Research Report

Measurement Error in Grip and Pinch Force Measurements in Patients With Hand Injuries

Background and Purpose. There is limited documentation of measurement error of grip and pinch force evaluation methods. The purposes of this study were (1) to determine indexes of measurement error for intraexaminer and interexaminer measurements of grip and pinch force in patients with hand injuries and (2) to investigate whether the measurement error differs between measurements of the injured and noninjured hands and between experienced and inexperienced examiners. **Subjects.** The subjects were a consecutive sample of 33 patients with hand injuries who were seen in the Department of Rehabilitation Medicine of Erasmus MC–University Medical Center Rotterdam in the Netherlands. **Methods.** Repeated measurements were taken of grip and pinch force, with a short break of 2 to 3 minutes between sessions. For the grip force in 2 handle positions (distance between handles of 4.6 and 7.2 cm, respectively), tip pinch (with the index finger on top and the thumb below, with the other fingers flexed) and key pinch force (with the thumb on top and the radial side of the index finger below) data were obtained on both hands of the subjects by an experienced examiner and an inexperienced examiner. Intraclass correlation coefficients (ICCs), standard errors of measurement (SEMs), and associated smallest detectable differences (SDDs) were calculated and compared with data from previous studies. **Results.** The reliability of the measurements was expressed by ICCs between .82 and .97. For grip force measurements (in the second handle position) by the experienced examiner, an SDD of 61 N was found. For tip pinch and key pinch, these values were 12 N and 11 N, respectively. For measurements by the inexperienced examiner, SDDs of 56 N for grip force and 13 N and 18 N for tip pinch and key pinch were found. **Discussion and Conclusion.** Based on the SEMs and SDDs, in individual patients only relatively large differences in grip and pinch force measurements can be adequately detected between consecutive measurements. Measurement error did not differ between injured and noninjured hands or between experienced and inexperienced examiners. Criteria for judging whether the measurement error does allow application of the measurements in individual patients are discussed. [Schreuders TAR, Roebroeck ME, Goumans J, et al. Measurement error in grip and pinch force measurements in patients with hand injuries. *Phys Ther.* 2003;83:806–815.]

Key Words: *Hand, Hand force, Hand injuries, Measurement error, Reliability of results.*

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Only data that have acceptable reliability and validity are valuable in the clinical decision-making process for determination of impaired function and comparison of surgical repair techniques to document progress during rehabilitation and to evaluate disability after injury. Such data will decrease the need for use of unsubstantiated opinions and will increase the physical therapist's ability to obtain reproducible findings and meaningful results.[1] Better reliability implies better precision of single measurements, which is a prerequisite for better tracking of changes in measurements in research and clinical practice.[2]

Generally accepted instruments in the evaluation of hand function measure grip and pinch force. Grip and pinch force measurements have been promoted as an important measure of outcome in, for example, the evaluation of peripheral nerve function.[3–5] For a correct interpretation of these force measurements, we contend information on the reliability (measurement error) of these measurements is required. The reliability of grip force measurements has been studied in patients with hand injuries[6,7] and in people without impairments of the hand.[8,9] It also has been studied in several other categories of patients, including women with nonspecific regional pain (NSRP)[10] and patients with reflex sympathetic dystrophy (RSD)[11] or epicondylitis,[12] and in people after a stroke.[13] The reliability of pinch force measurements has been studied in patients with RSD[11] and repetitive strain injury (RSI).[14]

The studies of Spijkerman et al[6] and Brown et al[7] on the reliability of force measurements in patients with hand injuries have important drawbacks. The study by Spijkerman et al included only 8 patients, and Brown et al, in their study of grip and pinch force measurements in patients with hand injuries, did not specify the measurement error. As in many studies, the intraclass correlation coefficient (ICC) was used as a measure of reliability. For

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Mr Schreuders, Dr Roebroeck, and Dr Stam provided concept/idea/research design. Mr Schreuders and Dr Roebroeck provided writing. Dr Goumans and Mr van Nieuwenhuijzen provided data collection, and Mr Schreuders, Dr Roebroeck, Dr Goumans, and Dr Stijnen provided data analysis. Mr Schreuders and Dr Goumans provided project management. Dr Roebroeck and Dr Stam provided fund procurement and facilities/equipment. Dr Stijnen and Dr Stam provided consultation (including review of manuscript before submission).

The Ethical Committee of the Erasmus Medical Center, the Netherlands, approved this study.

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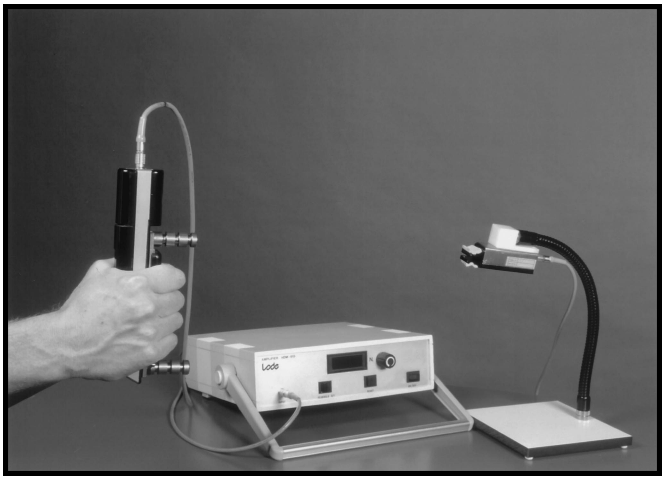

Figure 1.
Measurements were performed with the participant seated at a table on which the dynamometers were positioned.

clinical use, however, we believe the most relevant information is the magnitude of change between tests that is required to detect a real change, preferably quantified in the same units as the force measurement.[10,15] This magnitude of change is specified in the smallest detectable difference (SDD), which is calculated from the standard error of measurement (SEM), the absolute error component of the measurements.[16,17] The smaller the measurement error, the better the measure.[18]

Various factors relating to the patient's condition may influence the measurement error, such as the amount of pain and loss of normal function of the fingers or thumb after injury. The experience of the examiner also might influence the measurement error. However, studies on these aspects of grip and pinch force measurements for patients with hand injuries are scarce.

One aim of our study was to assess the SEM and related indexes of reliability for intraexaminer and interexaminer applications of grip (2 handle positions, with distances between the handles of 4.6 and 7.2 cm) and pinch (tip pinch and key pinch) force measurements for patients with hand injuries obtained with Lode handgrip and pinch-grip dynamometers (Fig. 1).* A second aim was to investigate whether the measurement error of grip and pinch force measurements differs between specific applications, such as measurements of injured and noninjured hands, measurements obtained by experienced and inexperienced examiners, and measurements between 2 handle positions for grip force and 2 different types of pinch force (ie, tip and key pinch force). A third aim was to judge whether the measurement error is small enough to justify use of these measurements to discern real changes in grip and pinch force in individual patients. Because no clear criteria to judge the SDD are available for grip and pinch force measurements, we compared our findings with the results of studies in which grip and pinch force measurements were examined in different patient categories (ie, patients with hand injuries, pain, RSD, or epicondylitis and people after stroke).

Method

Subjects

A consecutive sample of 33 patients (20 male, 13 female) who were seen in the Department of Rehabilitation Medicine of Erasmus MC–University Medical Center Rotterdam in the Netherlands participated in the study. They had a mean age of 36 years (SD 13.7, range=17–67). All patients had an injury on only one hand (6 with tendon lacerations, 9 with nerve lesions, 4 with fractures, and 14 with a combination of lesions or surgeries [eg, crush injury, finger amputation, arthrodesis]). During a period of 5 months, patients who were capable of being evaluated for grip and pinch force were asked to participate in this study. Patients who were not permitted to grip or pinch with maximum force because of injured tissue and patients who complained of pain were excluded. We presumed that pain would inhibit the patients from exerting full maximum force and that force measurements may reflect the amount of pain rather than the force-generating capacity of the patients. The participants were informed about the purpose of the study and gave informed consent.

The participants were in different phases of their rehabilitation process. Study entry was, on average, 22 months after injury or surgery when including one patient who had a 16-year period between the date of injury and time of examination. Excluding this patient, the average period was 9 months (SD=7.0, range 1–28) since injury or surgery. Force measurements of the hand are routinely obtained in our department during different phases of the rehabilitation process. Such measurements can be used to determine progression of muscle force recovery, the ability to perform in a vocation, and indications for continuing therapy and to assess long-term outcome after hand injuries.

Instrumentation

We used Lode handgrip and pinch-grip dynamometers (Fig. 1). The distances between the handles of the Lode handgrip dynamometer were adapted to create spaces between the handles comparable to those of the Jamar

* Lode Medical Technology, Zernikepark 16, 9747 AN Groningen, the Netherlands. Distributed in the United States by ElectraMed Corp, G-5332 Hill-23 Dr, Flint, MI 48507.

hand dynamometer.† For our study, the grip handle positions 2 (distance between handles=4.6 cm) and 4 (distance between handles=7.2 cm), which we designated "grip 2" and "grip 4," respectively, were used with the handgrip dynamometer.

With the Lode pinch-grip dynamometer, which is similar in design to the Preston pinch dynamometer,[†,19] 2 types of pinch were measured: tip pinch and key pinch. Tip pinch force was measured with only the index finger on top and the other fingers flexed with the thumb below, and key pinch force was measured with the thumb on top and the radial side of the index finger below.

The grip handle is connected to an amplifier from which the values give a digital readout on a display. According to the manufacturer, the measuring range is 0 to 1,000 N, with an accuracy of 1% deviation for 2 to 500 N and 2% for 500 to 900 N. Calibration was done with suspended weights according to the method described by Mathiowetz et al.[8] We believe the use of strain gauge technology is preferable to dynamometers, which are spring-based or use a hydraulic pressure system, because such dynamometers might produce erroneous data due to the wear and tear of metal, slow leaks, and hysteresis.[20]

Procedure

Measurements were taken according to the recommendations of the American Society of Hand Therapists (ASHT).[21] Participants were seated at a table on which the dynamometers were positioned (Fig. 1). The subjects were told to keep their elbow flexed without resting their arm or the grip handle of the dynamometer on the table. The digital display was not visible to the subjects. Corresponding to the ASHT recommendations for each measurement, the mean of 3 repetitions was recorded. Measurements were obtained of the left and right hands alternately, which is the method of testing used at our clinic. Testing both hands, we contend, enables comparisons of the injured and noninjured hands, as proposed by Gaul.[22]

The side (injured or noninjured) at which measurements were started and the order of tests (grip 2, grip 4, tip pinch, or key pinch) were randomly selected. Both examiners obtained all the measurements twice for each subject; the order of examiners was randomly selected. During each measurement session, the examiners obtained 12 measurements (2 grip and 2 pinch measurements × 3 repetitions from one hand. Then the examiners were changed while the subject took a short break (2–3 minutes) and moved the arm and hand out of the testing position. In this way, we attempted to reflect practice with examiners independently testing subjects, except there was a short time interval between examiners. Both examiners participated in 2 sessions per patient, which resulted in 48 measurements per hand. The total time required for testing, including the breaks, was 35 to 40 minutes per patient.

Examiners

Because we were interested in the effect of experience of the examiner on measurement error, we selected 2 examiners with widely differing experience. The first examiner was a 54-year-old male physical therapist (JFvN) with 20 years of experience in testing hand function. The second examiner (JG) was a 22-year-old female medical student with no previous experience with these tests. During a 2-week period, the inexperienced examiner had 5 hours of training by an experienced physical therapist to become familiarized with the equipment and testing protocol. During the training, measurements were practiced on several subjects without hand injuries and some patients with hand injuries. We believe that the results obtained by this student are reasonably representative of those that could be obtained by an inexperienced examiner, regardless of whether this is a starting physician or physical therapist, because at this stage they have comparable (ie, limited) knowledge, attitudes, and skills concerning force measurements.

Data Analysis

Statistical analyses were done to determine intraexaminer reliability of data obtained in the 2 sessions performed by the same examiner both for the experienced examiner (Texp1 and Texp2) and the inexperienced examiner (Tinx 1 and Tinx 2) separately. Interexaminer reliability was calculated between the first sessions of the experienced examiner (Texp1) and the inexperienced examiner (Tinx1). Analyses of the measurements of the injured hands (n=33) and noninjured hands (n=33) were conducted separately.

An analysis of variance (ANOVA) was conducted with an SPSS/PC+ program‡ to determine the multiple sources of measurement error. The variance attributed to differences among participants was designated "Var (P)." The variance attributed to differences between sessions by the same examiner (Texp1 and Texp2, Tinx1 and Tinx2) was designated "Var (S)." The variance ascribed to the different examiners (Texp1 and Tinx1) was designated "Var (T)." Variance due to interaction among participants for intraexaminer sessions was designated "Var (P×S)," and variance due to interaction among participants for interexaminer sessions was designated "Var (P×T)." The interaction components (P×S) and (P×T) were confounded by the residual

† Sammons Preston/Rolyan, 4 Sammons Ct, Bolingbrook, IL 60440.

‡ SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.

Table 1.
Grip and Pinch Force Measurements (in Newtons) Obtained by Experienced and Inexperienced Examiners for Both Hands of Participants With Hand Injury of One Hand (N=33)

		Experienced Examiner				Inexperienced Examiner			
		Session 1		Session 2		Session 1		Session 2	
Hand	Test[a]	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Injured	Grip 2	250	123	253	125	241	122	245	117
	Grip 4	231	110	231	111	231	113	223	109
	Tip pinch	39	17	39	16	37	16	38	16
	Key pinch	63	22	64	22	63	25	62	24
Noninjured	Grip 2	370	116	364	115	345	115	359	118
	Grip 4	326	110	323	108	325	112	317	109
	Tip pinch	55	13	53	12	54	12	54	12
	Key pinch	87	18	86	19	86	20	84	20

[a] Grip 2=measurements of grip force in the second handle position, grip 4=measurements of grip force in the fourth handle position.

error. In the intraexaminer analyses, Var (S) and Var (P×S) (ie, the variance within participants) constituted the error variance. Correspondingly, for the interexaminer analyses, the variance components Var (T) and Var (P×T) constituted the error variance.

From the error variance, the SEM was computed as its square root.[17] Based on the SEM, the SDD with 95% confidence was calculated as $1.96 \times \sqrt{2} \times$ SEM.[23] This SDD can be applied in such a way that only differences between 2 consecutive measurements greater than the SDD can be interpreted with 95% certainty as real change in grip or pinch force. Intraclass correlation coefficients were computed as the ratio of variances among participants (ie, Var [P]) and the total variance.[15]

Comparing SEMs

In order to test whether differences existed in error variances of different applications of grip and pinch force measurements, a test of equality of variances for paired samples was applied. In this analysis, scores between sessions were compared by calculating the correlation coefficient (Pearson *r*) between the sum and difference of the difference scores and testing whether this correlation differed from zero.[16,24(pp171–172)] In this way, we tested whether differences existed in error variance, and thus SEM and SDD, between the experienced and inexperienced examiners, between measurements of the injured and noninjured hands, and between the 2 handle positions of the grip force measurements and between the 2 pinch force measurements.

Commonly accepted criteria to judge whether the SEM and SDD of measurements are adequate for application of the measurements to individual patients do not exist. Therefore, we compared the SEMs found in our study with those from other studies in which grip and pinch force measurements were investigated. For an adequate comparison, We selected studies from the literature in which values for SEM or SDD were reported and studies from which SEM and SDD can be estimated by using the formulas: SEM = SD$\sqrt{(1-\text{ICC})}$[15(p119),23] or SEM = $\text{SD}_{\text{difference}}/\sqrt{2}$,[15(p120)] where SD=standard deviation. These studies included similar groups of patients as in our study (ie, patients with hand injuries or patients from different groups such as patients with pain, RSD, epicondylitis, and stroke).

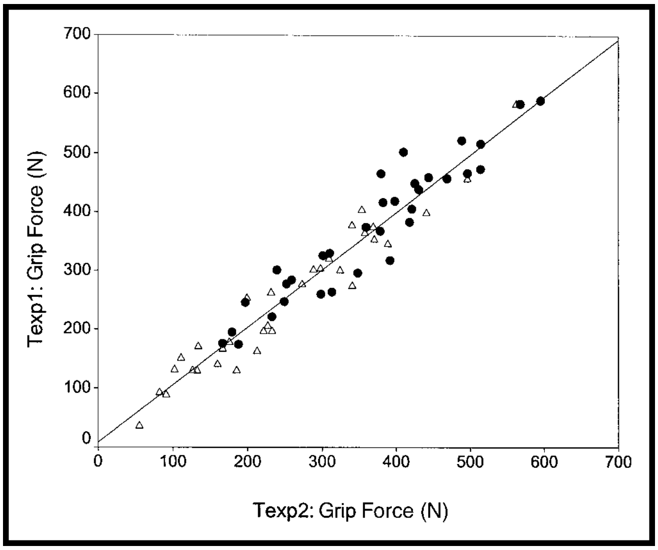

Figure 2.
Scatterplot of intraexaminer grip force measurements with the second handle position obtained in 2 sessions by an experienced examiner (Texp1 and Texp2). △ represents measurements of the injured hands (N=33); ● represents measurements of the noninjured hands (N=33), which are the higher values.

Results

Descriptive values (mean and standard deviations) were calculated for all measurements (2 grip and 2 pinch measurements) for the injured and noninjured hands and for the 4 sessions conducted by the experienced and inexperienced examiners (Tab. 1). Evidently noninjured

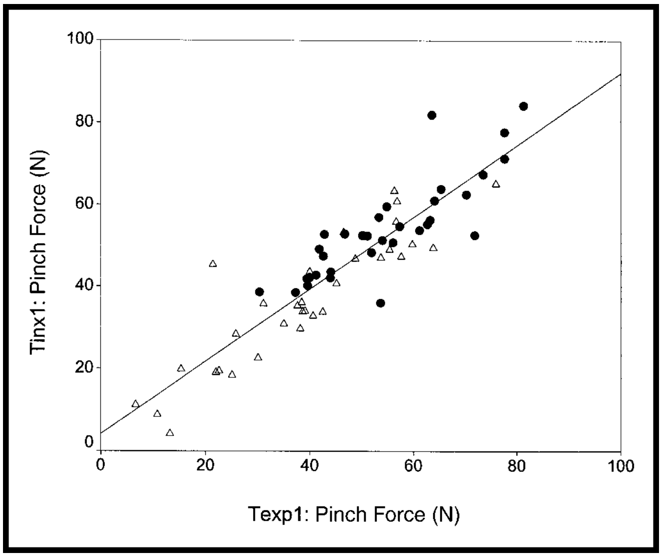

Figure 3.
Scatterplot of interexaminer tip pinch force measurements by an experienced examiner (Texp1) and an inexperienced examiner (Tinx1). △ represents measurements of the injured hands (N=33); ● represents measurements of the noninjured hands (N=33).

hands have stronger grip and pinch forces. The mean grip force in position 4 was less than in position 2. Key pinch had a considerably greater mean force than tip pinch.

Two scatterplots of measurements obtained for both injured and noninjured hands (n=66) are presented in Figures 2 and 3. Figure 2 shows the measurements of grip force with the second handle position for the 2 sessions conducted by the experienced examiner (Texp1 and Texp2). Figure 3 shows the measurements of the tip pinch force obtained by the 2 different examiners (Texp1 and Tinx1). Both scatterplots demonstrate that there was a high level of correspondence between the 2 sessions and the 2 examiners.

Table 2 contains the results of the ANOVA: the sum of squares, mean of squares, and estimated variance components attributed to different sources. Reliability indexes (ie, SEM, SDD, and ICC) for the intraexaminer grip and pinch measurements are presented, ordered by examiner (experienced and inexperienced) and by hand (injured and noninjured). The SEMs ranged from 4 to 29 N, and the corresponding SDDs ranged from 11 to 80 N. The lowest ICC was .82 and the highest ICCs were .97 which, according to the scale suggested by Shrout and Fleiss,[25] should be classified as excellent. The interexaminer data are presented in Table 3 and show comparable values.

No differences were found in the error variances of grip and pinch force measurements between injured and noninjured hands or performed by experienced and inexperienced examiners. Similarly, no differences were found in the error variances of the measurements between the 2 handle positions of grip force or between the 2 pinch techniques.

Tables 4 and 5 present comparisons among studies investigating grip and pinch force measurements, including the type of dynamometer used, characteristics of the subjects, means and standard deviations of force measurements, and reliability indexes (ie, SEM, SDD, and ICC). The measurement errors of the SEMs of grip force measurements are comparable in most of the studies, except for those of Nitschke et al[10] and Smidt et al,[12] in which relatively low values were found (Tab. 4). For pinch force measurements, the SEMs were 4 or 5 N, with the exception of the higher values of 11 N found by Geertzen et al[11] (Tab. 5).

Discussion

In our study, high ICCs were found for the reliability of grip and pinch force measurements in subjects with hand injuries. In our view, however, a high ICC should not be interpreted as a small measurement error because, in an ICC, measurement error and real variability between subjects are expressed in relative terms. Expressing the reliability as a dimensionless ratio of variances does not allow us to interpret the reliability in terms of an individual score. To decide whether a person's grip force has changed after a period of rehabilitation, a physical therapist must know which part of the change measured was real and which part by is due to measurement error. To accomplish this, we calculated the SEM and SDD.

In our study, the SDD of the grip force measurements (second handle position) of the injured hands was 61 N for measurements obtained by the experienced examiner (Tab. 2). This finding means that for grip force measurements taken by the experienced examiner (Texp), a change in force of at least 61 N is needed between 2 sessions to be 95% confident that a real change has occurred. The 2 different types of pinch force measurements (tip pinch and key pinch) showed a much smaller SDD; for the experienced examiner, the SDDs for the injured hands were 11 to 12 N (Tab. 2).

In the case of our 2 examiners with widely differing experience, comparison of the SEMs showed no differences between them. Thus, for grip and pinch force measurements, it appears that a brief training period was sufficient for an inexperienced examiner to reach a level of reliability comparable to that of an experienced examiner. Given the small number of examiners in our study, however, this cannot be stated with certainty.

Table 2.
Intraexaminer Measurements of Grip and Pinch Force (in Newtons) of Injured Hands of Participants (N=33) Obtained by Experienced and Inexperienced Examiners[a]

Examiner	Hand	Test	Source	SS	MS	Estimated Variance	SEM	SDD	ICC
Experienced	Injured	Grip 2	Between patients	972270	30383	14947			
			Within patients	15841	490	490	22	61	.97
		Grip 4	Between patients	758462	23702	11534			
			Within patients	20257	633	633	25	70	.95
		Tip pinch	Between patients	16035	501	241			
			Within patients	603	19	18	4	12	.93
		Key pinch	Between patients	30373	949	483			
			Within patients	510	16	16	4	11	.97
Inexperienced	Injured	Grip 2	Between patients	899327	28104	13849			
			Within patients	12989	406	402	20	56	.97
		Grip 4	Between patients	772010	24125	11868			
			Within patients	12443	389	406	20	56	.97
		Tip pinch	Between patients	15234	476	228			
			Within patients	657	21	21	5	13	.92
		Key pinch	Between patients	36315	1135	547			
		(n=32)	Within patients	1316	41	41	6	18	.93
Experienced	Noninjured	Grip 2	Between patients	835322	26104	12705			
			Within patients	22198	694	694	26	73	.95
		Grip 4	Between patients	738201	23069	11114			
			Within patients	26918	841	841	29	80	.93
		Tip pinch	Between patients	9482	296	140			
			Within patients	539	17	18	4	12	.89
		Key pinch	Between patients	21601	675	326			
			Within patients	754	24	24	5	13	.93
Inexperienced	Noninjured	Grip 2	Between patients	822792	26542	12922			
		(n=32)	Within patients	21624	698	698	28	77	.94
		Grip 4	Between patients	769145	24036	11823			
			Within patients	13478	408	408	20	56	.97
		Tip pinch	Between patients	8858	277	124			
			Within patients	892	28	28	5	15	.82
		Key pinch	Between patients	23848	745	351			
			Within patients	1383	43	43	7	18	.89

[a] Grip 2=measurements of grip force in the second handle position, grip 4=measurements of grip force in the fourth handle position. SS=sum of squares, MS=mean squares, SEM=standard error of measurement, SDD=smallest detectable difference, ICC=intraclass correlation coefficient.

More examiners, however, would entail a longer measurement time, which might fatigue the patient or decrease his or her concentration, both of which may influence the measurement error. We attempted to compensate for the small number of examiners by selecting 2 examiners with what we considered maximally different experience. Given that no differences in measurement error between the 2 examiners were found, we contend that having more examiners (eg, with intermediate levels of experience) obtain the measurements would not have affected our conclusions. Although we do not have data to support this view, we believe it is a reasonable interpretation.

Other factors also may influence the measurement error. For example, we also examined the difference in SEMs between grip and pinch force measurements of the injured and noninjured hands. The measurement error, however, did not differ between the injured and noninjured hands. No differences were found between the SEMs of grip force measurements in the 2 handle positions or between both types of pinch force measurements. Therefore, for applications in clinical practice, we contend one SEM value can be applied for grip force measurements for both handle positions and one SEM value can be applied for pinch force measurements, irrespective of injury and experience of the examiner.

Accepted criteria to judge the SDD of grip and pinch force measurements do not exist. Therefore, we compared our findings with those of 6 studies in which grip and pinch force measurements were investigated in similar and different patient categories (ie, patients with hand injuries,[6,7] women with NSRP,[10] patients with RSD,[11] patients with epicondylitis,[12] and patients after a stroke[23]) (Tab. 4). The SEMs of grip force measurements in these different studies are comparable. However, the differences in means and ranges of the mea-

Table 3.
Interexaminer Measurements of Grip and Pinch Force of Injured and Noninjured Hands of Participants (N=33)[a]

Hand	Test	Source	SS	MS	Estimated Variance	SEM (N)	SDD (N)	ICC
Injured	Grip 2	Between patients	948096	29628	14584			
		Within patients	16279	493	493	22	62	.97
	Grip 4	Between patients	763813	23869	11508			
		Within patients	27279	852	852	29	81	.93
	Tip pinch	Between patients	15805	494	234			
		Within patients	855	28	29	5	15	.89
	Key pinch	Between patients	33541	1048	509			
	(n=32)	Within patients	955	30	30	5	15	.94
Noninjured	Grip 2	Between patients	835379	26106	12899			
		Within patients	35320	1104	1111	33	92	.92
	Grip 4	Between patients	774343	24198	11857			
		Within patients	15495	484	484	22	61	.96
	Tip pinch	Between patients	9579	299	136			
		Within patients	857	27	27	5	14	.84
	Key pinch	Between patients	21771	680	315			
		Within patients	1594	49	50	7	20	.86

[a] Grip 2=measurements of grip force in the second handle position, grip 4=measurements of grip force in the fourth handle position. SS=sum of squares, MS=mean squares, SEM=standard error of measurement, SDD=smallest detectable difference, ICC=intraclass correlation coefficient, N=newtons.

Table 4.
Comparison of Intratester Measurements From 6 Grip Force Studies With Data From Our Study[a]

Study	Handheld Dynamometer	Subjects		n	$\overline{X}$	SD	SEM	SDD	ICC
Spijkerman et al[6]	Prototype Lode	No injuries		16	231	18	*14*	*39*	.98
		Hand injuries		8	434	10	*25*	*59*	.98
Brown et al[7]	Dexter grip[b]	Hand injuries		30	267	115	*30*	*84*	.93
Nitschke et al[10]	Jamar	Women with no injuries		32	325	69	*20*	*57*	.93
		Women with NSRP		10	174	62	*18*	*59*	.95
Geertzen et al[11]	CITEC grip[c]	RSD	Unaffected hand	29	123	66	*24*	*66*	.97
			Affected hand		84	51	*25*	*71*	.94
Smidt et al[12]	Jamar	Epicondylitis	Uninvolved hand	50	340	100	*13*	*37*[e]	.98
			Involved hand		300	110	*14*	*39*[e]	.98
Boissy et al[13]	Lafayette grip[d]	Not affected		10	382	87	*33*	*92*	.86
		Stroke		15	130	84	*25*	*69*	.91
Our study	Lode grip handle position 2	Hand injuries	Noninjured hand	33	367	115	26	73	.95
			Injured hand		252	123	22	61	.97
	Lode grip handle position 4		Noninjured hand		324	109	29	80	.93
			Injured hand		231	109	25	70	.95

[a] NSRP=nonspecific regional pain syndrome, RSD=reflex sympathetic dystrophy, SEM=standard error of measurement, SDD=smallest detectable difference, ICC=intraclass correlation coefficient (except for study by Nitschke et al, in which Pearson correlation coefficients were calculated). All data converted to newtons (data in studies by Nitschke et al, Geertzen et al, and Smidt et al were in kilograms of force and were converted to newtons by multiplying by 10; Brown and colleagues' within-patient data were in pounds and were multiplied by 4.448). Data are for intratester measurements, except for Geertzen et al and Smidt et al, who reported intertester data. Data from Brown et al are the mean of 3 testers. Figures in italics are estimated from ICC values presented in the studies.
[b] Dexter Extremity Evaluation & Therapy Systems, Cedaron Medical Inc, PO Box 2100, Davis, CA 95617.
[c] CITEC hand-held dynamometer, CIT Technics, Rijksstraatweg 384, 9752 CR Haren, the Netherlands.
[d] Lafayette Instrument Co, 3700 Sagamore Pkwy N, PO Box 5729, Lafayette, IN 47903.
[e] Figures from study by Smidt et al are estimated from the SD_{diff} values they reported. These values of the SDD differ from the values reported by Smidt et al, who submitted an erratum on this point.

Table 5.
Comparison of Data From Earlier Pinch Force Measurement Studies With Data From Our Study (All Data in Newtons)[a]

Study	Handheld Dynamometer	Subjects			n	Tester	$\bar{X}$	SD	SEM	SDD	ICC
Geertzen et al[11]	CITEC	RSD	Unaffected side	Key pinch	29		67	19	11	30	. . .[b]
			Affected side			Intertester	56	23	11	31	. . .[b]
Brown et al[7]	Dexter	Hand injuries		Tip pinch	30	Intratester (mean of 3 testers)	48	18.2	4	7.1	.96
				Jaw pinch			64	22.7	4	8.5	.96
Our study	Lode	Hand injuries	Noninjured hand	Tip pinch	33	Intratester	53	11.7	4	12	.89
			Injured hand				39	15.6	4	12	.93
	Lode		Noninjured hand	Key pinch			86	19	5	14	.93
			Injured hand				64	22.4	4	11	.97

[a] SEM=standard error of measurement, SDD=smallest detectable difference, ICC=intraclass correlation coefficient, RSD=reflex sympathetic dystrophy.
[b] No data available.

sured force levels in these studies are remarkable (eg, the mean grip force levels in the affected hands ranged from 84 to 300 N). To determine the value of a particular measurement in a population during clinical practice, we believe it is essential to know in which range the changes of muscle force take place. For example, in people with hand injury, the grip force will be lower shortly after the trauma. During later phases of rehabilitation, the increased muscle force will generally reach a plateau after many months. If the difference in the grip force between the start and end of the rehabilitation is, for example, 100 N, an SDD of 80 N will mean the measurement is inadequate to detect changes. If the range in which the forces change is as wide as 300 N, an SDD of 30 N is certainly sufficient to detect changes during the rehabilitation process. In this latter example, a virtual scale of 10 steps is achieved.

To determine whether the calculated measurement error is small enough to make a test valuable in clinical practice, different methods have been applied in the studies we cite. Geertzen et al[11] concluded that the SDD is too large in relation to the mean force measured to be useful in patients with RSD. Smidt et al[12] suggested that an SDD less than 10% of the total range of the measurements would be acceptable. The range, however, is determined by the extreme values of the measurement, whereas the standard deviation is less influenced by the extreme values. In our study, therefore, we re-examined the SDD in relation to the standard deviation of the measurements by calculating the SDD/standard deviation ratios. The SDD/standard deviation ratios were 0.5 to 0.6 for grip force measurements using the second handle position and 0.6 to 0.7 when using the fourth handle position. These findings mean that 6 to 7 steps of changes in force level can be detected within the 95% distribution ("virtual scale") of impaired to normal levels of grip force. In our opinion, this SDD/standard deviation ratio is useful in order to gain better insight as to whether measurements can be used to detect clinical meaningful changes. A more definitive conclusion concerning the usefulness of the measurements can be made by relating the SDD relative to the magnitude of changes in force measurements in a prospective study of patients throughout the entire rehabilitation process.

Conclusions

According to the ICC values obtained in our study, the reliability of grip and pinch force measurements is excellent. However, assessment of the measurement error and detectable change in muscle force between 2 consecutive measurements demonstrated that, in grip and pinch force measurements in individual patients, only relatively large changes can be adequately detected.

Measurement error did not differ between the experienced and inexperienced examiners or the injured and noninjured hands. Similarly, no differences were found in the grip force measurements for the 2 handle positions or in the tip pinch and key pinch force measurements. The limited number of examiners and the use of subjects who were pain-free should be considered when applying our results. Further study of the SDD/standard deviation ratio is needed to develop clear criteria to judge whether measurement error is acceptable to detect changes in individual patients.

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