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Background and Purpose. The extent of a patient's impairment can be established by comparing measurements of that patient's performance with normative values obtained from apparently unimpaired individuals. Only a few studies have described normative values for muscle strength measured by hand-held dynamometry. The purpose of this study of older adults, therefore, was to obtain normative values of maximum voluntary isometric force using hand-held dynamometers. **Subjects.** One hundred fifty-six asymptomatic adults (77 men, 70 women) participated in this study. The subjects' mean age was 64.4 years (SD=8.3, range=50–79). The male subjects' mean age was 64.5 years (SD=8.4, range=50–79), and the female subjects' mean age was 64.3 years (SD=8.2, range=50–79). **Methods.** Gender, age, dominant side, height, weight, and activity level were recorded. Eight upper-extremity movements (shoulder flexion, extension, abduction, and medial and lateral rotation; elbow flexion and extension; and wrist extension) and five lower-extremity movements (hip flexion and abduction, knee flexion and extension, and ankle dorsiflexion) were resisted by one of three experienced testers using a strain-gauge hand-held dynamometer. **Results.** Gender, age, and weight were identified as independent predictors of force for all muscle actions on both the dominant and nondominant sides. These variables were used, therefore, to create regression equations and normative values for the force of each muscle action. **Conclusion and Discussion.** The reference values provided may allow clinicians who follow the described testing protocol to estimate the severity of force-generating impairments in patients aged 50 to 79 years. [Andrews AW, Thomas MW, Bohannon RW. Normative values for isometric muscle force measurements obtained with hand-held dynamometers. *Phys Ther.* 1996;76:248–259.]

Key Words: *Dynamometry, Muscle, Strength.*

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Judgments about the extent of a patient's impairment require comparison with some reference value; one type of reference value is normative reference values against which the patient's performance can be compared.[1] An abundance of normative values exist for muscle force, defined herein as the maximum voluntary force or torque brought to bear on the environment under a given set of test conditions. Such values are typically presented as means and standard deviations of maximum voluntary forces or torques produced by apparently asymptomatic subjects. Most published normative values for muscle force, however, are for measurements obtained with isokinetic,[2–4] fixed,[5,6] or hand-grip[7,8] dynamometers. Although three articles[9–11] have presented normative values for measurements obtained with hand-held dynamometers, the usefulness of the values is limited by the subjects and muscle actions tested and by the devices used. The subjects tested in the studies have been younger than most of the patients typically treated by physical therapists in some settings. Bäckman et al[9] tested children aged 3.5 to 15 years, Bohannon[10] examined women aged 20 to 40 years, and van der Ploeg et al[11] measured the performance of men and women aged 20 to 60 years. The values reported by Bohannon were only for upper-extremity muscle actions. The maximum force measurements obtained with the different dynamometers used in these studies were all less than 350 N. Previous investigations[12,13] lead us to believe such maximum measurements (ceilings) are much lower than the forces that adults are capable of exerting with some muscle actions against a dynamometer.

Comparisons between clinically obtained measurements and normative values are legitimate only if the methods used to test a patient closely resemble those used to obtain the normative values. Among the testing variables known to influence the results of muscle tests are joint position or muscle length,[14,15] gravity correction,[16] type of muscle test (break versus make)[17,18] or activation (eg, concentric versus eccentric),[19] speed of movement,[15,20] and measurement variable (eg, force versus torque).[21] Muscle force measurements can also be affected by variables intrinsic to the individual tested. Such variables include dominant side,[22] gender,[22,23] age,[19,23,24] and weight.[24,25] The importance of these factors should also be considered when presenting normative values.

The purpose of this study was to obtain normative values for muscle force using a hand-held dynamometer and

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Partial results of this study were presented at the 68th Annual Conference of the American Physical Therapy Association, June 12–16, 1993, Cincinnati, OH, and at the Second Joint Congress of the Canadian Physiotherapy Association-American Physical Therapy Association, Toronto, Ontario, Canada, June 4–8, 1994.

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Table 1.
Characteristics of Subjects (N=156) Presented by Decade and Gender[a]

Decade	Gender (n)	Age (y)		Weight (N)		Height (cm)		Leisure Activity		Work Activity	
		X̄	SD	X̄	SD	X̄	SD	Median	Range	Median	Range
50–59	M (25)	54.0	3.4	835.7	101.3	176.1	6.5	3	1–4	3	1–3
	F (25)	54.6	2.8	684.9	143.4	162.9	6.6	2	1–3	2	1–3
60–69	M (26)	66.1	2.9	771.3	105.0	176.0	6.1	2	1–3	2	1–4
	F (29)	64.5	2.9	645.2	79.0	160.5	6.2	2	2–4	2	1–3
70–79	M (26)	72.9	2.7	745.2	93.6	174.2	5.7	2	1–4	2.5	1–4
	F (25)	73.8	3.2	597.6	81.8	158.8	5.8	2	1–4	2	1–3

[a]M=male, F=female, N=newtons.

specific testing procedures. The normative values were determined in the context of intrinsic variables that were shown to be predictive of muscle force in the sample of subjects tested.

Method

Subjects

A convenience sample of subjects was recruited using personal acquaintances, hospital volunteer offices, advertisements in local newsletters and newspapers, and notices posted at retirement communities. Subjects between 50 and 79 years of age were tested for this study if they did not report previous or current pathology known to affect muscle force and gave negative responses to all of the following questions: (1) Do you have any heart, lung, nervous system, bone, or joint problem that is currently being treated by a physician? (2) Are you unable to walk at least 30.5 m (100 ft) at one time without the need for assistance or a crutch, cane, or walker? and (3) Do you have any problems that will limit you from completing a strength test of the muscles in your upper or lower extremities? Subjects identifying a pathology affecting only one or two joints (eg, arthritis, tendinitis) were tested, but measurements from muscle actions of the affected joints were not included in the data set.

Figure 1.
Use of hand-held dynamometer to test shoulder lateral rotation.

Subjects who met the inclusion criteria and agreed to participate in the study provided written informed consent. Age and gender were recorded, and height and weight were measured for all subjects. The dominant upper and lower extremities (preferred for throwing a ball and kicking a ball, respectively)[26] were identified by the subjects. Subjects were asked to grade their work activity level and their leisure activity level according to the four-point ordinal activity scale (ie, I–IV) developed by Saltin and Grimby.[27] Work activity level for retired subjects was described as including any present part-time work, volunteer work, and work performed around the home. The median activity level score claimed by men in their 50s was III (for both work and leisure), that is, walking with some handling of material at work (eg, machinery worker) and regular leisure activity such as heavy gardening and tennis. The median activity level for all other subjects grouped by decade and gender was II (for both work and leisure). This score involved sitting and standing with some walking at work (eg, general office worker) and at least 4 hours per week of physical leisure activity, including walking and bicycling.

One hundred fifty-six asymptomatic subjects participated in this study. At least 25 men and 25 women in each decade were tested. The subjects' mean age was 64.4 years (SD=8.3, range=50–79). The male subjects' mean age was 64.5 years (SD=8.4, range=50–79), and the female subjects' mean age was 64.3 years (SD=8.2, range=50–79). The descriptions of the male and female subjects in each decade are presented in Table 1.

Testers

The three authors served as testers in this study. Each of the testers had experience using hand-held dynamometers. Each author had tested thousands of patients in his practice for at least the past 8 years. In this study, the first author (AWA) tested 82 of the subjects, the second

Table 2.
Subject Position, Placement of Dynamometer, and Location of Stabilization Provided for Each Tested Muscle Action

Muscle Action	Limb/Joint Positions	Dynamometer Placement	Stabilization of Subject
Shoulder flexion	Shoulder flexed 90°; elbow extended	Just proximal to epicondyles of humerus	Axillary region
Shoulder extension	Shoulder flexed 90°; elbow flexed	Just proximal to epicondyles of humerus	Superior aspect of shoulder
Shoulder abduction	Shoulder abducted 45°; elbow extended	Just proximal to lateral epicondyle of humerus	Superior aspect of shoulder
Shoulder lateral rotation	Shoulder abducted 45°; elbow at 90°	Just proximal to styloid processes	Elbow
Shoulder medial rotation	Shoulder abducted 45°; elbow at 90°	Just proximal to styloid processes	Elbow
Elbow flexion	Shoulder at neutral; elbow flexed 90°; forearm supinated	Just proximal to styloid processes	Superior aspect of shoulder or arm
Elbow extension	Shoulder at neutral; elbow flexed 90°; forearm in neutral	Just proximal to lateral styloid process	Anterior aspect of shoulder or arm
Wrist extension	Shoulder at neutral; elbow flexed 90°; wrist at neutral; fingers relaxed	Just proximal to metacarpophalangeal joints	Distal forearm
Hip flexion	Hip flexed 90°; knee relaxed; contralateral limb in neutral	At femoral condyles	Pelvis
Hip abduction	Both lower limbs in neutral	At lateral femoral condyles	Contralateral lower limb held in neutral
Knee flexion	Hips and knees flexed 90°; hands resting in lap	Just proximal to malleoli	Stabilized at shoulders by assistant
Knee extension	Hips and knees flexed 90°; hands resting in lap	Just proximal to malleoli	Stabilized at shoulders by assistant
Ankle dorsiflexion	Hip, knee, and ankle at 0°	Just proximal to metatarsophalangeal joints	Knee maintained in full extension; leg supported with foot off table

author (MWT) tested 53 subjects, and the third author (RWB) tested 21 subjects.

Instrumentation

Isometric force was measured with the Chatillon CSD400C hand-held dynamometer* (Fig. 1). This digital strain-gauge dynamometer displays force measurements to the nearest 0.2 lb to a maximum of 115.0 lb (512 N).[28] The three dynamometers used in this study were calibrated by the manufacturer before the initiation of the study and midway through the study period. Accuracy of the dynamometers was checked and confirmed by the manufacturer at the completion of the study. Specifically, each dynamometer was mounted upright and attached to a push calibration-check fixture.[28] One hundred pounds of calibrated weights were attached to the push fixture. The analog-to-digital converter was scaled according to the change (in millivolts) recorded from the load cell. This information was stored in the programmable read-only memory.

*John Chatillon & Sons Inc, PO Box 35668, Greensboro, NC 27425-5668.

Testing Procedure

Isometric force was measured bilaterally for eight upper-extremity muscle actions and five lower-extremity muscle actions by one of the three investigators. The eight upper-extremity muscle actions tested were shoulder flexion and extension, abduction, and lateral and medial rotation; elbow flexion and extension; and wrist extension. The five lower-extremity muscle actions tested were hip flexion and abduction, knee extension and flexion, and ankle dorsiflexion.

Table 2 lists the stabilization specifics for the tests used for each muscle action in this study. These test specifics are similar or identical to those illustrated elsewhere.[9,12,29,30] All tests were conducted with the subjects positioned supine, except for knee flexion and extension, which were tested with the subjects sitting upright.

Table 3.
Correlations Between Muscle Force and Six Independent Variables[a]

Muscle Action	Correlation With Independent Variable						
						Activity	
	Side[b]	Gender	Weight	Age	Height	Work	Leisure
Shoulder flexion	N	−.799	.693	−.289	.677	.207	.140
	D	−.793	.702	−.287	.679	.189	.107
Shoulder extension	N	−.816	.696	−.198	.714	.189	.041
	D	−.804	.697	−.218	.705	.195	.103
Shoulder abduction	N	−.819	.666	−.191	.687	.201	.152
	D	−.762	.663	−.250	.692	.213	.104
Shoulder lateral rotation	N	−.741	.597	−.228	.587	.182	.097
	D	−.754	.640	−.228	.612	.221	.165
Shoulder medial rotation	N	−.808	.701	−.234	.717	.253	.156
	D	−.809	.686	−.228	.718	.259	.186
Elbow flexion	N	−.820	.692	−.196	.747	.243	.171
	D	−.809	.712	−.248	.743	.234	.219
Elbow extension	N	−.779	.710	−.159	.626	.250	.095
	D	−.745	.710	−.215	.624	.195	.113
Wrist extension	N	−.794	.674	−.165	.658	.194	.055
	D	−.748	.683	−.203	.647	.211	.095
Hip flexion	N	−.658	.597	−.319	.700	.200	.205
	D	−.626	.569	−.321	.672	.126	.203
Hip abduction	N	−.635	.569	−.269	.623	.098	.101
	D	−.644	.594	−.237	.610	.114	.115
Knee flexion	N	−.637	.712	−.217	.630	.132	.085
	D	−.680	.689	−.236	.677	.091	.066
Knee extension	N	−.691	.694	−.296	.675	.142	.040
	D	−.674	.695	−.306	.682	.111	.023
Ankle dorsiflexion	N	−.555	.518	−.216	.434	.025	−.105
	D	−.558	.516	−.218	.440	.116	−.134

[a]Correlations between activity level and muscle group force are Spearman rank correlations; all other correlations are Pearson product-moment correlations.
[b]N=nondominant, D=dominant.

The shoulders and hips were at neutral rotation during all tests. Each muscle action was measured in a gravity-neutralized position. The shaft of the dynamometer was held perpendicular to the tested limb segment. During knee flexion and extension trials, an assistant helped with subject stabilization. Otherwise, the tester alone applied all manual stabilization.

Table 4.
Results of Analysis of Variance Comparing Muscle Force Measurements Between Sides and Muscle Actions

Source	*df*	SS	MS	*F*	*P*
Side (S)	1	839701	839701	244.3	.00001
Error	135	464065	3437		
Muscle action (M)	12	3753830	312819	346.5	.00001
Error	1620	1462559	902		
S×M	12	6742540	561878	523.5	.00001
Error	1620	1738787	1073		

At least one practice trial was given to the subjects to familiarize them with the feel of pushing against the dynamometer. Subjects were oriented to each desired action by the tester. The subject then performed the action actively until performed correctly. Isometric "make" tests were used as the subjects were asked to build their force gradually to a maximum voluntary effort over a self-determined 2-second period. They then maintained maximum effort for 5 additional seconds. The dynamometer was programmed so that each trial lasted 7 seconds, during which the tester held the dynamometer stationary against the limb segment. A rest period lasting 1 or 2 minutes was provided before a second (repeat) measure of an action was taken. Peak force values were recorded for each trial from the digital readout on the dynamometer.

Test-retest reliability was calculated for the first and second measurements obtained by all three testers using intraclass correlation coefficients (ICC[3,1]). The range of ICCs was from .932 to .984, depending on muscle action. Most values were greater than .960.

The interrater reliability of measurements obtained by two of the testers (AWA, RWB) was established previously in a sample of patients.[31] A preliminary study to assess the interrater reliability of measurements obtained by all three testers in this study was conducted. Nine apparently unimpaired adults agreed to participate in this pilot project. The force of eight selected muscle actions, three in the upper extremity and five in the lower extremity, was tested once unilaterally by each of the three examiners. The ICCs (3,1) for the eight muscle actions ranged from .511 to .950. All ICCs were greater than .770, with the exception of the values for hip abduction and ankle dorsiflexion.

Data Analysis

All data analyses were performed using the SYSTAT statistical program.[†32] The mean of the peak forces of the two trials obtained for each muscle action was used in all analyses. As a preliminary to the determination of normative values for muscle strength, the importance of gender, weight, height, age, dominant side, and activity level to the prediction of muscle force was examined for the sample of subjects tested. The correlations between muscle force and weight, height, and age were determined with Pearson product-moment correlation coefficients for the dominant and nondominant sides. A special form of the Pearson product-moment correlation, the point biserial correlation, was used to examine the relationship between the dichotomous variable gender and the continuous variable force.[33(pp54–58)] The correlations between muscle force and the ordinal activity level score were determined with Spearman's rank correlation coefficients.[33(pp58–60)] A 2×13 repeated-measures analysis of variance (ANOVA) was performed to determine whether force values differed between sides (dominant and nondominant) and muscle actions (n=13). As a follow-up, the force values of the 13 individual muscle actions were compared between sides using one-way repeated-measures ANOVAs. Step-wise multiple regression procedures were performed to provide prediction equations of muscle force for both the dominant and nondominant sides based on subject gender, weight, height, and age.

As these analyses (see "Results" section) showed side, gender, age, and weight to be predictive of the force of each muscle action, reference values for force measured with the hand-held dynamometer were reported by side, gender, and decade of age. Force measurements were described in actual units of force (nonnormalized) and

† SYSTAT Inc, 1800 Sherman Ave, Evanston, IL 60201.

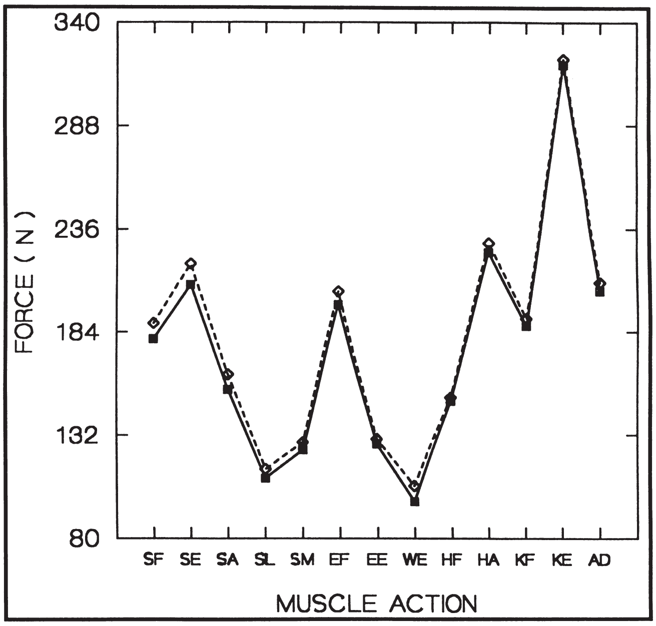

Figure 2.
Line graph illustrating the interaction of muscle action and side on muscle force measurements. Dominance exerts a greater influence for some muscle groups than others. (SF=shoulder flexion, SE=shoulder extension, SA=shoulder abduction, SL=shoulder lateral rotation, SM=shoulder medial rotation, EF=elbow flexion, EE=elbow extension, WE=wrist extension, HF=hip flexion, HA=hip abduction, KF=knee flexion, KE=knee extension, AD=ankle dorsiflexion).

as a percentage of body weight (normalized). The basis for deriving the latter normalized scores was the strong relationship between body weight and force.[1] The variability (relative dispersion) of the force scores was reduced by normalization against body weight.

Results

The correlations between the force of each muscle action of the dominant and nondominant sides and six independent variables are reported in Table 3. The correlations between muscle force and gender ($r=-.555$ to $-.820$), weight ($r=.516$ to $.712$), and height ($r=.434$ to $.747$) were moderate to high and significant at $P<.001$. The correlations between force and age ($r=-.159$ to $-.321$) were significant at $P<.05$, but weak. The correlations between force and both work activity levels ($r_s=.025$ to $.259$) and leisure activity levels ($r_s=-.134$ to $.219$) were sometimes significant at $P<.05$ but were too weak and inconsistent to be important.

The two-way ANOVA (Tab. 4) demonstrated that force differed ($P<.00001$) between the dominant and nondominant sides and between muscle actions. Moreover, an interaction was demonstrated between side and muscle action. One-way ANOVAs revealed that all upper-extremity muscle force values were different between sides ($P\leq.011$) but that none of the lower-extremity muscle force values were different between sides ($P\geq.083$) (Fig. 2). The multiple regression analyses identified gender, weight, and age

Table 5.
Regression and Correlation Results Describing the Relationship Between Three Independent Variables and Muscle Force

Muscle Group	Side[a] (n)	Regression Equation[b]	R	R^2
Shoulder flexion	N (152)	y=220.204−73.237S+0.130W−1.454A	.855	.730
	D (156)	y=234.947−74.442S+0.146W−1.718A	.864	.747
Shoulder extension	N (155)	y=224.567−97.507S+0.175W−1.357A	.869	.756
	D (155)	y=235.710−101.570S+0.189W−1.494A	.859	.738
Shoulder abduction	N (151)	y=172.206−69.368S+0.109W−0.891A	.848	.719
	D (155)	y=198.341−68.686S+0.135W−1.462A	.823	.677
Shoulder lateral rotation	N (150)	y=144.314−42.459S+0.057W−0.801A	.787	.620
	D (156)	y=122.721−40.947S+0.082W−0.686A	.798	.637
Shoulder medial rotation	N (154)	y=128.554−55.324S+0.113W−0.847A	.877	.770
	D (156)	y=141.066−59.539S+0.117W−0.984A	.858	.736
Elbow flexion	N (155)	y=209.154−79.303S+0.145W−1.125A	.863	.745
	D (155)	y=229.421−84.836S+0.165W−1.503A	.875	.766
Elbow extension	N (155)	y=93.477−47.565S+0.129W−0.490A	.840	.706
	D (156)	y=112.597−49.858S+0.139W−0.834A	.838	.702
Wrist extension	N (154)	y=86.992−40.223S+0.087W−0.436A	.845	.714
	D (155)	y=85.345−37.801S+0.103W−0.482A	.823	.677
Hip flexion	N (155)	y=214.609−52.922S+0.097W−1.657A	.750	.562
	D (156)	y=229.940−50.516S+0.081W−1.728A	.708	.501
Hip abduction	N (155)	y=288.847−65.538S+0.134W−1.969A	.705	.497
	D (156)	y=258.118−62.971S+0.150W−1.620A	.718	.516
Knee flexion	N (153)	y=114.508−40.473S+0.206W−0.804A	.771	.594
	D (155)	y=142.244−52.112S+0.189W−0.892A	.783	.614
Knee extension	N (150)	y=344.343−98.409S+0.286W−2.717A	.815	.665
	D (154)	y=358.455−87.581S+0.297W−3.136A	.792	.627
Ankle dorsiflexion	N (154)	y=246.464−51.379S+0.142W−1.751A	.624	.389
	D (155)	y=228.930−50.262S+0.168W−1.738A	.628	.394

[a]N=nondominant, D=dominant.
[b]S=gender (0=male, 1=female), W=weight (in newtons), A=age (in years).

as contributing to the prediction of the force of every tested muscle action on both sides. As height added independently to the prediction of force of only two muscle actions and as activity level did not add independently to the prediction of force of any muscle action, neither is included in the equations of Table 5. The multiple correlations associated with the regression equations ranged from .624 to .869, with all but those for ankle dorsiflexion equaling at least .705.

Table 6 presents descriptive statistics for the force of the muscle actions tested with the hand-held dynamometer. The normative reference values (nonnormalized and normalized for body weight) are reported for each side, gender, and decade of age. The mean force values ranged from 71 N (12% of body weight) for the nondominant wrist extension of women (70–79 years of age) to greater than 447.5 N (53.9% of body weight) for the dominant knee extension of men (50–59 years of age). The mean values for knee extension force of men in their 50s, it should be noted, are slightly depressed. Seven of the male subjects in their 50s and one male subject in his 70s generated forces at or above the dynamometer's measurement ceiling of 512 N.

Discussion and Conclusion

The purpose of this research was to generate reference values for muscle force obtained with a hand-held dynamometer and specific testing procedures. Consistent with a considerable volume of research already published, side,[22] gender,[22,23] age,[19,23,24] and weight[24,25] were shown statistically to influence force measures. Consequently, reference information was reported in two forms. The first form involved regression equations. The multiple correlations associated with the equations compare favorably to those reported by other researchers[4,34] who used different instrumentation. By inserting an individual's gender, weight, and age in the equations, his or her predicted muscle force can be calculated. That expected force then can be compared with the observed force, and an estimate of percentage of deficit then can be determined. The second form of reference information, normative values, entailed the presentation of data while controlling for side, gender, and decade of age.

Table 6.
Reference Values for Force Obtained With Hand-held Dynamometers and Reported by Muscle Action, Decade, Gender, and Side

Muscle Action	Decade	Gender[a]	Side[b] (n)	Force (lb)		Force (N)		Force (%)[c]	
				X̄	SD	X̄	SD	X̄	SD
Shoulder flexion	50–59	M	N (23)	57.3	11.5	254.9	51.0	30.9	5.3
			D (25)	60.2	10.3	267.7	46.0	32.1	4.3
		F	N (25)	33.6	5.9	149.6	26.4	22.2	3.9
			D (25)	36.3	6.8	161.6	30.4	24.0	4.2
	60–69	M	N (25)	50.0	7.4	222.6	32.9	29.2	4.8
			D (26)	52.1	9.5	231.8	42.4	30.3	5.3
		F	N (29)	31.6	6.1	140.7	27.2	21.9	3.7
			D (29)	33.2	6.9	147.5	30.9	23.0	4.9
	70–79	M	N (25)	46.8	8.8	208.2	39.3	28.3	5.3
			D (26)	48.9	7.8	217.6	34.8	29.6	5.6
		F	N (25)	27.1	4.8	120.7	21.3	20.5	4.2
			D (25)	27.4	5.0	122.1	22.1	20.7	4.3
Shoulder extension	50–59	M	N (25)	68.0	11.5	302.6	51.0	36.3	4.7
			D (25)	72.1	12.2	320.7	54.4	38.4	4.9
		F	N (24)	38.9	8.9	173.1	39.8	25.7	6.2
			D (25)	40.6	8.5	180.6	38.0	26.9	5.8
	60–69	M	N (26)	60.8	11.3	270.4	50.2	35.3	6.0
			D (26)	63.0	12.8	280.1	56.7	36.5	6.5
		F	N (29)	33.0	6.1	146.6	27.3	22.9	4.2
			D (29)	34.4	7.8	153.0	34.7	23.9	5.5
	70–79	M	N (26)	56.5	10.6	251.5	47.2	34.1	6.9
			D (26)	59.2	12.1	263.3	54.0	35.8	7.6
		F	N (25)	31.3	7.0	139.2	31.2	23.5	5.3
			D (25)	32.9	7.2	146.4	31.9	24.6	5.0
Shoulder abduction	50–59	M	N (24)	49.9	8.8	222.1	39.4	26.8	3.8
			D (25)	53.5	12.5	237.9	55.5	28.5	5.7
		F	N (24)	28.1	5.7	124.9	25.1	18.6	4.3
			D (25)	30.4	5.5	135.1	24.4	20.1	3.9
	60–69	M	N (25)	43.5	9.5	193.3	42.2	25.3	5.5
			D (26)	45.1	10.3	200.5	45.7	26.1	5.6
		F	N (29)	25.7	4.6	114.1	20.2	17.8	3.0
			D (29)	28.1	5.8	125.0	25.8	19.5	3.9
	70–79	M	N (24)	41.7	6.8	185.7	30.2	25.2	4.3
			D (26)	43.2	8.6	192.1	38.1	26.1	5.5
		F	N (25)	24.4	4.7	108.4	20.8	18.4	4.0
			D (24)	24.1	4.7	107.0	21.0	17.9	3.4
Shoulder lateral rotation	50–59	M	N (22)	34.2	6.1	152.3	27.3	18.4	2.6
			D (25)	35.1	7.4	155.9	33.1	18.7	3.3
		F	N (24)	21.6	4.6	96.2	20.2	14.3	2.9
			D (25)	22.6	4.6	100.4	20.3	15.0	3.2
	60–69	M	N (25)	29.5	5.6	131.3	25.0	17.3	4.3
			D (26)	31.3	6.1	139.2	27.2	18.2	3.6
		F	N (29)	19.2	3.7	85.6	16.5	13.3	2.1
			D (29)	19.9	4.2	88.4	18.9	13.7	2.7
	70–79	M	N (25)	29.1	6.4	129.2	28.6	17.7	4.3
			D (26)	29.9	5.5	133.0	24.5	18.2	4.2
		F	N (25)	17.9	3.1	79.8	14.0	13.6	3.2
			D (25)	18.5	2.8	82.1	12.5	13.9	2.6

(*Continued*)

Table 6.
Continued

Muscle Action	Decade	Gender[a]	Side[b] (n)	Force (lb) X̄	Force (lb) SD	Force (N) X̄	Force (N) SD	Force (%)[c] X̄	Force (%)[c] SD
Shoulder medial rotation	50–59	M	N(25)	41.0	8.5	182.2	37.7	21.8	3.3
			D(25)	43.4	9.0	193.3	40.2	23.1	3.5
		F	N(25)	22.7	4.5	100.9	19.9	15.0	3.1
			D(25)	22.9	4.5	100.7	19.9	15.1	3.1
	60–69	M	N(25)	35.1	5.1	156.2	23.0	20.3	2.7
			D(26)	36.7	6.5	163.3	28.9	21.2	3.1
		F	N(29)	20.2	4.1	90.1	18.3	14.0	2.5
			D(29)	20.8	4.2	92.3	18.7	14.4	3.0
	70–79	M	N(25)	33.7	6.4	150.0	28.6	20.5	4.2
			D(26)	34.1	7.5	151.6	33.4	20.6	4.8
		F	N(25)	18.9	3.1	84.0	14.0	14.2	2.3
			D(25)	19.3	3.9	86.0	17.1	14.5	2.6
Elbow flexion	50–59	M	N(25)	61.2	12.3	272.4	54.9	32.7	5.8
			D(24)	65.7	10.8	292.3	48.1	35.0	5.1
		F	N(25)	36.0	6.0	160.0	26.7	23.9	4.3
			D(25)	37.5	6.4	166.7	28.4	24.8	4.0
	60–69	M	N(25)	55.8	8.0	248.5	35.4	32.3	4.2
			D(26)	58.2	10.6	259.1	47.3	33.7	5.3
		F	N(29)	33.9	5.9	150.8	26.5	23.5	4.2
			D(29)	35.2	6.6	156.7	29.4	24.5	5.0
	70–79	M	N(26)	52.0	9.1	231.4	40.4	31.4	5.7
			D(26)	53.1	34.4	236.2	40.2	32.0	5.5
		F	N(25)	31.8	5.2	141.4	23.2	23.8	3.4
			D(25)	31.1	5.9	138.4	26.0	23.3	3.7
Elbow extension	50–59	M	N(25)	39.9	7.7	177.6	34.0	21.3	3.8
			D(25)	42.2	7.4	187.7	33.0	22.5	3.3
		F	N(25)	23.5	5.2	104.4	23.1	15.5	3.2
			D(25)	24.4	5.5	108.4	24.4	16.0	2.7
	60–69	M	N(26)	35.4	7.6	157.3	33.9	20.4	3.8
			D(26)	36.7	9.3	163.4	41.4	21.2	4.2
		F	N(29)	21.7	5.4	96.6	24.2	15.0	3.5
			D(29)	21.6	5.1	96.1	22.9	15.0	3.6
	70–79	M	N(25)	34.4	6.4	153.1	28.5	20.8	3.4
			D(26)	34.6	7.6	153.8	33.9	20.7	4.0
		F	N(25)	20.3	3.5	90.3	15.5	15.3	2.7
			D(25)	20.7	4.0	92.0	17.6	15.7	3.7
Wrist extension	50–59	M	N(25)	31.3	6.2	139.2	27.4	16.6	2.3
			D(25)	33.5	7.0	149.1	31.3	17.8	2.9
		F	N(25)	18.6	4.4	82.8	19.4	12.3	2.6
			D(24)	20.4	4.9	90.8	21.9	13.4	2.7
	60–69	M	N(25)	27.3	5.4	121.5	24.0	15.9	3.3
			D(26)	29.6	6.4	131.5	28.4	17.1	3.3
		F	N(29)	15.8	3.0	70.5	13.6	11.0	2.1
			D(29)	17.8	3.5	79.2	15.4	12.4	2.4
	70–79	M	N(25)	27.0	4.6	119.9	20.3	16.4	3.0
			D(26)	28.1	4.4	124.9	19.6	16.9	2.6
		F	N(25)	16.0	3.0	71.0	13.3	12.0	2.4
			D(29)	17.8	3.9	79.0	17.3	13.4	3.3

Table 6.
Continued

Muscle Action	Decade	Gender[a]	Side[b] (n)	Force (lb) X̄	Force (lb) SD	Force (N) X̄	Force (N) SD	Force (%)[c] X̄	Force (%)[c] SD
Hip flexion	50–59	M	N(25)	46.3	11.5	205.9	51.2	24.6	5.5
			D(25)	45.4	13.0	201.8	58.0	24.1	6.1
		F	N(25)	28.9	5.9	128.4	26.2	19.3	4.8
			D(25)	30.3	6.5	134.6	28.7	20.2	5.0
	60–69	M	N(26)	41.4	9.5	184.3	42.4	24.2	6.2
			D(26)	41.0	10.3	182.5	45.7	24.0	6.6
		F	N(29)	27.3	4.7	121.2	21.1	19.0	3.5
			D(29)	27.6	5.2	122.7	23.2	19.2	3.7
	70–79	M	N(26)	36.2	10.0	161.0	44.3	21.6	5.4
			D(26)	36.6	9.3	162.9	41.5	22.0	5.4
		F	N(25)	22.9	5.7	101.8	25.2	17.2	4.3
			D(25)	23.3	5.8	103.7	26.0	17.6	4.6
Hip abduction	50–59	M	N(25)	66.1	15.0	294.0	66.8	35.3	7.5
			D(25)	68.2	14.5	303.4	64.6	36.3	6.7
		F	N(25)	44.9	9.3	199.8	41.3	30.1	7.8
			D(25)	45.5	9.1	202.5	40.6	30.3	7.0
	60–69	M	N(26)	60.1	14.2	267.6	63.3	35.0	8.5
			D(26)	58.6	12.1	260.8	54.0	34.3	7.7
		F	N(29)	42.1	10.0	187.3	44.5	29.0	5.9
			D(29)	42.4	9.9	188.5	43.9	29.2	6.0
	70–79	M	N(26)	53.9	12.2	239.8	54.4	32.6	7.9
			D(26)	56.5	12.1	251.2	54.0	34.2	8.1
		F	N(25)	36.1	8.0	160.7	35.8	27.2	6.2
			D(24)	38.6	9.1	171.5	40.4	28.8	6.2
Knee flexion	50–59	M	N(25)	54.5	11.8	242.6	52.6	29.0	5.0
			D(25)	56.4	13.6	250.7	60.4	29.9	5.7
		F	N(25)	38.1	10.4	169.5	46.3	25.0	5.8
			D(25)	38.0	9.0	169.0	39.9	25.0	5.0
	60–69	M	N(24)	50.6	10.6	225.0	47.1	29.2	5.7
			D(26)	52.3	9.8	232.8	43.7	30.4	5.7
		F	N(29)	34.5	6.6	153.6	29.4	23.9	4.1
			D(29)	35.3	6.1	157.1	27.1	24.6	4.6
	70–79	M	N(26)	46.4	8.3	206.4	37.0	27.9	4.8
			D(26)	48.6	9.2	216.4	40.8	29.3	5.4
		F	N(25)	31.8	8.5	141.5	38.0	23.7	5.5
			D(24)	30.8	7.7	136.9	34.1	23.0	5.2
Knee extension	50–59	M	N(25)	98.7	15.3	439.2	68.2	52.9	8.1
			D(25)	100.6	15.0	447.5	66.8	53.9	8.4
		F	N(25)	66.1	17.5	293.9	77.8	43.6	10.8
			D(25)	67.0	19.4	298.0	86.5	44.2	12.4
	60–69	M	N(23)	85.1	15.6	378.4	69.6	49.3	8.0
			D(25)	81.5	16.1	362.5	71.8	47.4	8.5
		F	N(28)	55.7	14.9	248.0	66.4	38.4	8.8
			D(29)	57.8	13.0	257.2	58.0	39.9	8.0
	70–79	M	N(25)	81.9	15.1	364.2	67.4	49.3	8.2
			D(26)	80.3	18.1	357.1	80.4	48.2	10.2
		F	N(24)	50.6	11.5	224.9	51.2	38.0	8.6
			D(24)	50.7	10.7	225.6	47.4	38.0	7.2

(Continued)

Table 6.
Continued

Muscle Action	Decade	Gender[a]	Side[b] (n)	Force (lb) $\bar{X}$	Force (lb) SD	Force (N) $\bar{X}$	Force (N) SD	Force (%)[c] $\bar{X}$	Force (%)[c] SD
Ankle dorsiflexion	50–59	M	N(25)	63.8	17.1	284.0	76.0	34.0	8.2
			D(25)	65.4	18.7	290.9	83.2	34.7	8.3
		F	N(25)	42.5	11.1	189.1	49.4	28.5	8.9
			D(25)	43.7	13.4	194.4	59.6	29.4	11.0
	60–69	M	N(24)	54.5	13.5	242.4	60.1	31.4	8.8
			D(25)	52.9	13.4	235.3	59.6	30.6	7.7
		F	N(29)	39.9	11.3	177.7	50.1	27.6	6.7
			D(29)	38.5	9.5	171.3	42.3	26.5	5.2
	70–79	M	N(24)	47.3	11.8	210.5	52.4	28.6	7.6
			D(24)	49.8	12.7	221.5	56.5	30.1	8.2
		F	N(25)	34.5	8.2	153.4	36.5	25.9	6.6
			D(25)	35.9	9.9	159.7	44.0	27.1	8.9

[a] M=male, F=female.
[b] N=nondominant, D=dominant.
[c] Value=muscle force/body weight measured in the same units (eg, newtons/newtons, pounds/pounds).

Although separate values for the dominant and nondominant sides are probably not essential for lower-extremity actions (given the nonsignificant differences in force for specific muscle actions between sides), they are provided for those clinicians who wish to use them. The normative values are reported in both a normalized (against body weight) and nonnormalized format. The mean values, when demarcated by two standard deviations, provide a reasonable estimate of normal that can be used for judgments about force impairments. Any value that is less than two standard deviations below the mean value, therefore, can be considered a below-normal force measure.

An example from a patient tested by one of the investigators (RWB) illustrates how the regression equation and normative values of Tables 5 and 6 can be used. A 67-year-old patient who weighed 765 N and experienced a stroke 6 days prior to testing was suspected of having weakness on the side ipsilateral to his brain lesion. His measured elbow flexion force on the ipsilateral nondominant side was 130.8 N or 17.1% of body weight. The force predicted by the regression equation for the nondominant side was then 244.7 N ($209.154 - 79.303 \times 0 + .145 \times 765 - 1.125 \times 67$). The patient's force was, therefore, 46.5% below the predicted value. His force was also more than two standard deviations below the mean values (248.5 N and 32.3% of body weight) that are shown in Table 6. By comparing the patient's elbow flexion force with information in the tables, a suspected impairment is confirmed.

The reference values reported in this study should be more clinically useful, at least for individuals aged 50 to 79 years, than those reported in previous studies using hand-held dynamometers. The sample in this study included both men and women. The sample, although smaller than ideal, was larger and involved a greater number of muscle actions than previous studies. The dynamometer used in this study had a higher maximum value than those used in previous studies. This feature allowed for the measurement of the high forces produced by the elbow flexion, shoulder extension, knee flexion and extension, and ankle dorsiflexion actions of some of the subjects. The higher maximum value of the device precluded the measurement of the maximum knee extension force of eight subjects. As the testers in this project were able to hold steadily against these as well as all other forces, a dynamometer with a higher maximum value would have proven useful. Using such a dynamometer could have slightly elevated the normative values reported for knee extension for men. The regression equations for knee extension also would be altered slightly.

Despite the adequate force-generating capacity and considerable experience of the testers, the interrater reliability of some of their measurements (eg, hip abduction and ankle dorsiflexion) was disconcerting. The legitimacy of the regression equations and normative values for these 2 muscle groups is less certain than for the other 11 muscle groups. A limitation of the study, however, is the considerable experience of the testers. Whether less experienced examiners will be able to obtain similar levels of reliability is not known.

Although costly and somewhat cumbersome compared with manual muscle testing, hand-held dynamometry is much less expensive and more efficient than isokinetic dynamometry for providing quantitative measurements of the isometric force of multiple muscle actions. The repeated testing of all the muscle actions measured in this study required less than 40 minutes. Now that some normative values are available for the comparison of clinical measurements, the potential usefulness of hand-held dynamometry should be enhanced. Ultimately, the usefulness of the regression equations and normative values reported will depend on whether clinicians choose to use hand-held dynamometers. They must possess or develop adequate skill and force-generating capacity.[13] Otherwise, these normal values should not be generalized to measurements obtained by unskilled or weak examiners. The results also will not be applicable to other individuals if the testing procedures specified in this article are not followed. We believe clinicians should establish their own reliability. Eventually, the values reported should be validated in a manner similar to that used by Gross et al[34] with isokinetic measurements. That is, the multiple correlations associated with the regression equations and reference values should be confirmed on a different and ideally larger sample of adults aged 50 to 79 years.

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References

1 Rothstein JM, Echternach JL, eds. *Primer on Measurement: An Introductory Guide to Measurement Issues.* Alexandria, Va: American Physical Therapy Association; 1993:55–56.

2 Molnar GE, Alexander J. Development of quantitative standards for muscle strength in children. *Arch Phys Med Rehabil.* 1974;55:490–493.

3 Ivey FM, Calhoun JH, Rusche K, et al. Isokinetic testing of shoulder strength: normal values. *Arch Phys Med Rehabil.* 1985;66:384–386.

4 Gross MT, McGrain P, Demilio N, Plyler L. Relationship between multiple predictor variables and normal knee torque production. *Phys Ther.* 1989;69:54–62.

5 Edwards RHT, Young A, Hosking GP, Jones DA. Human skeletal muscle function: description of tests and normal values. *Clin Sci Mol Med.* 1977;52:283–290.

6 Christ CB, Boileau RA, Slaughter MH, et al. Maximal voluntary isometric force-production characteristics of six muscle groups in women aged 25 to 74 years. *American Journal of Human Biology.* 1992;4:537–545.

7 Montoye HJ, Lamphiear DE. Grip and arm strength in males and females, age 10–69. *Research Quarterly.* 1977;48:109–120.

8 Mathiowetz V, Kashman N, Volland G, et al. Grip and pinch strength: normative data for adults. *Arch Phys Med Rehabil.* 1985;66:69–72.

9 Bäckman E, Odenrick R, Henricksson KG, Ledin T. Isometric muscle force and anthropometric values in normal children aged between 3.5 and 15 years. *Scand J Rehabil Med.* 1989;21:105–114.

10 Bohannon RW. Upper extremity strength and strength relationships among young women. *J Orthop Sports Phys Ther.* 1986;8:128–133.

11 van der Ploeg RJO, Fidler V, Oosterhuis JHGH. Hand-held myometry: reference values. *J Neurol Neurosurg Psychiatry.* 1991;54:244–247.

12 Bohannon RW. Comparability of force measurements obtained with different hand-held dynamometers from older adults. *Isokinetics Exercise Science.* 1993;3:148–151.

13 Wikholm JB, Bohannon RW. Hand-held dynamometer measurements: tester strength makes a difference. *J Orthop Sports Phys Ther.* 1991;13:191–198.

14 Lunnen JD, Yack J, LeVeau BF. Relationship between muscle length, muscle activity, and torque of the hamstring muscles. *Phys Ther.* 1981;61:190–195.

15 Hopkins J, Sitler M, Ryan J. The effects of hip position and angular velocity on quadriceps and hamstring eccentric peak torque and ham/quad ratio. *Isokinetics Exercise Science.* 1993;3(1):27–33.

16 Winter DA, Wells RP, Orr RW. Errors in the use of isokinetic dynamometers. *Eur J Appl Physiol.* 1981;46:397–408.

17 Bohannon RW. Make versus break tests of elbow flexion force using a hand-held dynamometer. *Phys Ther.* 1988;68:193–194.

18 Stratford DW, Balsor BE. A comparison of make and break tests using a hand-held dynamometer and the Kin-Com. *J Orthop Sports Phys Ther.* 1993;19:28–32.

19 Poulin MJ, Vandervoort AA, Paterson DH, et al. Eccentric and concentric torques of knee and elbow extension in young and older men. *Can J Sport Sci.* 1992;17:3–7.

20 Ingemann-Hansen T, Halkjaer-Kristensen J. Force-velocity relationships in the human quadriceps muscles. *Scand J Rehabil Med.* 1979;11: 85–89.

21 Bohannon RW. Correlation of knee extension force and torque with gait speed in patients with stroke. *Physiotherapy Theory and Practice.* 1991;7:185–190.

22 Askew LJ, An K-N, Morrey BF, Chas EYS. Isometric elbow strength in normal individuals. *Clin Orthop.* 1987;222:261–266.

23 Freedson PS, Gilliam TB, Mahoney T, et al. Industrial torque levels by age group and gender. *Isokinetics Exercise Science.* 1993;3(1):34–42.

24 DiBrezzo R, Fort IL, Brown BS, Gorman DR. Correlations of body fat, body weight, and strength for women 25 and older. *Am Corr Ther J.* 1987;41:69–72.

25 Kroll WP, Bultman LL, Kilmer WL, Boucher J. Anthropometric predictors of isometric arm strength in males and females. *Clinical Kinesiology.* 1990;44(1):5–11.

26 Balogun JA, Onigbinde AT. Hand and leg dominance: Do they really affect limb muscle strength? *Physiotherapy Theory and Practice.* 1992;8:89–96.

27 Saltin B, Grimby G. Physiological analysis of middle aged and old former athletes. *Circulation.* 1968;38:1104–1115.

28 *Operation Manual for Chatillon Isometric Strength Dynamometers.* Greensboro, NC: John Chatillon and Sons Inc; 1992.

29 Bohannon RW. Comparability of force measurements obtained with different strain gauge hand-held dynamometers. *J Orthop Sports Phys Ther.* 1993;18:564–567.

30 Bohannon RW. Muscle strength testing with hand-held dynamometers. In: Amundsen LR, ed. *Muscle Strength Testing.* New York, NY: Churchill Livingstone Inc; 1990:69–88.

31 Bohannon RW, Andrews AW. Interrater reliability of hand-held dynamometry. *Phys Ther.* 1987;67:931–933.

32 Wilkinson L. *SYSTAT: The System for Statistics.* Evanston, Ill: SYSTAT Inc, 1990.

33 Edwards AL. *An Introduction to Linear Regression and Correlation.* 2nd ed. New York, NY: WH Freeman & Co; 1984.

34 Gross MT, Credle JK, Hopkins LA, Kollins TM. Validity of knee flexion and extension peak torque prediction models. *Phys Ther.* 1990;70:3–10.