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INTRA- AND INTER-TESTER RELIABILITY AND REFERENCE VALUES FOR HAND STRENGTH

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The intra- and inter-tester reliability for measurement of handgrip strength and indexgrip strength using the Jamar dynamometer was investigated in 32 healthy volunteers, and the intra-tester reliability in 13 patients with cervical radiculopathy. The results from the reliability studies showed that handgrip and indexgrip strength measured with the Jamar dynamometer is a reliable method (ICC values 0.85–0.98) and can be recommended for use in clinical practice. Age- and sex-specific reference values for handgrip strength and indexgrip strength were measured with the Jamar dynamometer in 101 randomly selected healthy volunteers, aged 25–64 years. The results from the reference value study showed that sex is a more important determinant of hand strength than age, height and body weight. The reference values for hand strength improve the potential for objective evaluation of patients with arm/hand disorders caused by cervical radiculopathy.

Key words: hand strength, grip, muscle strength, sex differences, reliability.

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INTRODUCTION

Hand strength may be negatively affected by local disorders of the hand as well as by radiculopathy caused by degenerative changes in the cervical spine. To improve assessment of hand function (1–6), objective and reliable instruments and knowledge about the reference values (7) are needed. Numerous authors have studied hand strength in healthy individuals (3, 8–13), and several of them have reported age- and sex-specific data (3, 10, 12).

Grip strength of the hand has been reported to decrease with age (3, 6, 9, 12–15). As for other muscles (16, 17), lower values have been reported for grip strength in women than in men (3, 5, 8–10, 12–14, 18). The Jamar has been reported to be a reliable and valid instrument for measuring handgrip strength (2, 5, 19, 20) in healthy individuals. To our knowledge, however, reliability studies of handgrip strength in patients with cervical radiculopathy are lacking.

In our study, handgrip strength and indexgrip strength (between the first metacarpal and phalanges, and the second metacarpal and phalanges of the index finger) were measured using the Jamar dynamometer, an isometric, hydraulic hand dynamometer. The indexgrip has not been studied previously. The advantage of also measuring the indexgrip strength with the Jamar is that it is practical to use only one dynamometer. The muscles activated in the indexgrip and in the handgrip are mainly innervated from lower cervical segmental levels, the cervical nerve roots most frequently affected in degenerative cervical spine disorders. Evaluation of muscles innervated by the lower segmental levels is therefore of particular interest. The indexgrip includes the thumb and index finger, with a greater demand on thumb strength compared to the handgrip test. Consequently, the two tests are complementary. The indexgrip mainly activates the same muscles as the pinchgrip, but generates greater force since the lever arms are different.

The purpose of the present study was to determine the intra- and inter-tester reliability of strength measurements of the handgrip and a new grip, the indexgrip, with the Jamar dynamometer in healthy volunteers, and to determine the intra-tester reliability in patients with cervical radiculopathy. We also determined age- and sex-specific reference values for strength in handgrip and indexgrip in order to improve the assessment of hand strength in disorders of the cervical spine, the arm and the hand.

METHODS AND MATERIAL

The study is divided into three parts, one aimed at testing intra- and inter-tester reliability in healthy volunteers, the second at testing intra-tester reliability in patients with cervical radiculopathy, and the third establishing reference values in a healthy population.

Intra- and inter-tester reliability study in healthy volunteers

The reliability study was performed by three test leaders, one of whom was a physiotherapist and two of whom were physiotherapy students. A convenient sample of 35 healthy volunteers was included in the study. Individuals with pain in the shoulder/arm/hand and cervical radiculopathy in the previous 3 months were not included.

Three women did not complete the trials since two of them got influenza, and one felt discomfort in the right ring-finger during the first trial, and they were excluded. The mean age for the 32 who completed the trials was 29 years (S.D. 10, range 20–64). Twenty-four were women (mean age 29, S.D. 11, range 20–64) and eight were men (mean age 29, S.D. 6, range 22–39). Twenty-six were physiotherapy students, five were teachers, and one was a Ph.D. student. Twenty-six were right-handed, four were left-handed, and two were ambidextrous.

The strength of handgrip (Fig. 1a) and indexgrip (between the first

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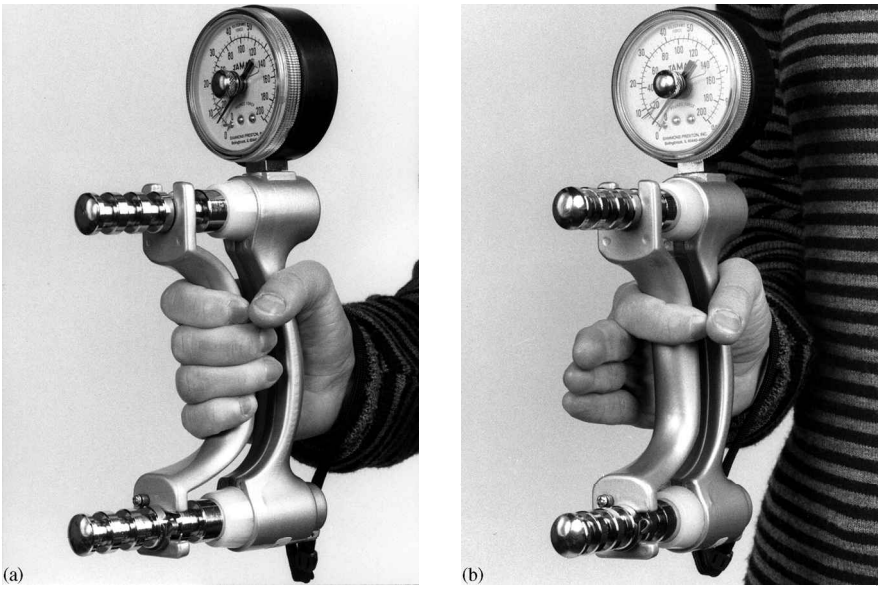

Fig. 1. (a) Handgrip with the Jamar dynamometer. (b) Indexgrip with the Jamar dynamometer.

metacarpal and phalanges, and the metacarpal and phalanges of the index finger, Fig. 1b) were measured with a newly calibrated Jamar (utilizing an adjustable-top workbench, positioning blocks, force collar and standardized test weights; Sammons Preston, Inc., Bolingbrook, IL 60440-4989; 744 West Michigan Avenue, Jackson, MI 49201, U.S.A.), which is an isometric, hydraulic hand dynamometer. The Jamar dynamometer was read in kilograms (kg) with 2 kg gradation.

The test was performed in the position recommended by the American Society for Hand Therapists (2, 8, 10, 12, 13, 19): (1) standing position with straight back; (2) the shoulder adducted and in neutral rotation; (3) the elbow flexed 90°; (4) the lower arm in neutral position; and (5) the wrist in neutral position.

Three measurements of each grip and hand (one test trial) were obtained with each of the three test leaders in a random order. There was at least 1 day of rest between the three different test trials, and all test trials were done within a 1-week period. To avoid diurnal variation, all the test trials were performed at the same time of the day. Since pain can affect performance of maximal muscle strength, every participant rated pain using a visual analogue scale (VAS) before each test trial. Before the test trial the individual was given technical instructions and performed a sub-maximal trial. Instructions were given to the volunteers as follows: "squeeze the handle as hard as possible". After a maximal squeeze for about 5 seconds the peak value was registered. No encouragement was given during the measurements. If an error during the maximal test was noted, e.g., rotation of the wrist, the test was repeated after a 5-minute rest. Women used grip breadth 2, and men grip breadth 3 (the smallest possible grip breadth is 1, and the largest is 5). The test was always performed with the dominant hand first.

During testing, there was no information of data between the test leaders or between the test leaders and the test person.

Intra-tester reliability study in patients with cervical radiculopathy

The study was performed by a physiotherapist. Thirteen patients (six women and seven men) with cervical disc disease and radiculopathy with a mean age of 50 years (S.D. 12, range 29–66) who were on the waiting-list for surgery (anterior decompression and fusion) were included in the study.

The patients has disc disease at different segmental levels from C3 to TH1. Eleven were right-handed, and two were left-handed. Ten of the patients had neurological deficits in the right arm/hand, and three in the left. Every patient rated pain in the neck and arm with VAS (median 4, range 0–7.6) prior to the test. The performance of the measurements and the instructions given to the patients were standardized, and were the same as described in the reliability study in the healthy volunteers, except that there was only one test leader.

Reference value study

Two hundred individuals (Table I) were randomly selected from the employee records of the University Hospital, Linköping, Sweden. Selection was performed after numbering and age stratification of all employees. The selection was weighted to constitute 100 men and 100 women, with 25 individuals in each of the following age intervals: 25–34, 35–44, 45–54 and 55–64 years of age. Individuals on short- or long-term sick-leave were excluded, as were individuals who in the last 3 years had received treatment for, or who currently had pain in the neck, arm or hand.

The 200 individuals selected were informed that participation was voluntary. Fourteen did not respond, and of the 186 who replied 50 did not agree to participate and two had changed jobs (59% of the drop-outs were men, and 41% were women, the mean age of the drop-outs was 43.5 (range 27–63) years of age). Thirty-one individuals had had treatment for a neck/hand disorder, and two were on a long-term leave of absence and were excluded. Among the remaining 101 participants there were 51 men and 50 women.

The mean age was 43 years for both men (S.D. 11, range 25–63) and women (S.D. 10, range 25–60). The mean weight for men was 81 kg (S.D. 8, range 62–105) and for women 66 kg (S.D. 11, range 47–100). The mean height for men was 181 cm (S.D. 5, range 171–191) and for women 166 cm (S.D. 6, range 147–178). Forty-seven men were right-handed, three were left-handed, and one was ambidextrous. All 50 women were right-handed.

The performance of the measurements and the instructions given to the test persons were standardized and were the same as described in the reliability studies, except that only one measurement in each grip and hand was performed by only one test leader. Some authors have recommended the use of the mean of three or more efforts (1, 3, 12, 20, 26). According to Hamilton et al. (5), however, there is a fatigue effect between test one and test three, and the mean of three efforts has not been shown to be a more reliable or valid test than the use of one maximal effort. The test leader was a physiotherapist well trained in the technique. The majority of the tests were performed after 10:00 h. In four individuals who worked at night, the tests were performed at 07:15 h, i.e. after work.

Statistical methods

For analysis of intra-and inter-tester reliability, repeated measure one-way analysis of variance (ANOVA) and intra-class correlation coefficient (ICC) were used. ICC was used since it measures accordance, and correlation analysis only measures relation. ICC-values ≥ 0.81 were considered almost perfect (21, 22). The differences in reference values between men and women in hand strength, and between patient's hand

Table I. *The occupations of the 200 individuals randomly selected and the 101 participants in the reference value study*

Occupations	200 selected individuals	101 participants
Operator, secretary, administrative assistant	25	13
Foremen/forewomen, manager, superintendent	16	9
Technician, engineer	10	6
Cleaner	2	1
Kitchen staff	4	1
Porter	5	4
Teacher, lecturer, professor	8	7
Chemist, laboratory assistant	5	5
Social worker, psychologist	6	4
Speech therapist	1	1
Physiotherapist, occupational therapist	5	2
Assistant nurse, children's nurse	32	13
Nurse, midwife	32	14
MD	49	21
Medical staff	128	58
Others	72	43

strength values and the reference values were analysed for statistical significance by the unpaired two-tailed Student *t*-test. The differences in strength between the right and the left hand were analysed for statistical significance by the paired two-tailed Student *t*-test. Age-related hand strength was studied by linear regression analysis. Correlation's between hand strength and body weight and height, respectively, were determined by bivariate Pearson correlation analysis. Correlations between hand strength and age, body weight, body height, dominant hand and gender, respectively, were determined by multiple regression analysis. $p < 0.05$ was considered to be statistically significant.

RESULTS

Reliability study in healthy volunteers

The intra-tester reliability of the Jamar dynamometer for the three test leaders expressed as the ICC varied between 0.94 and 0.98 for handgrip strength and between 0.88 and 0.92 for indexgrip strength (Table II). The inter-tester reliability among the three test leaders was 0.98 for right and left handgrip strength and 0.85 and 0.86 for indexgrip with the right and left hand, respectively (Table II).

In 50% of the test trials of handgrip strength measurement, two in the test series of three measurements was found to have the highest value, and in 83% measurement one was found to have the lowest value. For indexgrip strength the highest value varied between measurements one, two and three. Measurement one had a majority (50%) of lowest values. The maximal mean difference between the three measurements in the test series for all the three test leaders was 2 kp (range 0–2) and 1 kp (range 0–1) for handgrip and indexgrip strength, respectively.

Reliability study in patients with cervical radiculopathy

The intra-tester reliability of the Jamar dynamometer expressed as the ICC was 0.87–0.97 (Table II). In the majority of the cases, measurement one in the test trials of three measurements was found to have the majority of the highest values, and measurement three the lowest values, except for handgrip on the deficient side where measurement two was the lowest.

When the patients' highest hand strength values were compared with the age- and sex-specific reference values, the patients had significant lower values (right hand $p < 0.0001$, and left hand $p < 0.001$).

Reference value study

Handgrip strength (handgrip right and left) in women was 66% of that in men ($p < 0.05$), and indexgrip (indexgrip right and left) was 63% of that in men ($p < 0.01$) (Tables III and IV). The handgrip strength per kg body weight in women was 83% of that in men ($p < 0.0001$), and the indexgrip strength was 80% ($p < 0.001$) of that in men. However, the individual variation was large, and the strongest women were far stronger than the weakest men (Tables III and IV). There was no significant correlation between strength and body weight in either sex. However, for both sexes body height correlated significantly ($p < 0.05$, both in simple and multiple regression linear analysis split by gender) with handgrip strength, but not with indexgrip strength.

In the simple linear regression analysis there was no significant age-related change in strength for either sex, for

Table II. *Intra- and inter-tester reliability (ICC value) within and between test leaders A, B and C in handgrip and indexgrip strength for the right and the left hand measured with the Jamar dynamometer in 32 healthy volunteers. Intra-tester reliability for the neurologically deficient and the "healthy" side in 13 patients with cervical rhitzopathy within the test leader A test series*

Intra	Handgrip right	Handgrip left	Indexgrip right	Indexgrip left
Test leader A	0.98	0.94	0.92	0.92
Test leader B	0.97	0.97	0.91	0.92
Test leader C	0.97	0.97	0.88	0.92
Inter				
Between A B C	0.98	0.98	0.86	0.85
Patients (Intra)	Deficient hand	Healthy hand	Deficient hand	Healthy hand
	0.90	0.97	0.91	0.87

Table III. *Age- and gender-specific handgrip strength (kp) (mean, 95% confidence interval, individual reference interval (mean ± 2 S.D.)) measured in 101 healthy volunteers with the Jamar dynamometer*

Age	N	Handgrip right, mean	95% CI	Ref. interval	Handgrip left, mean	95% CI	Ref. interval
Men	51	51	50; 53	39; 63	50	48; 52	36; 64
Women	50	34	33; 36	26; 42	32	31; 33	22; 42
Men							
25–34	13	54	51; 57	42; 66	54	50; 58	42; 66
35–44	15	50	47; 54	38; 62	49	45; 52	35; 63
45–54	12	50	45; 55	34; 66	50	44; 55	32; 68
55–64	11	50	48; 53	42; 58	47	43; 51	35; 59
Women							
25–34	10	35	32; 39	25; 45	32	30; 35	26; 38
35–44	15	35	32; 37	27; 43	32	29; 35	24; 40
45–54	14	35	33; 38	27; 43	34	31; 38	22; 46
55–64	11	32	30; 34	26; 38	29	27; 31	25; 33

either the right or the left hand, or for handgrip strength or indexgrip strength. Although there were no statistically significant changes in strength with age, the tendencies were different for handgrip and indexgrip; the former decreased and the latter increased with age. In a multiple regression analysis for the dependent variable hand strength against the independent variables, age, body weight, body height, dominant hand and gender, gender was the most important factor ($p < 0.0001$). In the simple regression analysis gender explain the (R^2) value of 0.72 for the right handgrip, 0.69 for the left handgrip, 0.44 for the right indexgrip, and 0.47 for the left indexgrip. In the multiple regression analysis split by gender, the variables, age, weight and height, together explain the (R^2) value of only 0.11–0.21.

There was no significant difference between the strength of the dominant and the non-dominant hand for either men or women.

DISCUSSION

According to some authors, time of day may influence observed hand strength, with lower values in early morning tests (5, 9). This was taken into account in the reference value study, with a majority of the tests performed after 10:00 h. In order to avoid diurnal variations in the reliability study, all three test series were performed at the same time of day. Other sources of error are position of the patient (5, 18), position of the arm (2, 3, 5, 6, 9, 18, 23, 24), motivation of the tested individual (12, 19), and the motivational ability of the investigator. In an attempt to control known risk of errors we followed the American Society for Hand Therapists' standardized position, recommended by several authors (2, 10, 19, 20, 24).

In the present study we used position 2 on the Jamar dynamometer for women and position 3 for men, which means a wider breadth of grip for men. The rationale for this is that men generally have larger hands and they often find position 2 uncomfortable. Crosby et al. (8) reported that 60% of tested individuals performed better in position 2 than in positions 3 or 4. Similarly, Hamilton et al. (5) reported the highest grip strength in position 2 for 72% of volunteers, and in position 3 for 28%. Härkönen et al. (25) found only minor differences in reliability with different grip breadths. Although one can argue that every individual should use the most comfortable handgrip, it seems advantageous to standardize the method as much as possible, which justifies the use of position 2 in all women and 3 in all men.

Table IV. *Age- and gender-specific indexgrip strength (kp) (mean, 95% confidence interval, individual reference interval (mean ± 2 S.D.)) measured in 101 healthy volunteers with the Jamar dynamometer*

Age	*n*	Indexgrip right, mean	95% CI	Ref. interval	Indexgrip left, mean	95% CI	Ref. interval
Men	51	17	16; 18	9; 25	16	15; 17	10; 22
Women	50	11	10: 12	5; 17	10	9; 11	4; 16
Men							
25–34	13	17	15; 19	9; 25	15	13; 18	7; 23
35–44	15	17	15; 18	13; 21	15	14; 16	11; 19
45–54	12	18	14; 21	6; 30	16	13; 18	8; 24
55–64	11	17	15; 20	9; 25	17	15; 20	9; 25
Women							
25–34	10	11	8; 15	1; 21	9	6; 12	1; 17
35–44	15	11	9; 12	5; 17	10	9; 11	6; 14
45–54	14	11	10; 13	7; 15	11	9, 12	5; 17
55–64	11	10	9; 12	4; 16	9	7; 11	5; 13

Reliability study in healthy volunteers

The intra- and inter-tester reliability results for handgrip and indexgrip strength measured with the Jamar dynamometer were almost perfect (ICC values 0.85–0.98).

The results for handgrip reliability were in accordance with other studies (5, 19). Mathiowetz et al. (20) unfortunately reported intra- and inter-tester reliability in Pearson product–moment correlation coefficients, so it is difficult to compare their results with ours.

In the present study the mean differences among the three measurements within the test trial for handgrip strength was a maximum of 2 kp, which is in accordance with other studies (1, 5, 25).

Reliability study in patients with cervical radiculopathy

The intra-tester reliability results for handgrip and indexgrip strength measured with the Jamar dynamometer were almost perfect (ICC values 0.87–0.97).

Lagerström (26) has recommended the use of the mean of three or more measurements in handgrip strength for reliable results in patients with Colles' fracture, but in the present study measurement 1 in a test trial of three measurements was almost always the highest. We can assume that difference could be explained in that patients with a radius fracture are afraid of maximal strength performance, and patients with cervical radiculopathy have neurological deficiency and muscular fatigue in the arm/hand. There were no differences in the ICC values between the patients and the healthy volunteers, and one can conclude that Jamar can be used in clinical practice.

Reference value study

It is very difficult statistically to sample a material which has "general representativeness". However, it did not seem that the drop-outs (66 persons) represented a specific selection of people according to age, sex and occupation. The individuals in the study represented a number of different occupational groups, i.e. secretaries, cleaners, technicians, teachers, professors, nursing staff and doctors, i.e. a mini society, with different work and social demands.

It is possible that a so-called healthy worker effect has influenced the results, and the reference values for hand strength may be overestimated. However, it cannot be ruled out that individuals with minor arm or hand symptoms and anxious dispositions were more attracted than others to this health-control-like study, with the risk of an underestimation of the true levels of hand strength.

Because of the almost perfect intra- and inter-tester reliability in healthy volunteers and the almost perfect intra-tester reliability in patients with cervical radiculopathy, and because of the small differences (2 kp and 1 kp maximal mean difference for handgrip and indexgrip, respectively) between the measurements in the test trials in healthy volunteers, we could justify the use of only one measurement in the reference value study. Furthermore, we believe the use of one maximal effort is advantageous, particularly in patients with neurological deficiency and muscular fatigue.

In accordance with observations concerning hand strength in the present study, weaker muscle strength in women than in men has been reported for several muscle groups (27, 28). Knapik et al. (29) found that when strength was expressed relative to body weight, the differences between males and females were considerably reduced, and this was even more pronounced when expressed relatively to lean body mass. The explanation for greater strength in men is that women have about 40% less cross-sectional muscle fibre area than men, as estimated from needle biopsies of upper extremity muscles (17). Other explanations could be that men on average are physically more active, and that women have a higher percentage of body fat than men.

It has been well documented that in adulthood, skeletal muscle strength in general decreases with age (30). In the present study there was a non-significant tendency towards a deterioration in handgrip strength with age in both sexes, whereas the strength of the indexgrip did not change with age for either sex.

According to Mälkiä (31), handgrip strength decreases by only about 0.5% a year from the age of 30 until 45–49 years of age, after which the decline accelerates to about 1% a year until the age of 75, followed by an even larger decrease. In the present study, limited to volunteers aged 25–64 years, senile deterioration was not studied. With ideal sampling one might have been able to show decrease in strength with age, finding a significant decrease in handgrip strength. Several previous studies on hand strength (3, 9, 12, 14, 15) include subjects older than 75 years, and they have generally shown a deterioration in handgrip strength with increasing age. Another explanation for the non-significantly affected handgrip strength and the unaffected indexgrip strength with age may be that the use of the hands decreases relatively less with age compared to other parts of the body. This explanation is in accordance with Hackel et al. (15) and Bassey & Harris (14), who reported less loss of strength in frequently used muscles. Another less likely explanation for the lack of an age-related decrease in hand strength is a cohort effect, i.e. older people in today's society have previously done heavier manual work than younger individuals. Unfortunately, we have no information about the physical activity of the reference population in our study.

As previously reported by several authors, we found a significant correlation between height and grip strength in both men and women (3, 9, 32). Other authors have not offered an explanation for this phenomenon. One explanation for the correlation between height and grip strength could involve anthropometric factors. A tall person has longer fingers than a short person, and as a consequence longer lever arms and a better generation of power. Another possible explanation could be that height is more closely correlated to muscle volume than is body weight, which is more a reflection of fat than muscle tissue. Although not quantified in the present study, but

nevertheless supporting this point of view, lean body mass correlates well with strength (32).

In accordance with Härkönen et al. (10) and Jarit (11), we found only a slight, non-significant difference in hand strength between the dominant and the non-dominant hand. Several authors have, however, reported a difference (8, 14). Crosby et al. (8) studied 214 healthy individuals and reported that right-handed people were on average 10% stronger in the right hand compared to the left, whereas they observed no difference in left-handed individuals. However, it seems that the difference between the dominant and the non-dominant hand is limited.

Conclusion

The results from the reliability studies show that handgrip and indexgrip strength measured with the Jamar dynamometer is a reliable method and can be recommended for use in clinical practice. There are significant differences in absolute handgrip and indexgrip strength, as well as in handgrip and indexgrip strength per kilogram body weight, between men and women. In the present study there was a non-significant deterioration in handgrip strength, and no change in indexgrip strength between age groups. For both sexes there was a significant positive correlation between handgrip strength, but not indexgrip strength, and height. The reference values for handgrip and indexgrip strength that were observed can be used in objective functional assessment and has practical value for the clinical evaluation, especially in rehabilitation (1–5) in patients with cervical radiculopathy and upper extremity disorders.

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