence of age on the length and passive resistive force characteristics of the calf muscles of this important subset of older women.

2. Methods

2.1. Subjects

Fifteen community dwelling older women with goniometric active DF RoM ≤ 10° who demonstrated the ability to relax the calf muscles and the tibialis anterior muscle during passive movements of the ankle were recruited from the general population. Fifteen younger women without limited DF RoM who could relax the calf muscles and the tibialis anterior muscle during passive movements of the ankle were also recruited. The older women had a mean active DF RoM of 0.7° (SD, 3.5°) (range: −4°–8°) and the younger women had a mean active DF RoM of 8.7° (SD, 4.1°) (range: 2°–18°). Descriptive statistics for the subjects’ age, height, and mass are presented in Table 1. All women were without a history of orthopaedic or neurological disorders that could confound the results, and they were considered non-sedentary and active for their particular age groups. Although their physical activities varied both within and between the groups, they all participated in activities such as gardening, walking, hiking, or dancing. All subjects self-assessed their current general health

<table>
<thead>
<tr>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger</td>
<td>23.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Older</td>
<td>78.7</td>
<td>6.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger</td>
<td>163.6</td>
<td>4.5</td>
</tr>
<tr>
<td>Older</td>
<td>159.4</td>
<td>5.5</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger</td>
<td>60.8</td>
<td>6.9</td>
</tr>
<tr>
<td>Older</td>
<td>68.5</td>
<td>8.5</td>
</tr>
</tbody>
</table>
status as good-to-excellent, with no difference between the groups (Mann–Whitney \( U = 97.5, P = 0.472 \)). All subjects signed an informed consent form for the study, which was approved by Institutional Review Board for the Use of Human Subjects in Research of The University of Montana.

2.2. Instrumentation

A Kin-Com\textsuperscript{®} isokinetic dynamometer (KINETIC COMMUNICATOR II 500H, Software Version 4.03, Chattecx Corp., Chattanooga, TN, USA) was used for all tests. The Kin-Com\textsuperscript{®} ankle–foot apparatus was used to stretch the calf muscles by passively moving the ankle from PF into DF at 5° s\textsuperscript{-1} and immediately returning the ankle to the starting position in PF at 5° s\textsuperscript{-1}. The lever arm was held constant at 20 cm. Surface EMG with pre-amplification (GCS 67, Therapeutics Unlimited, Iowa City, IA, USA) was used to monitor the activity of the soleus, the medial head of the gastrocnemius, and the tibialis anterior muscles during the tests. The bandwidth of the frequency response was 20 Hz to 4 kHz. The common mode rejection ratio was 87 dB at 60 Hz, and the input impedance was greater than 25 M\textOmega{}.

The raw EMG signals were amplified (×5000), high pass filtered at 20 Hz, and the analogue signals were converted to digital format at a sampling rate of 2000 Hz and recorded using Biopac MP150\textsuperscript{®} data acquisition hardware and AcqKnowledge\textsuperscript{®} software version 3.7.3 (BIOPAC Systems, Inc., Santa Barbara, CA, USA). The angle, velocity and force signals from the Kin-Com\textsuperscript{®} (sampled at 500 Hz) were simultaneously interfaced with the EMG activity from the muscles.

2.3. Procedures

2.3.1. Subject preparation

The subjects were positioned supine on an examination table and a line was drawn between the fibular head and lateral malleolus to represent the longitudinal axis of the leg. The axis of the ankle was estimated using a procedure described previously (Blanpied and Smidt, 1992). The subjects then completed a regimen of supervised static calf muscle stretching to help ensure that maximal passive DF would be achieved during the passive tests. They completed 10 repetitions of 15 s of maximal static stretching as tolerated during each repetition. Details of the stretching exercise have been reported elsewhere (Gajdosik et al., 1999).

After stretching, surface EMG electrodes were attached over the appropriate muscle bellies. The subjects then assumed a supine, relaxed position on the Kin-Com\textsuperscript{®} table with the right knee fully extended. The angle and foot were secured in the apparatus and the ankle was aligned with the axis of the Kin-Com\textsuperscript{®} armature. Stabilization straps were placed across the right knee and the chest. Using visual oscilloscope tracings and auditory feedback, the subjects were taught to recognize EMG activation and EMG silence of the muscles to help ensure that calf muscle activation was minimal during the passive stretch and release trials.

2.3.2. Passive tests

The subjects were then encouraged to maintain “flat EMG tracings” (muscle silence) during the test session, which was conducted in a quiet room with the lights dimmed. The maximal passive DF angle was first determined blindly by manually moving the ankle slowly into DF for several careful trials. The end point of DF RoM was defined just prior to the point that caused pain or discomfort, by a marked presence of EMG activity in the calf muscles (Gajdosik et al., 1996, 1999), or when the heel started to move out of the ankle–foot apparatus (Singer et al., 2003). The end point of the DF stretch was defined just prior to discomfort in the majority of the subjects. Thus, the subjects’ perceived tolerance to the maximal passive stretch was the primary criterion used to define the maximal DF angle, which operationally defined the maximal length of the calf muscles. We acknowledge that the end point of stretch was based on psychophysiology phenomena and not necessarily a true mechanical endpoint of calf muscle length. All subjects, however, indicated a stretching sensation in the muscle bellies of the calf muscles.

After the maximal DF angle was defined, the ankle–foot apparatus was moved from this angle to 45° of PF. The ankle was then stretched passively by the Kin-Com\textsuperscript{®} from this PF position to the maximal DF angle and returned to the starting position. A 90° angle between the foot and the leg was defined as 0°, DF degrees were positive, and PF degrees were negative. Three stretch and release trials were performed at the predetermined velocity of 5° s\textsuperscript{-1}. After the passive tests, EMG activity was recorded from the calf muscles at 0° of DF and from the tibialis anterior muscle at maximal active DF during maximal isometric activations. The EMG activity during the actual stretch and release trials was standardized as a percent of this maximal EMG activity (100%). The maximal PF force was recorded during the maximal PF activations, which permitted age group comparisons of calf muscle strength. The maximal DF force was not recorded during the maximal DF activations because of technical limitations.

2.4. Data reduction of passive measurements

Because data were collected in real time, all force and EMG recordings were standardized to the angular displacement of the stretch and release trials. The maximal DF angle was defined at 1° less than the maximal passive DF angle that was used during the stretching trials. This accounted for the small deceleration artifact and an
observed loss of Kin-Com® angle data at the end of the RoM that has been described previously (Mayhew et al., 1994). The maximal passive resistive force was measured at this adjusted maximal DF angle. The initial passive DF angle was identified at 0 Newtons (N) of passive force after deducting the force associated with the inertia of the apparatus. The difference between this initial DF angle and the maximal DF angle was called the angular change, which defined the full stretch RoM and represented the calf muscles’ length extensibility (Gajdosik et al., 1999).

Root mean square (RMS) values were calculated from EMG recordings during the stretch and release trials. These values were standardized to the RMS values from the maximal effort isometric muscle activations undertaken at the completion of the testing session. Stretch and release trials were operationally defined as passive if the RMS activity was less than 5% of the RMS value recorded from the maximal isometric activations. The actual mean RMS EMG activity calculated for each group was <1% of the RMS EMG activity recorded during the maximal activation of each of the three muscles.

A linear regression line of best fit was used to determine the passive-elastic stiffness as the slope of the change in the passive resistive force divided by the change in the angle (N/°). Similar methods have been used previously (Salsich et al., 2000a,b). This was done for the full stretch RoM, and for the first half and the last half of this full stretch RoM separately. The following variables were averaged across the three trials: initial angle, full stretch angular change, maximal passive resistive force, mean passive-elastic stiffness for the full stretch ROM and for the first half and the last half of this full stretch ROM, and the total integrated area under the full stretch curve and the full release curve (passive-elastic energy [° N]).

The reliability and the precision of the method used to determine the maximal passive DF angle and the maximal passive resistive torque were examined and reported previously (Gajdosik et al., 1999). The intraclass correlation coefficient (ICC) and the standard error of measurement (SEM) for measuring the maximal DF angle were 0.91° and 1.2°, respectively. The ICC and SEM for measuring the maximal passive resistive torque were 0.90 and 3.9 Nm, respectively. These values indicated excellent reliability and precision for these measurements.

### 2.5. Data analysis

A multivariate analysis of variance (MANOVA, Pillai Trace) was used to examine the overall effects of age groups on the following operationally defined variables:

1. maximal passive DF angle—maximal calf muscle length,
2. initial angle—initial calf muscle length,
3. angular change—calf muscle extensibility,
4. maximal passive resistive force—force at maximal calf muscle length,
5. average passive-elastic stiffness for the full stretch RoM,
6. average passive-elastic stiffness for the first half of this stretch RoM,
7. average passive-elastic stiffness for the last half of this stretch RoM,
8. integrated area under the full stretch curve—absorbed passive-elastic energy, and
9. integrated area under the full release curve—retained passive-elastic energy.

The MANOVA was followed by separate one-way ANOVAs for each dependent variable to examine group differences. Separate one-way ANOVAs were used to examine group differences of the angle-specific stiffness at 0° and 5° of DF. Because two of the older women had maximal DF angles that were less than 5° of DF, the sample size for the ANOVA at 5° of DF was 13; including this smaller sample in the MANOVA would have decreased the power of the test. Because only nine older women could achieve 10° of passive DF, the sample was considered too small to allow for a valid comparison of the angle-specific stiffness at this angle, and therefore, was not included in our analysis.

The area under the full stretch curves and the area under the full release curves were also examined with a two-way ANOVA for repeated measures to evaluate differences between the two curves, and if there was an interaction effect. The maximal force of the PF isometric activations was tabulated and also examined for group differences using a one-way ANOVA. The level of statistical significance for all comparisons was set at $P \leq 0.05$.

### 3. Results

The mean passive curves for the full stretch and release RoMs for both groups are depicted in Fig. 1. The shape and the form of the passive curves within the full stretch RoM appeared similar between the two groups. The maximal passive DF angle for the older women was shifted to the left, and the maximal passive resistive force for the older women was of lesser magnitude. The initial DF angle for the older women was to the right of those for the younger women. The curves of both groups showed a loss of stored passive-elastic energy between the stretch and release phases as demonstrated by the hysteresis loop. The MANOVA results indicated an overall group effect among the nine dependent variables ($F = 7.91, P < 0.001$). Descriptive statistics, 95% confidence intervals of the mean (CIM), and separate ANOVA
results for the angular variables and the maximal passive resistive force are presented in Table 2. The maximal passive DF angle, initial angle, angular change and maximal passive resistive force were all decreased for the older women ($P \leq 0.027$).

Descriptive statistics, 95% CIM and separate ANOVA results for the average passive-elastic stiffness within the three stretch RoMs are presented in Table 3. The passive-elastic stiffness within the RoMs did not differ between groups. The angle-specific stiffness at $0^\circ$ and $5^\circ$ of DF, however, were greater for the older women than for the younger women ($P = 0.001$; See Table 4).

Descriptive statistics, 95% CIM and separate ANOVA results for the area under the stretch curves and under the release curves are presented in Table 5. The older women had less absorbed passive-elastic energy during the stretch phase and less retained passive-elastic energy.

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**Table 2**

Descriptive statistics and ANOVA results for the maximal passive dorsiflexion (DF) angle, initial passive DF angle, passive angular change, and maximal passive resistive force (PRF) for the younger women (Younger, $n = 15$) and older women (Older, $n = 15$)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>95% CIM</th>
<th>Statistical test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F$</td>
<td>df</td>
<td>$P$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal passive DF angle ($^\circ$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger</td>
<td>27.6</td>
<td>7.2</td>
<td>18–45</td>
<td>24.5–30.7</td>
<td></td>
</tr>
<tr>
<td>Older</td>
<td>10.3</td>
<td>4.3</td>
<td>4–19</td>
<td>7.2–13.5</td>
<td>63.31</td>
</tr>
<tr>
<td>Initial passive DF angle ($^\circ$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger</td>
<td>−36.4</td>
<td>3.8</td>
<td>−41–(−27)</td>
<td>−40.2–(−32.7)</td>
<td></td>
</tr>
<tr>
<td>Older</td>
<td>−30.4</td>
<td>9.3</td>
<td>−40–(−4)</td>
<td>−34.2–(−26.6)</td>
<td>5.41</td>
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<td>Passive angular change ($^\circ$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger</td>
<td>64.0</td>
<td>9.0</td>
<td>51–86</td>
<td>59.1–69.0</td>
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<tr>
<td>Older</td>
<td>40.7</td>
<td>9.7</td>
<td>19–56</td>
<td>35.8–45.7</td>
<td>46.66</td>
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<tr>
<td>Maximal PRF (N)</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Younger</td>
<td>152</td>
<td>29</td>
<td>110–211</td>
<td>138–166</td>
<td></td>
</tr>
<tr>
<td>Older</td>
<td>85</td>
<td>24</td>
<td>54–139</td>
<td>71–99</td>
<td>48.08</td>
</tr>
</tbody>
</table>

All variables were decreased for the older women.

*Confidence interval of mean.

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**Table 3**

Descriptive statistics and ANOVA results for the average passive elastic stiffness (N/$^\circ$) (PES) for the full dorsiflexion (DF) stretch ROM, and for the first half and the last half of the full stretch ROM for the younger women (Younger, $n = 15$) and older women (Older, $n = 15$)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>95% CIM</th>
<th>Statistical test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F$</td>
<td>df</td>
<td>$P$</td>
<td></td>
<td></td>
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<tr>
<td>Average PES for the full DF stretch ROM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger</td>
<td>1.90</td>
<td>0.36</td>
<td>1.29–2.49</td>
<td>1.67–2.13</td>
<td></td>
</tr>
<tr>
<td>Older</td>
<td>1.88</td>
<td>0.49</td>
<td>1.08–3.04</td>
<td>1.65–2.11</td>
<td>0.03</td>
</tr>
<tr>
<td>Average PES for the first half DF stretch ROM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger</td>
<td>0.74</td>
<td>0.12</td>
<td>0.63–1.11</td>
<td>0.57–0.90</td>
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<tr>
<td>Older</td>
<td>0.89</td>
<td>0.43</td>
<td>0.41–2.03</td>
<td>0.72–1.05</td>
<td>1.66</td>
</tr>
<tr>
<td>Average PES for the last half DF stretch ROM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Younger</td>
<td>3.49</td>
<td>0.73</td>
<td>2.50–4.64</td>
<td>3.13–3.85</td>
<td></td>
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<tr>
<td>Older</td>
<td>3.20</td>
<td>0.63</td>
<td>1.88–3.93</td>
<td>2.84–3.56</td>
<td>1.32</td>
</tr>
</tbody>
</table>

The average passive-elastic stiffness did not differ between groups.

*Confidence interval of mean.
during the release phase \((P < 0.001)\). In addition, both groups showed a loss of the area under the curve between the stretch and release phases \((F = 23.85, P < 0.001)\) and a significant interaction \((F = 11.41, P = 0.002)\). Further calculations indicated that the younger women lost 12\% of their absorbed passive-elastic energy and the older women lost 8\% of their absorbed passive-elastic energy between the stretch and release phases, but the percent loss was not significantly different. As would be expected, the older women had less maximal isometric PF force \(\text{mean} = 378 \text{[SD, 68 N]}\) than the younger women \(\text{mean} = 545 \text{[SD, 73 N]}\) \((P < 0.001)\).

### 4. Discussion

Previous studies examined the passive characteristics of the calf muscles of older people from the general population, which has yielded conflicting information. This was the first attempt to provide a comprehensive profile of the passive characteristics of the calf muscles of a group of older women with known limited DF RoM. We acknowledge that the differences we found between the younger and older women may have been influenced by structures other than the calf muscles. Changes in the ankle joint capsule, associated ligaments, fascia and the skin could have contributed to the age group differences. Researchers generally agree, however, that the calf muscle-tendon unit, as opposed to other tissues, contributes the primary passive resistive force and passive-elastic stiffness to the passive stretch \((Gajdosik et al., 1999)\). Within the calf muscle–tendon unit, the calf muscle tissue, including the intrinsic sub-cellular cytoskeletal proteins \(\text{(i.e. titin, desmin)}\) \((Waterman-Storer, 1991)\), the associated connective tissues \(\text{(epimysium, perimysium and endomysium)}\), and the tendons \((Herbert et al., 2002)\) were probably the main tissues lengthened.

The maximal passive DF angle for the older women was shifted to the left with a decrease in the magnitude of maximal passive resistive force, which indicated a marked decrease in the maximal length and the passive resistive force of the calf muscles as reported previously for older women \((Gajdosik et al., 1996, 1999)\). The initial angle of the curves, however, was shifted to the right, which differed from previous reports that showed no influence of age on the initial angle of stretch \((Gajdosik et al., 1996, 1999)\). The previous studies defined the initial angle at 10\% of the maximal passive resistive torque, whereas the initial angle of the current study was defined more precisely after the inertial force of the apparatus was deducted, which could account for the differences. Furthermore, the previous studies did not examine older women with limited DF RoM. The shift
to the right of the initial angle may be explained as a characteristic of older calf muscles that are very short. Peripheral denervation of animal skeletal muscles have shown that their passive curves have longer initial lengths, decreased extensibility between their initial lengths and their maximal lengths, and steeper passive curves compared with those of controls (Thomson, 1955; Stolov et al., 1970). The shift to the right of the initial angle for the older women, although small, could have resulted from similar changes. Aging is known to bring about a loss of functional motor units (Brown et al., 1988; Campbell et al., 1973), which results in partial denervation. Aging also causes a decrease in the number and the size of both slow twitch (type I) and fast twitch (type II) muscle fibers, with the possibility of selective atrophy of type II fibers (Lexell et al., 1983, 1988). The reduction in the number of functional motor units and muscle fiber atrophy partially account for the decreased muscle mass and the strength deficits reported in the muscles of older people (Doherty et al., 1993; Lexell, 1995), which could explain the decreased initial length and extensibility observed for the older women.

Animal muscles immobilized in the shortened position showed decreased muscle length because of a reduction in the number of sarcomeres (Tabary et al., 1972; Williams and Goldspink, 1978). The limited DF RoM for the older women corresponded with the shortening mechanical adaptations observed in animal muscles immobilized in the shortened position. The proposal that calf muscle shortening and decreased passive resistive forces can occur concomitantly with the loss of motor units (Brown et al., 1988; Campbell et al., 1973), and muscle mass and strength (Doherty et al., 1993; Lexell, 1995) during normal aging seems plausible. The older women in the current study had decreased maximal isometric strength of the calf muscles. The loss of muscle mass, combined with the decreased calf muscle length would decrease the calf muscles’ ability to withstand a maximal passive stretch.

Compared to the younger women, the older women showed no difference in the average passive-elastic stiffness within the full stretch RoM, or within the first and last halves of the full stretch RoM. These results suggested that the loss of passive resistive force probably had a similar relative contribution to the average passive-elastic stiffness as the loss of passive angular DF RoM. Thus, the calf muscles of the older women in the current study appeared to retain their average passive-elastic stiffness compared to older women without limited DF RoM reported previously (Gajdosik et al., 1999).

The increased passive-elastic stiffness at 0° and 5° of DF for the older women also conflicts with some studies that showed no differences between older and younger women at these angles (Chesworth and Vandervoort, 1989; Gajdosik et al., 1999). Because the passive-elastic stiffness ratios for the previous studies were reported in Newton-meters per degree (Nm/°), the passive-elastic stiffness at these angles in the current study were converted to Nm/° in order to compare the results with those previously reported studies. This conversion indicated that the mean passive-elastic stiffness at 0° and at 5° was 0.68 and 0.85 Nm/°, respectively for the women with limited DF ROM. The passive-elastic stiffness was 0.26 Nm/° at 0°, and 0.41 Nm/° at 5° for the older women (61–80 years) in the study by Chesworth and Vandervoort (1989), and 0.39 Nm/° at 0°, and 0.47 Nm/° at 5° for the older women (60–84 years) in the study by Gajdosik et al. (1999). The nearly twofold increase in the passive-elastic stiffness at these angles for the women in the current study indicated a marked increase in passive-elastic stiffness at these angles for the older women with known limited DF ROM compared to older women from the general population.

The lack of a significant loss of average passive-elastic stiffness, and increased angle-specific stiffness within their ambulatory functional DF ROM for the women in the current study could have resulted from increased amounts and remodeling of relatively inextensible collagenous connective tissue that would bring about greater force per unit of length change. Studies with animal muscles immobilized in the shortened position have indicated an apparent increase in passive-elastic stiffness (Tabary et al., 1972; Williams and Goldspink, 1978), associated with greater abundance (Tabary et al., 1972) and remodeling (Williams and Goldspink, 1984) of the connective tissues of the muscle. Human studies have shown that decreased muscle mass in older people may be replaced by increased fat and connective tissue within the muscle (Lexell, 1995; Rice et al., 1989; Sipila and Suominen, 1995), but the relative contributions of increased fat compared to increased collagenous connective tissue have not been related to the changes in the passive resistive force and passive-elastic stiffness. Even so, changes in the relative amount and arrangement of connective tissues could alter the passive characteristics of short calf muscles of older people, even with a decline in active muscle force.

The decreased stored passive-elastic energy for the older women was expected because their curves were much smaller than the curves of the younger women. The decrease in energy absorbed for the older women with less DF RoM may have implications for metabolic costs associated with ambulation. That is, the potential for elastic energy recovery would be decreased. Furthermore, the ability to absorb more energy is thought to be a protective mechanism for decreasing the likelihood of a strain type of injury to muscle (Mair et al., 1996). Thus, these older women may be at a greater risk of injury. Although both groups showed a significant loss of stored passive-elastic energy between the stretch and release phases, the significant interaction
suggested that the calf muscles of the older women responded differently by retaining relatively greater passive-elastic energy during the release phase (92%) than the younger women (88%). Further study is indicated to examine this characteristic of aged calf muscles, and whether the results of therapeutic interventions designed to improve standing static and dynamic balance are related to changes in their stored passive-elastic energy. Therapeutic interventions designed to both lengthen and strengthen the calf muscles of people with very limited DF RoM may enhance calf muscle function, or help to prevent age-related declines in calf muscle function. These possibilities are worthy of future study.

5. Conclusions

The results of this study demonstrated that calf muscle length, length extensibility, passive resistive force, and the stored passive-elastic energy were less for older women with limited DF RoM compared to younger women without limited DF RoM. The angle-specific stiffness at 0° and 5° of DF, angles within their ambulatory functional DF RoM, however, was greater for the older women compared to the younger women, as well as when compared to previously tested older women from the general population. The decreased length, passive resistive force, and stored passive-elastic energy characteristics are worthy of future study to examine their possible contributions to changes in calf muscle function in the elderly, including the impact on ambulation and static and dynamic standing balance. The influence of therapeutic interventions designed to promote changes in calf muscle physiologic characteristics and function are particularly worthy of future study.

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