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Age and Sex Effects on Mobility of the Human Ankle

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We investigated whether values for passive resistive torque, dorsiflexion strength, and active mobility of the ankle joint varied with age in a randomly selected sample of middle-aged and elderly males and females. The main effects of sex and age group were significant, without an interaction effect, on values for passive resistive torque and voluntary strength. The trends indicated that females had lower values for both variables and that passive torque increased and strength decreased with respect to age. Dorsiflexion range of motion also showed a highly significant trend to decrease across age groups, and more so for females than males. Mean values for middle-aged men vs old men went from 20.0 to 13.5 degrees, while corresponding values for women decreased from 20.7 degrees of dorsiflexion to 10.1. Functional ankle movement thus becomes limited with age, but could be improved by strengthening weak dorsiflexor muscles.

HEALTH surveys have indicated that loss of flexibility in joints is a major cause of discomfort and disability in elderly people (1,2). While joint function is usually assessed with subjective methods in the clinical setting, it is also possible to make objective measurements by recording the passive mechanical resistive torque to stretch of the connective tissues within the involved muscles, tendons and joint capsules (3).

In the past, studies regarding age and passive resistive torque have been conducted on finger (4–8), knee (9), and elbow (10) joints; there was a positive relationship in the finger and knee joints, but no age-related trend for the elbow study. We have studied the ankle joint complex because of its significant role in gait, posture control, and many activities of daily living (11–13). Several studies have reported passive resistance values for normal ankles of young adults (14–20). Our preliminary pilot studies on this issue with small samples of subjects have suggested that there was no trend to increased passive torque with aging, when the ankle was rotated within the functional range of 10 degrees of dorsiflexion (21,22).

Furthermore, the effect of age on the ability to rotate the ankle against the intrinsic passive resistance using voluntary muscle contraction has not been examined. Therefore, the purpose of this study was to acquire values for passive resistive torque, voluntary strength of the ankle dorsiflexors, and active range of motion during ankle dorsiflexion in a large sample of middle-aged and elderly men and women.

METHODS

Subjects. — A sample of 214 middle-aged and elderly men and women was recruited from a larger pool of 420 subjects who had participated in a previous fitness survey of citizens of London, Ontario (23). Names of potential volunteers were originally generated from the city's municipal roll. Exclusion criteria thus included unstable angina, blindness, and orthopaedic or neurological dysfunction that prevented the subject from independently completing a test of self-selected walking pace. Subjects also needed to be mentally competent to comply with the test procedures. Each of the subjects who participated in this prior investigation was asked to consider participating in future research protocols, and over 90% agreed.

Subjects were first screened for medical conditions contraindicative to the passive and active testing procedures, e.g., severe arthritis, other history of bone or muscle disorders, ankle fracture, neural disorder causing spasticity or contracture, and painful or swollen ankles. A simple screening test of passive range of dorsiflexion motion was used in which subjects were asked to lean in a lunge position so that the ankle to be tested was rotated into dorsiflexion. Written informed consent was obtained before commencing any assessments.

Anthropometric measurements were taken of body weight and height (shoes removed) and maximum girth of the lower leg. Girth was assessed with a spring-loaded tape measure which did not squeeze the tissue. Subjects were in a relaxed standing position, and the highest of three repeated measurements was recorded. Skinfold thickness at the mid-calf site was also assessed with the knee flexed and leg supported. The highest of three repeated measurements using Lange skinfold calipers was recorded.

Test Procedures

Passive resistive torque. — This variable was measured using an electric stepper torque motor system which drives a rotatable footplate. The technology and data analysis software have been described in a previous report (21). The subject was placed in a prone-lying position on a standard mobilization table and the foot was secured in the footplate with velcro straps — two over the dorsum of the foot and one which held the heel down as firmly as possible by crossing over the area of the head of the tarsus. The ankle joint was then stretched from a starting position of 10° plantarflexion (when the longitudinal line of the sole of the foot is 10° beyond forming a right angle with the lower leg) to the maximum passive range of dorsiflexion and then returned to the initial position. The test continued uninterrupted for six complete cycles. Strain gauges mounted on the unit's driving arm provide a reading of the combined passive resistive torque of the stretched plantarflexor muscles and their associated tendons, as well as the joint capsule. Angle of the footplate was obtained from the output of a potentiometer attached to the rotating axle. Data acquisition and analysis were done using special software written for an IBM personal computer. Of the six cycles of passive resistance recorded, the last five were averaged and the first one was eliminated because it was considered an acclimatization cycle (18). Resistive torque and position were plotted against each other to generate a curve from which data points were obtained. The measure reported here is the resistance of the joint to passive dorsiflexion movement when it was at a position of 10° of dorsiflexion. This extent of movement was selected as the criterion position because it was considered to be the normal excursion of the ankle during walking on a level surface (24). Furthermore, by choosing a position which was within the limits of passive range of motion for even the oldest age groups, it was possible to compare across the entire age span of the study.

Electromyographic (EMG) activity of the calf musculature was monitored by attaching 9mm surface electrodes to skin over the soleus muscle, just distal to the bifurcation of the gastrocnemii heads. A high gain amplification was used to allow detection of very slight muscle contraction. Most subjects found it very easy to keep their muscles relaxed at the slow, 6 °/s velocity utilized in this study. Our method of assessing passive resistive torque has been shown to have acceptable reproducibility over repeated measurement sessions (25).

Maximum voluntary strength of the ankle dorsiflexor muscles. — After passive movement cycles were completed, the footplate was locked in the neutral position so that isometric dorsiflexion strength could be measured. Subjects contracted their muscles as forcefully as possible, with a rest period of 60 seconds between each of three trials. The tester gave verbal encouragement and feedback after each contraction about the torque produced. The highest torque reading was recorded in N·m.

Active dorsiflexion range of motion. — The final test consisted of observing the maximum degree of dorsiflexion to which the subject could rotate the unloaded footplate with voluntary contraction of his or her muscles. The greatest range of motion achieved out of three trials was recorded in degrees of dorsiflexion.

Data Analysis

Descriptive statistics of mean and standard deviation were calculated, and a two-way analysis of variance (with age group and sex) was performed by means of the SPSS package for the IBM PC.

RESULTS

Anthropometric characteristics. — Male groups had consistently greater mean values for height and weight than females. While the males also had higher values for calf girth, the differences between males and females were small and the effect of sex was the opposite for calf skinfold (Table 1). These observations suggest that subcutaneous fat makes up a greater proportion of the lower leg of females than males and that the amount of lean tissue for a given calf girth is less. Values of the different age groups generally varied by less than 10% within the male and female samples.

Passive resistive torque. — The main effects of sex and age group were significant on values for passive torque at 10° dorsiflexion ($p < .001$, and $p < .03$, respectively). As can be seen in Table 2 and Figure 1, males had consistently higher values than females. The youngest female group had the lowest mean value of 5.96 ± 1.65 N·m, which increased to 8.74 ± 2.48 N·m in the 81- to 85-yr-old group. Corresponding male values went from 8.84 ± 2.14 N·m in the youngest

Table 1. Mean Values for Height, Weight, Calf Girth, and Calf Skinfold by Sex and Age Group.

		Age Groups					
		55–60	61–65	66–70	71–75	76–80	81–85
Males	*N*	20	18	18	20	18	17
Height (m)	Mean	1.73	1.74	1.70	1.73	1.68	1.69
	SD	.05	.07	.05	.04	.06	.07
Weight (kg)	Mean	83.8	81.9	80.6	79.6	74.9	73.8
	SD	10.4	14.2	9.3	9.5	9.8	9.4
Calf Girth (cm)	Mean	37.2	36.4	35.8	36.0	34.9	33.2
	SD	2.3	3.0	2.7	2.1	2.6	2.3
Calf Skinfold (mm)	Mean	10.3	8.9	8.7	8.4	10.3	7.5
	SD	6.4	3.6	3.0	3.6	7.1	2.7
Females	*N*	16	17	17	18	17	18
Height (m)	Mean	1.57	1.57	1.59	1.56	1.55	1.56
	SD	.05	.07	.05	.04	.06	.07
Weight (kg)	Mean	72.3	66.5	64.3	63.1	64.9	65.2
	SD	14.3	12.3	11.2	6.4	13.1	10.2
Calf Girth (cm)	Mean	35.3	33.9	33.7	32.7	33.8	33.4
	SD	2.7	2.9	2.8	2.3	4.0	2.5
Calf Skinfold (mm)	Mean	19.2	19.5	19.5	16.2	20.9	17.9
	SD	6.9	9.6	7.4	8.2	9.8	8.7

Table 2. Mean Values for Passive Torque, Maximum Strength, and Active Range of Motion in Dorsiflexion, by Sex and Age Group.

		Age Groups					
		55–60	61–65	66–70	71–75	76–80	81–85
Males	*N*	20	18	18	20	18	17
Torque (N·m)	Mean	8.8	8.2	8.8	9.9	9.7	9.4
	SD	2.1	2.0	2.6	2.6	3.1	4.0
Strength (N·m)	Mean	42.9	43.1	38.8	36.9	30.8	28.7
	SD	8.2	6.5	7.3	4.2	8.2	7.8
Active ROM (deg)	Mean	20.0	19.4	15.7	13.8	13.1	13.5
	SD	4.0	3.6	2.7	3.5	4.1	5.1
Females	*N*	16	17	17	18	17	18
Torque (N·m)	Mean	6.0	6.4	6.9	7.5	7.7	8.7
	SD	1.7	1.9	2.5	1.7	3.0	2.5
Strength (N·m)	Mean	27.0	23.6	23.6	22.6	19.4	19.0
	SD	5.3	5.3	6.5	5.4	5.7	6.8
Active ROM (deg)	Mean	20.7	13.8	12.0	12.3	10.8	10.1
	SD	4.8	3.8	5.5	3.6	4.8	5.2

Note. Active ROM is the maximum ankle dorsiflexion achieved by voluntary movement. The effects of sex and age group were significant for each of the variables at $p < .001$, except age group on passive resistive torque, $p = .029$.

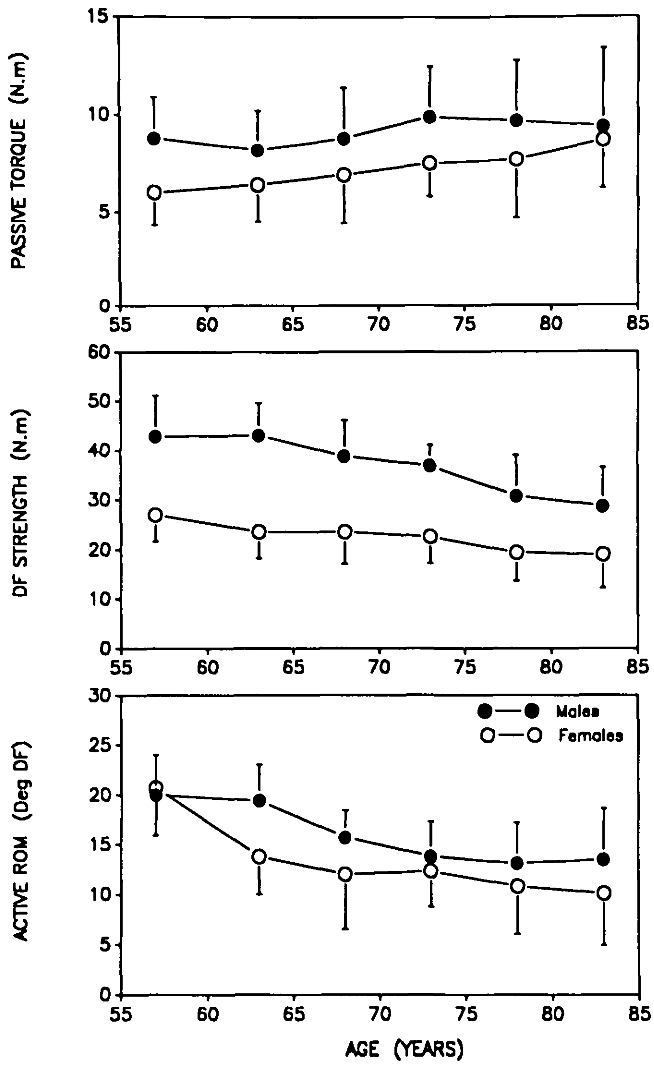

Figure 1. Passive resistive torque, maximum voluntary strength, and active range of motion in dorsiflexion. Values shown are means and one *SD*, *n* per group = 16–20.

group to a high of 9.94 ± 2.63 in the 71- to 75-yr-olds, and a value of 9.35 ± 4.00 in the oldest men.

Maximum voluntary strength. — Sex and age group factors both had strong effects on values for maximum strength of the ankle dorsiflexor muscles during an isometric voluntary contraction (see Table 2 and Figure 1, $p < .001$ for both). Males had higher values than females across all groups. In terms of relative decreases, the male and female values dropped by about the same amount of 30% between the sixth decade and ninth decade. However, total decreases in absolute torque with age were greater in men, going from a high mean of 43 N·m to a low of 29 N·m, whereas female mean values went from 27 to 19 N·m.

Active dorsiflexion range of motion. — Sex and age group also had strong effects on values for the variable of active dorsiflexion range of motion (Table 2 and Figure 1, $p < .001$ for both). There was also a significant interaction effect between these two factors ($p < .02$), and it can be seen from Figure 1 that females had a greater decrease across age groups than males. Mean values for women went from 20.7 degrees of dorsiflexion to 10.1, corresponding male values from 20.0 to 13.5 degrees.

Discussion

Passive resistive torque of stretched connective tissue, generated by rotating the ankle into dorsiflexion, showed overall trends to increase in the older age groups of our sample of 55- to 85-year-old men and women and to be greater in males than in females. While the latter gender effect is consistent with our preliminary reports on passive torque values (21,22), we did not report an age effect in them. Values for middle-aged adults in the present research agree with those previously observed for young and middle-aged subjects (21,22), but by sampling a larger group of elderly subjects in the present research, we have obtained a clearer picture of passive resistance about the aged ankle joint. The limited volume of research focusing on the relationship between age and passive resistance of joints has been directed primarily toward finger joint evaluation and suggests that there are increases with age (4–8). For other joints, Such et al. (9) found that there was a significant increase with age in their study of the knee, while Wiegner and Watts (10) found no association with age in their study of passive elbow rotation. If an age-related increase in passive joint resistance does exist, it appears to be joint-specific and different between males and females. Research involving standardized tests to assess several joints of the same men and women should be undertaken.

Part of the reason that males had larger values than females for passive torque may be that this variable appears to depend on muscle size. For example, Hufschmidt and Mauritz (18) found that passive torque at 10 degrees of DF was significantly related to calf cross-sectional area, with a moderate positive correlation coefficient (r = .506). Wiegner and Watts (10) found a stronger relationship (r = .76) between passive elbow joint resistance and upper arm volume. Such et al. (9) found that both knee joints and thighs with a larger circumference exhibited greater amounts of passive torque than small ones. Yet, despite the atrophy of the ankle musculature which occurs with aging (26), passive torque did not decrease in the very old. Some insight can be gained from the fact that leg size, as measured by calf girth, did not change substantially across age groups. It has been shown that elderly muscles contain an extensive amount of connective tissue (27,28), which presumably contributes to their passive resistance. Perhaps related to the potential of stretched connective tissue for tension generation, we have recently observed that elderly females demonstrated relatively less strength loss when activating their muscles under a lengthening condition, than when performing shortening movements (27).

Strength of the ankle dorsiflexor muscles decreased about 30% in both men and women between our youngest and oldest age groups. This amount is consistent with previous reports of the relationship between age and strength of voluntary isometric muscle contraction in this type of mobile, elderly population. Kallman et al. (29) recently reported that grip strength decreases in an accelerating, curvilinear fashion across the adult age span, according to both their longitudinal and cross-sectional results. Although the present sample only involved half of the adult age range, our values for the middle-aged groups agree well with previous tests on young adults (26), a finding which also supports the conclusion that strength differences do not become evident until the seventh decade. Loss of strength can be explained in part by a decreased muscle bulk, but other factors remain undetermined (29,30).

In an elderly person, it thus takes a larger proportion of total dorsiflexor muscle strength to move the ankle actively through range against the intrinsic passive resistance. Muscles can become quite ineffective in turning the foot up when weakness and high resistive torque are both present. Research on exercise programs needs to examine whether elderly individuals with large passive resistance to ROM can achieve the above-normal strength needed. Furthermore, observations on young men indicated that as the dorsiflexor muscles shorten during contraction, their tension-generating capacity decreases rapidly because of the length-tension curve (31). It is important to verify whether the elderly show the same length-tension pattern and if their muscles can be strengthened substantially in a dorsiflexed ankle position.

Decreased strength and flexibility of the muscles around the ankle joint have been identified as risk factors when elderly people with a history of falling have been compared to nonfaller controls (32). Movement of the ankle during gait is a precisely controlled motor task, and inadequate foot clearance would predispose an individual to an accidental stumble and fall (33). Fiaterone et al. (34) recently demonstrated that even nonagenerians had the capacity to improve their quadriceps muscle strength significantly, using appropriate weight-training methods. However, it still remains to be shown via a controlled trial whether strengthening the leg muscles of elderly people is an important aspect of the prevention of falls and their devastating sequelae such as fractures, hospitalization, and dependency (35).

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