Validity and Reliability of the Measurement of the Quadriceps Femoris Muscle Strength with a Hand-Held Dynamometer on the Affected Side in Hemiplegic Patients

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Abstract: The purpose of this study was to investigate validity and reliability of measuring the quadriceps femoris muscle strength on the affected side in hemiplegic patients with a hand-held dynamometer (HHD) to prepare for a multi-center cooperative study. Measurements of the known weights (8.972 kg and 18.665 kg) with HHD were 8.98 ± 0.00 kg and 18.57 ± 0.00 kg, respectively, and measurements with HHD were almost consistent with those with KIN-COM (gold standard), because the Pearson’s product-moment correlation coefficient was 0.99 (P < 0.001). There were significant differences in measurements of the quadriceps femoris muscle strength on the affected side in a hemiplegic patient between just anterior to the face of the ankle and 7 cm proximal to the ankle, and on a chair with or without a backrest (t-test, P < 0.05), but no significant difference was found between the 90° and 60° flexed position of the knee (t-test, 0.1 > P > 0.05). There were also no significant differences in muscle strength measured by three different examiners and on four trials, but significant differences were found among three patients (General Linear Model, P < 0.001). Therefore, by using the standardized measuring procedure, the HHD is reliable to measure strength of the quadriceps femoris muscle on the affected side in hemiplegic patients.

Key words: reliability, validity, hand-held dynamometer (HHD), muscle strength, hemiplegia.

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Introduction

Manual muscle testing (MMT) is one of the most important clinical evaluations that physiatrists and physiotherapists perform for patients with neurological or musculoskeletal diseases and indeed, provides useful information regarding the topographical distribution of muscle weaknesses. But MMT is less sensitive to detect subtle changes in progress or recovery of muscle strength than muscle testing with a dynamometer. In recent years, various types of instruments to measure muscle strength have become available: some are quite reliable but difficult to use in clinical and epidemiological settings, while others provide less accurate results but are easy to use. A small and easy dynamometer is suitable for measuring muscle strength during clinical practice with large populations. For example, although the measurements obtained with an isokinetic dynamometer are highly reliable and reproducible, it is troublesome to install patients with mobility problems in the seat of the isokinetic dynamometer, especially hemiplegic patients, and to fit its cuff and belts to the extremities of the patients. Moreover, it costs a great deal and is too huge to carry about.

Hand-held dynamometers (HHD) have been proposed as simple alternatives; these devices are portable, useful in every clinical setting, relatively inexpensive, and easy to use. In spite of these advantages, reports on reliability and inter-rater agreement have been controversial [1–14]. Validity and reliability of the measurements with a HHD is questionable [1–4], especially when it is applied to patients with spastic paralysis or without a standardized protocol. For example, isometric muscle strength may vary substantially, depending on the joint angle, the way a subject is stabilized in a chair, and the process used to generate force (progressive vs. explosive increments). In addition, warm-up before testing may influence muscle strength, and older persons sometimes have problems in understanding the task they are asked to perform.

One has to confirm the validity and reliability of measurements of the quadriceps femoris muscle on the affected side in hemiplegic patients with a HHD before performing an epidemiological survey, because there are few reports on hemiplegic patients in this situation. Our present study, therefore, was planned to prove that measurements of the quadriceps femoris muscle strength on the affected side in hemiplegic patients with a HHD are valid and reliable when they are based on a standardized procedure.

Materials and Methods

Subjects were three male hemiplegic patients due to cerebral infarction, whose severity of hemiplegia was moderate (their scores of the knee extension test in Stroke Impairment Assessment Sets [15] were 3/5). The subjects were undergoing rehabilitation treatment in University Hospital of Occupational and Environmental Health, could follow simple commands,
and did not have any objection in measuring their muscle strength. After the aim and details of measurements were explained, the subjects voluntarily gave their consent to join in the study.

Muscle strength of the quadriceps femoris was measured with a HHD (Power Track II Commander TM, ZEVEX Company, Salt Lake City, USA; Fig. 1). The HHD consisted of a main body, pad and processor: the curved pad that was in direct contact with the subject’s affected extremity was attached to the main body, the main body with the curved pad was then pressed against the extremity, and the processor indicated muscle strength. The range of measurement is 0 to 200 Newtons (N*, *: 1 kg = 9.8 N) with an interval of 0.1 N.

The HHD was calibrated by measuring two known weights (8.972 and 18.665 kg) five times for each (Fig. 2). To examine criterion-related validity, the HHD was pressed against the sensor of KIN-COM (Chettex Corp, Chattanooga, TN, USA), which is generally regarded as a gold standard in muscle strength measurements, in the same way as we measure muscle strength of the quadriceps femoris on the affected side in the hemiplegic patients. Considering muscle strength of the hemiplegic patients, we added pressure at about 40 N, 100 N and 180 N, monitoring with indications of the HHD processor, measured four times for each, and then compared the measurements between the HHD and KIN-COM.

To examine fluctuations of measurements with the HHD, muscle strength of the quadriceps femoris on the affected side in a hemiplegic patient was measured by pressing the HHD

![Hand-held dynamometer](image-url)

**Fig. 1.** Hand-held dynamometer.
The curved pad is attached to the back of the main body, and the main body with the pad is pressed against the subject’s lower limb. The processor indicates a measured value.
CP: curved pad, MB: main body of the hand-held dynamometer, PR: processor.
against different parts of the lower limb and in different postures. Test 1: the subject was asked to sit on a chair with a backrest, keeping his affected hip and knee at a 90° flexed position, and was instructed to extend his knee, avoiding explosive contraction, and to exert all his effort for five seconds after an examiner shouted, "Ready, go." After the examiner confirmed that the subjects were able to reproduce what he had learned, the examiner measured muscle strength 8 times at intervals of more than one minute, pressing the HHD against the anterior face of the ankle or 7 cm proximal to the ankle alternately. Test 2: the subject was asked to sit on a chair with or without a backrest, keeping his knee flexed in a 90° position. Each measurement was also repeated 8 times alternately. Test 3: the subject was asked to sit on a chair with a backrest, keeping his knee in a 60° or 90° flexed position. Each measurement was repeated 8 times alternately.

To examine intra-rater and inter-rater reliability of the HHD measurements, muscle strength of the quadriceps femoris on the affected side in the three hemiplegic patients was measured at each trial by three examiners for four successive days (Test 4). The examiners, one medical doctor and two physical therapists, who had never used the HHD, came to an agreement on measuring procedures based on the results of the test 1, 2 and 3 in the study, instructions on extending the affected knee, confirmation on their movement, avoiding explosive contraction and exertion of maximum effort. Each measurement was repeated three times at an interval of more than one minute for one trial. The highest value of the three measurements was regarded as the muscle strength for the trial. If the subjects complained of failure to achieve maximum effort or poor stabilization of their body during the test, a
measurement was repeated. The examiners performed measurements separately, communicating no information about the results to each other.

All data were stored in a spreadsheet of a personal computer, and were analyzed with the SPSS version 11.5 J for Windows. The relationship of the values between the HHD and KIN-COM was analyzed by using Pearson’s product-moment correlation coefficient. The $t$-test was applied to examine the differences in measurements between two positions, two chairs and two angles. To confirm reliability of the measurements with the HHD, the General Linear Model was applied to examine the effects of three factors, patient, examiner and trial, on the measurements. The $P$-value of less than 0.05 was regarded as significant.

**Results**

Measurements for the two known weights (8.972 kg and 18.665 kg) as calibrations were $8.98 \pm 0.00$ kg (means ± standard deviation) and $18.57 \pm 0.00$ kg, respectively (Fig. 2). The measurements with the HHD and KIN-COM showed Pearson’s product-moment correlation coefficient of 0.99 ($P < 0.001$). There were significant differences in measurements between two positions, just anterior to the face of the ankle and 7 cm proximal to the ankle.

![Bar chart showing force measurements](image)

**Fig. 3a.** Measurements at different pressed positions.
- □: ankle, □: 7 cm above ankle.

The HHD was pressed against either the ankle or 7 cm proximal to the ankle during measuring muscle strength of the quadriceps femoris. The measurement against the ankle was $52.8 \pm 4.6$ N, and the measurement against 7 cm above the ankle was $66.6 \pm 3.7$ N; $t$-test, $P < 0.05$. 

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Fig. 3b. Measurements with and without a backrest.

\[
\begin{array}{c}
\square: \text{with backrest, } \blacksquare: \text{without backrest.}
\end{array}
\]

The subject sat on a chair either with a backrest or without a backrest during measuring muscle strength of the quadriceps femoris. The measurement on a chair with a backrest was $81.5 \pm 9.8$ N, the measurement on a chair without a backrest was $54.7 \pm 8.0$; $t$-test, $P < 0.05$.

Fig. 3c. Measurements at $90^\circ$ and $60^\circ$ knee flexed positions.

\[
\begin{array}{c}
\square: 90^\circ, \quad \blacksquare: 60^\circ.
\end{array}
\]

The subject sat on a chair with a backrest, keeping his knee in either a $90^\circ$ or $60^\circ$ flexed position during measuring muscle strength of the quadriceps femoris. The measurement at the $90^\circ$ knee flexed position was $100.1 \pm 10.1$ N, and the measurement at the $60^\circ$ knee flexed position was $90.1 \pm 10.7$; $t$-test, $0.10 > P > 0.05$. 
Fig. 4. Measurements among patients, examiners and trials.

- : Examiner A, - : Examiner B, - : Examiner C.

Measurements of the three hemiplegic patients were performed at four trials by three examiners. There was no obvious tendency in the examiner factor and trial factor but there was a difference in the patient factor.

1: Fig. 3a; t-test, \( P < 0.05 \), and between a chair with and without a backrest (Test 2: Fig. 3b; t-test, \( P < 0.05 \), but no significant difference was found between the 90° and 60° flexed positions of the knee (Test 3: Fig. 3c; t-test, 0.10 > \( P > 0.05 \)). No obvious tendency of measurements in the examiner factor and trial factor is noted in Fig. 4, but differences among the patient factors are seen. The General Linear Model revealed that only the patient factor of the three factors had a significant effect on the measurements (Table 1).

**Discussion**

According to the studies on HHDs, a HHD is reliable in measuring muscle strength in patients with postpolio syndrome [4] and spinal cord injury [3] as well as the elderly at home [11]. Because there have been few reports on muscle strength of the lower limb in hemiplegic patients measured with a HHD, especially on the affected side, validity and reliability of the HHD should be confirmed before we perform a cooperative multi-center survey including measurements of muscle strength of the quadriceps femoris muscle in hemiplegic patients.

In this study, because the error of the HHD was less than 0.5% when the HHD was calibrated with the known weights, and the measurements with the HHD were almost consistent
Table 1. Factors affecting measurements with the hand-held dynamometer

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean square</th>
<th>F value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
<td>2</td>
<td>9363.412</td>
<td>97.757</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Examiner</td>
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<td>6.052</td>
<td>0.063</td>
<td>0.939</td>
</tr>
<tr>
<td>Trial</td>
<td>3</td>
<td>80.403</td>
<td>0.839</td>
<td>0.484</td>
</tr>
</tbody>
</table>

The General Liner Model was applied to analyze factors affecting the measurements.

with those with the gold standard method (KIN-COM), measuring muscle strength with the HHD is regarded conceptually as valid. When muscle strength to be measured is very great, measurements of the HHD have a tendency toward smaller values [4]. Our previous study on the HHD revealed that an examiner could not press or hold the HHD firmly against a subject’s ankle during measuring the knee extensor muscle strength if the subject’s muscle strength of the quadriceps femoris was more than 200 N [16]. At application of the HHD measurement to the quadriceps femoris muscle on the affected side in hemiplegic patients, the predicted highest value of the muscle strength seems to be less than 200 N, and the HHD is sufficiently accurate within this range.

Deciding a subject’s body position and regular procedures are important in attaining reliable measurements of muscle strength with the HHD. We recommend subjects to sit on a chair with a backrest, keeping their affected hip and knee position at 90°. Stabilizing the trunk, muscle strength during sitting with a backrest is 20% greater than that during sitting without a backrest (Test 2, Fig. 4b). The flexion angle of the knee joint is important to improve reliability when measure with the HHD, but one does not need to pay much attention to the flexion angle of the knee joint while measure a hemiplegic patient, because no significant difference but only a tendency in measurements between the 90° and 60° flexed positions were found (Test 3, Fig. 4c). However, we recommend to have subject’s knee joint flexed at 90° during measurement, because the 90° flexed position of the knee joint had a tendency to generate higher muscle strength. The position of the lower leg against which the HHD is pressed is also important, and we usually select the anterior face of the ankle joint, that is, the distal end of the lower leg. If the position is shifted to 7 cm proximal to the ankle, the measured muscle strength increases by 15% (Test 1, Fig. 4a).

When the subjects repeat an isometric muscular contraction during measurement with the HHD, the measured muscle strength is low at the first muscular contraction, and generally reaches the maximal value at the 3rd or 4th contraction in case of several time repetitions. In the case of from 8 to 10 repetitions, the measured muscle strength usually peak at the 2nd or 3rd contraction from the final muscular contraction [16]. According to these facts and,
moreover, considering that subjects in a future cooperative study are hemiplegic patients, we have adopted the procedure that the subjects repeat muscular contractions three times during measurement and the maximal value of the three is regarded as the muscle strength obtained with the HHD.

From the results gained by measuring the known weights and the knee extensor muscle strength on the affected side in hemiplegic patients, we consider the measurements with the HHD as valid and reliable. However, because muscle strength is one of the unstable parameters in the rehabilitation field, based on our present and previous results\cite{16}, we should follow the standardized procedure, that is, 1) sitting on a chair with a backrest, 2) keeping affected hip and knee at the 90° flexed position, 3) pressing the HHD firmly against the anterior face of the ankle joint, 4) measuring three times at intervals of more than one minute, 5) selecting the maximal value as the muscle strength, 6) exerting all their effort for five seconds, 7) standing in front of the subject when measuring.

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References

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徒手筋力計を用いた片麻痺患者の麻痺側大腿四頭筋筋力測定の妥当性と信頼性

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要旨： 多施設共同研究の実施を前提にして、徒手筋力計を用いて片麻痺患者の麻痺側大腿四頭筋筋力測定の妥当性と信頼性を検討した。既知の重りを測定すると徒手筋力計の値は一定で正確であり、KIN-COMとの測定値もほぼ一致した。片麻痺患者1名の測定値では、徒手筋力計を用いる部位（足関節と7 cm近位部）、膝の角度（90°と60°）には有意差はなかった（t-test, 0.1 ＞P＞0.05）。3人の片麻痺患者を3人の検者が4回測定を行った、各施行とも3回筋力測定し、その最大値を筋力とした。測定値は患者による相違はあるが、検者や施行による相違はなく（General Linear Model, P＜0.001）、徒手筋力計は標準的測定手順に従えば、妥当性があり信頼性があると考えられる。

キーワード： 妥当性、信頼性、徒手筋力計、筋力、脳卒中。

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