



Original Article

## Evaluation of bilateral force deficit in shoulder flexion using a handheld dynamometer in healthy subjects

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**Abstract.** [Purpose] This study aimed to develop a simple, inexpensive, and accurate method for measuring the strength of shoulder flexion (Experiment 1) and evaluate the bilateral force deficit in shoulder flexion (Experiment 2) in healthy subjects. [Subjects and Methods] In Experiment 1, maximal voluntary contractions (MVCs) in isometric shoulder flexion were measured on both sides using an isometric dynamometer (ID) and a hand-grip dynamometer (HGD), as an alternative dynamometer, in six subjects. In Experiment 2, bilateral force deficit was evaluated using HGD in 21 subjects who performed unilateral and bilateral MVCs in isometric flexions of the shoulder. The peak value of electromyography (PVE) in the lateral head of the biceps brachii and anterior deltoid was measured during MVCs. [Results] In Experiment 1, ID and HGD showed almost similar coefficients of variation. A strong positive correlation was found between the values obtained using the two methods. In Experiment 2, the bilateral force deficit in shoulder flexion associated with a reduced PVE (−10.9%) was found in 85.7% of subjects. [Conclusion] The reproducibility of measurements was similar between ID and HGD. HGD could evaluate the bilateral force deficit in shoulder flexion and is a practical tool for measuring shoulder strength.

**Key words:** Isometric contraction, Strength dynamometer, Electromyography

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### INTRODUCTION

In the rehabilitation field, the evaluation of muscle strength is important. Specific isometric and/or isokinetic dynamometers (IDs) such as Biodex and Cybex are used for the evaluation, and the evaluation using these is employed as the gold standard. However, because these dynamometers are extensive and too large, use in sports-medicine practices are limited<sup>1)</sup>. In recent years, the validity and reliability of simple handheld dynamometers have been investigated for alternative measurements of muscle strength<sup>2, 3)</sup>. Significant correlation coefficients between the values obtained using handheld dynamometers and isometric dynamometers have been reported<sup>2, 4, 5)</sup>.

When handheld dynamometers are alternatively used to evaluate muscle strength, most studies measure a lower limb muscle strength. In this context, there are limited data reporting analyses of muscle strength in upper limbs, especially in shoulders. Shoulder injuries often occur at work and in sports<sup>6)</sup>. Particularly, for athletes, recovery of both shoulder muscle strength and function are important in the rehabilitation program. Assessment of bilateral force deficit is one of the methods used to evaluate muscle function in the practical situation. Bilateral force deficit is a reduction in the maximal voluntary strength induced by simultaneous bilateral muscle contractions compared with that induced by the sum of right and left

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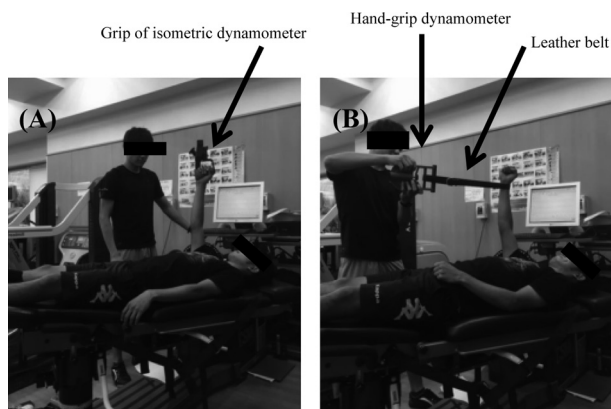
unilateral contractions<sup>7-9</sup>). Bilateral force deficit is common in untrained individuals, whereas it is not found in competitive oarsmen<sup>10</sup>), implying that an habitual bilateral training influences to the bilateral force deficit. In the rehabilitation of athletes who perform sports using bilateral limbs simultaneously, assessment of bilateral force deficit is one of the important methods for evaluating muscle function. The validity, reliability, mobility, and low cost of equipment for the evaluation of muscle strength are considered highly advantageous in the rehabilitation field. Therefore, the aims of this investigation were to develop a simple, inexpensive, and accurate method of measuring muscle strength using a hand-grip dynamometer (HGD) (one of the inexpensive handheld dynamometers) as an alternative dynamometer (Experiment 1) and to determine whether HGD is able to evaluate bilateral force deficit in shoulder flexion (Experiment 2).

## SUBJECTS AND METHODS

All experimental procedures were performed in accordance with the guidelines of the Declaration of Helsinki and were approved by the Ethics Committee of the Teikyo University (approval no. 16-031). The subjects were informed regarding the experimental procedures, risks, and purpose of the study and signed an informed consent prior to undergoing the experimental procedures. Six healthy adult male volunteers (age,  $21.5 \pm 0.8$  years; height,  $174.6 \pm 5.1$  cm; body weight,  $68.3 \pm 6.9$  kg) with no known neuromuscular disorders or functional limitations participated in Experiment 1. The data of muscle strength obtained using IDs are employed as a reference in research field<sup>2</sup>). Therefore, to evaluate the validity and reproducibility of the subjects' strength of shoulder flexion with a digital HGD (TKK5401, Takei Scientific Instruments Co., Ltd., Niigata, Japan), correlation analysis was performed between HGD and ID (Cybex Norm, Medica Co., Ltd., Fukuoka, Japan). The subjects were randomly divided into two groups. In three subjects we measured the maximal voluntary contractions (MVCs) of the right shoulder flexion during maximal isometric contractions for 3 s/repetition at  $90^\circ$  of shoulder flexion, at  $0^\circ$  of elbow (full extension of elbow), and neutral angle ( $0^\circ$ ) of the wrist using ID (Fig. 1A), and then the MVC of their left shoulder flexion using HGD was measured in a posture same as that for ID measurement. After a minimum 24-h interval, we measured the MVCs of the same subjects' left shoulder flexion using ID and right shoulder flexion using HGD (Fig. 1B). We also measured the MVC of the other three subjects' shoulder flexion using a protocol same as that for the first group in the reverse order. The subjects were tested in a gravity-neutral, supine position. For HGD measurement, a leather belt was hung between the center of the HGD grip and the processus styloideus radii (Fig. 1B). To calculate the torque of the shoulder flexion using HGD, the length from the acromion to the processus styloideus radii was measured in each subject. To evaluate the reproducibility of both HGD and ID, each measurement was repeated three times at a 10-min interval between each repetition, and the respective coefficients of variation (CVs) were calculated. To analyze the correlation of torque of the shoulder flexion between ID and HGD, the mean torque values of each of the three repetitions in each apparatus were used as the representative values for each apparatus.

Twenty-one healthy subjects (males,  $n=17$ ; age,  $20.8 \pm 1.3$  years; females,  $n=4$ ; age,  $18.8 \pm 0.5$  years) with no known neuromuscular disorders or functional limitations participated in Experiment 2 to investigate if bilateral force deficit in shoulder flexion could be detected using HGD. The subjects were seated on a chair with their back straight along with a backrest to fix their trunk during the measurements (Fig. 2). They were randomly divided into two groups. In 11 subjects, we measured the MVC of isometric bilateral strength of their shoulder flexion. After a 10-min interval, the right and left unilateral MVCs of shoulder flexion were measured. The same MVC measurements were performed in the other 10 subjects but in the reverse order. The subjects performed one repetition of maximal shoulder flexion for 3 s at  $90^\circ$  of shoulder flexion, at  $0^\circ$  of elbow flexion, and at  $90^\circ$  of wrist pronation. For HGD measurement, a leather belt was hung between the center of HGD grip and processus styloideus radii. Because the limitation of detection for the HGD used in this study was  $\geq 5.0$  kg, measurements for the subjects with strengths of  $<5.0$  kg were obtained using the leather belt hung from their elbow (two males and three females). The data from each of the right and left unilateral and bilateral tasks were used to calculate the bilateral indices (BIs). The BI was defined as follows:  $BI = \text{bilateral} / (\text{left unilateral} + \text{right unilateral})$  in HGD strength. BIs  $>1.0$  indicated that the bilateral values were greater than the unilateral values (bilateral force facilitation), whereas BIs  $<1.0$  indicated that the sum of the right and left bilateral values was less than that of the unilateral values (bilateral force deficit). One week after the first assessment of bilateral force deficit, the subjects who were found to have a bilateral force deficit were asked to visit to the laboratory, where electromyography (EMG) signals during bilateral and unilateral MVCs were recorded from the biceps brachii and anterior of deltoideus. EMG signals were recorded from the side that was found to have a larger BI among the right and left sides (ME6400; Nihon Medix, Tokyo, Japan). Bipolar surface electrodes (Ambu Blue Sensor M-00-S/50; Nihon Medix) were placed over the belly of the muscles with a constant interelectrode distance of 30 mm. The EMG data were band-pass filtered at frequencies between 8 and 500 Hz, and sampled at 1,000 Hz. The obtained values were averaged per 10 ms to exclude artifactual influences; subsequently, the peak values of electromyography (PVE) in the lateral head of biceps brachii and anterior deltoid were obtained.

All values were expressed as mean  $\pm$  standard deviation (SD). In Experiment 1, correlation analyses were used to compare the values of ID and HGD using the Pearson's product moment correlation coefficient. The differences between the values of ID and HGD were examined using the paired Student's t-test. In Experiment 2, the differences between the values of bilateral and unilateral measurements were examined using the paired student's t-test. The BIs were examined using the one-sample t-test. To analyze PVE the relative values (bilateral PVE/unilateral PVE) were examined using the one-sample t-test. A prob-



**Fig. 1.** Measurement methods in ID (A) and HGD (B)



**Fig. 2.** Measurement method while sitting

ability ( $p$ ) value of  $<0.05$  was considered to be statistically significant. Statistical analyses were performed using a statistical software (IBM SPSS Statics 23, IBM Japan).

## RESULTS

ID and HGD measurements showed almost similar CVs (Table 1). The values of shoulder flexion torque using HGD were significantly higher than those using ID ( $p<0.01$ ) (Table 1). ID and HGD measurements were significantly correlated ( $p<0.01$ ) with correlation coefficients of 0.775 (95% CI, 0.364–0.934). Bilateral force deficit was detected in 18 out of 21 (85.7%) subjects. The mean BI was 0.884 ( $p<0.01$ ) (Table 2). Although each PVE in the lateral head of the biceps brachii or anterior deltoid did not significantly decrease during bilateral MVCs compared to that during unilateral MVCs, the mean value of PVE in the lateral head of the biceps brachii and anterior deltoid during bilateral contractions was significantly lower ( $p<0.05$ ) than that during unilateral contractions (Table 2).

## DISCUSSION

The results of the present study showed no significant differences in CV between ID and HGD. In addition, we found a significant correlation between ID and HGD. Therefore, we believe that HGD is acceptable for use in evaluating the strength of shoulder flexion. However, a few points should be considered. In this study, HGD showed a significantly higher torque (26.1%) compared with ID. During the measurement of shoulder flexion torque in this study, the researchers had to pull HGD toward the opposite direction against the direction of shoulder flexion to maintain a constant angle of shoulder flexion; thus the muscles involved in shoulder flexion might have been forced to eccentrically contract. This eccentric muscle contraction may have caused the generation of a large amount of force. It has been reported that eccentric muscle contractions generate greater strength than isometric and concentric muscle contractions<sup>11, 12</sup>. Although evaluations of time course changes in the muscle strength of individuals using HGD are thought to be fully accessible in the rehabilitation field, attention must be paid in the comparisons of the absolute values between the different measurement equipment.

It is well known that a decrease in the maximal voluntary strength is induced by simultaneous bilateral exertion and not with unilateral exertion<sup>7, 8</sup>. This phenomenon is known as bilateral force deficit. It is also known that all exertions do not necessarily show the same extent of bilateral force deficit. Exertions using smaller muscles such as hand grip and finger flexion still show bilateral force deficit to a smaller extent compared with exertions using larger muscles such as arm flexion and knee extension<sup>7, 13–15</sup>. Because shoulder and biceps brachii muscles are larger than finger muscles, we predicted that the detection of bilateral force deficit is possible in shoulder flexion. Although bilateral force deficit was not observed in some of the subjects (14.7%), it was detected in most of the subjects (BI=0.884). A study has shown that healthy subjects who have not experienced any bilateral training of the upper extremities show bilateral force deficit in shoulder flexion with a certain degree of variation, implying that some subjects do not show the bilateral force deficit<sup>13</sup>. Our study also detected bilateral force deficit in shoulder flexion in majority of the participants. Because the assessment of bilateral force deficit is one of the important methods for evaluating muscle function, HGD is a useful measuring tool as an alternative dynamometer in the rehabilitation field.

Bilateral force deficit is considered to be induced by a neural limitation during bilateral exertions<sup>16, 17</sup>. It has been reported that reduced electromyographic activation is associated with reduced muscle strength under bilateral knee extensions<sup>18</sup>. In this study, EMG data were obtained from shoulder and biceps brachii muscles because anatomically, these muscles were

**Table 1.** Coefficients of variation (CVs) in ID and HGD, and the torque of ID and HGD

	ID	HGD
CV	0.046	0.038
95% CI	0.021–0.071	0.025–0.051
Shoulder flexion torque (N·m) ± SD	46.77 ± 9.23	59.04 ± 10.30*
95% CI	40.95–52.46	52.65–65.54

\*p&lt;0.01

ID: isometric dynamometer; HGD: hand-grip dynamometer; 95% CI: 95% confidence interval

**Table 2.** Bilateral index (BI) and the relative peak values of electromyography (PVE) in bilateral muscle contraction

BI ± SD	0.884 ± 0.050**	
95% CI	0.859–0.909	
	relative PVE ± SD	95% CI
Shoulder	0.925 ± 0.207	0.822–1.028
Biceps brachii	0.857 ± 0.298	0.709–1.005
(Shoulder + Biceps brachii)/2	0.891 ± 0.200*	0.792–0.990

The relative PVE was calculated as follows: (PVE in bilateral contraction/PVE in unilateral contraction)

\*p&lt;0.05, \*\*p&lt;0.01

considered to be mainly activated during shoulder flexion. Our EMG data showed that significant reductions of PVE were not observed in the shoulder and biceps brachii muscles individually under bilateral contractions compared to those under unilateral contractions. However, the mean value of the two muscles showed significant reductions under bilateral contractions compared with those under unilateral contractions, implying that bilateral force deficit in an exertion using multiple muscles is not necessarily induced evenly in all muscles related to the exertion.

Because commercially available HGDs are used to measure the hand-grip strength in children and adults, much lower strength than predicted hand-grip strength in children is not detected. The limitation of detection for the HGD used in this study was  $\geq 5.0$  kg. A part of the subjects in this study was not over 5.0 kg when a leather belt was hung between the center of HGD grip and processus styloideus radii. However, measurements for the subjects with strengths of  $< 5.0$  kg were obtained using the leather belt hung from their elbow. Therefore, it is possible to measure low strength by moving the hanging point of the leather belt to more proximal point, e.g. from processus styloideus radii to elbow.

In conclusion, HGD is a valid, reproducible, portable, and cost-effective tool as an alternative dynamometer that is practical and useful for the assessment of shoulder strength and function in the rehabilitation field. Using this HGD method, bilateral force deficit in shoulder flexion was found. Because the assessment of bilateral force deficit is one of the important methods for evaluating sports specific muscle function, HGD is an alternative measuring tool in the rehabilitation field.

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