**BRIEF REPORT**

New Assessment of Forearm Strength: Reliability and Validity

Christopher Kevin Wong, Neil Moskovitz

**KEY WORDS**
- forearm
- muscle strength dynamometer
- reproducibility of results

**OBJECTIVE.** The objective was to determine the reliability of a portable forearm strength hydraulic dynamometer with a doorknob handle and assess its validity compared with a Cybex 6000 (Cybex International, Inc., Medway, MA) isometric torque assessment.

**METHOD.** Eighteen volunteers (with a total of 30 forearms) participated in this one-session methodological study to determine the intra- and interrater reliability and criterion validity of a forearm dynamometer.

**RESULTS.** Intrarater reliability for both assessors for pronation was (intraclass correlation coefficient [ICC]3,1 = .937–.961) and for supination was (ICC3,1 = .923–.968). Interrater reliability for pronation was ICC3,2 = .927 and for supination was ICC3,2 = .847. Criterion validity of the Baseline hydraulic dynamometer (Fabrication Enterprises Inc., White Plains, NY) compared with the Cybex 6000 was .574–.664 for pronation and .749–.750 for supination.

**CONCLUSION.** The Baseline hydraulic dynamometer with a more functional doorknob handle had good intra- and interrater reliability and demonstrated moderate validity compared with Cybex 6000 strength testing.


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strength assessments (Bandy & McLaughlin, 1993). O’Sullivan and Gallwey (2005), however, pointed out that “forearm torque strength is not commonly measured” (p. 707), perhaps because clinicians lack a portable clinical assessment device that is both reliable and valid.

Work simulators and isokinetic assessment devices both measure isometric torque as the patient or client attempts to twist a bar-shaped vertical handle (Droll et al., 2006; Ellenbecker et al., 2006). The elbow has often been set in a position of 90° flexion (Gordon, Pardo, Johnson, King, & Miller, 2004; Shigeyama et al., 1993), a position found to maximize supination strength (O’Sullivan & Gallwey, 2002) because the position optimizes the moment arm of the biceps. Pronation strength was strongest in 45°/C176° elbow flexion (O’Sullivan & Gallwey, 2002). The position of the forearm has also been found to affect forearm strength and muscle activity. On the one hand, strength has been greatest when the relevant muscles were lengthened (i.e., supination torque was greatest in a pronated forearm position and vice versa; Matsuoka et al., 2006; O’Sullivan & Gallwey, 2002). On the other hand, forearm muscle activation as measured with electromyography has been greater when the muscle was in the shortened position (i.e., supination activation was greatest in the supinated position; Gordon et al., 2004). Grip position may also affect strength, because it has been found that forearm position alters grip strength (Richards, Olson, & Palminter-Thomas, 1996). Although the bar-shaped vertical handle is common (Gordon et al., 2004; Matsuoka et al., 2006; Shigeyama et al., 1993), a bar handle inclination angle of 70° has been tried to move closely approximate the power grip position (O’Sullivan & Gallwey, 2005).

In the course of performing a typical range of activities of daily living (ADLs), it is inevitable that people will grasp many different objects, such as doorknobs or screwdrivers, with a variety of different grasps. A new Baseline hydraulic dynamometer (BHD; Fabrication Enterprises Inc., White Plains, NY) designed to assess forearm pronation and supination strength has multiple attachments that mimic different everyday objects that may be manipulated. The BHD is a portable unit that can be outfitted with a bar-shaped vertical handle, doorknob, lever-style door handle, or screwdriver to simulate a variety of functional grips used in ADLs.

The objective of this study was to determine the reliability of the BHD portable forearm strength hydraulic dynamometer outfit with a doorknob handle and to assess its validity compared with a Cybex 6000 isometric torque assessment.

Method

Participants

This study examined a convenience sample of 18 healthy volunteers without disabilities recruited from a school of health sciences. All 18 volunteers were allied health science students: 17 were right-hand dominant, and 1 was left-hand dominant (Table 1). Six forearms were excluded because of ipsilateral upper-extremity pain or past dysfunction: 2 because of pain at rest, 2 because of rotator cuff pathology, 1 because of shoulder osteoarthritis, and 1 because of history of wrist fracture. Ultimately, 12 dominant and 18 nondominant forearms were included. The institutional review board of Touro College School of Health Sciences approved this study, and all participants signed an informed consent.

Design

We used a single-group repeated-measures design to establish the (1) test–retest intrarater reliability, (2) interrater reliability, and (3) criterion validity, compared with the Cybex 6000, of forearm pronation and supination strength assessment using the BHD.

Procedures

All volunteers came for one fall afternoon session during which pronation and supination strength were assessed with the BHD and the Cybex 6000. The BHD was outfitted with a 5.5-cm-diameter doorknob handle (5.8-cm depth) mounted securely on a tabletop platform. Each participant was instructed by a single assessor to sit grasping the doorknob with both shoulder and elbow positioned in visually approximated 45° flexion. The forearm was positioned in neutral and strapped to the platform with a hook-and-loop elbow band (Figure 1). The wrist was positioned in slight extension, and the participant was allowed to grasp the doorknob with a degree of ulnar deviation that was comfortable to generate an isometric twisting force to the knob. Isometric twisting force on the BHD results in force measured in kilograms. The Cybex 6000 was set up with a standard vertical bar handle (12.5 cm length, 3.7 cm diameter) with elbow and shoulder in 45° flexion; each participant was seated with his or her forearm stabilized in neutral and resting on a cushioned stand. The wrist was positioned in neutral with approximately 0° of ulnar deviation because of the vertical position of the bar handle (Figure 2). The Cybex 6000 results in torque measured in Newton-meters (Nm).

Two assessors measured the pronation and supination strength of each forearm using the BHD; a third assessor measured forearm pronation and supination strength using the Cybex 6000. All assessors were 3rd-yr doctor of physical therapy students specifically trained in BHD and Cybex forearm strength assessment during 5 hr of training over three sessions by the first author (Wong), who is a licensed physical therapist and orthopedic-certified specialist. Test order for the assessors was randomized, and all assessors were blinded to the other assessors’ results as well as to their own past results. Test order for pronation or supination was also randomized.

Participants were instructed to perform one pretest maximal isometric contraction with the verbal prompt “turn as hard as possible” and to rest 30 to 60 sec before testing. Thereafter, participants were instructed to perform another maximal isometric contraction per each test condition while the verbal prompt was “twist as hard as possible.” Testing was repeated three times in each condition.

The Cybex 6000 isokinetic dynamometer (BHD; Fabrication Enterprises Inc., White Plains, NY) has multiple attachments that mimic different everyday objects that may be manipulated. The BHD is a portable unit that can be outfitted with a bar-shaped vertical handle, doorknob, lever-style door handle, or screwdriver to simulate a variety of functional grips used in ADLs.

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Participants were instructed to perform one pretest maximal isometric contraction with the verbal prompt “turn as hard as
you can” spoken at conversational volume. The assessors then repeated three trials of each strength assessment using the same verbal prompt, recording the average of the three trials for each motion, with 30-s rests between each repetition. After a 1-min rest period, each participant then performed three trials of the next motion with 30-s rests between repetitions. Each participant had a 3-min rest period before being assessed by the next assessor.

**Statistical Analysis**

The test–retest intrarater reliability of an assessment is obtained when the same rater administers the same assessment by the same rater twice. Interrater reliability of an assessment is obtained when the same assessment is administered by two or more assessors.

Criterion-referenced validity of a new assessment method can be determined by comparing the results of the new method with those of an accepted or gold-standard method. Data were collected to analyze (1) the test–retest intrarater reliability of the two assessors using the BHD to assess forearm pronation and supination strength, (2) the interrater reliability of the two BHD assessors, and (3) the criterion-referenced validity of the BHD assessments of the two assessors compared with Cybex strength assessment by the third assessor.

All statistical analysis was performed with SPSS 16.0 statistical package (SPSS–UK Ltd., Surrey, UK). Test–retest intrarater reliability was assessed using single-measure intraclass correlation coefficients (ICC$_{3,1}$). Interrater reliability of the average measures was assessed by calculating ICC$_{3,2}$. An acceptable level for good reliability was set at ICC ≥ .75 using common guidelines for the magnitude of reliability (Portney & Watkins, 2000). Criterion-referenced validity was determined by calculating Pearson’s correlation coefficient; an acceptable range was set at $r$ ≥ .70 for average measures of BHD and Cybex 6000 strength assessments.

**Results**

Participant characteristics are presented in Table 1. Intrarater reliability of the two assessors for pronation strength (ICC$_{3,1}$) ranged from .937 to .961; for supination strength, it ranged from .923 to .968. Interrater reliability for pronation strength (ICC$_{3,2}$) was .927; for supination strength (ICC$_{3,2}$), it was .847 (Table 2). The Pearson correlation coefficient for the two assessors using the BHD compared with the Cybex 6000 strength assessment for pronation ranged from .574 to .664 and for supination ranged from .749 to .750.

**Discussion**

Using the doorknob-equipped BHD, both assessors demonstrated good intrarater reliability for assessment of both pronation and supination strength with all ICC coefficients >.90. Interrater reliability between the two assessors for both motions was also good, although assessment of supination strength (ICC = .847) demonstrated lower reliability than pronation (ICC = .927). The reliability for forearm strength assessed with the BHD was consistent with the range of reliability coefficients (.82–.99) reported for intrarater reliability of upper-extremity strength assessments with other dynamometers (Bohannon, 1986; Magnusson, Gleim, & Nicholas, 1990; May, Burnham, & Steadward, 1997), suggesting that the BHD with doorknob handle can be used to...
obtain isometric pronation or supination strength measures that are as reliable as other dynamometers currently in use.

Criterion-referenced validity compared with the Cybex 6000 was moderate for pronation and good for supination using common guidelines for the magnitude of reliability (Portney & Watkins, 2000). The correlation coefficients for forearm strength assessed with the BHD compared with Cybex testing ranged from .574 to .750 for the two assessors, which was somewhat lower than the .86 previously reported using a handheld dynamometer compared with a Cybex strength assessment (Magnusson et al., 1990). Although the shoulder and elbow position were kept consistent between the Cybex 6000 and BHD assessments, the difference between testing with a doorknob compared with an upright bar handle may account for the difference in strength assessments. The bar handle involves a different grip and angle of wrist deviation than the doorknob. The bar handle may allow a greater moment arm because of its larger width, particularly for people with large hands. Participants with larger hands may also have found the doorknob’s relatively small diameter and depth to be difficult to manipulate, which may have forced them to grasp the doorknob in different adaptive hand positions that emphasized the fingers, preventing a power grip and twist. Regardless of the differences in wrist and hand positions when grasping the doorknob and bar handle (see Figures 1 and 2), it appears that the BHD provides a moderately valid measure of forearm pronation–supination strength compared with Cybex testing. In addition, the BHD with doorknob handle provides clinicians with a portable and reliable clinical tool for the assessment of forearm pronation and supination that may more closely mimic the functions encountered in people’s everyday life.

Average pronation and supination strength observed in this study (see Table 1) were compared with the known normal data for average pronation and supination strength. The strength measured by the BHD (kg) and the Cybex (Nm) were not in the same unit of measure, however. The BHD strength values in this study (61.9–65.3 kg) were similar to the strength values obtained in another study that reported forearm strength of 47.9–68.9 kg-cm (Shigeyama et al., 1997). The Cybex measures of forearm strength in this study (5.0–5.4 Nm) were also comparable to past research. For instance, one study with participants of both genders found pronation and supination strength that ranged from 5.4 to 7.4 Nm (Matsuoka et al., 2006). Past research has found that women demonstrated 53%–58% of the forearm strength of men (Kramer et al., 1994), and a similarly significant difference was observed when strength values were normalized for body weight (Forthomme, Croiser, Foidart-Dessalle, & Creilhaar, 2002). Likewise, a gender disparity was also observed in the current study: Men were 63% stronger in forearm pronation ($p < .001$, independent $t$ test) and 68% stronger in supination ($p < .05$, independent $t$ test) than women. Gender-related differences in forearm strength might explain why dominant arm forearm strength has been observed to be as high as 12.6 to 14.8 Nm in a group of men (O’Sullivan & Gallwey, 2002).

The nondominant arm has been found to perform at 81%–95% of the dominant arm in most positions of forearm rotation (Forthomme et al., 2002; Matsuoka et al., 2006), consistent with the findings of the current study, in which the nondominant arm had 87% and 94% of dominant arm pronation and supination strength, respectively, although the difference was not statistically significant ($p > .05$, independent $t$ test). Average pronation strength was 5.5% or 8.0% (measured with the BHD or Cybex, respectively) greater than supination strength in this study. This result may be because of the positioning of the elbow at 45°, a position that has been found to produce the strongest pronation strength measurements, as opposed to 90° of elbow flexion, which optimizes the biceps muscle moment arm and has been found to maximize supination strength (O’Sullivan & Gallwey, 2002). Although no significant difference was found in this study, the findings are consistent with the findings of other researchers, who attributed greater pronation strength in the dominant arms of tennis athletes to the specific demands of their sport (Ellenbecker et al., 2006).

Limitations of this study include the small number of participants and non-normal distribution of participant ages, which limit the generality of the conclusions. Another limitation of the study was the lack of precise control of wrist and forearm position when the participants grasped the doorknob. Control for forearm position is important, because it has been found that muscle activation levels and performance on strength assessments vary with degree of forearm rotation (Gordon et al., 2004; Matsuoka et al., 2006; O’Sullivan & Gallwey, 2002). The effects of varied ulnar deviation angles on forearm rotation strength is unknown. Although efforts were made to maintain a standardized upper-extremity position during both the BHD and Cybex testing using a strap and careful initial positioning in this study, some slight variations that may have affected the reliability of both the BHD and the Cybex assessments inevitably occurred. Finally, the strength of the supinator and pronator were calculated from the average of three trials, a data reduction process that has been used in other studies (Gordon et al., 2004). This process may not reveal the absolute peak strength performance, which has been recorded by others using a different process (Shigeyama et al., 1997).

Precise control of functional activities, such as twisting a doorknob to open a door, are difficult to maintain because of individual variations in body height, hand size, strength, and the context in which the activities occur. This study measured forearm strength using a device mimicking the functional activity of twisting a doorknob, which is common to all people and cannot be measured by existing assessments of

### Table 2. Intraclass Correlation Coefficients (ICCs) for Intra- and Interrater Reliability of Forearm Strength

<table>
<thead>
<tr>
<th>Reliability</th>
<th>Intrarater 1 (95% CI)</th>
<th>Intrarater 2 (95% CI)</th>
<th>Interrater (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pronation</td>
<td>.937 (.892–.966)</td>
<td>.961 (.931–.979)</td>
<td>.927 (.845–.966)</td>
</tr>
<tr>
<td>Supination</td>
<td>.923 (.869–.958)</td>
<td>.968 (.944–.983)</td>
<td>.847 (.692–.924)</td>
</tr>
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</table>

*Note.* CI = confidence interval.
forearm strength such as Cybex. Future research should pursue forearm strength measures in symptomatic and dysfunctional patient populations, such as those with lateral epicondylitis or healing fractures. A potential line of inquiry is to involve correlating forearm strength assessed using the doorknob-outfit BHD with the functional performance level of related ADLs, such as opening a door or a jar. The BHD comes with other alternate attachments designed to mimic functional tasks, including a 20-cm-long, 3-cm-diameter screwdriver and a 24-cm-long, 2-cm-thick, lever-style door handle. Future research may investigate the reliability and validity of the BHD using these alternate attachments. Another line of inquiry is to determine whether strength changes documented using the BHD occur after a course of treatment and whether any strength change correlates to changes in functional performance. Such research may be useful to support treatment interventions for those with upper-extremity dysfunction and pain.

Conclusion

The BHD is a portable, reliable, and valid tool for measuring forearm strength when outfitted with a doorknob-shaped handle. Assessing strength with a device that mimics common functional tasks of daily living may provide the clinician with more insight into a person’s abilities and limitations. ▲

Acknowledgment

These data were previously reported in the context of another study in a research poster at the 2009 American Physical Therapy Association Annual Conference in Baltimore, Maryland.

References


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