Reference Values for Extremity Muscle Strength Obtained by Hand-Held Dynamometry From Adults Aged 20 to 79 Years

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ABSTRACT. Bohannon RW. Reference values for extremity muscle strength obtained by hand-held dynamometry from adults aged 20 to 79 years. Arch Phys Med Rehabil 1997;78:26-32.

Objective and Design: Only a few studies have provided reference values for muscle strength obtained by hand-held dynamometry. Such values are essential for establishing the degree to which an individual's strength is impaired. This descriptive study was conducted to provide reference values for the strength of 10 extremity muscle actions.

Subjects and Instrumentation: A convenience sample of 106 men and 125 women volunteers was tested twice with an Ametek digital hand-held dynamometer.

Results: The measurements were found to be reliable. Predictive equations are provided for the measurements. Reference values generated are expressed in Newtons and as a percentage of body weight and are organized by gender, decade of age, and side.

Conclusions: The values can be employed in a clinical setting to document whether an individual is impaired relative to healthy subjects of the same gender and age.

ALTHOUGH THE ESSENCE of rehabilitation has always been the restoration of function, the centrality of disability has been emphasized increasingly in recent years. This trend and its appropriateness notwithstanding, impairments remain important because of their implications for function. A specific impairment well established as a correlate with function is muscle weakness.[1-5] The degree to which a patient's muscle strength is impaired, however, can only be established if the clinician has objective normal values against which to compare the patient's strength.[6] Manual muscle testing does not provide such values.[7,8] Instrumented tests can provide quantitative values to which a patient's performance can be compared, but most such tests cannot be conducted efficiently in diverse settings. Hand-held dynamometry is an exception. In the hands of a tester with adequate strength and skill,[9,10] hand-held dynamometry can be used to measure in less than 15 minutes the strength of 10 or more actions on both sides of a patient's body. Despite its potential, hand-held dynamometry remains limited in utility by the dearth of reference values to which measurements obtained with hand-held dynamometers can be compared.[11-17] The usefulness of the few reference values that have been published (table 1) is diminished by factors such as the age range or size of the samples tested, the specific actions tested, the type of test performed, or the upper limit of force measurement of the dynamometer used.

The primary purpose of this research, therefore, was to use a hand-held dynamometer with a high upper limit of force measurement and specific test procedures to obtain reference values for extremity muscle strength. As a preliminary to the presentation of the reference values, statistical determinants of the strength values were established for the sample tested. A secondary purpose, but initial component, of this study was the description of the reliability of the hand-held dynamometer measurements obtained.

METHOD

Subjects

A convenience sample of 106 men and 125 women, who on entrance into the study were without any known neuromuscular, musculoskeletal, or cardiovascular pathology, participated after providing written informed consent. Age and gender were recorded for the subjects as were their height and weight (table 2). The dominant upper (preferred for throwing a ball) and lower (preferred for kicking a ball) extremities were identified also. Subjects' work and leisure activity levels were self-rated using the four category ordinal (1-4) scale of Saltin and Grimby.[18] The subjects' median and modal rating of both work and leisure activity was 2. A few subjects were found after the initiation of testing to have an isolated problem with one or two joints (eg, arthritis). In such cases, the subject was retained but data from the affected joint were excluded.

Instrumentation

Muscle strength, defined as the maximum voluntary force that subjects were able to exert on the environment under specific testing conditions, was measured using an Accuforce II hand-held dynamometer.[a] The dynamometer incorporates a load cell and has a digital display. The dynamometer was set to read force in Newtons. The upper limit of the dynamometer exceeds 650N; it measures force to the nearest 0.1 Newton. The accuracy of the dynamometer was verified periodically over the course of the study by vertically loading it with certified calibration weights. The dynamometer was found consistently to accurately measure forces up to 650N. Because the instrument was not dependable for measuring higher forces, the few measurements surpassing 650N were recorded as 650N.

Procedure

All strength measurements were obtained by one male tester. At the time the study began the tester was 36 years old and

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Table 1: Summary of Studies Reporting Reference Values Obtained by Hand-Held Dynamometry

Reference	Subjects			Actions Tested	Test Type	Dynamometer	
	Age Range	Gender	Number			Operating Range*	Type†
11	3.5-1.5	M, F	217	UE, LE	Break	0-35kg	P&G
12	17-70	M, F	128	UE, LE	Break	0-60kg	P&G
13	20-60	M, F	100	Neck, UE, LE	Break	0-250N	MWPG
14	18	M	100	UE, LE	Break	0-300N	MWPG
15	16-78	M, F	60	Neck, UE, LE	Break	?	P&G
16	20-40	F	31	UE	Make	0-60lb	Spark
17	50-79	M, F	156	UE, LE	Make	0-115lb	Chatillon

Abbreviations: M, male; F, female; UE, upper extremity; LE, lower extremity.
*Presented in primary units reported.
†Dynamometers: P&G, Penny and Giles, Christchurch, Dorset, UK; MWPG, modified Wika pressure gauge; Spark, Spark Instruments and Academics, Inc., Coralville, IA; Chatillon, Chatillon, Greensboro, NC.

weighed approximately 760Newtons. His strength, as characterized by hand-grip force (650 Newtons) was approximately one standard deviation above the average for men his age.[19] His strength was sufficient to fix the hand-held dynamometer against the forces produced by all subjects.

The isometric strengths of six upper extremity and four lower extremity muscle actions of distal, middle, and proximal joints were measured twice bilaterally by a single tester with more than 10 years of experience with hand-held dynamometry. At least 1 minute of rest was allowed between repeated tests of the same action. Specifically tested were wrist extension, elbow flexion and extension, shoulder lateral rotation, extension and abduction, ankle dorsiflexion, knee extension, and hip flexion and abduction. Specifics of the test positions, stabilization, and dynamometer placement used in this study were identical to those that have been presented in detail elsewhere.[17,20,21] Because gravity effects can result in measurement errors unless accounted for,[22] all actions were tested in gravity-neutralized positions. With the exception of knee extension, which was tested with subjects sitting, this meant that all tests were performed with subjects supine on a padded table. Knee extension testing was performed with subjects sitting in a test chair with stabilizing straps or on a table with an assistant helping to stabilize. All other tests involved manual stabilization by the tester only. The hips and shoulders were tested while in neutral rotation. Further details of the test positions and dynamometer placements used are provided in table 3.

Strength was measured using isometric ''make'' tests. Subjects were asked to build their force to maximum over a 2-second period of time. By increasing force gradually in this manner it is easier for the tester to hold the dynamometer stationary against the subject's exertion. Subjects were thereafter to continue with a maximum effort for another 4.0 to 5.0 seconds, at which time the tester told them to stop. This duration has been shown by previous research to be adequate for most subjects to reach maximum force.[23] The peak force values were recorded for each trial from the digital display of the dynamometer. The knee extension forces of 21 subjects (20 men and 1 woman) met or exceeded 650N and were recorded as 650N.

Data Analysis

Data analysis was completed using the Systat statistical program.[24] The intrasession reliability of the repeated measures of each action on each side was checked by looking for differences in forces (using analysis of variance), calculating reliability coefficients (intraclass correlation coefficient, equation 3, 1)[25] and computing the technical error of measurement.[26] Internal consistency was estimated using Cronbach's alpha.[27] Thereafter the first measure was used in all additional analysis. Pearson and Spearman correlations and multiple regression analysis were used to determine the variables which should be used to organize the presentation of reference values. Descriptive reference values were then calculated.

Table 2: Characteristics of Subjects Grouped by Decade and Gender

Decade/Gender (*n*)	Age, yr		Weight, N		Height, cm	
	$\bar{X}$ (SD)	Range	$\bar{X}$ (SD)	Range	$\bar{X}$ (SD)	Range
20s						
M (16)	23.9 (3.2)	20-28	791 (92)	618-987	177 (7)	168-191
F (22)	22.3 (2.3)	20-29	578 (64)	476-703	164 (7)	155-178
30s						
M (13)	34.2 (2.9)	30-39	788 (128)	605-1,081	176 (6)	168-183
F (23)	35.1 (2.7)	30-39	651 (185)	476-1,410	164 (7)	145-175
40s						
M (15)	44.9 (2.6)	41-49	845 (133)	681-1,129	175 (7)	160-183
F (21)	44.1 (2.4)	40-49	620 (130)	458-1,005	163 (8)	147-178
50s						
M (22)	54.8 (3.1)	50-59	855 (140)	685-1,263	175 (8)	160-193
F (21)	53.8 (2.8)	50-59	633 (112)	498-841	162 (5)	150-168
60s						
M (18)	66.2 (2.8)	60-69	795 (96)	676-996	175 (5)	165-183
F (18)	64.8 (3.0)	60-69	622 (95)	467-778	160 (5)	150-170
70s						
M (22)	73.0 (2.7)	70-79	757 (89)	520-898	174 (6)	157-185
F (20)	73.1 (3.1)	70-79	581 (85)	436-796	157 (5)	145-168

Table 3: Details of Test Positions and Dynamometer Placements Used During the Testing of 10 Muscle Actions With a Hand-Held Dynamometer

Muscle Action	Extremity/Joint Positions	Location of Dynamometer Application
Wrist Extension	Shoulder neutral, elbow 90°, wrist neutral	Just proximal to metacarpophalangeal joints
Elbow Flexion	Shoulder neutral, elbow 90°, forearm supinated	Just proximal to styloid processes
Elbow Extension	Shoulder neutral, elbow 90°, forearm neutral	Just proximal to styloid processes
Shoulder Lateral Rotation	Shoulder abducted 45°, elbow 90°	Just proximal to styloid processes
Shoulder Extension	Shoulder flexed 90°, elbow flexed	Just proximal to humeral epicondyles
Shoulder Abduction	Shoulder abducted 45°, elbow fully extended	Just proximal to later epicondyle of humerus
Ankle Dorsiflexion	Hip and knee fully extended, ankle neutral	Just proximal to metatarsophalangeal joints
Knee Extension	Hips and knees flexed 90°	Just proximal to malleoli
Hip Flexion	Hip flexed 90°, knee flexed, contralateral hip neutral	Just proximal to femoral condyles
Hip Abduction	Both hips neutral, knees extended	Just proximal to lateral joint line (of knee)

RESULTS

Table 4 summarizes the statistics that describe the test-retest reliability of the hand-held dynamometer measurements. Only in the case of the ankle dorsiflexion measurements of the nondominant side was there a significant difference in the forces of a first and second measurements. All intraclass correlation coefficients were greater than .940. The technical error of measurement ranged from a low of 8.0N for shoulder lateral rotation to a high of 26.8N for knee extension. The Cronbach alpha value for the first force measurements of all actions was .974.

Table 5 presents Pearson correlations between muscle action strength and sex, age, weight, and height and Spearman correlations between muscle action strength and activity levels. Sex, weight, and height were correlated significantly ($p < .001$) with the strengths of all actions. Age was correlated significantly ($p < .001$) with the strengths of most actions. Less than half of the correlations between work and leisure activity and muscle action strength were significant at $p < .001$. Regression established sex, age, and weight as the best set of independent predictors of the muscle action strengths (table 6). Together these three variables predicted between 44.8% and 82.2% of the strengths of the muscle actions tested.

Table 7 and table 8 present reference values for the strengths of the tested actions. Based on the correlational and regression analysis, the values are presented separately for each sex. Values are also presented separately for each decade of age and side. Given the relationship between weight and strength, values are presented both as absolute forces and as a percentage of (normalized against) body weight.

DISCUSSION

Verification of the reliability of the measurements obtained in this study is important but not surprising given the findings of previous research.[9,10,17] The reliability data presented herein, however, goes beyond that usually offered. The technical error of measurement statistics provide clinicians with error estimates that are expressed in the units of measurement of the dynamometer. These are the force levels that would need to be exceeded on a second measurement if the clinician is to assume that a real difference exists between a first and subsequent measurement. The Cronbach alpha value found in this study supports the strong internal consistency of the muscle strength measurements obtained. The Cronbach alpha value is comparable to those described elsewhere for two different samples of subjects.[28] The Cronbach alpha suggests that the measurements provide a consistent indication of a global underlying construct, ie, extremity muscle strength. Such consistency obviates the measurement of numerous muscle actions if the intent of strength measurements is merely to characterize an individual's strength.

There is nothing novel in the demonstration in this study of significant correlations between muscle strength and sex,

Table 4: Statistics Summarizing the Test-Retest Reliability of Hand-held Dynamometer Measurements of Force Obtained During a Single Session by One Examiner

		Mean Force(N)		ANOVA			
Muscle Action	Side	Test 1	Test 2	*F*	*p*	ICC	TEM(N)
Wrist Extension	Non	117.1	116.5	.511	.475	.953	9.0
	Dom	121.9	122.3	.254	.615	.961	8.2
Elbow Flexion	Non	199.9	199.9	.002	.968	.964	12.5
	Dom	202.7	200.9	2.697	.102	.973	11.5
Elbow Extension	Non	147.6	145.7	3.192	.075	.975	11.2
	Dom	146.4	146.5	.015	.903	.969	10.2
Shoulder Lateral Rotation	Non	126.4	124.9	2.539	.112	.952	9.8
	Dom	133.3	132.1	2.597	.108	.972	8.0
Shoulder Extension	Non	246.4	246.3	.002	.964	.973	15.9
	Dom	255.9	253.2	3.251	.973	.974	16.3
Shoulder Abduction	Non	166.9	165.9	.772	.381	.955	13.1
	Dom	174.7	172.8	3.257	.972	.968	11.7
Ankle Dorsiflexion	Non	271.7	273.1	.686	.408	.953	17.6
	Dom	276.9	284.6	15.423	.000	.945	21.7
Knee Extension	Non	403.0	406.8	2.940	.088	.972	23.3
	Dom	407.9	412.8	3.860	.051	.963	26.8
Hip Flexion	Non	148.2	148.5	.084	.772	.965	10.7
	Dom	150.2	150.4	.058	.809	.956	11.5
Hip Abduction	Non	235.8	235.9	.002	.960	.949	17.2
	Dom	240.9	240.6	.028	.866	.950	16.9

Abbreviation: Non, nondominant; Dom, dominant; ICC, intraclass correlation coefficient (equation 3,1); TEM, technical error of the measurement.

Table 5: Pearson Correlations and Spearman Correlations Between Muscle Action Strengths and Six Independent Variables

Muscle Action	Side	Sex*	Age*	Weight*	Height*	Work Activity†	Leisure Activity†
Wrist extension	Non	−.703	−.276	.623	.599	*.111*	*.154*
	Dom	−.720	−.267	.641	.634	*.112*	*.174*
Elbow flexion	Non	−.829	*−.096*	.692	.717	*.204*	.248
	Dom	−.860	*−.075*	.726	.764	.221	.238
Elbow extension	Non	−.746	−.235	.658	.614	*.118*	*.207*
	Dom	−.748	−.239	.652	.605	*.128*	*.194*
Shoulder lateral rotation	Non	−.671	−.282	.572	.558	*.164*	*.192*
	Dom	−.699	−.296	.601	.580	*.158*	.237
Shoulder extension	Non	−.721	−.270	.640	.624	*.148*	*.191*
	Dom	−.747	−.273	.650	.663	*.181*	.231
Shoulder abduction	Non	−.756	*−.193*	.652	.661	*.212*	.235
	Dom	−.736	−.245	.635	.669	*.145*	*.205*
Ankle dorsiflexion	Non	−.498	−.464	.511	.445	*.002*	*.097*
	Dom	−.399	−.462	.467	.347	*−.019*	*.060*
Knee extension	Non	−.464	−.584	.498	.531	*.029*	.217
	Dom	−.447	−.588	.502	.540	*.002*	*.204*
Hip flexion	Non	−.654	*−.210*	.450	.657	*.163*	.245
	Dom	−.667	−.224	.474	.653	*.118*	.216
Hip abduction	Non	−.669	−.221	.650	.642	*.139*	*.210*
	Dom	−.624	−.227	.627	.590	*.169*	*.198*

All correlations except those italicized are significant at $p < .001$.
*Pearson correlations.
†Spearman correlations.

age, and weight.[17,29,30,31] Nevertheless, the verification provides a necessary justification for the organization of the reference values presented. That age did not correlate more highly with strength was somewhat surprising. Correlations between age and strength that surpass those of this study have been reported elsewhere. The regression equations presented herein may serve also as the source of rather specific reference values if a clinician wants to take the time to insert relevant patient data into them. By comparing the extremity muscle strength predicted by a patient's sex, age, and weight with that actually measured, an estimate of his or her impairment can be derived.

The reference values of tables 7 and 8 are not the only ones available to the clinician who is seeking normative values against which to compare a patient's performance.[11-17] The values in this article, however, are derived from a larger sample than used in previous studies. The sample in this study also incorporates a greater age range of subjects than all but one previous study involving hand-held dynamometry. The operating range of the dynamometer employed in this study was considerably greater than that of dynamometers used in earlier normative values studies. Consequently, with the exception of the knee extension forces of men (20 to 59) and women (30 to 39), the reference values reported herein are not depressed in magnitude by a ceiling effect caused by the upper force-measuring limit of the dynamometer. For subjects in this study in the decades 50 to 59, 60 to 69, and 70 to 79 years of age, the reference values reported are quite comparable to those presented for the same decades in the study by Andrews and coworkers.[17] Such comparability should exist if the results of the two studies are valid; the procedures employed in the two studies were the same. Only the dynamometer differed. Previous research has shown that forces measured with the two dynamometers are comparable when obtained from older adults.[21]

In spite of the advantages inherent in this study relative to

Table 6: Regression Equations and Multiple Correlations of Sex, Age, and Weight with Muscle Strength (Newtons)

Muscle Action	Side	Equation*	R	R^2
Wrist extension	Non	114.36 − 45.1S − .774A + .094W	.825	.680
	Dom	123.65 − 48.5S − .784A + .092W	.826	.683
Elbow flexion	Non	188.25 − 89.2S − .650A + .132W	.882	.779
	Dom	188.36 − 96.5S − .610A + .140W	.907	.822
Elbow extension	Non	150.37 − 71.5S − 1.044A + .126W	.852	.726
	Dom	156.49 − 73.0S − 1.032A + .116W	.853	.727
Shoulder lateral rotation	Non	140.32 − 50.2S − 50.164A + .080W	.786	.618
	Dom	147.66 − 54.5S − .930A + .088W	.810	.656
Shoulder extension	Non	260.18 − 113.5S − 1.868A + .202W	.842	.709
	Dom	278.99 − 120.0S − 1.99A + .202W	.855	.731
Shoulder abduction	Non	165.16 − 74.9S − .910A + .126W	.843	.710
	Dom	178.90 − 77.1S − 1.128A + .134W	.843	.710
Ankle dorsiflexion	Non	302.54 − 60.9S − 2.203A + .159W	.742	.550
	Dom	285.46 − 47.6S − 2.367A + .193W	.669	.448
Knee extension†	Non	480.70 − 95.0S − 4.868A + .310W	.826	.683
	Dom	465.22 − 84.7S − 4.803A + .325W	.820	.673
Hip flexion	Non	216.48 − 74.6S − .926A + .026W	.718	.516
	Dom	219.30 − 72.6S − .977A + .027W	.731	.534
Hip abdcution	Non	203.32 − 73.3S − 1.247A + .192W	.794	.630
	Dom	195.24 − 62.4S − 1.184A + .198W	.764	.584

*S, sex (male = 0, female = 1); A, age (years); W, weight (Newtons).
†The equations for knee extension are compromised by the upper limit of force (650N) recorded for 21 subjects.

Table 7: Strength Reference Values for Men Presented by Muscle Action, Decade, and Side

			Force (N)		Force/Wt (%)	
Muscle Action	Decade	Side (*n*)	X̄	SD	X̄	SD
Wrist extension	20-39	Non (16)	171.1	23.6	21.7	2.7
		Dom (16)	184.3	27.6	23.3	2.5
	30-39	Non (13)	172.5	39.9	22.0	4.5
		Dom (13)	169.5	41.5	21.8	5.1
	40-49	Non (15)	178.6	32.2	21.5	4.5
		Dom (15)	185.1	38.1	22.0	3.6
	50-59	Non (22)	144.7	35.9	16.9	2.6
		Dom (21)	148.9	35.0	17.9	4.1
	60-69	Non (18)	125.8	24.4	16.0	3.7
		Dom (18)	138.3	29.9	17.5	4.0
	70-79	Non (22)	126.5	22.1	16.9	3.4
		Dom (22)	130.1	22.3	17.3	2.8
Elbow flexion	20-29	Non (16)	278.5	47.8	35.5	6.9
		Dom (16)	285.0	38.2	36.4	5.9
	30-39	Non (13)	281.2	54.3	36.1	7.4
		Dom (13)	268.5	47.1	34.6	7.4
	40-49	Non (15)	269.8	29.7	32.5	5.2
		Dom (15)	268.5	33.6	33.3	3.5
	50-59	Non (22)	268.2	49.6	31.6	5.6
		Dom (21)	286.9	38.5	33.8	4.9
	60-69	Non (18)	243.6	42.7	30.8	5.1
		Dom (17)	259.4	48.9	32.6	5.7
	70-79	Non (22)	237.5	38.1	31.4	4.3
		Dom (22)	237.3	39.9	32.2	4.8
Elbow extension	20-29	Non (16)	244.5	39.5	31.1	5.0
		Dom (16)	243.1	50.5	30.8	5.1
	30-39	Non (13)	231.1	68.0	29.5	8.0
		Dom (13)	214.3	50.8	27.6	7.2
	40-49	Non (15)	214.1	36.7	25.8	5.5
		Dom (15)	209.9	33.4	25.3	5.2
	50-59	Non (22)	186.1	38.5	21.9	3.7
		Dom (22)	196.9	37.2	23.3	4.5
	60-69	Non (18)	164.7	32.6	20.7	3.5
		Dom (18)	168.5	41.6	21.1	4.2
	70-79	Non (22)	169.5	36.6	22.4	4.0
		Dom (22)	163.2	35.3	21.5	3.6
Shoulder lateral rotation	20-29	Non (16)	205.0	33.5	26.0	3.9
		Dom (16)	206.8	39.6	26.3	4.9
	30-39	Non (13)	181.1	48.9	23.1	6.1
		Dom (13)	188.2	43.0	24.0	4.7
	40-49	Non (15)	175.7	23.6	21.1	3.6
		Dom (15)	189.9	36.9	22.9	5.2
	50-59	Non (18)	152.3	36.4	17.8	2.6
		Dom (22)	166.7	42.7	19.6	4.4
	60-69	Non (17)	134.3	28.6	17.2	4.9
		Dom (17)	150.4	36.5	19.0	5.0
	70-79	Non (22)	134.1	30.0	17.9	4.2
		Dom (22)	140.1	29.0	18.8	4.5
Shoulder extension	20-29	Non (16)	385.1	68.2	48.8	7.5
		Dom (16)	396.5	75.2	50.1	7.8
	30-39	Non (13)	376.4	93.5	48.1	10.8
		Dom (13)	402.5	88.3	51.8	12.2
	40-49	Non (15)	409.4	71.6	49.3	10.1
		Dom (15)	400.1	78.6	48.0	10.3
	50-59	Non (22)	303.4	54.3	35.9	6.5
		Dom (22)	332.1	60.0	39.1	5.9
	60-69	Non (17)	272.2	55.2	34.4	7.1
		Dom (18)	270.9	59.7	34.2	7.2
	70-79	Non (22)	259.4	53.1	34.2	5.5
		Dom (22)	276.0	45.6	36.8	6.4
Shoulder abduction	20-29	Non (16)	246.3	43.9	31.4	6.4
		Dom (16)	258.4	61.0	32.7	6.8
	30-39	Non (13)	237.2	69.6	30.5	9.1
		Dom (13)	249.2	60.2	31.9	7.7
	40-49	Non (15)	244.9	43.1	29.1	4.2
		Dom (15)	245.5	37.5	29.6	5.8
	50-59	Non (20)	222.5	47.5	26.1	4.7
		Dom (20)	240.4	57.6	28.2	5.7
	60-69	Non (17)	195.8	44.7	24.9	6.4
		Dom (17)	203.0	45.1	25.5	5.6
	70-79	Non (22)	187.9	33.7	25.0	4.5
		Dom (22)	191.8	31.5	25.6	5.0
Ankle dorsiflexion	20-29	Non (16)	368.7	44.2	46.9	5.9
		Dom (16)	385.9	64.4	49.0	7.2
	30-39	Non (13)	388.4	81.5	49.6	8.7
		Dom (13)	372.6	89.6	47.3	8.8
	40-49	Non (15)	362.7	58.5	43.9	9.9
		Dom (15)	376.1	63.7	45.3	9.0
	50-59	Non (22)	311.0	63.3	36.7	7.1
		Dom (22)	323.2	90.8	36.9	13.5
	60-69	Non (18)	272.7	61.2	34.8	9.4
		Dom (18)	269.0	76.9	33.8	10.4
	70-79	Non (22)	246.0	47.6	32.7	6.1
		Dom (22)	240.0	47.3	32.1	7.2
Knee extension*	20-29	Non (16)	578.6	94.7	74.0	14.9
		Dom (16)	575.2	92.3	73.7	15.3
	30-39	Non (13)	572.5	82.8	73.7	12.3
		Dom (13)	572.9	76.5	73.6	11.0
	40-49	Non (14)	588.9	72.5	70.6	10.2
		Dom (15)	583.0	73.7	69.8	9.4
	50-59	Non (22)	467.7	103.1	55.1	11.2
		Dom (22)	470.9	92.3	55.7	11.1
	60-69	Non (18)	376.5	67.3	47.7	8.7
		Dom (18)	386.9	94.3	48.9	12.4
	70-79	Non (22)	365.9	76.9	48.4	8.8
		Dom (22)	360.3	72.6	47.7	8.4
Hip flexion	20-29	Non (16)	206.7	41.4	26.5	6.2
		Dom (16)	211.7	39.7	27.0	5.4
	30-39	Non (13)	225.9	58.1	28.9	6.7
		Dom (13)	223.6	47.7	28.5	5.2
	40-49	Non (15)	184.2	37.3	22.4	5.9
		Dom (15)	190.7	43.3	23.2	6.5
	50-59	Non (22)	203.1	58.6	24.0	6.8
		Dom (22)	195.2	61.9	23.1	7.1
	60-69	Non (18)	167.6	47.6	21.1	5.6
		Dom (18)	169.1	49.0	21.4	6.4
	70-79	Non (22)	162.1	39.2	21.5	5.0
		Dom (22)	167.4	38.7	22.2	4.6
Hip abduction	20-29	Non (16)	318.8	61.2	40.2	5.8
		Dom (16)	321.2	84.7	40.2	7.9
	30-39	Non (13)	333.3	54.3	42.7	6.3
		Dom (13)	329.1	66.6	42.0	7.6
	40-49	Non (15)	321.4	66.9	38.4	8.0
		Dom (15)	311.1	41.1	37.3	5.7
	50-59	Non (22)	303.6	69.8	35.7	7.9
		Dom (22)	308.9	74.7	36.2	7.8
	60-69	Non (18)	261.4	67.1	33.1	8.6
		Dom (18)	258.9	49.4	32.8	6.8
	70-79	Non (22)	246.0	42.6	32.8	6.2
		Dom (22)	250.8	42.7	33.6	7.2

*Knee extension force met or surpassed 650N and was recorded as 650N for 6 men in their 20s, 4 men in their 30s, 7 men in their 40s, and 3 men in their 50s. Reference values for these decades, therefore, may be depressed.

others previously published, it has several notable limitations. The upper force-measuring limit of the dynamometer, already acknowledged, compromises the magnitude of the reference values for knee extension strength and the accuracy of the regression equations for the strength of that action. This compromise is apparent when the normalized knee extension strengths of men and women subjects are compared. The data presented in this study show that women in their twenties produce more knee extension force as a percentage of body weight than men. Such a finding contradicts what is known about the relation between gender and strength. The sample tested in this study was one of convenience and may not be perfectly representative of the population from which it was drawn. The age range of the sample also is limited. The strength of subjects who are younger or older than those tested in this research cannot be compared legitimately to the values reported herein.

Table 8: Strength Reference Values for Women Presented by Muscle Action, Decade, and Side

			Force (N)		Force/Wt (%)					Force (N)		Force/Wt (%)	
Muscle Action	Decade	Side (*n*)	X̄	SD	X̄	SD	Muscle Action	Decade	Side (*n*)	X̄	SD	X̄	SD
Wrist extension	20-29	Non (22)	94.4	19.0	16.3	2.8	Shoulder abduction	20-29	Non (22)	135.3	21.2	23.4	2.9
		Dom (22)	99.6	16.8	17.2	2.1			Dom (22)	153.2	28.8	26.5	4.0
	30-39	Non (23)	98.0	19.8	15.4	2.7		30-39	Non (23)	135.5	28.4	21.2	3.7
		Dom (23)	104.6	17.6	16.5	3.0			Dom (23)	138.5	25.2	21.8	3.4
	40-49	Non (21)	99.4	21.2	16.4	3.9		40-49	Non (21)	129.1	26.2	21.4	5.1
		Dom (21)	102.1	17.5	16.9	3.5			Dom (21)	139.0	33.1	22.8	4.5
	50-59	Non (21)	98.5	17.2	15.8	2.6		50-59	Non (21)	134.9	29.9	21.5	4.1
		Dom (21)	99.7	18.4	16.1	3.2			Dom (21)	137.2	24.7	22.0	4.1
	60-69	Non (18)	85.2	19.8	13.9	3.6		60-69	Non (18)	103.7	16.1	17.1	3.9
		Dom (17)	83.2	17.7	13.8	3.4			Dom (18)	112.1	25.1	18.4	4.9
	70-79	Non (20)	61.4	17.8	10.8	3.6		70-79	Non (19)	101.6	21.3	17.8	4.6
		Dom (20)	69.8	17.6	12.4	4.1			Dom (20)	95.9	21.9	16.7	4.2
Elbow flexion	20-29	Non (22)	152.6	21.8	26.5	3.4	Ankle dorsiflexion	20-29	Non (22)	273.3	45.5	47.4	7.1
		Dom (22)	154.9	20.7	26.8	2.6			Dom (22)	294.9	51.1	51.4	9.2
	30-39	Non (23)	160.8	31.8	25.1	3.3		30-39	Non (23)	252.9	55.8	39.8	8.2
		Dom (23)	163.8	28.1	25.7	3.0			Dom (23)	248.7	75.5	38.6	8.6
	40-49	Non (21)	156.9	25.3	26.0	5.1		40-49	Non (21)	247.1	51.3	41.1	11.3
		Dom (21)	151.3	21.7	25.0	4.4			Dom (21)	251.0	54.4	41.5	10.7
	50-59	Non (21)	156.3	22.4	25.2	4.4		50-59	Non (21)	240.1	48.7	39.1	10.5
		Dom (21)	155.3	25.3	24.9	4.0			Dom (21)	252.9	53.3	41.3	12.1
	60-69	Non (18)	134.2	19.0	22.0	4.4		60-69	Non (18)	230.5	57.3	37.8	10.7
		Dom (18)	130.6	21.6	21.4	4.4			Dom (18)	235.7	74.9	38.9	15.2
	70-79	Non (20)	130.3	28.7	22.7	5.0		70-79	Non (20)	153.3	36.1	26.7	7.2
		Dom (20)	129.9	27.0	22.6	4.9			Dom (20)	166.2	48.7	29.1	9.9
Elbow extension	20-29	Non (22)	115.2	22.5	20.0	3.7	Knee extension*	20-29	Non (22)	465.7	97.7	80.5	14.0
		Dom (22)	116.2	20.2	20.2	3.3			Dom (22)	467.3	88.8	80.8	12.3
	30-39	Non (23)	118.7	33.8	18.4	3.2		30-39	Non (23)	410.8	122.6	63.8	15.0
		Dom (23)	116.7	31.2	18.2	3.4			Dom (23)	408.3	128.8	63.3	15.5
	40-49	Non (21)	112.3	26.6	18.5	4.4		40-49	Non (21)	362.7	60.0	59.7	10.4
		Dom (21)	109.7	21.8	18.1	4.1			Dom (21)	380.6	86.5	62.6	14.3
	50-59	Non (21)	106.7	20.8	17.5	3.7		50-59	Non (21)	318.7	72.6	51.2	12.4
		Dom (21)	111.2	19.1	17.9	3.4			Dom (21)	334.7	75.8	53.7	12.8
	60-69	Non (18)	95.3	18.2	15.5	2.8		60-69	Non (18)	265.9	83.2	43.3	14.0
		Dom (18)	92.9	20.6	14.8	3.2			Dom (18)	273.6	80.0	44.6	13.6
	70-79	Non (20)	88.6	16.5	15.5	3.1		70-79	Non (20)	204.7	43.9	35.8	9.1
		Dom (20)	89.0	17.8	15.6	3.2			Dom (20)	210.1	45.6	36.6	8.8
Shoulder lateral rotation	20-29	Non (22)	97.0	19.3	16.8	3.1	Hip flexion	20-29	Non (22)	132.9	29.6	22.9	4.2
		Dom (22)	108.4	18.8	18.8	3.0			Dom (22)	139.9	27.0	24.3	4.6
	30-39	Non (23)	105.5	23.2	16.6	3.2		30-39	Non (23)	115.5	36.5	18.7	6.0
		Dom (23)	115.4	23.1	18.2	3.6			Dom (23)	119.0	38.3	19.2	6.3
	40-49	Non (21)	113.6	24.4	18.8	4.4		40-49	Non (21)	122.4	46.9	20.6	9.4
		Dom (21)	115.6	23.2	19.1	4.3			Dom (21)	124.8	43.2	20.6	5.0
	50-59	Non (21)	107.7	23.3	17.4	4.5		50-59	Non (21)	115.1	21.6	18.8	4.6
		Dom (21)	107.9	19.0	17.4	3.5			Dom (21)	116.2	30.5	18.9	5.4
	60-69	Non (18)	86.5	22.0	14.1	3.5		60-69	Non (18)	98.7	24.6	16.3	4.5
		Dom (18)	87.2	19.5	14.4	4.2			Dom (18)	103.3	26.7	17.1	4.9
	70-79	Non (19)	79.3	16.2	13.9	3.5		70-79	Non (20)	91.8	28.9	16.1	5.4
		Dom (20)	81.8	10.8	13.6	3.2			Dom (20)	92.1	27.2	16.2	5.4
Shoulder extension	20-29	Non (22)	192.2	37.9	33.2	5.2	Hip abduction	20-29	Non (22)	189.9	45.7	32.7	5.9
		Dom (22)	205.6	39.2	35.5	5.2			Dom (22)	193.5	37.6	33.7	6.7
	30-39	Non (23)	196.9	50.0	30.7	6.1		30-39	Non (23)	211.1	54.6	33.1	8.2
		Dom (23)	207.4	48.0	32.6	6.8			Dom (23)	212.3	58.9	35.5	7.6
	40-49	Non (21)	202.0	44.7	33.2	7.4		40-49	Non (21)	201.5	36.1	33.3	7.0
		Dom (21)	210.9	41.1	34.6	6.4			Dom (21)	218.4	37.6	36.0	6.6
	50-59	Non (21)	191.0	47.2	30.5	6.7		50-59	Non (21)	207.4	35.1	33.4	6.4
		Dom (21)	194.5	37.4	31.3	6.5			Dom (21)	214.8	40.0	34.7	7.8
	60-69	Non (18)	160.9	34.7	26.4	6.7		60-69	Non (18)	164.2	33.9	26.7	5.5
		Dom (18)	154.1	37.5	25.3	7.2			Dom (18)	172.3	43.8	28.2	7.7
	70-79	Non (20)	136.5	26.8	23.9	5.7		70-79	Non (20)	147.1	28.5	25.8	5.9
		Dom (20)	143.9	34.9	24.9	5.9			Dom (20)	152.7	34.4	26.7	6.7

*Knee extension force met or surpassed 650N and was recorded as 650N for one woman in her 30s. Reference values for this decade, therefore, may be depressed.

CONCLUSIONS

This study confirms that reliable measurements of muscle strength can be obtained using a hand-held dynamometer. Reference values presented in this study provide a standard against which the performance of patients 20 to 79 years of age can be compared to estimate impairments in muscle strength. Such comparisons, however, are legitimate only if the tester is strong enough to hold against the patients' efforts and if the tester uses the exact method reported herein to obtain the measurements.

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