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Hand-held myometry: reference values

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Abstract

In thirteen major muscle groups of 50 healthy females and 50 males, aged 20–60 years, maximum voluntary contraction was measured with a hand-held dynamometer. The intrasession variation, the left-right variation, and the fifth and fiftieth centile values were calculated. The ratio of two observations within one session ranged from 0·85 to 1·18 and the ratio of left to right ranged from 0·82 to 1·22 (95% reference limits). In 20 volunteers the repeatability was tested after one week. The ratio of averages of three measurements in two successive weeks ranged from 0·82 to 1·23 (95% reference limits). There were only small differences between muscle groups concerning these ratios. A significant relation with age and weight/Quetelet Index could be demonstrated in some muscle groups. The mean strength of females is approximately two thirds of the strength of males. The data may be useful as reference values in the application of hand-held myometry.

Hand-held myometry is gaining popularity as a means of expressing strength in a quantitative manner.[1] It has obvious advantages over clinical scales[1] and has advantages compared with most other dynamometers: it is portable, useful in nearly every clinical setting in a method rather similar to manual strength testing and is available at low cost.

Although there are reports about repeatability[2–4] and interobserver agreement[2 3] reference values for adults on normal strength and normal left-right differences are still lacking.[5] This paper reports the reference values of 50 normal female and 50 normal male volunteers.

In addition the influence of age, weight and height on strength was analysed and the repeatability was tested.

Methods

Maximum voluntary contraction (MVC) was measured with a hand-held dynamometer in 13 muscle groups (table 1), 10 on both sides, in 100 healthy volunteers, 50 females and 50 males, in age varying from 20–60 years (see table 2 for subject information). None was engaged in active sports for more than two hours per week. They were aware of the purpose of the test and were not paid for their cooperation. Each person was tested once and in this session every muscle group was measured three times,

Table 1 Standard positions for muscle groups tested

Muscle group	*Subject position*	*Dynamometer position*
Neck extensors	Sitting upright; head up at 90° from horizontal	Back of the head, just above ear shelf level
Neck flexors	As for neck extensors	Centre of forehead, just above eyebrows
Shoulder abductors	Sitting upright; shoulder 90° abducted, elbow 135° flexed, forearm pronated	Lateral epicondyle of humerus
Elbow flexors	Supine; shoulder adducted, elbow 90° flexed, forearm supinated	just proximal to wrist crease (flexor surface)
Elbow extensors	As for elbow flexors	Just proximal to wrist crease (extensor surface)
Wrist extensors	Sitting; forearm supported and pronated, wrist in neutral position, fingers flexed	Just proximal to 3rd metacarpal head
Three point grip	Sitting; forearm pronated, wrist extended	Distal phalanx of thumb under applicator, distal two phalanges of dig 2 and 3 above collar
Hip flexors	Supine; hip and knee 90° flexed, ankle supported by examiner	Anterior surface of distal thigh
Hip abductors	Supine; hip 45° flexed, knee 90° flexed, contralateral knee supported by chest of examiner	Lateral epicondyle of knee
Knee extensors	Prone; knee 90° flexed	Anterior surface of distal shant just proximal to ankle joint
Knee flexors	Prone; knee 45° flexed	Heel
Foot dorsiflexors	Supine; foot 90° dorsiflexed	Just proximal to metatarsophalangeal joints (dorsal surface)
Foot plantarflexors	As for foot dorsiflexors	Just proximal to metatarsophalangeal joints (plantar surface)

Table 2 Age height weight and Quetelet Index of the subjects

Variable	*Women* *Mean*	*(SD)*	*Range*	*Men* *Mean*	*(SD)*	*Range*
Age (years)	33·8	(10·0)	20–60	34·4	(9·9)	23–60
Height (cm)	168·8	(7·1)	145–183	182·3	(6·2)	170–196
Weight (kg)	62·8	(8·3)	41–80	78·2	(8·4)	60–98
QI	220	(25)	177–286	235	(22)	182–296

QI = 10 × weight in kg/(length in m)^2

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with an interval of about ten seconds. The dynamometer and the measuring technique have been described elsewhere.[6] The range of our dynamometer was 0–250 newton (N) in this investigation. The standard positions for every muscle group are shown in table 1. The hip abductors were tested on one side only, because MVC is not possible without contraction of the contralateral muscle in the position we used. Additionally the same procedure was repeated in 20 volunteers (nine female, 11 male) after one week to test repeatability.

All measurements were carried out by the first author, who had more than five years experience with hand-held myometry.

Statistical analysis

Multiple regression analysis was used to evaluate effects of weight, height and the Quetelet Index (QI, weight/length^2) on the MVC for each muscle group. For this purpose the MVC value for each individual was determined as the mean of the available measurements (mostly three replications on the left and three on the right side); regression coefficients were considered significant for two-sided p-values below 5%.

Separate analyses were performed for different muscle groups. For some muscle groups it was sometimes impossible to obtain exact measurements and only a lower limit of the MVC could be noted. To analyse data involving these so called right censored observations a special form of multiple regression analysis had to be employed (the module SURVIVAL of the statistical package SYSTAT was used for computations).[7] The results of regression analysis were used for construction of reference limits. A significant regression coefficient, for example, that of weight, suggests that a correction for weight may be required.

For estimation of within-person variance components (within session, left-right, week to week) methods of analysis of variance were applied to logarithmically transformed data. The transformation was needed to stabilise the variance. From the estimated variance components we calculated approximately 95% reference limits, on the log scale, for difference between: a) two observations on the same side within one session, b) means of three observations on each side within the same session, c) means of three observations on the same side in two different sessions. Transformed back to the original scale these limits become the 95% reference limits for a ratio of two observations. The latter limits are presented in this paper. A similar description of between-subject variability, by a reference interval for a ratio of means of observations within one session of two different subjects, is complicated by the fact that the between-subject variability was better described by the normal rather than by the log-normal distribution. The required limits depend on the coefficient of variance (CV) and thus on both the variance and the mean. We do not present these limits but note that for a CV of 20% (a typical value of these data) the 95% reference values are (0·53, 1·9).

Results

Not all data could be obtained. In the neck flexors only 43 women and 49 men were available, instead of 50, because of pain. In the knee flexors only 36 women and 39 men could be measured, because of cramp.

Right censored observations were obtained in the stronger muscles. In the neck extensors, knee extensors and foot plantarflexors all or nearly all observations were right censored.

Tables 3 and 4 summarise the basic results of regression analysis concerning the best fit models. The analysis was performed separately for men and women as the—on average higher values of men showed a larger variability when compared with women. An inspection of residuals suggested that the underlying distribution (for all muscle groups) could be well approximated by the normal distribution. If the best fit model does include some covariables then the percentiles are for "average persons", that is, individuals with these covariables equal to group means, and an adjustment for other

Table 3 and 4 Results of regression analysis, expressed in newtons—women and men

*Muscle group**	*Minimum*	*Maximum*	*Constant*	*Age*	*Height*	*Weight*	*QI*	*Residual SD*
			Women					
Neck flexors	47	112	75	—	—	—	—	16
Shoulder abductors	72	142	105	—	—	—	—	18
Elbow flexors	127	>250	103	—	—	—	0·38	28
Elbow extensors	68	141	43	—	—	—	0·26	15
Wrist extensors	77	160	111	—	—	—	—	18
Three point grip	58	117	86	—	—	—	—	13
Hip flexors	113	>238	167	—	—	—	—	26
Hip abductors	155	>250	238	—	—	—	—	39
Knee flexors	81	188	122	—	—	—	—	27
Foot dorsiflexors	134	>250	62	−1·8	—	—	1·1	43
			Men					
Neck flexors	87	>125	131	—	—	—	—	15
Shoulder abductors	97	232	57	−1·3	—	—	0·63	30
Elbow flexors	193	>250	—	—	—	—	—	—
Elbow extensors	88	225	76	—	—	1·0	—	25
Wrist extensors	118	214	96	—	—	0·95	—	22
Three point grip	88	192	31	—	—	1·2	—	19
Hip flexors	156	>250	82	−2·7	—	—	1·1	40
Hip abductors	215	>250	—	—	—	—	—	—
Knee flexors	119	233	123	−1·3	—	1·1	—	27
Foot dorsiflexors	199	>250	267	—	—	—	—	21

*Neck extensors, knee extensors and foot plantarflexors are absent because all or nearly all subjects exceeded the limit (see results).

Table 5 The fifth and fiftieth centile values (P5 and P50) of 50 normal females and males (average of three measurements, left and right combined, expressed in newtons)

Muscle group	Women P5	Women P50	Men P5	Men P50
Neck extensors	118	>125	>125	>125
Neck flexors	49	75	107	>125
Shoulder abductors	75	105	111	160
Elbow flexors	146	190	216	>250
Elbow extensors	80	105	115	156
Wrist extensors	81	111	126	170
Three point grip	65	86	94	125
Hip flexors	124	167	190	>250
Hip abductors	174	238	223	>250
Knee extensors*	>160	>160	>160	>160
Knee flexors	78	122	118	162
Foot dorsiflexors	164	235	232	>250
Foot plantarflexors†	>250	>250	>250	>250

*All subjects stronger than maximum value possible to be measured in test position.
†All these subjects were stronger than maximum of dynamometer scale.

individuals is needed. For example, consider the muscle group elbow flexors for women (see table 3): the listed percentiles apply for women with QI = 220 (see table 2). For a woman with QI = 200 the adjustment equals to (200–220) × 0·38 = −7·6 and thus the fifth centile value = 146–8 = 138 N. In clinical practice these adjustments are of minor importance. The standard error of the fifth centiles is about one fifth of the residual standard deviation.[8]

The fifth and fiftieth centile values of strength in 50 female and 50 male volunteers, based on the average of the three measurements of both sides (except neck flexors and extensors, and hip abductors), are shown in table 5. The fifth centile value of women ranges from 46 to 77%, mean 67%, of the male value and the fiftieth centile value from 65 to 75%, mean 68%.

Many muscles especially in healthy males exceed 250 N, which complicates a statistical analysis. Moreover, it appeared that measuring the knee extensors could not be done carefully beyond 160 N, because the applicator tended to move aside, and when this value had been reached, we stopped measuring. Contraction of the neck extensors and flexors produced pain in many of the subjects beyond values of 125 N and therefore it was decided to stop after reaching this value. Knee flexor contraction produced muscle cramp in 25% of the persons.

The 95% reference interval for the ratio of two observations within one session is on average 0·85–1·18, range 0·83–1·20 (knee flexors) to 0·87–1·15 (elbow extensors). For the left-right ratio the interval is on average 0·82–1·22, range 0·78–1·28 (elbow flexors) to 0·88–1·14 (foot dorsiflexors). For the week to week ratio the interval is on average 0·82–1·23, range 0·74–1·36 (shoulder abductors) to 0·86–1·17 (elbow flexors).

Discussion

In the analysis of muscle function the most fundamental approach is the measurement of force.[9] In routine practice grading of strength according to the MRC-scale will suffice, but for a more quantitative approach a dynamometer is essential.[6] Hand-held myometry has proved to be simple, acceptable and reproducible. Reference values strongly depend on the standard position and measuring technique. Our technique[6] is similar to the technique described by Wiles *et al*[2] and consists of a "careful break test", which is virtually isometric. Our test positions are partly different. As far as we know the only reference values have been published by Hosking *et al*[4] for 215 children, aged five to 15 years. Their fifth centile values are therefore difficult to compare with our results, although the values in 15 year old children are in the same order (except a much lower value of the foot dorsiflexors). As expected the fifth centile values for men differ only slightly from the values we described previously in 100 18 year old men.[6]

All male neck extensors exceeded 125 N, all knee extensors exceeded 160 N and all foot plantarflexors exceeded 250 N. This complicates statistical analysis but these values are still useful in clinical practice. For instance, any woman and especially a man with knee extensor strength below 160 N and body weight >40 kg, can be regarded as having subnormal strength, consistent with the normal values of Edwards *et al.*[10] The foot plantarflexors generate ±2–4 times as much strength as the foot dorsiflexors[11–13] and in relation to the fifth centile value of the foot dorsiflexors a foot plantar value <250 N is certainly subnormal. According to Vandervoort[13] *et al* the plantar flexors of adult males are on average (SD) 171 (34) newton meter, which is in the order of 800–1000 N on the hand-held dynamometer.

Many normal male volunteers exceeded the dynamometer scale of 250 N with several muscle groups. Expanding the scale beyond 250 N to 300 or 350 N is possible but for the average examiner these forces are too high for a careful measurement.[2] Moreover, when values higher than 250 N are measured in the elbow flexor, hip flexor, hip abductor or foot dorsiflexor the patient will not have many complaints or functional restrictions!

The mean ratio of females to males is about two thirds as well for the fifth as the fiftieth centile values, and this figure compares well with the findings of other authors.[11 13–15]

The results of multiple regression analysis with variables age, height, weight and QI showed no significant influence of age in most muscle groups of our volunteers, aged 20–60 years, which is consistent with earlier reports that show that there is little or no decline in strength before 60 years of age.[11 15] Although we found a significant influence of weight in four male muscles (see table 4), this influence was relatively small in absolute terms and in normal ranges weight is an ineffective predictor of strength, and supports the work of other authors.[15 16] (In routine clinical practice we do not adjust the values for practical reasons). We found no significant influence of height. Some authors[17 18] find positive correlations of strength and height, but this concerns strength expressed as torque. When expressed in force (N) there is only a poor correlation with height.[12 16] Hosking *et al*[4] found linear correlations of hand-held myometry and length, but these results were obtained in children.

The 95% reference limits for the ratio left to right is on average 0·82 to 1·22, which means in practice that the stronger side does not exceed the weaker one by more than 22%. Hosking *et al*[4] found the difference in strength on the two sides less than 15% of the right sided values in 80%. Because there is a large variation of strength in normal individuals,[14] as shown by table 5, this left-right variation can be very useful for detecting weakness.[19] If a right elbow flexor is 40% weaker than the left side but within the fifth centile value, there still must be a suspicion of a pathological condition.

The repeatability was tested by comparing the mean of three values of two sessions with an interval of one week. It is preferable to use the mean instead of the highest score.[20] There is a good repeatability after one week, with only small differences between the muscle groups. The results mean in practice that a second measurement seldom differs more than 20% from a first measurement, which confirms earlier reports. Wiles *et al*[2] found in 80% a percentage difference <20% in pairs of measurements up to four days apart. In those terms our percentage difference from week-to-week is in 90·9% less than 20%. Boonstra[21] found, with the same dynamometer as in this study, a coefficient of variation (CV) of 8·3 and 7·4% for wrist extensors and three point grip. The CV of our results from week-to-week varied from 3·6% (elbow flexors, R) to 10·9% (knee flexors L). Expressed as percentage change, our week to week results per muscle vary from 5·1% to 14·2%, mean 8·9%, which compares well with the results of Andres *et al*,[22] who found intrarater three to five hour test-retest changes ranging from 4·3% to 10·3%, mean 6·5%. Although they use a strain gauge with an immovable strap, their method yields only slightly better results. This agrees with Wiles *et al*,[2] who found the repeatability of the hand-held method as good as the muscle chair with a more rigorous technique. Bohannon[23] published good test-retest reliability during a single session. Our variation within one session is as good as the repeatability of averages with one week interval. These results are very encouraging, but it must be pointed out that for hand-held dynamometry a skilled examiner is required. From our own interobserver study[6] but also from other authors[2,3] we know the repeatability will suffer with different observers. The results of interobserver studies will depend on the skill and experience of the observers.

In the case of one experienced examiner who measures several muscles in a disease with more or less generalised muscle weakness (polymyositis, Guillain-Barré Syndrome), one has many parameters, with opportunities to make mean muscle scores, which will give a very good and reliable representation of the course of the disease.

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