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Validity of Isometric Muscle Strength Measurements of the Lower Limbs Using a Hand-held Dynamometer and Belt: a Comparison with an Isokinetic Dynamometer

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Abstract. [Purpose] The aim of this study was to evaluate the validity of isometric muscle strength measurements of the lower limbs and hips made with a hand-held dynamometer and belt by comparing them with measurements obtained by an isokinetic dynamometer. [Subjects] The subjects were 24 healthy adults (12 men, 12 women) with a mean age of 20.4 years. [Method] Measurements were made with both instruments on the flexors, extensors, abductors, adductors, external rotators and internal rotators of the hip and flexors and extensors of the knee. [Results] Measurements obtained with the hand-held dynamometer and belt were significantly lower than those obtained with the isokinetic dynamometer. Pearson's correlation coefficients for the measurements made with the two instruments ranged from 0.52 to 0.88 for all muscle groups except the hip abductors which was 0.34. In the hip abductors, the coefficient was 0.65 when forces of 450 N and higher were excluded. [Conclusion] Isometric muscle strength measurements of the lower limbs and hips obtained with a hand-held dynamometer and belt are considered to be valid except for measurement of hip abduction of subjects with high muscle strength.
Key words: Hand-held dynamometer, Muscle strength Measurements of lower limbs, Validity

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INTRODUCTION

Hand-held dynamometers (HHD) are commonly used to quantitatively measure muscle strength. The HHD is conventionally held in the examiner's palm and pressed directly against the part of the body under test. However, this method requires the examiner to have sufficient strength to hold the HDD steady, which can be difficult when measuring isometric muscle strength of the lower limbs, especially when the subject is strong and the examiner weak. The limit of the manual resistance was reported to be from 220 to 294.2 N (30 kg) in previous studies[1–6)]. Methods previously reported for fixing a HHD to overcome this problem and prevent the angle of the joint from changing include using a stick[7)], a steel support [8)], and a belt[9–15)].

Among these studies, Katoh et al.[12,13)] used a belt to help steady the HDD and investigated the reliability of isometric muscle strength measurements of the lower limbs (flexion, extension, abduction, adduction, internal rotation and external rotation of the hip, flexion and extension of the knee, and dorsiflexion and plantar flexion of the ankle), in healthy men and women with a mean age of 20 years. After each measurement, the subjects rested for 30 seconds before the measurement was taken again by the same examiner and the intraclass correlation coefficient [ICC (1,1)], used to describe agreement between the pairs of measurements, ranged from 0.75 to 0.97[13)]. In addition the intraclass correlation coefficient [ICC (2,1)], used to describe interrater agreement between 2 examiners, ranged from 0.97 to 0.99 for measurements made using the HHD and belt fastened to an anchor point, and from 0.21 to 0.88 for measurements without the belt. The measurements were significantly higher (paired t-test: $p<0.05$) when the belt was used[12)].

Katoh et al.[14,15)] also investigated the reliability of isometric muscle strength measurements of knee extension using the HHD and belt of elderly subjects and hemiplegic patients. In the latter, ICC (1,1), obtained as above, was 0.91 for males and 0.88 for females, but the second values within the pairs of measurements were significantly higher than those of the first values (paired t-test: $p<0.05$)[14)]. In hemiplegic patients, 3 measurements separated by 30-second rests were taken in 2 sessions over a period of days, and ICC(1,1) were 0.98, 0.99 for the paralyzed side and

0.98, 0.99 for the non-paralyzed side. Multiple comparison (Bonferroni) analysis indicated the 1st measurement in session 2 for the paralyzed side was significantly lower than the 2nd and 3rd measurements[15].

The validity of measurements obtained with a HHD in comparison with those obtained with an isokinetic dynamometer (IKD) has been reported in various studies[8,16–19], however, to the best of our knowledge, there are no reports on the validity of such comparative measurements obtained with a HHD and belt[12–15]. Therefore, the purpose of this study was to investigate the validity (instrumental validity) of isometric muscle strength measurements of the hips and lower limbs obtained with a HHD and belt by comparing them with those obtained with an IKD.

SUBJECTS AND METHODS

Subjects comprised 24 healthy adults (12 males, 12 females, mean ± SD age 20.4 ± 2.2 yrs, height 165.4 (SD=9.4) cm, weight 59.0 (14.1) kg who had given their written informed consent. The isometric muscle strengths of the hip and dominant lower limb (determined by kicking a ball) were measured using a HHD and belt (HDD μTasF-1, Anima Corp., Tokyo) and an IKD (Cybex NORM). Measurements were made with the subjects making the following 8 exertions: flexion, extension, abduction, adduction, internal rotation and external rotation of the hip, and flexion and extension of the knee. The subjects also acted as the examiners taking all measurements under direct supervision of the researcher. The examiners had practiced until becoming familiar with the procedure beforehand. Examiners did not disclose any measurements until they had all been taken.

The subjects were positioned on a mat table, bed or a mat for the HHD and belt method and in a Cybex NORM chair with the trunk and pelvis fixed using a lap belt as per the manufacturer's protocol for the IKD method. They maintained a seated posture (with feet off the floor) during hip flexion, adduction and abduction and knee flexion and extension, a supine position during external and internal hip rotation, and a prone position during hip extension. The HHD sensor was fastened by Velcro tape to the distal part of the thigh for flexion, extension, adduction and abduction of the hip and to the distal part of the lower leg for internal and external rotation of the hip as well as flexion and extension of the knee, while the anchor belt was fixed to an available structure to directly oppose the movement of the body part under test (Table 1, Fig. 1). The pad of the IKD was positioned at the same locations as the HHD sensor.

Subjects were instructed to perform isometric movements by pushing or pulling their body part being tested against the immoveable sensor anchored by the belt and to maintain maximum exertion for 5 seconds during which the maximum force was noted. Each trial was repeated once after 30 seconds of rest. The highest measurement for each pair of trials was recorded. For HHD and belt, the unit of force recorded was Newton (N). For IKD, the unit was Newton meter (Nm) which was divided by the distance (m) from the centre of the pad to the centre of the dynamometer axis to convert it to Newton (N). The order in which the 8 types of muscle actions were measured and also the use of HHD and belt or IKD was random.

Measurements made with the HHD and belt and the IKD were analyzed using the paired Student's t-test and Pearson's correlation coefficient (SPSS ver15.0J for Windows, SPSS Japan Inc., Tokyo); p values of <0.05 were considered significant.

RESULTS

Mean measured values by HHD and belt and IKD for all muscle actions, as well as Pearson's correlation coefficients are shown in Table 2. For all muscle actions, values were significantly higher when obtained by IKD than by HHD and belt ($p<0.05$). In hip abduction, no significant correlation was obtained, ($r=0.34$). When subjects with the highest measurements of hip abduction in IKD were excluded from the calculation, the correlation coefficients became $r=0.49$ ($n=23$), 0.51 ($n=22$), and 0.65 ($n=21$), and showed significant correlations ($p<0.05$). The highest measurements of hip abduction by IKD were 543 N, 500 N and 457 N. Ratios of the mean values of all muscle actions for the two methods ranged from 0.26 to 0.82. The correlation coefficients of the difference of measurements by the two methods and measurements by IKD were from 0.49 to 0.99, and were significant ($p<0.05$).

DISCUSSION

In the present study, the range of Pearson's correlation coefficients between measurements made using a HHD and belt and those made using an IKD was from 0.52 to 0.88, excluding those of hip abduction. In hip abduction, the ratio of measurements by the two methods was low by several samples with high measurements of IKD. In hip abduction, the correlation coefficient when two subjects with high measurements were excluded was $r=0.51$. The range of correlation coefficients in previous research[8,16–21] comparing measurements obtained using HHD and IKD is from 0.519 to 0.93 (Table 3). Therefore, we consider the validity of muscle strength measurements of the hips and lower limbs using a HHD and belt fastened to an anchor point, based on the validity of methods using IKD, to be similar to when measurement is made with an HHD fastened to the examiner's hand, except when the measured values for hip adduction using an IKD is 500 N or greater. Future studies will need to investigate the measuring method of hip abduction by HHD and belt which makes an appropriate measurement possible when measurements by IKD exceed 500 N.

Many previous studies[8,16–21] have reported lower measured values with HHD compared with IKD (Table 3). Measurements of muscle strength of the lower limbs reported in these previous studies were not conducted on healthy male subjects, which could explain why the measured values reported in those studies were lower than the measured values obtained in this study. Katoh et al.[12]

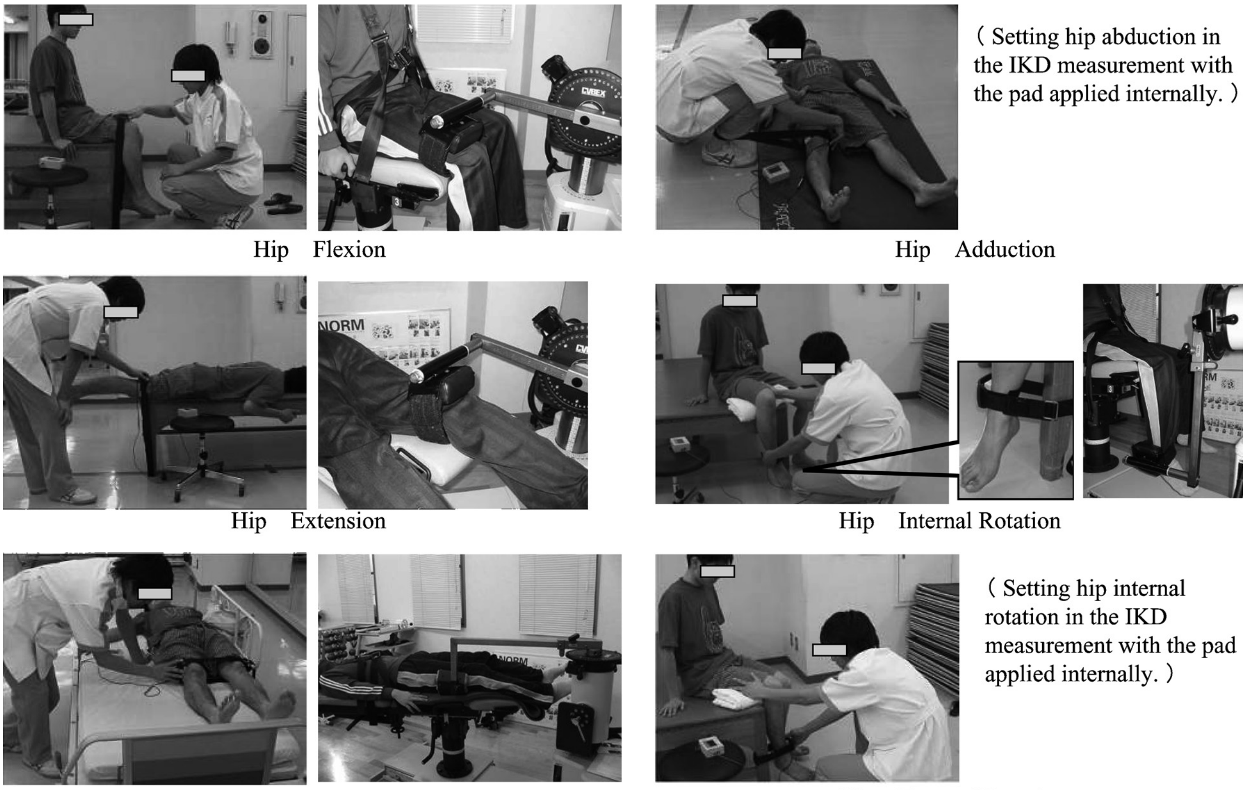

Fig. 1a. Two methods of isometric muscle strength test for the hip
Photographs show two measurements of isometric muscle strength for the hip, using the hand-held dynamometer and belt (left) and isokinetic dynamometer (right).

Fig. 1b. Two methods of isometric muscle strength test for the knee
Photographs show two measurements of isometric muscle strength for the knee, using the hand-held dynamometer and belt (left) and isokinetic dynamometer (right).

Table 1. Subjects' posture, dynamometer position and belt fixation method during isometric muscle strength measurements made using a hand-held dynamometer with belt

Muscle action	Posture	Joint Position	Dynamometer Position*	Belt Fixation Method
Hip flexion	Sitting upright (1)	Hip flexed 90°, popliteal fossa floating	epicondylus of femur	Under table leg
Hip extension	Prone (2)	Hip at 0°, distal femur floating	epicondylus of femur	Under table leg
Hip abduction	Supine (3)	Hip at 0°, opposite pelvic side on pillow,touching bed rail	epicondylus of femur	Around bed rail
Hip adduction	Supine(4)	Hip at 0°, pelvis held by tester's hand	epicondylus of femur	Around tester's lower leg
Hip external rotation	Sitting upright (1)	Hip at 0°, thigh horizontal	Medial maleolus	Around table leg
Hip internal rotation	Sitting upright (1)	Hip at 0°, thigh horizontal	Lateral maleolus	Around table leg
Knee flexion	Sitting upright (1)	Knee flexed 90°, thigh horizontal	Medial maleolus	Around tester's lower leg
Knee extension	Sitting upright (1)	Knee flexed 90°, thigh horizontal	Medial maleolus	Around table leg

*lower part of sensor placed on top of part of body under test in opposite direction to movement, (1) On edge of a table, (2) On table, more proximal than sensor, (3) On bed, (4) On mat.

Table 2. Isometric muscle strength measurements by the hand dynamometer and belt method and the isokinetic dynamometer method

Muscle action		n	HHD-Belt[1)] [N]	IKD[2)] [N]	Cor. Co[3)]	Ratio[4)]	Difference[5)] [N]	Cor. Co[6)]
Hip	flexion	24	192.9 (53.0)	261.1 (86.1)	0.52**	0.74	68.2 (74.1)	0.79**
	extension	24	229.4 (96.4)	336.9 (129.7)	0.84**	0.68	107.5 (72.0)	0.68**
	abduction	24	103.8 (36.3)	305.9 (96.5)	0.34	0.34	202.1 (90.8)	0.93**
	abduction[7)]	23	104.9 (36.8)	295.6 (84.0)	0.49*	0.35	– –	–
	abduction[7)]	22	103.9 (37.3)	286.3 (72.9)	0.51**	0.36	– –	–
	abduction[7)]	21	104.7 (38.1)	278.2 (63.7)	0.65**	0.38	– –	–
	adduction	24	81.9 (26.4)	315.7 (157.5)	0.52**	0.26	233.8 (145.6)	0.99**
	external rotation	24	90.3 (40.6)	110.1 (52.7)	0.86**	0.82	19.8 (27.6)	0.65**
	internal rotation	24	93.5 (35.0)	136.9 (56.5)	0.77**	0.68	43.4 (37.0)	0.80**
Knee	flexion	24	110.4 (72.2)	191.2 (82.8)	0.88**	0.58	80.8 (39.0)	0.49*
	extension	24	215.0 (101.9)	445.0 (223.0)	0.75**	0.48	230.0 (161.7)	0.91**

1&2) mean(SD), 1) Hand-held dynamometer and belt method, 2) Isokinetic dynamometer method, 3) Pearson's correlation coefficients for the two methods, 4) Ratio of measurements by the two methods: (HHD-Belt)/(IKD), 5) Difference of measurements by the two methods: (IKD)-(HHD-Belt), 6) Pearson's correlation coefficients for the refference of measurements by the two methods and measurements by IKD, 7) Measurements when subjects with the highest measurements of hip abduction in IKD were excluded from the calculation, *: p<0.05, **: p<0.01.

Table 3. Validity of measurement of muscle strength using a Hand-held dynamometer

reporters		subjects	n	age	muscle action	HHD*	IKD**	Cor.Co†
Sullivan,et al.[16)]	(1988)	Healthy male	14	23	shoulder external rotation	47 Nm[1)]	49 Nm	0.519
						48 Nm[2)]	47 Nm	0.78
Bohannon,et al.[17)]	(1990)	Healthy female	20	29.2	knee extension	129.4 Nm	126.3 Nm	0.797[13)]
Reed,et al.[18)]	(1993)	Healthy older male and female	32	70.3	elbow flexion	33 kg	39 Nm[12)]	0.84
					elbow extension	24 kg	32 Nm[12)]	0.85
					knee flexion	26 kg	75 Nm[12)]	0.77
					knee extension	32 kg	122 Nm[12)]	0.74
Deones,et al.[19)]	(1994)	Male and female who had knee pathologies	21	24.2	knee extension	240.8 N[3,5)]	509.7 N[12)]	0.80
						256.7 N[4,5)]	622.1 N[12)]	0.66
						255.0 N[3,6)]	509.7 N[12)]	0.73
						256.8 N[4,6)]	622.1 N[12)]	0.57
Jackson,et al.[20)]	(1994)	Healthy female	30	28.4	knee flexion	12.49 kg[7)]	13.08 kg	0.85
						7.49 kg[8)]		0.83
Gagnon,et al.[8)]	(1998)	Male and female who had undergone TKA (total knee arthroplasty)	25	68.2	knee flexion	47.5 Nm[9,11)]	50.9 Nm	0.85
						47.4 Nm[10,11)]		0.83
						42.2 Nm[9,6)]	37.3 Nm	0.90
						41.3 Nm[10,6)]		0.91
					knee extension	33.2 Nm[9,11)]	27.5 Nm	0.73
						31.1 Nm[10,11)]		0.75
						43.6 Nm[9,6)]	55.5 Nm	0.86
						39.8 Nm[10,6)]		0.91
		Male and female who had undergone THA (total hip arthroplasty)	25	67.0	knee flexion	45.0 Nm[9,11)]	52.1 Nm	0.89
						45.0 Nm[10,11)]		0.92
						45.0 Nm[9,6)]	42.0 Nm	0.91
						45.5 Nm[10,6)]		0.90
					knee extension	46.6 Nm[9,11)]	49.5 Nm	0.78
						47.8 Nm[10,11)]		0.86
						54.3 Nm[9,6)]	72.9 Nm	0.87
						56.4 Nm[10,6)]		0.93
Martin,et al.[21)]	(2006)	Healthy older male and female	20	72.6	knee extension	68.9 Nm	83.4 Nm	0.91

*: Hand dynometer and belt method, *: Isokinetic dynamometer method, †:Pearson's correlation coefficient of the measurements excluding 10), 1)Day 1, 2)Day 2, 3)Injured, 4)Noninjured, 5)0° of knee flexion,6)60° of knee flexion,7)HHD 1, 8)HHD 2, 9)Evaluator 1, 10)Evaluator 2, 9)10)HHD was fixed to the chair with the steel suport, 11)30° of knee flexion,12) 60° /sec, 13)Intraclass correlation coefficient formula 3,1.

measured the muscle strength of lower limbs of healthy young male and female subjects using a HHD and belt anchored to an immovable object, as well as a HHD fastened to the examiner's hand. The mean measured values obtained using the anchored HHD and belt, were higher than those obtained when the HHD was fastened to the examiner's hand. Therefore, though use of a HHD and belt produces lower values of measurement than use of an IKD, we suspect that values measured using an anchored HHD and belt are smaller than those measured using a HHD fastened to the examiners hand and those obtained using an IKD.

The correlation coefficients of the difference of measurements by the two methods and measurements by IKD ranged from 0.49 to 0.99, and showed significant correlations. Therefore, we think that it is necessary to consider the difference of the measurements by two methods for subjects with high muscle strength. We think that one factor of the difference of the measurements by the two measurement methods was systematic errors of the measuring method. Possible factors contributing to this difference between the HHD and belt and the IKD include the fixation of the pelvis and trunk in IKD, and using a special back support and belt. Also, the thickness and the softness of the pad that presses against the body at the sites to be measured in IKD to alleviate pain or the sensation of pressing may have additional effects. Future studies will need to investigate the factors contributing to the higher measured values obtained when using an IKD compared to those obtained when using a HHD and belt. It will also be necessary to improve the HHD and belt method so that its results better resemble the measurements by IKD.

Based on the above findings, isometric muscle strength measurement of the hip and knees using a HHD and belt are considered to have criterion-related validity compared with measures obtained when using an IKD. However, the findings also showed that there is a need to consider that the measured values obtained when using a HHD and belt are lower than those obtained when using an IKD.

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