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Adequacy of Belt-Stabilized Testing of Knee Extension Strength

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Abstract

Tester strength can limit the forces that can be measured using a hand-held dynamometer (HHD). A solution is to use belt-stabilization in conjunction with a HHD. The purposes of this study were to determine if a portable belt-stabilized HHD (BSHHD) set-up was capable of measuring a broad range of isometric knee extension torques and whether isometric knee extension torques measured using a portable BSHHD system were comparable to those obtained using a Biodex isokinetic dynamometer. Participants in the study were 113 women and 71 men (14–85 years of age) community-dwelling enrollees in the NIH Toolbox for the Assessment of Neurological and Behavioral Function. Knee extension torques measured using a BSHHD ranged from 35.0–416.0 Nm. Torques measured with the BSHHD were significantly lower ($p < .001$) than those measured using the isokinetic dynamometer (mean difference: 35.6 Nm left, 33.7 Nm right). However, the measures were highly correlated ($r > .86$, $p < .001$). Torques obtained with a BSHHD may not equal the maximum that individuals can generate, but they reflect such torques. We conclude, therefore, that a portable BSHHD set-up is a viable option for measuring a wide spectrum of knee extension torques in diverse settings.

Keywords

muscle; measurement; knee; dynamometry

INTRODUCTION

Sufficient strength of the knee extensor muscles is a prerequisite to the optimal performance of weight bearing tasks such as walking, standing from a chair, and climbing stairs (7,8,13). It is understandable, therefore, that the strength of the muscle group is so often tested. The objective measurement of knee extension strength can be accomplished through the use of dynamometers. Among such dynamometers are those held in the hand of a tester and applied against an individual's knee extension efforts. These hand-held dynamometers (HHDs) are

portable, simple, and relatively inexpensive. Nevertheless, the validity of measurements obtained with them is dependent on a tester having adequate strength to hold the device against the effort of the individual being tested(14). As testers do not always possess sufficient strength, “belt-stabilized” testing with the HHD has been suggested(3,9). In such testing the tested individual’s effort is restrained by a belt so that the tester needs only to maintain a proper orientation of the HHD during testing. The reliability of belt-stabilized testing has been examined(3,9), but its adequacy for measuring knee extension forces has not been detailed. The purpose of this study was to answer 2 questions relevant to the adequacy of an isometric belt-stabilized testing of knee extension strength. First, does portable belt-stabilized testing enable a broad range of knee extension torques to be measured? Second, are knee extension torques measured by a portable belt-stabilized testing set-up comparable to those obtained with a “gold standard” isokinetic dynamometer(10)?

METHODS

Experimental Approach to the Problem

This investigation was part of the validation phase of the NIH Toolbox study, a study designed to identify a brief but comprehensive battery of portable, low-cost and lay-administered measures of cognitive, motor, sensory, and emotional health and function for use in large cohort studies (4). The present study employed motor domain data gathered by 7 trained testers at 2 participating sites. More specifically, it involved bilateral measurements of knee extension torque obtained via two options, belt-stabilized HHD (BSHHD) and isokinetic dynamometry.

Participants

The institutional review boards of the University of Connecticut and the Rehabilitation Institute of Chicago approved the study. Prior to enrollment in the study all participants were fully informed regarding the study’s purpose, procedures and risks. Written informed consent was obtained from all participants, or in the case of participants less than 17 years, from the participants and a parent/guardian. Inclusion in the study required that participants were fluent in English, were able to walk without an assistive device, were between 14 and 85 years of age, and had no heart, vascular, lung, or bone/joint problems that precluded their standing from a chair or climbing steps.

Procedures

Basic demographic (age, gender) and anthropometric (height, weight [body mass index]) data were first obtained. Thereafter, isometric knee extension strength (torque) was measured bilaterally in varying order using both a BSHHD and an isokinetic dynamometer while subjects were seated with their knees at about 90 degrees of flexion (ie, with their legs vertical). For the BSHHD testing, participants were seated on an elevated commercially available chair with foam padding and stabilizing straps for the proximal thighs and waist. A dynamometer stabilizing belt passed around a bar secured behind the back legs of the chair and over a calibrated Micro FET HHD that was placed against the anterior legs of participants just proximal to the malleoli (Figure 1a). The distance from the estimated knee axis of rotation (lateral epicondyle of femur) to the midpoint of HHD application was measured in centimeters for later calculation of torque. Test-retest (6–14 day interval) reliability of measures obtained with the BSHHD at our 2 test sites was good ($n = 32$, intraclass correlation coefficient = .88 [95% CI = .76–.94]). For isometric testing with an isokinetic dynamometer, a Biodex isokinetic dynamometer was used. Participants were stabilized with thigh, waist and chest straps (Figure 1b). The reliability of measurements of knee extension torque obtained with the Biodex is well established(4).

Three trials with each extremity, separated by a 30 second rest, were performed using both a BSHHD and a Biodex. The first trial was a strong but not maximal effort and served as a “warm-up.” It was not recorded. The following 2 test trials were at maximal effort. Regardless, participants were requested to “take a second or 2” to come to the requested effort and then continue pushing their leg out as requested until told to stop (ie, after a total of 5 seconds). For testing with BSHHD, peak force was read from the Micro FET’s digital display. This value was multiplied by the distance between the knee and point of HHD to obtain torque (in Nm). For tests with the Biodex dynamometer peak torques were determined from computer displayed torque curves.

Data Analysis

For both BSHHD and Biodex testing, the best of the 2 maximal effort torques measured on each side was used in subsequent analysis. Statistical calculations were performed using the Statistical Package for Social Sciences (version 14.0). After standard descriptive statistics were calculated, differences in BSHHD and Biodex measures of knee extension torque were determined using paired t-tests. Linear regression, Pearson correlations, and scatter plots were used to examine the relationship between measurements obtained using the 2 procedures.

RESULTS

One hundred eighty-four participants contributed data to this study. There were 113 women and 71 men whose ages ranged from 14 to 85 years (46.3 ± 22.7 years). Their height ranged from 1.51 to 2.09m (1.69 ± 0.11 m) and their mass ranged from 42.6 to 135.8kg (73.3 ± 16.7 kg). Body mass index, therefore, ranged from 14.9 to 42.3 kg/m² (25.5 ± 4.9 kg/m²).

It was possible to measure the knee extension torque of all participants using both procedures. The mean torques measured using the BSHHD exceeded 135 Nm. The torques of many participants surpassed 250 Nm. Table 1 compares the best knee extension torque measurements of the left and right sides obtained using the BSHHD and Biodex procedures. The t-tests demonstrated that the knee extension torque measurements obtained with the Biodex were significantly higher ($p < .001$) than those obtained with the BSHHD on both the left (mean difference = 35.6 Nm) and on the right (mean difference = 33.7 Nm). Figure 2 shows scatter plots of measurements obtained with each procedure. The linear regression equations and correlations in Table 2 ($r > .860$) support the linear relationship between torques while confirming that those obtained with the Biodex were systematically higher.

DISCUSSION

This component of the NIH Toolbox validation shows that trained testers can measure knee extension torque using BSHHD, even if those tested are generating high torques. Thus the limitations that tester strength can impose on measurements obtained with an unstabilized HHD (9,11,14) do not appear to apply when a BSHHD is used.

Nevertheless measurements obtained with the BSHHD in this study were significantly less than those documented using the gold-standard Biodex. The differences in torques obtained with the 2 procedures (33.7 and 35.6 Nm) were greater than those reported by Martin et al, but they tested only women (> 60 years) and did not use belt-stabilization in conjunction with their HHD (10). We are uncertain why torques measured with the 2 procedures differed in our study, but believe it might stem from superior stability and comfort offered by the Biodex test chair.

Hart et al established long ago that trunk stabilization affects measured knee extension torques(6). Both comments by participants and observation of the participants during testing suggested that the Biodex chair provided better stabilization than was possible with the commercially available chair used with the BSHHD. The depth of the chair used in BSHHD testing, unlike the Biodex test chair, did not allow the thigh of many individuals to be fully supported. As both dynamometer testing set-ups involved a first class lever system, where some point under the posterior thigh acts as a fulcrum, a failure to fully support the thigh could alter the location of that fulcrum. It is interesting to note that previous research comparing isometric measurements obtained with a HHD and an isokinetic dynamometer showed no significant difference in torques when both types of measurement were obtained with subjects seated in the same isokinetic dynamometer test chair(10,12).

Another explanation for the difference in torques obtained with a BSHHD and the isokinetic dynamometer is greater comfort during testing in the Biodex chair. Several participants reported discomfort behind their thighs during testing with the BSHHD. The lack of full thigh support (addressed heretofore) may have been a factor; less thigh support would result in less contact area with the chair and thus more pressure on the posterior thigh. This could be aggravated by inadequate stabilization. Several participants also reported discomfort at the dynamometer-shin interface during testing with the BSHHD. The contact area of the dynamometer pad is substantially less with the HHD than with the Biodex. Again, with less area there would be more pressure.

Test-set-ups that provide for greater stabilization and comfort should be investigated. Use of additional or differently positioned stabilizing straps may help. Grasping the sides of the test chair may also increase stabilization (11). Additional padding on the seat of the chair and on the HHD may increase comfort.

Tester strength is not a likely determinant of differences in torques in our study as very high torques were measured with both procedures. Moreover the relationship between the measures was essentially linear and unaffected by torque magnitude(slope close to 0).

The linear relationship ($r=.864$ & $.884$) between measures obtained using the 2 procedures also provides evidence that the same underlying construct was being measured, that is, knee extension strength. Similar correlations between measures obtained using a HHD without stabilization and an isokinetic dynamometer in other studies provide further evidence (1,2,10). Nevertheless, if strength is defined as the maximum torque that can be brought to bear on the environment, a BSHHD used in conjunction with a commercially available and portable chair did not capture maximum torque. This finding may not generalize to patients who are weaker than the normal individuals tested in this study as such patients may not require as much stabilization. Moreover, the results may not generalize to other muscle groups for which testing with HHD(belt-stabilized or not) can be performed while tested individuals are supine.

PRACTICAL APPLICATIONS

Measurements obtained with a BSHHD are significantly lower but highly correlated with those obtained with an isokinetic dynamometer. As the BSHHD is more portable and less expensive than the Isokinetic dynamometer and as limitations imposed by tester strength do not appear to apply, use of a BSHHD is suitable for testing the knee extension strength of healthy individuals wherever the test chair can be transported and accommodated. It, therefore, has been recommended for inclusion in the NIH Toolbox. As such, the BSHHD will be normed with a population-based sample of 4600 people aged 3 to 85 to provide population reference data for comparative purposes.

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Figure 1.
Test set-ups for measuring knee extension strength using Biodex testing (top) and belt-stabilized testing (bottom)

Figure 2. Scatterplots illustrating the relationship between knee extension torques obtained using belt-stabilized and Biodex testing of the left (top) and right (bottom) sides.

Table 1

Comparison of measurements of knee extension torque (Nm) obtained using 2 procedures

Side	Belt-resisted Torque Mean±SD (min-max)	Biodex Torque Mean±SD (min-max)	T-Test T value (p)
Left	135.6±59.2 (35.0–349.0)	171.2±72.7(35.6–420.0)	–13.073(.001)
Right	138.9±63.4(37.0–416.0)	172.62±70.6(33.7–416.4)	–13.826(.001)

Table 2

Results of linear regression and Pearson correlational (r) comparison of knee extension torques(Nm) obtained using two procedures

Side	Regression Equation	r (p) r ²
Left	Biodex torque = 27.26+ 1.06* Belt-resisted torque	.864(.001).746
Right	Biodex torque = 37.79+.98* Belt-resisted torque	.884(.001).781