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Is Hand-Held Dynamometry Useful for the Measurement of Quadriceps Strength in Older People? A Comparison with the Gold Standard Biodex Dynamometry

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Key Words
Hand-held dynamometry · Quadriceps muscle strength · Methodology, quadriceps strength measurement

Abstract
Background: The lower limb muscle strength is an important determinant of physical function in older people. However, measurement in clinical and epidemiological settings has been limited because of the requirement for large-scale equipment. A protocol using a novel, versatile hand-held dynamometer (HHD) has been developed to measure the quadriceps strength in a supine position. ***Objective:*** The objective of this study was to assess the validity of this new methodology for measuring the lower limb muscle strength compared to the gold standard Biodex dynamometer. ***Methods:*** The supine quadriceps strength was measured twice with each of the Biodex and the HHD in 20 men and women, aged 61–81 years, on their non-dominant leg. The agreement between the peak torques obtained by Biodex and HHD was analyzed. ***Results:*** The mean peak Biodex and HHD results were 83.4 ± (SD) 28.0 Nm and 68.9 ± 19.6 Nm, respectively. The HHD undermeasured the quadriceps strength by an average of 14.5 Nm (95% CI 8.5, 20.6) compared to the Biodex, and this effect was most marked in the strongest participants. Nevertheless, there was a good correlation between the measures ($r = 0.91$, $p < 0.0001$). Classification of individuals into tertiles of muscle strength showed good agreement between the two methods (Kappa = 0.69, $p < 0.0001$). ***Conclusions:*** Our findings suggest that the HHD using a supine positioning offers a feasible, inexpensive, and portable test of quadriceps muscle strength for use in healthy older people. It underestimates the absolute quadriceps strength compared to the Biodex particularly in stronger people, but is a useful tool for ranking muscle strength of older people in epidemiological studies. It may also be of value for quick and objective assessment of physical function in the clinical setting.

Introduction

Loss of muscle strength in adulthood has been linked to frailty [1], increased risk of disability [2–6], and morbidity [7] – all of which can lead to a loss of independence in older people. Muscle strength also predicts survival in middle age and later life [8, 9], and there has been grow-

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ing interest in the development of suitable portable methodology to measure muscle strength in clinical and epidemiological settings.

Isokinetic dynamometers, such as the Biodex system II dynamometer, provide accurate assessments of dynamic and also static muscle strengths [10] and are usually the preferred option for clinical studies. However, their use in large-scale epidemiological studies is limited, because the equipment is costly and not portable. Thus muscle strength measurement is often omitted or limited to the use of a hand-held device such as a handgrip strength dynamometer. This has been widely used [11–13], and good validity and repeatability have been demonstrated [14, 15]. However, it cannot be adapted to measure other muscle groups, and assessment of lower limb strength has been more difficult.

A novel, versatile hand-held dynamometer (HHD) has been developed which can measure the strength of most upper and lower body muscle groups. Standardized protocols exist for isometric measurement of quadriceps strength, namely the seated knee extension technique [16]. However, when using a HHD, this position requires considerable observer strength in order to stabilize the HHD and maintain the isometric positioning. Therefore, we have tested a supine technique to measure isometric quadriceps femoris strength using hand-held dynamometry [17] in older people and compared it with findings from the gold standard Biodex system II dynamometer.

Subjects and Methods

Twenty participants (9 men, 11 women), aged 61–81 years, were recruited through local retirement clubs, churches, and activity clubs (table 1). Full ethical approval was obtained for the study, and written informed consent was obtained from all participants.

The participants attended a 45-min appointment at the University of Southampton's Biomechanics Laboratory. Height, weight, and current age were recorded before commencement of testing. The lever (lower leg) length was measured using a standard circumference measure (CMS Instruments), from the lateral epicondyle of the non-dominant knee to the medial malleolus. The participants were asked to perform basic warm-up and cool-down exercises before and after the test. These consisted of gentle marching on the spot and bending over to touch ankles. Half the participants performed the Biodex first followed by the HHD, whereas the other half performed the HHD first followed by the Biodex, in order to eliminate any possible effect of participant fatigue. A 10-min resting period was provided for participants in between testing on the two machines to further reduce the effects of participant fatigue. Standardized encouragement was provided during the contractions; however, no feedback on results was given until after completion of testing with both machines. All men and women were measured by the same female examiner on their non-dominant leg.

Table 1. Participant characteristics (n = 20)

	Mean (SD)
Peak Biodex strength, Nm	83.4 (28.0)
Peak HHD strength, Nm	68.9 (19.6)
Age, years	72.6 (5.0)
Height, m	1.67 (0.08)
Weight, kg	77.1 (14.2)
Lever length, m	0.35 (0.02)

Biodex System II (Biodex) Dynamometry

The Biodex was calibrated and warmed up before each testing session as recommended in the Biodex manual (Biodex Medical, New York, N.Y., USA) [18]. The seat was converted into a flat couch using foam pillows to resemble a standard examination couch. The dynamometer was positioned with the lever arm immediately adjacent to the participant's non-dominant leg, and the lateral epicondyle of the non-dominant knee was aligned with the axis of the dynamometer. The Biodex isokinetic dynamometer was set to measure isometric knee extension strength at a 35-degree angle. It was programmed to perform three timed repetitions with a muscle contraction duration of 5 s and a relaxation period of 120 s between each repetition. The time of the start and finish of the muscle contraction was indicated by a traffic light system on the Biodex computer interface. The observer instructed the participant with the following commands: amber = get ready, green = go, red = stop and rest.

As shown in figure 1, the participants were asked to lie supine on the Biodex couch, with a bolster (SCA Hygiene Products, Dunstable, UK) positioned under the knee of the non-dominant leg. The bolster consisted of a solid tube wrapped with several hundreds of tightly rolled paper towels [17]. The bolster was checked after each test on each machine, and no compression had occurred; however, a new bolster was used for each participant as a precautionary measure. The positioning of the bolster ensured that the knee was flexed at an angle of 35° from the fully extended position, and this was verified using a goniometer. The participants were instructed to maintain their knee in contact with the bolster throughout the testing, and this was checked by the observer. The observer can more easily stabilize the HHD and maintain the positioning at this angle, and thus it is more likely to yield reliable results [17, 19]. The HHD is designed as a portable tool and has the advantage of being able to be used in a community-based environment. As it is not always feasible to use hip restraints outside of a clinic/laboratory environment, the hips were not restrained in this study. However, in order to address this issue, the dominant (untested) leg was flexed at the hip and knee so that the foot lay flat on the couch; this positioning helps stabilize the pelvis. The participants were also instructed to keep their hips still and retain buttocks flat on the couch and their knee in contact with the bolster to keep the 35-degree angle. This was monitored throughout the test, and any deviation from this positioning resulted in a repeat of the test. The participant's arms were positioned loosely across their chest. A padded strap connected to the dynamometer lever arm was fixed around

Fig. 1. Biodex dynamometer and study participant positioning for Biodex and HHD measurements.

the ankle of the non-dominant leg proximal to the medial malleolus. On the examiner's instruction, the participants were asked to push maximally against the pad, trying to straighten their leg from the knee. One practice go was performed and discarded, followed by two further attempts which were recorded. The peak torque of each of the two attempts was recorded in newton metres (Nm).

Set-Up of the HHD

The HHD shown in figure 2 (model 01163; Lafayette Instrument Company, Lafayette, Ind., USA) was programmed to measure the peak force in kilograms during 5 s of muscle contraction. The HHD indicated the start and the finish of the 5-second duration by audible beeps (1 for start and 3 successive for stop). In between each of three repetitions, a 120-second relaxation period was timed using a standard sports LCD chronograph stopwatch. Set-up of the couch and positioning of the participant were the same as for the Biodex; however, the pad of the Biodex was removed from the ankle and replaced with the pad connected to the HHD. The examiner used an isometric make test, whereby she held the HHD in a fixed position, and the participants were asked to push against it maximally. A make test as opposed to a break test (whereby observers attempt to break the participants force) is thought to be easier for participants to perform and, therefore, produces more reliable results [20]. One practice go was performed and discarded, followed by two further attempts which were recorded.

The peak force of each attempt was recorded in kilograms and later converted into torque (Nm) in order to compare the results with the Biodex. The following conversion formula was used:

HHD reading (kg) $\times$ 9.81 $\times$ lever length (m) = torque (Nm)

Statistics

The peaks of the Biodex and the HHD readings from the two attempts were used for the analysis. The agreement between the Biodex and the HHD was assessed using Pearson correlations and a Bland-Altman analysis [21]. The HHD and Biodex peak readings were categorized into tertiles of strength. A Kappa coefficient was then used to assess the agreement between the tertiles.

Fig. 2. Hand-held dynamometer.

Results

The overall mean peak Biodex and the HHD results were 83.4 $\pm$ (SD) 28.0 and 68.9 $\pm$ 19.6 Nm, respectively. Figure 3a shows that the HHD results correlated well with those of the Biodex ($r = 0.91$, $p < 0.0001$); however, although the results are correlated in that if the Biodex records a high reading so does the HHD, it is important to also consider the magnitude of any differences between the two tools. Bland-Altman analysis shows the abso-

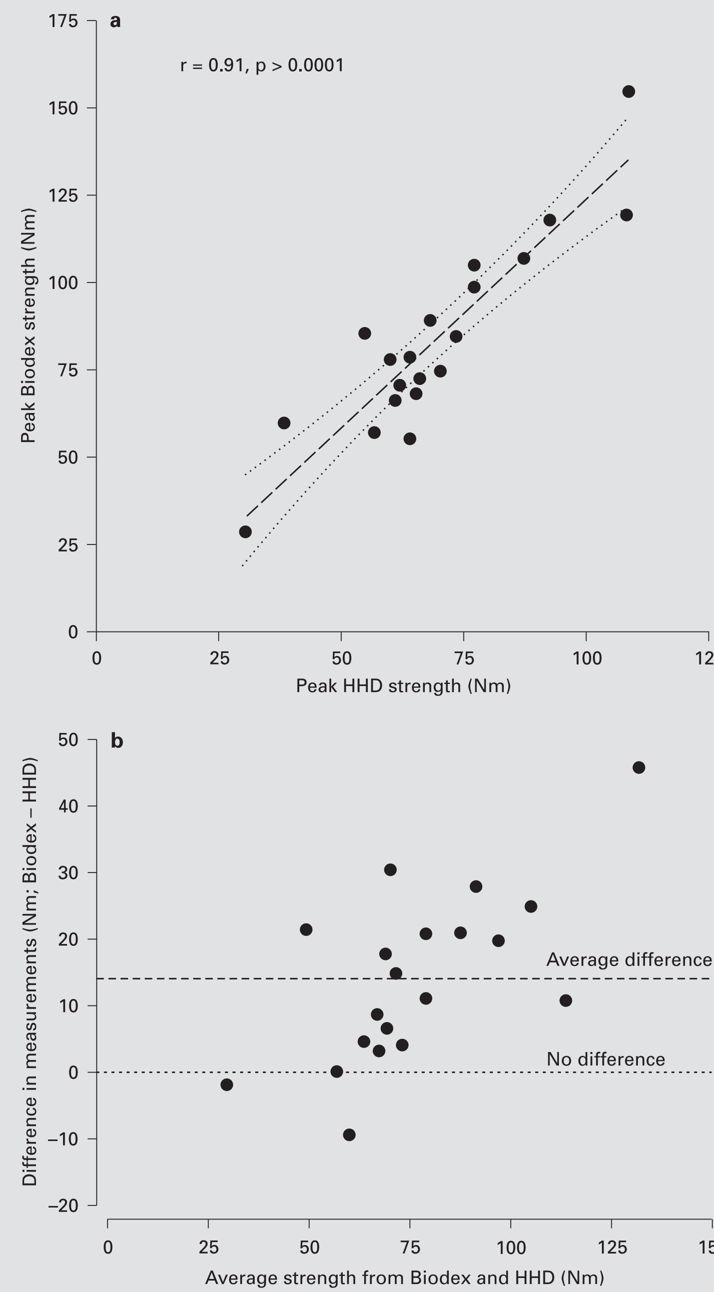

Fig. 3. a Correlation between Biodex and HHD measurements. Regession line of best fit (Biodex = –6.54 + 1.31 × HHD) and 95% CI. **b** Bland-Altman plot for Biodex and HHD measurements.

lute differences between the Biodex and HHD readings (fig. 3b). This shows that the HHD tended to underestimate the quadriceps strength by an average of 14.5 (95% CI 8.5, 20.6) Nm as compared with the Biodex, and differences between the Biodex and the HHD readings became increasingly more apparent amongst the stronger people.

The Biodex and the HHD readings were further assessed using a Kappa coefficient. Table 2 shows the frequency distribution of the participants classified accord-

Table 2. Frequency distribution by tertiles of Biodex and HHD measurements

Tertiles of strength by Biodex, Nm	Tertiles of strength by HHD, Nm		
	<63	–76	>76
<72	5	2	0
72–97	2	5	0
>97	0	0	6

ing to tertiles of muscle strength using the two methods. The agreement between these two classifications was good (Kappa = 0.69, $p < 0.0001$).

Discussion

We have tested a novel dynamometer (HHD) using a supine knee extension technique to measure quadriceps strength in older people. This method is feasible for use in older populations and has the great advantage of being portable and inexpensive. The positioning offers a good alternative to the standard seated knee extension position [16]. Several studies have assessed the use of a HHD for a seated knee extension test in terms of validity, repeatability, and reliability [22–25] in younger people, but few have included healthy older participants, and the results have been conflicting [26, 27]. Poor reliability using this technique has been attributed to low observer strength and poor stabilization of the participant which is especially apparent when measuring powerful muscle groups such as the quadriceps [22, 28, 29]. We have previously reported such difficulties with the seated technique and the high level of difficulty in performing this test, and we have started to address the issue of reliability in a study primarily conducted to measure the reliability of supine HHD of quadriceps measurements from different observers [30]. However, further studies need to explore the reliability using the HHD for supine quadriceps measurement.

Supine and seated knee extension strength are correlated, but the supine strength is lower [31]. We have, therefore, used a HHD to measure the knee extension strength in a supine position and compared the findings with those obtained with the gold standard Biodex system II dynamometer in a group of healthy older people. We have found the supine technique both easier for the participants to perform and also easier for the observer to stabilize and maintain the testing position. The results showed a good correlation between the two dynamometers. However, there were important differences between the results for the two devices that need to be considered.

On average, the HHD underestimated absolute quadriceps strength by 14.5 Nm relative to the Biodex. Of more concern was the evidence that the underestimation was more marked in the strongest people, as this could result in systematic error in measurement of muscle strength using a HHD. This problem is likely to reflect observer bias, where the observer was not strong enough to maintain the testing position in stronger participants, and is a problem previously recognized in the literature with the seated testing position [22, 28, 29]. We suggest that the strength of the observer relative to the participants is an important consideration, particularly when measuring larger muscle groups such as quadriceps femoris, and the development of muscle-group-specific protocols is essential.

In addition to looking at absolute muscle strength, we also used our data to rank participants into tertiles of muscle strength and again compared the methodologies. This showed good agreement between the two approaches, consistent with previous studies [22, 26]. The HHD did not misclassify any of the participants who were in the highest tertile for muscle strength according to the Biodex measurement, and only 2 people in each of the middle and lowest tertiles were misclassified. Therefore, a HHD used to measure the supine quadriceps strength may be most useful for ranking the lower-limb muscle strength of older people in epidemiological studies. It may also be of value for quick, objective assessment of lower-limb physical function in the clinical setting.

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