SCIENTIFIC ARTICLE

Forearm Torque and Lifting Strength: Normative Data

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Purpose To establish reference values for new methods designed to quantitatively measure forearm torque and lifting strength and to compare these values with grip strength.

Methods A total of 499 volunteers, 262 males and 237 females, aged 15 to 85 (mean, 44) years, were tested for lifting strength and forearm torque with the Kern and Baseline dynamometers. These individuals were also tested for grip strength with a Jamar dynamometer. Standardized procedures were used and information about sex, height, weight, hand dominance, and whether their work involved high or low manual strain was collected.

Results Men had approximately 70% higher forearm torque and lifting strength compared with females. Male subjects aged 26 to 35 years and female subjects aged 36 to 45 years showed highest strength values. In patients with dominant right side, 61% to 78% had a higher or equal strength on this side in the different tests performed. In patients with dominant left side, the corresponding proportions varied between 41% and 65%. There was a high correlation between grip strength and forearm torque and lifting strength. Sex, body height, body weight, and age showed a significant correlation to the strength measurements. In a multiple regression model sex, age (entered as linear and squared) could explain 51% to 63% of the total variances of forearm torque strength and 30% to 36% of lifting strength.

Conclusions Reference values for lifting strength and forearm torque to be used in clinical practice were acquired. Grip strength has a high correlation to forearm torque and lifting strength. Sex, age, and height can be used to predict forearm torque and lifting strength. Prediction equations using these variables were generated.

Clinical relevance Normative data of forearm torque and lifting strength might improve the quality of assessment of wrist and forearm disorders as well as their treatments. *(J Hand Surg Am. 2018;■(■):1.e1-e17. Copyright © 2018 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Forearm torque, lifting strength, normative data, reference values, strength measurement, wrist dynamometer.

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INCREASED INTEREST AND understanding of the wrist and upper extremity has raised the need for more precise and reliable assessment of function. Load-bearing and optimization of torque are important features of upper extremity function and the distal radioulnar joint in particular.[1–3] Even so, lifting capability and forceful forearm rotation are rarely measured in the clinical situation and few attempts have been made to establish their normative values.[4–8]

A possible cause for this lack of quantitative assessment in relation to upper extremity pathology might be the absence of reliable tests that are quick and easy to use in the clinical setting. Therefore, we recently developed 2 methods with the intent to quantify lifting capability and force of forearm rotation.

The general term "lifting strength test" was chosen for the test of lifting capability. This test evaluates a complex function, which is the result of the action and state of multiple anatomical structures and can thus be regarded as a nonspecific functional test of the upper extremity. The "forearm torque test" is more specifically directed to the measurement of forearm rotational strength, even though not exclusively a reflection of that activity. These procedures have been described in detail previously and have shown high reliability and validity.[9,10]

The primary purpose of this study was to obtain normative data for our methods of measuring to enable comparison and interpretation of future recordings. A secondary objective was to compare normative values for lifting strength and forearm torque with grip strength.

MATERIALS AND METHODS

Subjects

The investigation included 499 volunteers, 262 males and 237 females, aged 15 to 85 (mean, 44) years (Fig. 1, Appendix A, available on the *Journal's* Web site at www.jhandsurg.org). The subjects were randomly enrolled at shopping centers, in the suburbs of Göteborg, a Swedish city with approximately 500,000 inhabitants. Other recruitment locations were hospital entrances and a primary care center. Subjects were eligible to participate if they had no health condition or previous history of injury that could affect upper extremity function. Recorded descriptive data included age, sex, hand dominance, height, and weight. We also noted if subjects considered themselves to have or have had a predominantly light or heavy type of work. The subjects were asked, "Do you consider yourself to have had a manually heavy or light type of work during the major part of your working life?"

Institutional review board approval was obtained for this study.

Methods

We evaluated grip, torque, and lifting strength with the use of Jamar, Kern, and Baseline dynamometers. The test procedures are described briefly below. Peak values of isometric muscle actions were recorded. All recordings were performed with subjects standing up, the shoulder adducted, and the elbow at 90° of flexion. No external stabilization was used. After being informed of the purpose of the measurement, a short demonstration of the examination procedure was performed. The subject was told to increase muscular power gradually up to maximum. The test was then executed and peak values were recorded. Each subject was measured with the different tests (grip, lifting, and forearm rotation), one time for each upper limb.

Test of forearm torque

Torque was measured with a dynamometer (Baseline digital wrist dynamometer, Fabrication Enterprises, White Plains, NY) equipped with a shovel handle. The dynamometer was attached to vertical, wall-mounted rails to be able to adjust it according to the subject's height (Fig. 2). Testing was performed with the handle in a vertical position. Specific instructions on torque testing included avoiding leaning the trunk or letting the elbow leave the side of the body during the test. Because the Baseline dynamometer reads in kilograms, these values were converted to Newton-meter (Nm) by the use of our previously obtained sensitivity factors, 0.053 ± 0.005 Nm/kg (clockwise) and 0.055 ± 0.004 Nm/kg (counter clockwise).

Test of lifting strength

Lifting strength was measured by a hanging scale dynamometer (KHCB 50 kg/20 g, Kern & Sohn, Balingen, Germany). Measurements were done in a standing position. The subjects fixed the Kern scale to the floor by standing on a strap attached to the bottom of the instrument. The length of the strap was adjusted to the subject's height to have the forearm parallel to the floor (Fig. 3). Measurements were done in the following order: neutral forearm rotation position, maximum supinated position, and maximum pronated position. Specific instructions related to lifting strength testing included maintenance of a

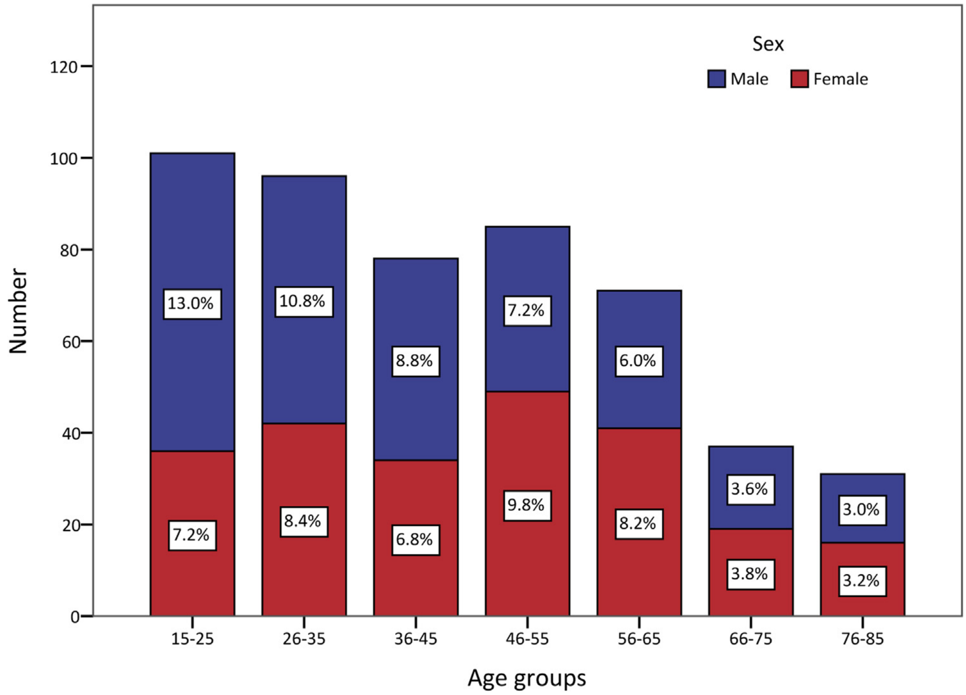

FIGURE 1: Participants' age and gender distribution.

straight wrist position and avoidance of associated elevation of the shoulder or leaning of the trunk. Recordings were read in Nm.

Test of grip strength

Grip strength was recorded using the Jamar dynamometer (Sammons Preston, Bolingbrook, IL). All tests were performed standing with the dynamometer in the second handle position. Measurements were read in kg.

Statistical analysis

On the basis of the resources available and the observed data scatter after an intermediate evaluation of 300 subjects, we decided to recruit approximately 500 females and males in different age groups. It was more difficult to obtain volunteers in the age groups above 65, which is why those results include a higher degree of uncertainty.

Preliminary analysis focused on the relation between strength measurements and age. This relation was stratified by sex and age intervals of 10 years starting from the age of 15 years. Descriptive statistics including measures of central tendency and dispersion were calculated for strength tests across subgroups. All variables were normally, or close to normally, distributed according to Q-Q plots and the Kolmogorov-Smirnov tests. Relative frequencies were calculated for categorical variables. Pearson's correlation coefficient (r) was used to examine the bivariate correlation between strength measurements and sex, age, height, weight, and type of work.

Bivariate correlations were also calculated for grip strength in relation to forearm torque and lifting strength. Several multivariable linear regression models were built using the Enter method to explore independent factors associated with the dependent variables, forearm torque, and lift and grip strength. Body height and weight had similar bivariate correlations. Because collinearity statistics revealed strong correlation in between them, weight was excluded from our models. The variable age was evaluated by curve-fitting analyses and was found to have a quadratic distribution. Thus, age, as a quadratic term (age*age), was included, in addition to linear age, to each model. Thus, in the final models sex, age (linear and squared) and height were included as independent factors. Adjusted R^2 value in % was given to describe the predictive value of each model. Equations were computed for each side. The limit of significance was set at $<.05$.

RESULTS

Descriptive data for the strength tests are summarized in Table 1. Sex, body height, body weight, and age showed statistically significant correlation to all strength measurements. Pearson correlation coefficients for the independent variables are

FIGURE 2: Forearm torque testing.

summarized in Table 2. Next to sex, height showed the strongest correlation to both lifting strength ($r = 0.49-0.53$) and forearm torque ($r = 0.64-0.70$). Weight also correlated to all strength tests ($r = 0.44-0.63$). Males were stronger in all age groups for all strength tests (Table 1). Overall and in all tests, the right hand was the strongest (Table 3). Separate comparisons of the dominant versus the nondominant side did, however, reveal that the side claimed by the subject to be the dominant was not the strongest in a predictable way. In 462 subjects with dominant right side, 61% to 78% had a higher or equal strength on this side in the 6 different tests performed. In 37 patients with dominant left side, the corresponding proportions varied between 41% and 65%. Lifting strength and torque peaked in the 26 to 35 age group for males and 36 to 45 age group for females. At higher ages, there was a gradual decline (Fig. 4, Appendix B to D, available on the *Journal's* Web site at www.jhandsurg.org). The finding was less pronounced for pronation torque and lifting with the forearm in the pronated position. Mean values for lifting strength and forearm torque, stratified for age intervals and sex,

FIGURE 3: Lifting strength testing.

are presented in Appendix E, available on the *Journal's* Web site at www.jhandsurg.org. Grip strength showed a strong correlation to all measurements of torque and lifting strength (r = 0.63−0.79, $P < .05$, Fig. 5).

Sixteen (6.1%) males and 21 (8.9%) females of a total of 499 subjects defined themselves to be left-handed. We regarded this group of left-handed subjects too small to determine reliable normative values. There was no significant correlation between hand dominance and the strength measurements ($P > .19$). Evaluation of the dominant and nondominant side also showed small differences. Because hand dominance had low predictive value when entered as an independent variable in our subsequent regression models, we omitted this parameter from further analysis (data not shown). Of the 499 subjects, 95 (19%) graded their work duties as "manually strenuous." This variable showed a significant but weak (r = 0.12−0.16) correlation to the strength measurements and did not add further predictive information in the subsequent regression models and was therefore also omitted.

TABLE 1. Mean Values, Standard Deviation, 95% Confidence Limits, Related to Type of Test, Side, and Sex; Ratios Between Males and Females

	Grip Right (kg)	Grip Left (kg)	Torque S* Right (Nm)	Torque S* Left (Nm)	Torque P† Right (Nm)	Torque P† Left (Nm)
Male	53 ± 11	51 ± 11	9.1 ± 2.3	8.9 ± 2.3	7.9 ± 2.2	7.6 ± 2.2
	52–55	*50–52*	*8.9–9.4*	*8.6–9.2*	*7.7–8.2*	*7.2–7.8*
Female	34 ± 8	31 ± 7	5.4 ± 1.3	5.2 ± 1.4	4.5 ± 1.2	4.3 ± 1.2
	32–34	*30–32*	*5.2–5.6*	*5.0–5.3*	*4.1–4.4*	*4.1–4.4*
Ratio	1.56	1.64	1.68	1.71	1.76	1.77

	Lift N‡ Right (N)	Lift N‡ Left (N)	Lift S* Right (N)	Lift S* Left (N)	Lift P† Right (N)	Lift P† Left (N)
Male	238 ± 89	229 ± 87	239 ± 89	230 ± 87	157 ± 62	153 ± 57
	227–249	219–240	228–250	219–240	150–165	146–160
Female	142 ± 57	136 ± 57	137 ± 58	132 ± 55	96 ± 41	94 ± 40
	135–150	129–144	130–145	125–139	91–102	89–99
Ratio	1.68	1.68	1.81	1.74	1.64	1.63

*Supination position or direction.
†Pronation position or direction.
‡Neutral position.

TABLE 2. Pearson Correlation Coefficients for Sex, Age, Height, and Weight

Muscle Force	Sex	Age	Height	Weight
Grip R	−0.72	−0.31	0.73	0.60
Grip L	−0.74	−0.29	0.73	0.63
Lift N R	−0.54	−0.14	0.50	0.46
Lift N L	−0.53	−0.12	0.51	0.47
Lift S R	−0.56	−0.18	0.53	0.46
Lift S L	−0.55	−0.17	0.52	0.48
Lift P R	−0.50	−0.14	0.49	0.44
Lift P L	−0.51	−0.14	0.49	0.45
Torque S R	−0.72	−0.30	0.70	0.59
Torque S L	−0.70	−0.26	0.67	0.59
Torque P R	−0.70	−0.12	0.65	0.63
Torque P L	−0.68	−0.14	0.64	0.61

Correlation is significant at the $P < .05$ level for each variable.
L, left; N, neutral; P, pronation; R, right; S, supination.

Predicting forearm torque and lifting strength

Twelve multiple regression models, one for each side and test, were created, examples seen in Appendix F, available on the *Journal's* Web site at www.jhandsurg.org. With sex, age, age squared, and height as independent variables, we were able to build regression equations that could explain approximately 67% to 68% of the variance for grip strength, 51% to 63% of the variance for forearm torque, and 31% to 36% of the variance for lifting strength. R^2 values and prediction equations are shown in Appendix G, available on the *Journal's* Web site at www.jhandsurg.org. An example of the prediction intervals generated with the equation is shown in Figure 6.

DISCUSSION

Normative values for grip and pinch strength are established,[11,12] but few studies have evaluated other

TABLE 3. Comparison Between the Right- and Left-hand Side

Muscle Force	Right	Left	D*	CI	r	Ratio
Grip (kg)	43.8	41.5	2.3	1.85−2.69	0.94	1.06
Lift neutral (N)	193	186	7	5.18−9.17	0.97	1.04
Lift supinated (N)	191	183	8	5.87−9.64	0.97	1.04
Lift pronated (N)	129	125	4	1.69−5.47	0.94	1.03
Torque supination (Nm)	7.4	7.1	0.2	0.12−0.35	0.88	1.03
Torque pronation (Nm)	6.3	6.0	0.3	0.05−0.41	0.89	1.05

CI, 95% confidence interval of the difference; *D*, difference; *r*, Pearson correlation coefficients.
**P* < .05 for each value.

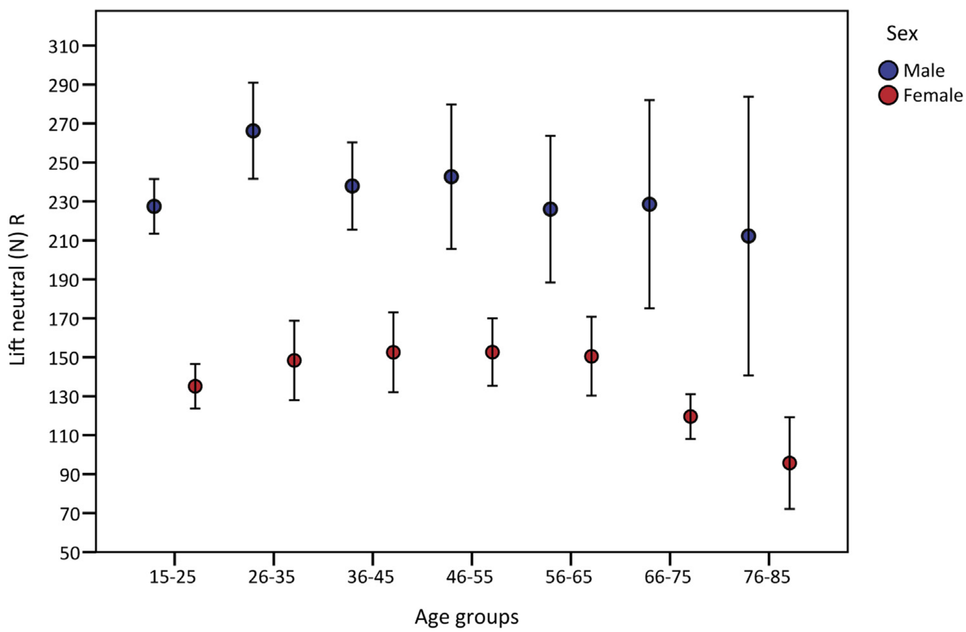

FIGURE 4: Mean lifting strength, neutral forearm position with 95% confidence intervals for males and females stratified by age groups (right-hand side).

quantitative methods to assess upper extremity disorders or their treatments. We recently developed 2 new methods that could consistently measure lifting strength and forearm torque.[10] To enable use of these methods in clinical situations, knowledge about normative values is necessary.

Our grip strength values showed ranges similar to previously published normative values.[12] As in earlier studies, we found female grip strength to be approximately 60% of that observed in males.[13] The difference seemed even higher for forearm torque and lifting strength. However, it should be noted that the individual variation was large. As in several previous reports on grip strength, we found that forearm torque and lifting strength peak in young adulthood and then gradually decline with age.[14] We noted that for pronation torque and, to a lesser degree, lifting with pronated forearm, this pattern was less pronounced, especially in males. There was also a trend suggesting that female strength peaks at a higher age than for males. Earlier studies have documented a correlation between grip strength and physiological factors.[15] We could confirm a similar association also for forearm torque and lifting strength, where body height had a slightly higher correlation than body weight. It has been suggested that height more closely relates to muscle volume and also correlates to longer lever arms, which enables generation of more power.[16]

In our regression models, the proportion of the variance that could be explained by the independent variables chosen was comparatively high (r^2 value = 0.30−0.68). The remaining unexplained variability

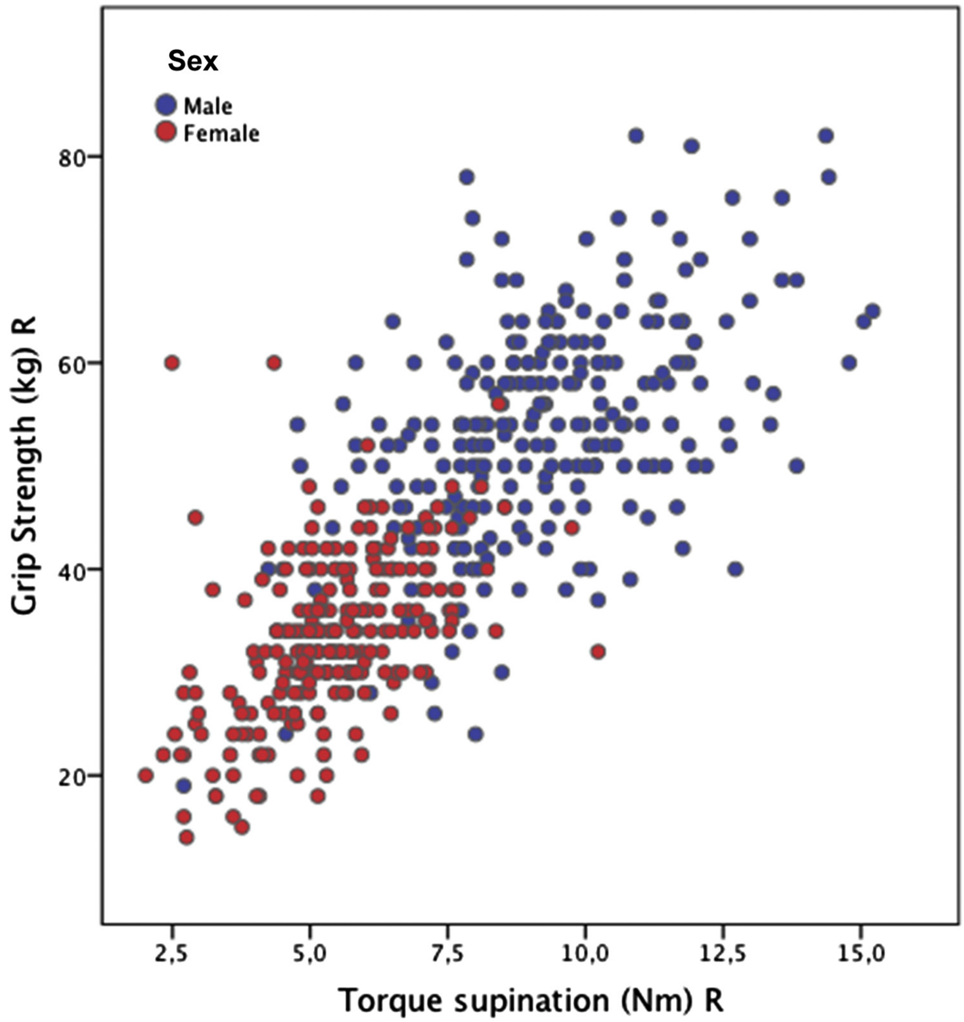

FIGURE 5: Scatter plot of correlation between Grip strength and supination torque (right-hand side).

could probably be related to variations in body anatomy, life time history of physical activity, and other unknown factors.

Crosby et al[17] found that the dominant side in right-handed individuals on average had 10% stronger grip force, whereas a corresponding asymmetry was not observed in left-handed subjects. We also found very small side-related differences of forearm torque and lifting strength in left-handed subjects, but these subjects were too few to allow for further analysis. Because the differences in strength recordings between the hands were small and hand dominance had no significant influence when entered in our prediction models, we decided to include the left-handed individuals in a compiled study group.

There are a few studies of forearm torque with the use of the Baseline dynamometer in the literature. Rey et al[18] measured 99 subjects and found a supination torque of 8.9 Nm and pronation torque of 5.3 Nm for males and females combined. Wong and Moskovitz[7] compared the reliability of the Baseline dynamometer with a Cybex work simulator for 18 individuals. Our interpretation of their Baseline recordings converted to Nm produces an average maximum supination torque of 3.3 Nm and a pronation torque of 3.5 Nm. Our corresponding values were 7.2 Nm and 6.1 Nm. Explanations for the discrepancy might be differences in body position or elbow angle and that Wong and Moskovitz used a door-knob handle instead of the shovel handle. Askew et al[4] found torque in a supinated direction to be 6.3 Nm and in a pronating direction to be 5.2 Nm, whereas Herzberg et al[6] found lower values, with a supinating force of 3.8 Nm and a pronating force of 3.5 Nm. Kramer et al[19] compared a Baltimore Therapeutic Equipment work simulator with a Cybex dynamometer and found higher values in relation to ours, with an average supination torque of 8 Nm and an average pronation torque of approximately 9 Nm. Matsuoka et al[5] reported levels of torques to be about the same as ours but with a lower resisted

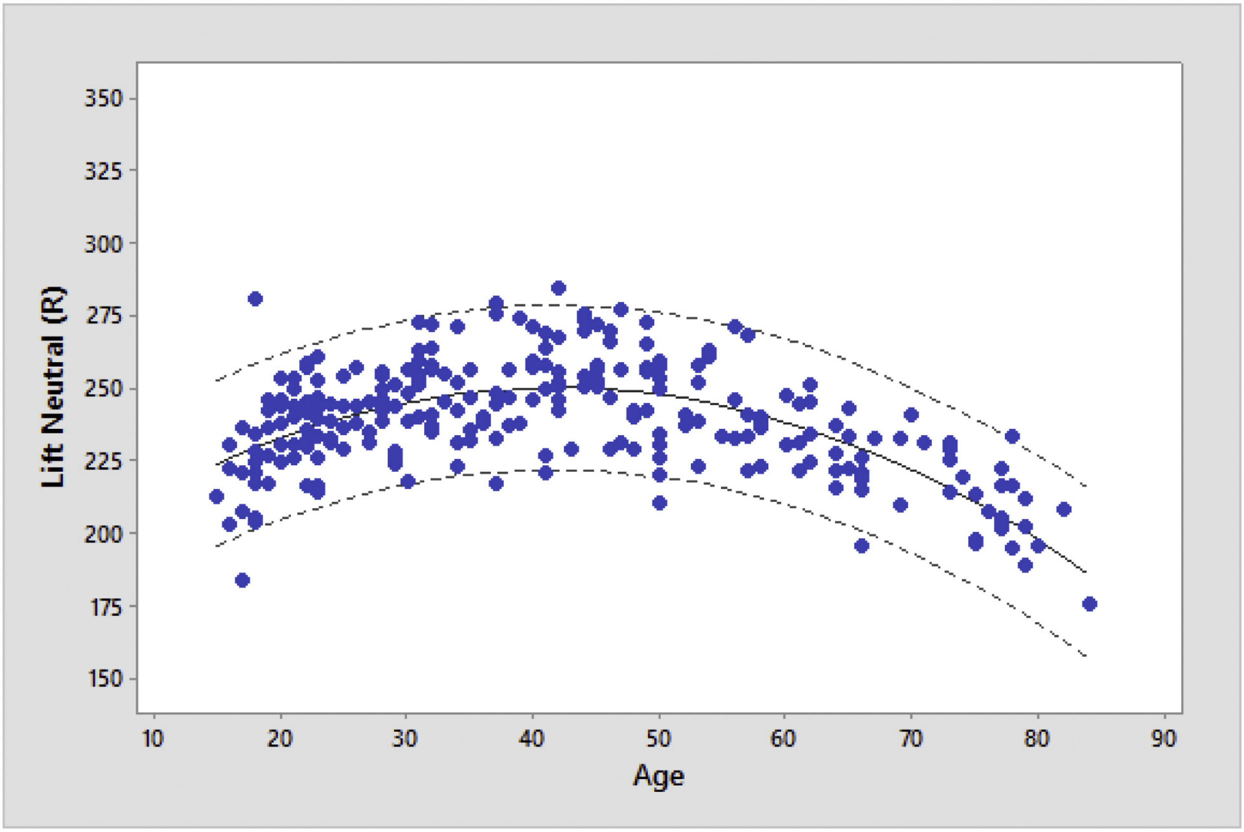

FIGURE 6: Lifting strength, neutral forearm position, with 95% prediction intervals for males (right-hand side).

supination torque, 5.5 Nm, and a higher resisted pronation torque, 7.4 Nm. Their use of 45° elbow flexion compared with our 90° position might be an important reason for the inverse relation in strength between torque directions, since the 45° position weakens supination strength. Other reasons for differences in reported measurements might be the use of different custom-made dynamometers and that our testing was performed standing. When we tested normal subjects, both sitting and standing, we found little difference between recordings (data not shown). Finally, it should be noted that the population used as controls in different studies come from different parts of the world. Factors such as sex ratio and body height have, according to our observations, a profound influence on the results.

To our knowledge, no tests of lifting strength similar to ours have previously been presented. However, Garcia-Elias et al[8] used a hand-held device to assess the ability to sustain loads at the wrist while standing. Their study produced much lower values for lifting capability, approximately 50 N, but their testing method was different from ours, which makes comparisons less relevant. There are other reports of elbow flexion strength and elbow flexion torque where some have presented values similar to ours[20–23] and others have not,[4] but the techniques used in these studies are not truly comparable.

We included 499 subjects, which we think is an adequate number to define normal values for our methods of measuring. However, in the age groups over 65 years, the numbers were too small to confidently determine if these results reflect the general population. Our subjects were not selected randomly, but were volunteers. This might have caused a selection of subjects who felt confident with their physical performance, whereas subjects who thought that they would perform poorly might have been more reluctant to participate. Overrepresentation of young males in our study may support this hypothesis. Such factors are difficult, if not impossible, to control in a study based on voluntary participation. Multiple raters were involved, which can be expected to increase the variation. However, this mirrors the situation often present in clinical practice.

This study represented an effort to develop a standardized method to quantify forearm torque and lifting strength for clinical use. The number of subjects made it possible to create prediction equations that we hope can be valuable to objectively evaluate future clinical recordings. To facilitate the use of these equations, an app, "GTB forearm tests," was created. This app can be downloaded free of charge from the App store.

Our methods have a potential to detect wrist or forearm disorders and may be suitable to evaluate treatments. We think that forearm torque and lifting strength reflect aspects of wrist and upper extremity function different from grip strength. Further investigations are needed to establish if the measurement of forearm torque and lifting strength will provide additional information to grip strength testing alone for certain pathologies.

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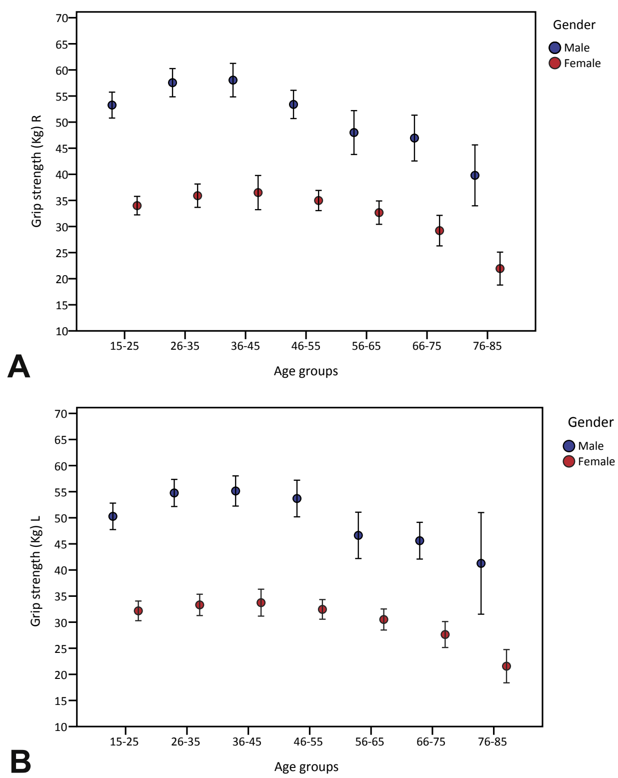
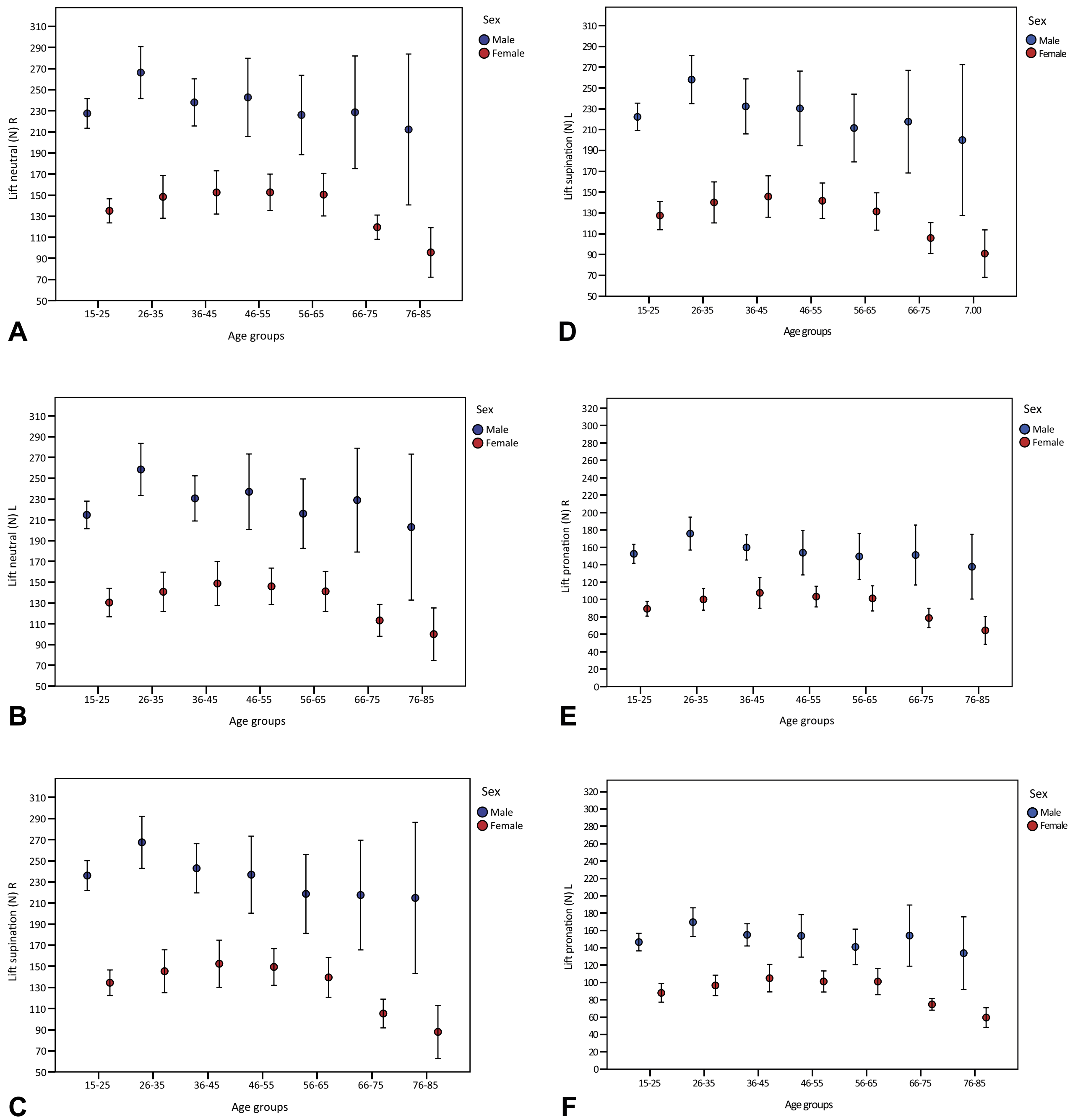
APPENDIX A. **Basic Demographics of the Study Population; Mean Values, Standard Deviation, 95% Confidence Limits, and Range Are Presented**

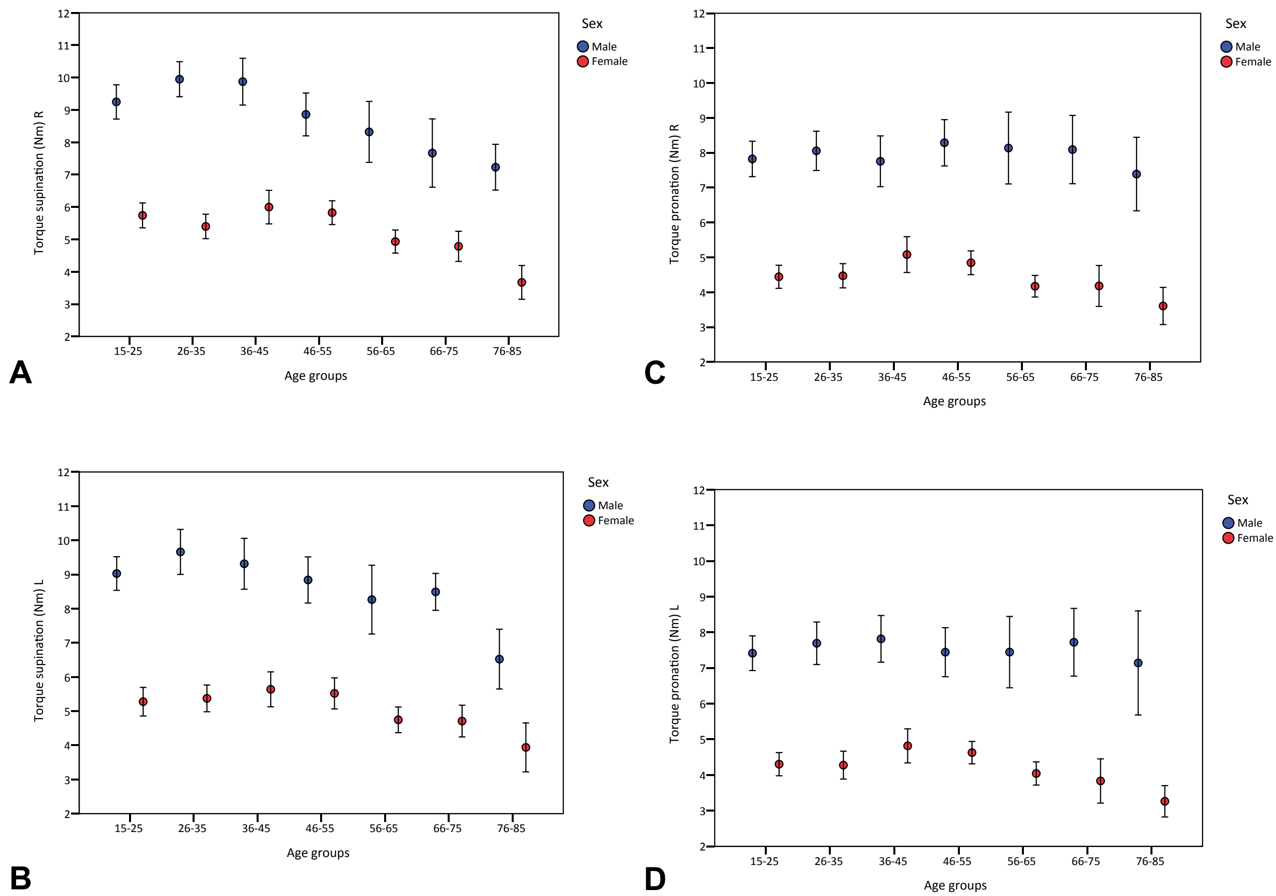
	Age (y)	Height (cm)	Weight (kg)	Dominant Hand, No.	Work Type, No.
Male 262	41 ± 18	180 ± 8	84 ± 14	Right 246	Heavy 64
	39−44 (15−84)	*179−181* (160−209)	*82−85* (52−125)	Left 16	Light 173
Female 237	47 ± 18	166 ± 6	66 ± 11	Right 216	Heavy 31
	44−48 (15−85)	*165−167* (149−181)	*64−67* (38−116)	Left 21	Light 189



APPENDIX B: Mean grip strength with 95% confidence intervals for males and females stratified by age groups. **A** Right-hand and **B** left-hand.



APPENDIX C: Mean lifting strength with 95% confidence intervals for males and females stratified by age groups. **A**, **B** Neutral forearm position, right- and left-hand side. **C** and **D** Supinated forearm position, right- and left-hand side. **E**, **F** Pronated forearm position, right- and left-hand side.



APPENDIX D: Mean forearm torque with 95% confidence intervals for males and females stratified by age groups. **A**, **B** Supination, right- and left-hand side. **C**, **D** Pronation, right- and left-hand side.

APPENDIX E. Grip Strength (kg), Stratified by Sex, Age Group, and Hand

Age (y)	Side	Male			Female		
		Mean	SD	Range	Mean	SD	Range
15–25	R	53	10.0	34–82	34	5.2	24–45
	L	50	10.2	31–84	32	5.6	22–44
26–35	R	58	9.9	35–82	36	7.2	18–52
	L	55	9.5	38–86	33	6.6	16–46
36–45	R	58	10.6	30–81	37	9.4	20–60
	L	55	9.5	32–80	34	7.4	18–48
46–55	R	53	8.0	38–68	35	6.7	18–48
	L	54	10.4	38–99	32	6.6	14–44
56–65	R	48	11.2	19–66	33	7.1	18–60
	L	47	11.9	16–68	31	6.4	18–46
66–75	R	47	8.8	29–64	29	6.1	20–45
	L	46	7.1	31–58	28	5.2	18–42
76–85	R	40	10.5	24–62	22	5.9	14–34
	L	41	17.6	26–95	22	6.0	14–40

Lifting Strength (N), Neutral Forearm Position Stratified by Sex, Age Group, and Hand

		Male			Female		
Age (y)	Side	Mean	SD	Range	Mean	SD	Range
15–25	R	227	57	99–502	135	34	100–248
	L	215	54	91–450	130	41	87–267
26–35	R	266	90	135–560	148	65	35–359
	L	258	92	141–592	141	60	38–363
36–45	R	238	74	102–566	153	59	87–358
	L	231	72	90–528	149	61	86–329
46–55	R	243	110	120–598	153	60	72–330
	L	237	108	102–582	146	61	70–323
56–65	R	226	101	65–482	150	64	83–300
	L	216	89	71–505	141	61	77–306
66–75	R	229	107	98–530	120	24	78–171
	L	229	100	141–500	113	32	73–207
76–85	R	212	129	116–513	96	44	36–195
	L	203	127	108–539	100	47	50–213

Lifting Strength (N), Supinated Forearm Position Stratified by Sex, Age Group, and Hand

		Male			Female		
Age	Side	Mean	SD	Range	Mean	SD	Range
15–25	R	236	57	111–461	134	36	80–255
	L	222	53	121–424	127	40	71–273
26–35	R	267	90	145–590	145	65	44–392
	L	258	85	117–541	140	63	53–402
36–45	R	243	77	105–578	152	64	81–374
	L	232	87	101–600	146	57	72–342
46–55	R	237	108	116–580	149	61	78–323
	L	230	106	107–592	142	59	54–330
56–65	R	219	100	78–521	140	60	67–282
	L	212	87	72–519	131	57	69–279
66–75	R	218	104	77–516	105	28	62–164
	L	218	99	113–407	106	31	51–176
76–85	R	215	129	111–556	88	47	21–209
	L	200	131	102–545	91	43	46–209

Lifting Strength (N), Pronated Forearm Position Stratified by Sex, Age Group, and Hand

Age	Side	Male Mean	Male SD	Male Range	Female Mean	Female SD	Female Range
15–25	R	153	44	66–378	89	25	55–189
	L	147	41	72–356	88	32	42–199
26–35	R	176	69	91–469	100	40	27–263
	L	170	61	89–406	97	38	41–245
36–45	R	160	48	77–331	108	51	47–265
	L	155	42	77–302	105	45	50–233
46–55	R	154	76	65–402	103	41	49–235
	L	154	73	59–392	101	42	49–222
56–65	R	149	71	66–376	101	46	60–215
	L	141	55	60–279	101	48	41–255
66–75	R	151	69	54–280	79	23	49–160
	L	154	71	94–331	75	14	46–91
76–85	R	138	67	68–280	65	30	29–145
	L	134	76	61–308	60	21	36–103

Forearm Torque (Nm), Supinating Direction Stratified by Sex, Age Group, and Hand

Age	Side	Male Mean	Male SD	Male Range	Female Mean	Female SD	Female Range
15–25	R	9.2	2.1	1.0–15.1	5.7	1.1	2.9–7.9
	L	9.0	2.0	3.6–12.3	5.3	1.2	0.8–7.3
26–35	R	9.9	2.0	5.6–14.4	5.4	1.2	2.8–7.6
	L	9.7	2.4	0.9–15.7	5.4	1.3	2.4–8.4
36–45	R	9.9	2.4	4.8–15.2	6.0	1.5	2.7–9.8
	L	9.3	2.4	4.3–14.8	5.6	1.5	2.2–9.2
46–55	R	8.9	2.0	4.2–11.8	5.8	1.3	3.3–10.2
	L	8.8	2.0	3.5–12.3	5.5	1.6	0.7–9.2
56–65	R	8.3	2.5	2.7–14.8	4.9	1.1	2.5–7.1
	L	8.3	2.7	3.8–15.3	4.7	1.2	2.4–7.7
66–75	R	7.7	2.1	0.8–10.3	4.8	1.0	2.3–6.0
	L	7.5	1.1	7.0–11.6	4.7	1.0	2.8–6.3
76–85	R	7.2	1.3	4.4–9.5	3.7	1.0	2.0–5.4
	L	6.5	1.6	3.3–9.4	3.9	1.3	2.5–8.0

Forearm Torque (Nm), Pronating Direction Stratified by Sex, Age Group, and Hand

		Male			Female		
Age	Side	Mean	SD	Range	Mean	SD	Range
15–25	R	7.8	2.0	2.9–15.7	4.4	1.0	2.5–6.8
	L	7.4	2.0	3.6–13.1	4.3	1.0	2.3–6.6
26–35	R	8.1	2.1	4.6–14.2	4.5	1.1	2.3–6.7
	L	7.7	2.2	4.9–15.6	4.3	1.3	0.4–6.5
36–45	R	7.8	2.4	0.6–14.2	5.1	1.5	2.1–9.2
	L	7.8	2.2	4.2–15.2	4.8	1.4	2.4–8.2
46–55	R	8.3	2.0	3.3–12.4	4.8	1.2	2.5–7.6
	L	7.4	2.0	0.9–11.5	4.6	1.1	2.5–7.3
56–65	R	8.1	2.8	4.2–15.7	4.2	1.0	1.7–6.5
	L	7.4	2.7	3.2–15.1	4.0	1.0	1.7–6.5
66–75	R	8.1	2.0	4.8–12.0	4.2	1.2	2.3–6.9
	L	7.7	1.9	5.1–11.5	3.8	1.3	0.4–6.0
76–85	R	7.4	1.9	5.3–12.7	3.6	1.0	2.2–5.9
	L	7.1	2.6	3.3–12.9	3.3	0.8	1.6–4.8

APPENDIX F. Regression Model: Lifting Strength, Neutral Forearm Position (Right-Hand Side)

Coefficients*

		Unstandardized Coefficients		95% Confidence Interval for *B*	
Model		*B*	Sig.	Lower Bound	Upper Bound
1	(Constant)	−170.10	.060	−347.71	7.51
	Sex	−68.45	.000	−87.02	−49.88
	Age	3.22	.001	1.34	5.00
	Age (squared)	−0.04	.000	−0.06	−0.02
	Height	1.93	.000	0.99	2.88

Adjusted $R^2 = 0.33$.
*Dependent variable: lift neutral.

Regression Model: Forearm Torque, Supinating Direction (Right-Hand Side)

Coefficients*

		Unstandardized Coefficients		95% Confidence Interval for *B*	
Model		*B*	Sig.	Lower Bound	Upper Bound
1	(Constant)	−6.81	0.001	−10.66	−2.96
	Sex	−2.53	0.000	−2.94	−2.13
	Age	0.08	0.000	0.04	0.12
	Age (squared)	−0.001	0.000	−0.002	−0.001
	Height	0.08	0.000	0.06	0.10

Adjusted $R^2 = 0.63$.
*Dependent variable: torque supination.

APPENDIX G. Regressions Equations for Calculation of Reference Values

Muscle Force	Regression Equations	R^2
Grip R (kg)	$-51.16 - 11.94 \times S + 0.71 \times A - 0.009 \times A^2 + 0.52 \times H$	0.67
Grip L (kg)	$-43.88 - 12.57 \times S + 0.66 \times A - 0.008 \times A^2 + 0.46 \times H$	0.68
Lift n R (N)	$-170.10 - 68.45 \times S + 3.22 \times A - 0.036 \times A^2 + 1.93 \times H$	0.33
Lift n L (N)	$-222.13 - 63.18 \times S + 3.34 \times A - 0.036 \times A^2 + 2.15 \times H$	0.33
Lift s R (N)	$-204.15 - 69.47 \times S + 2.87 \times A - 0.035 \times A^2 + 2.19 \times H$	0.36
Lift s L (N)	$-198.40 - 67.42 \times S + 2.88 \times A - 0.034 \times A^2 + 2.09 \times H$	0.36
Lift p R (N)	$-158.91 - 39.40 \times S + 2.30 \times A - 0.026 \times A^2 + 1.52 \times H$	0.30
Lift p L (N)	$-130.16 - 39.85 \times S + 2.27 \times A - 0.025 \times A^2 + 1.34 \times H$	0.31
Torque s R (Nm)	$-6.81 - 2.53 \times S + 0.08 \times A - 0.0011 \times A^2 + 0.083 \times H$	0.63
Torque s L (Nm)	$-7.19 - 2.50 \times S + 0.08 \times A - 0.0010 \times A^2 + 0.083 \times H$	0.58
Torque p R (Nm)	$-7.06 - 2.39 \times S + 0.065 \times A - 0.0006 \times A^2 + 0.076 \times H$	0.54
Torque p L (Nm)	$-6.73 - 2.23 \times S + 0.058 \times A - 0.0006 \times A^2 + 0.073 \times H$	0.51

A, age (y); A^2, age squared; H, height (cm); L, left; n, neutral position; p, pronated position or direction; R, right; s, supinated position or direction; S, sex (1 for female, 0 for male).