STRENGTH OF THE INTRINSIC MUSCLES OF THE HAND MEASURED WITH A HAND-HELD DYNAMOMETER: RELIABILITY IN PATIENTS WITH ULNAR AND MEDIAN NERVE PARALYSIS

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The aim of this study was to assess the reliability of a technique to measure the strength of the intrinsic hand muscles. Intraclass Correlation Coefficients showed an excellent level of reliability for the comparison of muscle strength between groups of patients. However, for the results of individual patients, the calculated Standard Error of Measurements (10–16%) and the Smallest Detectable Differences for intraobserver (31–36%) and interobserver (37–52%) values indicate that only relatively large changes in strength can be confidently detected with this technique. The results of the present study were compared with those of four previous grip strength studies.
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Many functions of the hand are derived from the intrinsic muscles of the hand. According to Ketchum et al. (1978) loss of the intrinsic muscles causes an "awesome decrease" in the functional efficiency of the hand. When the ulnar and/or median nerve is affected by injury, compression or by other neurological pathology, the intrinsic muscles of the hand are weakened or paralysed. Testing the strength of the hand muscles provides information for diagnosis, and for the assessment of the outcome of surgery and therapy. In view of the many recently developed techniques for nerve reconstruction (Frykman, 1993) (e.g. tubes, laser, glue, etc.) it is important to have a precise, reproducible and standardized method of evaluating the muscle strength recovery.

Manual Muscle Strength Testing (MMST) according to the Medical Research Council (MRC) Scale (Medical Research Council, 1954) is routinely used by physicians and therapists (Brandsma et al., 1995). MMST is a reliable and quick method but is difficult to quantify (ordinal scale) and its sensitivity to change between grades 3 and 5 is low (van der Ploeg et al., 1984).

Quantitative measurements of muscle strength with grip and pinch meters may provide more accurate measurements of strength and may be more sensitive to change. Dynamometry is a popular means of expressing strength in a quantitative manner (American Society of Hand Therapists, 1981; Fess, 1986; Mathiowetz, 1991), and grip and pinch strength measurements are used to determine the efficacy of hand therapy and surgical treatment (Swanson et al., 1995). Other instruments which can be used include the MicroFET (van Langeveld et al., 1996), the sphygmomanometer (Lusardi and Bohannon, 1991), and the Citec hand-held dynamometer (Geertzen et al., 1998). However, these instruments mainly measure the strength of the extrinsic muscles and not the intrinsic muscles of the hand in isolation (Bohannon, 1995). Mannerfelt (1966, 1997) has developed an instrument which can measure the muscle strength of some intrinsic hand muscles, but Rosén (1996) has reported that this instrument is difficult to handle and read.

Test–retest reliability is concerned with the extent to which an instrument yields reproducible results with repeated measurements under the same conditions. Reliability can be expressed for the same observer (intraobserver reliability) and for different examiners (interobserver reliability). Reliability of measurements is a prerequisite for proper application in clinical practice.

The aims of this study were to evaluate a clinically applicable, objective method of measuring the intrinsic muscle strength in a quantitative way, and to determine the intra- and interobserver reliability of these measurements in the hand.

MATERIAL AND METHODS

The testing device was a lightweight (0.5 kg), battery operated, strain gauge dynamometer (Aikoh Model 9520AB, Aikoh Engineering Co. Ltd Tokyo, Japan) which is generally used for industrial precision measurements. The measuring range of the dynamometer, which records peak forces, is 0 kg to 20 kg, with an accuracy of 0.2%. A gutter shaped, 1.5 cm wide pad was custom made to match the shape of the finger and was fitted to the dynamometer (Fig 1).

We tested both hands of 24 patients with peripheral nerve lesions: there were 20 males and 4 females with age range of 16 to 71 (mean, 39) years. All patients had

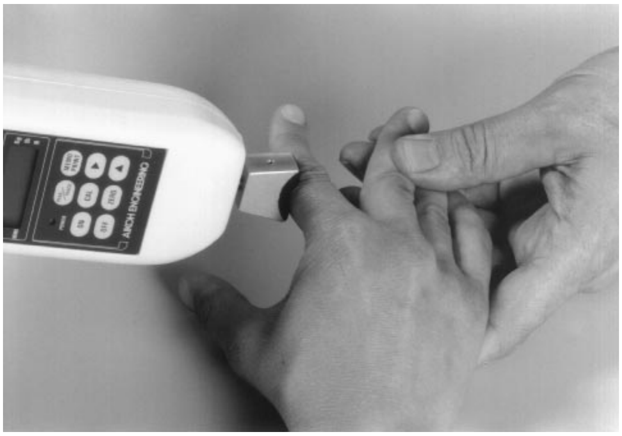

Fig 1 Photograph of the modified dynamometer.

undergone ulnar and/or median nerve repairs more than 2 years before the measurements. Of the 24 patients, nine had an isolated ulnar nerve injury, 12 a median nerve injury and three had both ulnar and median nerve injuries. The dominant hand was involved in 19 patients.

Manual Muscle Strength Testing (MMST) was done according to the Medical Research Council, 0–5 Scale (MRC, 1954). The dynamometer measurements were made in a similar way to the MMST with respect to posture and the anatomical reference point where pressure was applied. Each patient was seated at a table opposite the observer and given standard verbal instructions. The careful break test as described by Ketchum et al. (1978) was used, in which the patient had to exert maximum force against the pad on top of the dynamometer. The examiner then exerts a little more force until movement (breaking) occurs. Within one session the strength of three movements were tested: 1) abduction of the little finger; 2) abduction of the index finger; 3) palmar abduction of the thumb. The finger or thumb was placed in maximum abduction and the index and little finger MP joints were fully extended: the patient was then told to keep the finger/thumb in place. Pressure was applied at the proximal interphalangeal joint of the little and index finger and the metacarpophalangeal joint of the thumb. The order of a testing session was always the same: abduction of the little finger, abduction of the index finger and finally the abduction of the thumb of the injured, and then the uninjured, hands. For each test the mean of three peak values was calculated.

The tests in each patient were all done on the same day and did not take longer than 45 minutes. The test sessions were first done by one observer (TARS = Tal) and directly after this the second observer (JNMS = Tb) did the same tests without knowledge of the results of the first session; finally the first observer repeated the dynamometer measurements once again (Ta2).

DATA ANALYSIS

Statistical analyses were performed to determine intraobserver (between Ta1 and Ta2) and interobserver (between Ta1 and Tb) reliability. For each of the three movements separate analyses were performed, using data from both the injured and non-injured hands ($n = 48$). This analysis provides one reliability index for each movement, each of which applies to a broad range of muscle force; from paralysed to normal force levels. The use of one reliability index is preferable for the application of measurements in clinical practice. Because patients will be measured over time with force increasing from low to almost normal levels. In addition, ratios of the muscle force of the injured hand to those of the non-injured hand of a patient are frequently used when interpreting muscle strength.

The scatterplot (Fig 2) of repeated (intraobserver) measurements showed a fan-shaped appearance, implying that the amount of error variance between the first and second measurement was associated with the magnitude of muscle force. Therefore, a logarithmic transformation of the data was performed prior to further analysis. On the transformed data Analysis of Variance (ANOVA) was performed with a SPSS/PC + program to determine the multiple sources of measurement error, which were calculated as the percentage of the total variance. The variance attributed to differences between patients and tester was designated Var (P). Var (T) is the variance attributed to differences between sessions by the same (Ta1 and Ta2) and different (Ta1 and Tb) testers and Var ($P \times T$) is the variance due to interaction between patient and tester (Roebroeck et al., 1998; Streiner et al., 1995).

Intraclass Correlation Coefficients (ICC) were computed as the ratio between the variance between patients (Var (P)), and the total variance (the sum of Var (P), Var (T) and Var ($P \times T$)). The last two components (Var (T) and Var ($P \times T$)) constitute the error variance. From the error variance the Standard Error of Measurement (SEM) is computed as its square root. Based on the

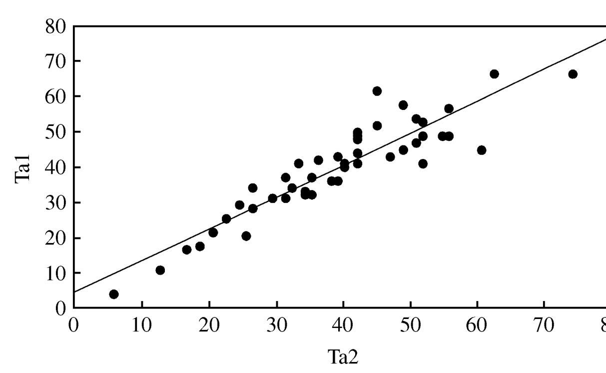

Fig 2 Scatterplot of intra-observer muscle strength tests (N) of abduction of the little finger.

SEM, the Smallest Detectable Difference (SDD) is calculated as $1.96 \times \sqrt{2} \times \text{SEM}$ (Roebroeck, 1998). By back-transforming the results, antilogs of the SEM and SDD provide proportional indices of measurement error, which are expressed as percentages of the measurements.

RESULTS

For all three movements tested (abduction of little finger, abduction of index finger, and palmar abduction of thumb) mean (SD) values were calculated. This was done for the injured hands ($n = 24$) and non-injured hands ($n = 24$) separately, as well as for both hands combined ($n = 48$) (Table 1). For the hands with an ulnar nerve injury ($n = 12$), measurements with the dynamometer showed that the mean strength of little finger abduction was 25.3 N (range, 3.9–57.8) and of index finger abduction was 44.6 N (range, 10.8–108.8). For the hands with a median nerve ($n = 15$) injury the mean strength of the thumb abduction was 52 N (range, 12.9–123.9). The recovery of muscle strength was also calculated as a percentage of the non-injured hand. The mean value for recovery of little finger abduction was 57%, of index finger abduction was 58% and for thumb abduction was 50%. The mean muscle strength according to the MRC scale for little finger abduction was 4.2, for index finger abduction was 3.5 and for thumb abduction was 3.6.

Analysis of variance (ANOVA) showed that the sources of measurement (the variance between test sessions (Var T) and the variance due to interaction between patient and test session (Var P × T)) contributed 4.2–9.1% to the total variance (Table 2). The largest part of the error variance was attributed to the interaction between patient and test session. This implies that some patients produced the highest forces in the first test session or with the first tester, whereas others performed better in the second test session or with the second therapist.

The intraclass correlation coefficients (ICC) for both intra- and interobserver reliability are given in Table 3. For all three movements, ICCs were greater than 0.90. This indicates that the force measurements are very reliable as far as differences between groups of patients are concerned.

For the interpretation of measurement results of individual patients, the SEM and SDD inform us about the amount of measurement error that should be taken into account. For the movements tested the SEMs and SDDs are presented in Table 3, which shows that the intraobserver values are smaller than the interobserver values. SEMs range from 10–16%, and the SDDs for intraobserver values range from 31–36% and for interobserver values from 37–52%. This implies that

Table 1—Intrinsic muscle strength (Newton) measured with the modified dynamometer

	Session	*Ta1*	*Ta2*	*Tb*
1. Injured hands ($n = 24$)	Little finger ($n = 12$)	24.3 (12.3)	24.2 (10.5)	27.5 (14.8)
	Index finger ($n = 10$)*	44.7 (30.7)	47.3 (27.7)	41.9 (28.7)
	Thumb ($n = 15$)	51.2 (30.9)	52.6 (29.8)	52.2 (31.7)
2. Non-injured hands ($n = 24$)	Little finger	45.3 (10.2)	44.5 (12)	45 (13.8)
	Index finger	77.4 (19.8)	79.6 (19.7)	70.4 (15.8)
	Thumb	108.7 (29.4)	103.3 (27.2)	99.4 (24.9)
3. Both hands ($n = 48$)	Little finger	40.0 (13.6)	39.4 (13.7)	41.7 (15.4)
	Index finger	71.0 (25.3)	72.7 (24.2)	65.2 (21.9)
	Thumb	88.1 (37.9)	85.1 (35.4)	82.6 (33.9)

n = number of hands, * = for index finger abduction data of 2 patients were missing. Data are mean and standard deviation (SD) of sessions by the first tester (Ta1 and Ta2) and the second tester (Tb). Three groups are presented: 1) data on the muscles with ulnar and/or median nerve paralysis: 2) data on all the non-injured hands ($n = 24$): 3) data on both hands of each patient ($n = 48$).

Table 2—Intrinsic muscle strength measurements (mean) of both hands of 24 patients with ulnar and/or median nerve paralyses, and variance (%) indicating reliability

	Little finger abduction		*Index finger abduction*		*Thumb abduction*	
	Intraobserver	*Interobserver*	*Intraobserver*	*Interobserver*	*Intraobserver*	*Interobserver*
Mean (N)	39.7	40.9	71.9	68.1	86.6	85.3
Var (P)	95.7%	90.9%	94.9%	90.9%	95.8%	95.9%
Var (T)	0%	0%	0.1%	1.1%	0%	0.5%
Var (P*T)	4.3%	9.1%	5%	8%	4.2%	3.7%

Mean is given in Newton (N), all other data after logarithmic transformation. Analysis of variance: where Var (P) = variance to be attributed to differences between patients. Var (T) = variance attributed to differences between tests by same observer (Ta1 and Ta2), and between different observers (Ta and Tb), and Var (P*T) = variance due to interaction between patient and tester.

Table 3—Intraclass correlation coefficient (ICC), standard error of measurement (SEM) and smallest detectable difference (SDD) of strength measurements of the intrinsic muscles of the hand

	Little finger abduction		*Index finger abduction*		*Thumb abduction*	
	Intraobserver	*Interobserver*	*Intraobserver*	*Interobserver*	*Intraobserver*	*Interobserver*
ICC	0.96	0.91	0.95	0.91	0.96	0.95
SEM	10%	16%	11%	15%	12%	12%
SDD	31%	52%	32%	46%	36%	37%

for individual patients assessed by the same tester, only differences of more than 31–36% between consecutive measurements may be interpreted as real changes.

Finally, the SEM and SDD results of the present study were compared with those of several earlier grip strength studies (Table 4).

DISCUSSION

In practically all studies evaluating peripheral nerve function, grip and pinch strength are measured. However, grip strength measurements do not necessarily provide useful information about the motor function of the ulnar and median nerve in the forearm. Patients with a complete ulnar nerve lesion can have a considerable grip strength, evidently because the extrinsic muscles are not paralysed. In our opinion, grip and pinch strength measurements provide information on the combined function of all the muscles of the hand, including the wrist extensors innervated by the radial nerve. In addition, the peripheral nerves are generally injured in combination with one or more finger or wrist tendons. In such cases it is even more difficult to determine the contribution of the intrinsic muscles to the total grip strength.

An attempt to analyse the contribution of the intrinsic muscles to grip and pinch strength was made by Kozin et al. (1999). They measured a 38% decrease in grip strength after ulnar nerve block and a 32% decrease after median nerve block. The only median innervated intrinsic muscles contributing to grip are the two lumbrical muscles to the index and middle finger, and it is questionable whether two small lumbricals can contribute as much as 32% to grip strength. Apparently, grip strength measurements show changes after nerve paralysis but it is difficult to determine whether this is due to loss of extrinsic or intrinsic muscle strength, or perhaps due to loss of sensory function.

In the present study we evaluated a device that we modified to measure the strength of the intrinsic muscles in isolation. The first step in assessing this new method is to establish the reliability of these measurements (Fess, 1986).

The intraobserver and interobserver reliability calculated as ICCs was high. This indicates good reliability of the measurements when used to compare groups of patients. For the purpose of measuring individual patients to assess changes in muscle strength over time, the standard errors of measurement (SEMs) and the smallest detectable differences (SDDs) are appropriate indices of measurement error. These provide information about the width of the error band around a measured value and the amount of measurement error that should be taken into account when comparing two consecutive measurements (Roebroeck et al., 1998; Streiner and Norman, 1995). The relatively large values for these indices in the present study implies that the reliability of the force measurements for assessing changes in individual patients is less satisfactory than for groups of patients. Only changes of more than 30% to 50% in muscle force in a patient can be interpreted as real changes. It is questionable whether this amount of measurement error is satisfactory when assessing clinically relevant change in patients with hand and nerve injuries.

As we are unaware of any study concerning the reliability of intrinsic muscle strength measurements, we compared the SEM and SDD results of the present study with those of earlier grip strength studies (Boissy et al., 1999, Geertzen et al., 1998, Nitschke et al., 1999, Spijkerman et al., 1991). Because we used a log transformation, the outcome was a SDD percentage. The data from the other studies did not use the log transformation, and thus the SDDs are in the original unit of measurement. To allow comparison of the SDDs from these latter studies with our results, we assessed the SDD as a percentage of the mean (Table 4). It was found that in intra-tester reliability studies with normal subjects the percentage of the SDD of the mean was 9–24% (mean 15%). The SDD as percentages of the mean in the different patient groups were between 30–53% (mean 39%). Geertzen et al. (1998) also studied the intra-tester reliability of grip strength in Reflex Sympathetic Dystrophy (RSD) patients and found large SDDs in the unaffected (54% of mean) and affected (85% of mean) hands. Geertzen and colleagues concluded that their reliability study of muscle strength measurements in RSD patients gives values which should be "treated with scepticism". Except for Geertzen's group, all other studies concluded that the intra-tester reliability was satisfactory.

From our clinical experience we assume that an SDD of 30% or larger is not sufficient to assess clinically relevant changes in patients with hand and nerve injuries. The SDD for inter-tester reliability of 37–52%

Table 4—Data on grip strength measurements from earlier reliability studies compared with data from the current study

Study	*Handheld dynamometer*	*Unit*	*subject*		*n*	*Observer*	*Mean*	*SD*	*ICC*	*SEM*	*SDD*	*% of mean*
Boissy	Lafayette grip	N	Healthy		10	Intra	381.7	87.3	0.86	33	91.5	24%
			Stroke		15		130.3	83.7	0.91	25	69.3	53%
Geertzen	Citec	N	RSD	Unaffected hand	29	Inter	123	66	0.97	24	66	54%
				Affected	29		84	51	0.94	25	71	85%
Nitschke	Jamar	kg	Healthy women		32	Intra	32.5	6.9	0.93	1.8	5.7	18%
			Women with NSRP		10		17.4	6.2	0.95	1.4	5.9	34%
Spijkerman	Strain-gauge grip	Nm	Healthy		16	Intra	43.3	9.9	0.98	1.4	3.9	9%
			Injured hands		8		23.1	17.7	0.98	2.5	6.9	30%
Schreuders	AIKOH intrinsic dynamometer	N	Peripheral nerve injury	Abduction little finger	48	Intra	40	13.6	0.96	10	31%	
				Abduction index finger			71	25.3	0.95	11	32%	
				Abduction thumb			88.1	37.9	0.96	12	36%	

N = Newton; Nm = Newton meters; *n* = number of subjects; NSRP = Non-specific regional pain syndrome; ICC = intraclass correlation coefficient; SEM = standard error of measurement; SDD = smallest detectable difference; SDD % of mean = SDD percentage of the mean.

leads us to conclude that we would not recommend this dynamometer for use by different testers for measurements in the same patient.

To further reduce the amount of measurement error we suggest that the shape of the dynamometer is modified, because it was not designed for hand-held measurements and is cumbersome to use. Secondly, because a small change in the angle between the device and the finger causes large differences in the recorded strength, measurements made by pulling on a string, rather than pushing the finger against the device, might improve the reliability. Adaptations to the device, and the elucidation of the relationship between grip strength, MMST and the dynamometry of the intrinsic muscles of the hand, will be the focus of future studies.

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