Assessment of Postural Muscle Strength in Sitting: Reliability of Measures Obtained with Hand-Held Dynamometry in Individuals with Spinal Cord Injury

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Background and Purpose: Muscle weakness frequently impairs the ability to maintain upright sitting in individuals with spinal cord injury (SCI). The primary purpose of this study was to examine the intrarater and interrater reliability of hand-held dynamometry to assess postural muscle strength for maintaining upright sitting in individuals with SCI. We also assessed reliability of forces measured in four directions of force application and of measures obtained by experienced versus student physical therapist examiners.

Methods: Twenty-nine individuals with SCI (mean age, 32.4 ± 11.0 years; injury level C4–L1; American Spinal Injury Association Impairment Scale (AIS) classification A–D) participated in this study. The raters were two experienced physical therapists and two student physical therapists. Force was applied to the anterior, posterior, and right and left lateral trunk. Values were acquired in a group of participants who did not require upper extremity support for sitting (n = 22) and a group who did require upper extremity support (n = 7).

Results: Intrarater reliability was good to excellent (intraclass correlation coefficients, 0.80–0.98 [unsupported]; 0.79–0.99 [supported]) for all raters in the four directions of force application. Interrater reliability was excellent (intraclass correlation coefficients, 0.97–0.99 [unsupported]; 0.96–0.98 [supported]) for all directions. There were no significant differences among peak forces obtained among the four directions of force application or by experienced raters compared with student raters.

Discussion and Conclusion: The use of hand-held dynamometry to assess postural muscle strength for maintaining upright sitting in individuals with SCI has high intrarater and interrater reliability. The direction of force application and experience of the rater did not influence the level of reliability. Future research is needed to identify the minimum muscle strength required to maintain the seated posture and to understand how this measure relates to seated postural control and balance.

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INTRODUCTION

Loss of motor function and muscle weakness due to spinal cord injury (SCI) may impair the ability to maintain an upright sitting posture. An outcome measure that objectively measures postural muscle strength during upright sitting would be useful when documenting improvements due to intervention. In previous studies in individuals with SCI,[1,2] stroke,[3–5] and brain injury,[3] a hand-held dynamometer (HHD) has been used to quantify peak force while subjects attempted to maintain a sitting posture. To assess trunk strength, force was applied anteriorly to the midsternum,[1,2,4,5] posteriorly on the interscapular area,[1,2] or laterally on the shoulders[3–5]; no study has examined all four directions of force application in the same subject pool.

Although sitting posture is primarily maintained by the trunk muscles, pelvic, hip, and lower extremity muscles also assist in maintaining upright sitting in individuals without disability and those with chronic low back pain.[6] In individuals with SCI, muscles used to maintain upright sitting are dependent on the level of injury. In the absence of abdominal muscles, an individual with SCI may use neck and upper trunk muscles or recruit available arm muscles to maintain the sitting position. For example, individuals with paraplegia used "nonpostural" muscles, including the latissimus dorsi, trapezius, and pectoralis major, in addition to their innervated abdominal and paraspinal muscles, to maintain the sitting position.[7–11] In individuals with SCI, maintaining an active, upright sitting position against an external force cannot accurately be described as testing only trunk muscle strength. Therefore, the outcome measure examined in this study will be more generally described as postural muscle strength in the sitting position with or without bilateral upper extremity (UE) support.

Testing strength in upright sitting using HHD has several advantages over other methods, such as isokinetic dynamometry[6,12–14] or manual muscle testing (MMT).[15,16] When using an isokinetic dynamometer to test trunk flexion and extension strength, an individual may be required to move as little as 20 degrees to as much as 70 degrees at velocities of 30 to 180 degrees/sec, which may be impossible for individuals with SCI.[6,12–14] In addition, an isokinetic dynamometer may not be available in many clinical settings because of the high cost and space requirements, or not used because of the time-consuming nature of the test procedures. Performance of the specific movements required by standardized MMT procedures[15,16] may be problematic for individuals with SCI.[17] For example, testing the strength of the abdominal muscles requires performance of a partial sit-up from the supine position along with active stabilization of the pelvis and legs, a maneuver that is frequently impossible for individuals with SCI. Key trunk flexor muscles include the rectus, internal and external oblique abdominis, and iliopsoas muscles, and key trunk extension muscles include the iliocostalis, longissimus, spinalis, multifidi, gluteus maximus, and hamstrings muscles.[12,18] Testing all of these muscles is time consuming, and it is often difficult for individuals with SCI to assume the required test positions. In particular, many individuals with SCI do not tolerate the prone position because of respiratory compromise. In addition, MMT scales are nonlinear, ordinal, and relatively insensitive to change in muscle strength during the course of rehabilitation.[19–22] MMT scores have been reported to plateau, whereas hand-held dynamometry measurements continued to increase over time after SCI.[19] An MMT grade of 4/5 may be assigned with as little as 10% of predicted muscle strength and may be associated with forces that range from 10 to 250 N.[19–21] Hand-held dynamometry is a more objective method of recording strength and is more sensitive to change over time.[19] Finally, for the majority of individuals with SCI, functional activities such as dressing, hygiene, eating, transfers, and wheelchair mobility are typically performed in the sitting position. This makes documentation of the force-generating capacity of the postural muscles during sitting a functionally relevant approach.

In the clinical setting, assessment of the postural muscle strength in sitting is typically performed by applying manual force and offering a subjective description of the amount of force (minimal, moderate, or maximal) that the individual can resist; or using a four- or five-point ordinal scale for which psychometric properties of the scoring systems are not known.[3,23,24] To our knowledge, the reliability and validity of these scoring systems have never been documented. HHD provides an objective means of quantifying forces generated by the postural muscles in the upright sitting posture.

Before the use of HHD can be recommended for the assessment of postural muscle strength in sitting, information must be obtained about reliability of this measure in different directions of force application and under different UE support conditions, as well as the possible influence of rater experience. Numerous studies have reported good to excellent intrarater and interrater reliability when using HHD to measure strength of the extremity muscles.[25–29] We identified only a single study that used hand-held dynamometry to obtain test-retest measurements of lateral trunk muscle strength in sitting within a single session; the study participants were 11 individuals who had sustained a stroke or traumatic brain injury.[3] In addition, a majority of the studies have used testers who were experienced in using the HHD. Test-retest,[28] intrarater,[30] and interrater[29] reliabilities have been reported to be good to excellent for novice examiners using HHD to test elbow[30] or hip, knee, and shoulder[28] muscle strength. None of these studies examined the influence of the level of experience of the rater on reliability of the hand-held dynamometry strength values obtained.

The primary purpose of this study was to examine the intrarater and interrater reliability of hand-held dynamometry for the assessment of postural muscle strength during sitting in individuals with SCI. We also compared forces generated in each of the four directions of force application and values obtained by experienced versus student physical therapist examiners. Strength was operationally defined as peak force recorded with a hand-held dynamometer.

METHODS

The study was approved by the Wayne State University's Human Investigating Committee and Oakland University's Institutional Review. Twenty-nine individuals with SCI (five women, 24 men; mean age, 32.4 ± 11.0 years; range, 19–69 years) who were participating in an outpatient rehabilitation program took part in this study. Participants had sustained spinal cord injuries injury level between C4 and the cauda equina (19 with tetraplegia and 10 with paraplegia). American Spinal Injury Association Impairment Scale[31] (AIS) scores of the 29 participants included were as follows: 12 AIS A, 10 AIS B, five AIS C, and two AIS D. The mean time since injury was 4.5 ± 4.6 years (range, 0.5–19 years). Exclusion criteria included being dependent on a ventilator, medical instability, or having musculoskeletal impairments that could confound results of the study. Before participation in the outpatient therapy program, all individuals who had SCI for >1.5 years were routinely screened for osteoporosis as measured by bone density scan of the spine and femur; individuals identified as having osteoporosis, defined as having T scores ≤−3.0, were excluded from the study.

The four raters were two experienced physical therapists and two student physical therapists. Of the two licensed physical therapists, one had 25 years of experience and the other had five years of clinical experience. The two student physical therapists were enrolled in the second year of an entry-level doctorate of physical therapy program. Before the start of the study, all four raters were trained in the procedures outlined below by the primary investigator during a one-hour session, and then practiced the test procedures on a minimum of four individuals with SCI.

Procedures

After signing the institute-approved informed consent forms and Health Insurance Portability and Accountability Act form, demographic information was obtained through interview or medical record examination. Participants were positioned in sitting on a height-adjustable table, with feet flat on the floor, with hips and knees at 90 degrees, and with the popliteal fossa against the mat edge to maximize thigh contact with the support surface and provide a stable base of support (BOS). Participants were instructed to sit in a posture that was as erect as possible. A back support was not used because it was previously reported that individuals with SCI

FIGURE 1. Positioning for lateral force application. The hand-held dynamometer was placed over the proximal tip of the acromion; force was applied perpendicular to the long axis of the trunk while the examiner maintained horizontal forearm alignment.

tilt the pelvis posteriorly and use the backrest of a chair for passive support to compensate for instability of the pelvis and lower spine.[9] If the participant was able to assume an erect seated posture without UE support (with shoulders in neutral and elbows flexed to 90 degrees) and maintain this posture and for at least five seconds, then the test was conducted without UE support (unsupported condition). However, if the participant was unable to maintain an erect seated posture without UE support, then the UEs were placed in the best position (as judged by both the participant and examiner; typically, with shoulders extended ~15 degrees and externally rotated, elbows and wrists fully extended, and fingers flexed) for the individual to maintain the seated UE-supported position (supported condition). Participants who required UE support for sitting were neither encouraged nor discouraged from using their UEs to assist in the test. A MicroFet2 HHD (Hoggan Inc., West Jordan, UT) was used to measure peak force. The device was at low threshold setting capable of measuring peak force from 0.36 to 68.04 kg (0.8–150 lb) with a sensitivity of 0.045 kg (0.1 lb). The HHD device was placed between the examiner's hand and the participant's body with the force applied perpendicular to the trunk while the examiner maintained horizontal forearm alignment (Fig. 1). The examiner applied force to the trunk in four directions by placing the HHD in four different locations: anterior, over the mid-sternum; posterior, over the thoracic spine midway between the superior and inferior angles of the scapula; and right and left lateral, over the lateral aspect of the acromial process. The proximal tip of the acromion was used to avoid confounding the data if the participant used shoulder abduction balance reactions (Fig. 1). Instructions were either "hold, do not let me move you" or "push, push as hard as you can." The examiner gradually built up force over a three- to four-second period to allow time for the participants to respond and produce their maximal force.[17] The test concluded when the participant was displaced ~2.5 cm (1 in) in the direction in which force was being applied (visually estimated by linear trunk movement). Force was released gradually to avoid protective responses or substantially disrupting the participant's sitting posture. The peak force registered by the HDD was recorded for that trial. Two practice and three actual trials were performed for each direction of force application with rest periods of ~15 seconds between trials. Two practice trials were used to allow the participant to develop a strategy for maximum force generation, whereas no more than three actual test trials were performed to avoid fatigue. The order of testing was randomized for direction of force application. A second person was available to both record the force values and guard the participant for safety purposes. To determine interrater reliability, all participants were tested by all four raters (randomized order) on the same day or within one to two days. To test intrarater reliability, the participants were tested again within a one-week time interval by all four raters. Raters were blinded to the force measures obtained by the other raters.

Data Analysis

Using SPSS version 13.0 (SPSS, Chicago, IL), demographic descriptive statistics were generated. Intrarater and interrater reliability was determined using intraclass correlation coefficients (ICC; two-way, mixed model, absolute agreement). When examining interrater reliability, data were pooled across the two test sessions. When examining the peak force data for the unsupported and supported conditions, 2 (test 1, test 2) × 4 (raters) analyses of variances with repeated measures and Bonferroni post hoc tests were performed for the four directions of force application. Variability was determined using coefficients of variation (COV) (standard deviation [SD]/mean × 100%). Means, SDs, and 99% confidence intervals were generated for data obtained from each of the four trunk locations at which the HDD was positioned, for data obtained from subjects tested in the supported and the unsupported conditions. Multivariate, general linear-model analyses of variances were used to determine whether forces measured were different for experienced versus student raters.

To obtain preliminary insights into the relationship between balance and postural muscle strength in sitting, participants were categorized into one of the three (modified) balance categories[3,23,24] based on the ability to maintain upright sitting position: poor (maintains upright sitting for 5–15 seconds), fair (maintains upright sitting for 15–60 seconds, holds against minimal resistance), and good (maintains upright sitting and holds against moderate to maximum resistance without UE support).

RESULTS

Twenty-two participants were able to perform the test without UE support, and seven participants performed the test with UE support during the first session (test 1). Because of

TABLE 1. Intrarater Reliability (Intraclass Correlation Coefficients)

	Rater 1: Experienced	Rater 2: Student	Rater 3: Student	Rater 4: Experienced
Unsupported sitting: without UE support, n	19	17	16	17
Anterior	0.97	0.90	0.87	0.98
Posterior	0.92	0.97	0.94	0.97
Right lateral	0.90	0.94	0.86	0.97
Left lateral	0.93	0.87	0.80	0.92
Supported sitting: with UE support, n	7	6	6	7
Anterior	0.99	0.87	0.91	0.92
Posterior	0.91	0.83	0.91	0.95
Right lateral	0.95	0.95	0.85	0.79
Left lateral	0.92	0.86	0.86	0.84

Abbreviation: UE, upper extremity.

TABLE 2. Interrater Reliability (Intraclass Correlation Coefficients): Tests 1 and 2 Pooled

	Unsupported Sitting (Without UE Support), n = 22	Supported Sitting (With UE Support), n = 7
Anterior	0.98	0.98
Posterior	0.99	0.98
Right lateral	0.97	0.96
Left lateral	0.97	0.97

Abbreviation: UE, upper extremity.

scheduling difficulties, not all participants were retested during session 2 (test 2; see sample sizes [n] in Tables 1 and 2).

Reliability of Postural Muscles Strength Tested in Sitting: Without UE Support

Force measures acquired in participants who could sit without UE support had good to excellent intrarater reliability; ICCs were 0.80 to 0.98 for all four raters for the four force-application locations (Table 1). Interrater reliability was excellent, with ICCs ranging from 0.97 to 0.99 for the four force-application locations (Table 2). For sitting without UE support, mean ± 1 SD peak forces generated by the participants for anterior, posterior, right lateral, and left lateral force-application locations are illustrated in Figure 2. Within each force-application direction, mean peak force obtained by raters 1 to 4 (R1, R2, R3, and R4) for tests 1 and 2 (T1, T2) are consecutively presented (Fig. 2). For all four force-application locations, there were no significant differences in peak force between tests 1 and 2 (P = 0.32–0.68) or between the four raters (P = 0.32–0.80), with no significant interactions between the parameters. There were no differences among the peak forces generated for the four force-application locations ($F_{3,604}$ = 0.36; P = 0.64). Between-subject force COVs were 11%, 10%, 9%, and 10% for the

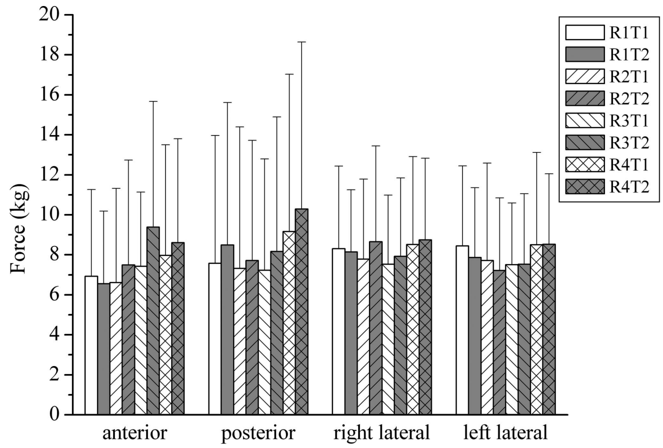

FIGURE 2. Forces generated by postural muscles in sitting without upper extremity support. Mean ± 1 SD force (kg) for test 1 (T1; white) and test 2 (T2; gray), for the four raters (R1–R4 in consecutive order) for the anterior, posterior, right lateral, and left lateral force-application locations.

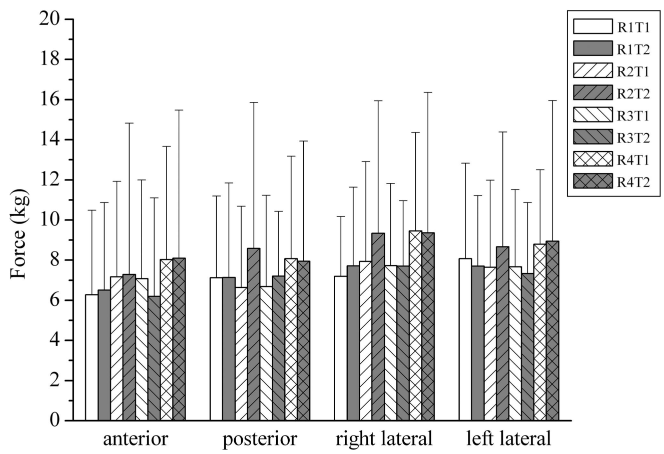

FIGURE 3. Forces generated by postural muscles in sitting with upper extremity support. Mean ± 1 SD force (kg) for test 1 (T1; white) and test 2 (T2; gray), for the four raters (R1–R4 in consecutive order) for the anterior, posterior, right lateral, and left lateral force-application locations.

anterior, posterior, right lateral, and left lateral force-application locations, respectively, for the four raters.

Reliability of Postural Muscles Strength Tested in Sitting: With UE Support

When testing postural muscle strength in participants who required UE support for sitting, intrarater reliability was good to excellent; ICCs were 0.79 to 0.99 for all four raters in the four force-application locations (Table 1). Interrater reliability was excellent, with ICCs ranging from 0.96 to 0.98 for the four force-application locations (Table 2). For sitting with UE support, mean ± 1 SD peak forces generated by the participants for anterior, posterior, right lateral, and left lateral force-application locations obtained by raters 1 to 4 for tests 1 and 2 are displayed in Figure 3. For all four force-application locations, there were no significant differences in

TABLE 3. Sitting Strength Partitioned by Balance Category[a]

	Poor	Fair	Good
Unsupported: without UE support			
Anterior	4.3 ± 2.1 (9.4 ± 4.7)	7.4 ± 4.0 (16.4 ± 8.9)	12.4 ± 4.1 (27.3 ± 9.1)
	3.5–5.0 (7.8–11.0)	5.8–9.1 (12.8–20.1)	10.7–14.0 (23.7–30.8)
Posterior	4.4 ± 1.5 (9.6 ± 3.4)	9.8 ± 9.0 (21.7 ± 19.9)	12.2 ± 6.2 (26.8 ± 13.7)
	3.8–4.9 (8.4–10.8)	6.1–13.5 (13.5–29.8)	9.8–14.6 (21.5–32.1)
Right lateral	6.0 ± 2.0 (13.2 ± 4.5)	9.0 ± 4.7 (19.8 ± 10.4)	10.9 ± 2.9 (24.0 ± 6.4)
	5.3–6.7 (11.7–14.8)	7.0–10.9 (15.5–24.0)	9.8–12.0 (21.5–26.4)
Left lateral	5.6 ± 2.2 (12.4 ± 4.9)	8.3 ± 3.4 (18.3 ± 7.4)	11.1 ± 3.6 (24.4 ± 8.0)
	4.9–6.4 (10.7–14.1)	6.9–9.7 (15.3–21.4)	9.7–12.5 (21.3–27.5)
Supported: with UE support			
Anterior	4.4 ± 1.5 (9.8 ± 3.3)	8.2 ± 5.9 (18.1 ± 12.9)	—
	3.4–5.6 (7.4–12.3)	5.6–10.7 (12.4–23.7)	—
Posterior	4.3 ± 0.8 (9.4 ± 1.7)	8.7 ± 5.0 (19.2 ± 11.1)	—
	3.7–4.9 (8.1–10.7)	6.5–10.9 (14.3–24.1)	—
Right lateral	6.0 ± 1.7 (13.3 ± 3.8)	9.3 ± 5.1 (20.4 ± 11.3)	—
	4.8–7.3 (10.5–16.1)	7.0–11.5 (15.4–25.4)	—
Left lateral	6.6 ± 3.2 (14.5 ± 7.1)	8.8 ± 4.7 (19.3 ± 10.4)	—
	4.2–9.0 (9.3–19.8)	6.7–10.8 (14.7–23.9)	—

[a] Values are expressed as mean ± 1 SD peak force, in kg and lb, with a 99% confidence interval, in kg and lb in the next row.
Abbreviation: UE, upper extremity.

peak force between tests 1 and 2 ($P = 0.66–0.94$; intrarater reliability) or between the four raters ($P = 0.71–0.94$; interrater reliability) with no significant interactions between the parameters. There were no differences among the peak forces generated in the four force-application locations ($F_{3,216} = 0.77$; $P = 0.51$). Between-subject peak force COVs were 14%, 9%, 8%, and 10% for the anterior, posterior, right lateral, and left lateral force-application locations, respectively, for the four raters.

Postural Muscles Strength Tested in Sitting: Experienced Versus Student Raters

Overall, peak force variability was 9% to 14%. There were no significant differences among the peak forces obtained in the sitting without UE support condition when participants were examined by experienced compared with student raters for the anterior ($F_{1,157} = 0.06$; $P = 0.81$), posterior ($F_{1,157} = 1.24$; $P = 0.27$), right lateral ($F_{1,157} = 1.3$; $P = 0.26$), or left lateral ($F_{1,157} = 0.2.4$; $P = 0.12$) force-application locations. Likewise, there were no significant differences among the peak forces obtained in the sitting with UE support condition when participants were examined by experienced compared with student raters for the anterior ($F_{1,54} = 0.04$; $P = 0.84$), posterior ($F_{1,54} = 0.07$; $P = 0.79$), right lateral ($F_{1,54} = 0.05$; $P = 0.83$), or left lateral ($F_{1,54} = 0.22$; $P = 0.64$) force-application locations.

Muscle Forces, UE Support, and Balance

For participants who did not require UE support for sitting, mean ± 1 SD peak forces and 99% confidence intervals for the four force-application locations were determined based on their balance category (poor, fair, and good balance; Table 3). Generally, those participants who could sit without UE support were categorized as having poor, fair, and good balance generated mean peak forces in the 3.5 to 6.7, 5.8 to 13.5, and 9.7 to 14.6 kg (7.8–14.8, 12.8–29.8, and 21.3–32.1 lb) ranges, respectively. When examining the 99% confidence interval results, a criterion estimate for the minimum strength required to maintain the sitting position without UE support for five to 15 seconds was 3.5 kg (7.8 lb), 3.8 kg (8.4 lb), 5.3 kg (11.7 lb), and 4.9 kg (10.7 lb) at the anterior, posterior, right lateral, and left lateral force-application locations, respectively.

Of the three balance categories, participants who did require UE support for sitting fell into either the poor or the fair balance category. Mean ± 1 SD peak forces and 99% confidence interval for the four force-application locations were determined for participants in each of these two categories (Table 3). Because there were no significant differences among the force-application locations, the data for all locations were pooled. Those participants with poor balance generated forces in the range of 3.4 to 9.0 kg (7.4–19.8 lb), whereas participants with fair balance generated forces in the range of 5.6 to 11.5 kg (12.4–25.4 lb).

DISCUSSION

Test of Postural Muscle Strength in Sitting: Intrarater and Interrater Reliability

The use of HHD to assess postural muscle strength in sitting (defined as peak force generated in upright sitting with or without UE support) showed good to excellent intrarater and interrater reliability as applied in this study. This provides preliminary evidence to suggest that HHD used in this manner is a reliable measure in individuals with SCI. These findings support and extend the reliability of strength testing with handheld dynamometry findings reported by past studies examining trunk strength in individuals with stroke or traumatic brain injury[3] and examining extremity strength in healthy adults[25,27,28] and individuals with a variety of pathologies.[4,26,29]

There were no differences obtained in measures of postural muscle strength in sitting for the experienced physical therapists compared with student physical therapists. It is likely that the high level of rater agreement is attributable to standardization of the testing procedure because before beginning the study all examiners participated in a training session and practiced the procedures. Previous studies reported training durations of as little as one practice test for one muscle for a single healthy individual[29] to as much as three to five hours of practice using the HHD.[28,30] A number of seemingly minor technical factors can influence the data acquired during hand-held dynamometry; among these are patient position, examiner position, force application and velocity, and instructions given to the patient.[6,13,17] To facilitate acquisition of reliable and repeatable hand-held dynamometry measurements of postural muscle strength in sitting, standardized procedures for testing and practice by the examiners are recommended.

The verbal instructions used during strength testing were intended to reflect what typically occurs in the clinical setting. The raters' instructions were either "hold, do not let me move you" (break test) or "push, push as hard as you can" (make test). Break tests elicit an eccentric contraction in which the examiner applies resistance sufficient enough to overcome the maximal effort of the subject,[17] causing the subject to move in the opposite direction.[29] When performing a make test, if the examiner has sufficient strength to resist movement by the subject, then an isometric contraction is generated; otherwise, a concentric contraction is produced. It has been suggested that, given high reliability, there is no clear reason to choose one test over another[29]; however, others have stated that because the make-and-break tests measure different forces, they cannot be used interchangeably.[17,26] Break-make ratios of 1.4 to 1.5 with break-force exceeding make-force by 10% to 70% have been reported.[29] In this study, the position of the examiner prevented the participant from moving the HHD, and the test was terminated if the force applied by the examiner caused the participant to move. Thus, it is likely that in this application, the type of verbal instructions used does not influence the outcome.

Test of Postural Muscle Strength in Sitting: SCI

Mean anteriorly and posteriorly directed forces generated in sitting without UE support by the participants in this study were less than forces reported for athletes with SCI.[1] The athletes had comparatively lower levels of SCI (T10–L2) and were participating in the Paralympic Games; therefore, they were likely more physically fit than the participants in this study. Compared with the participants in this study, individuals who had stroke generated greater forces in the anterior and lateral directions (both toward the involved and noninvolved sides).[5] Matched control subjects generated forces that were approximately double and significantly greater than forces generated by the subjects who had stroke.

In this study, there were no significant differences among the peak forces generated by the participants with SCI for the four force-application locations. This finding was surprising because it is our observation that individuals with SCI most often fall forward or backward, indicating primary weakness of the posterior and anterior muscles, respectively. Significant differences in trunk strength have been reported; specifically, weaker lateral trunk flexion on the involved compared with the noninvolved side of the body in individuals who had stroke.[5] We recommend that postural muscle strength in sitting be measured at the anterior, posterior, and right and left lateral locations to assess muscle strength symmetry and to guide intervention.

All participants with SCI could perform the test of postural muscle strength in sitting. The participants were, on average, 4.5 years post-injury and were concurrently participating in an outpatient SCI rehabilitation program. It is possible that individuals in the earlier stages of the rehabilitation process may be unable to perform the test of postural muscle strength in sitting; however, participants in this study did have spinal injuries over a broad range of neurologic levels. The participants who performed the test with UE support were classified as having tetraplegia, and the participants tested without UE support were classified as having either tetraplegia or paraplegia.

Postural Muscle Strength in Sitting: Balance and Function

The authors readily acknowledge that trunk strength may not directly correlate with sitting balance.[2,32,33] A positive correlation between lateral trunk flexion strength and sitting balance has been reported for individuals who had stroke and head injury,[3] whereas trunk strength did not correlate with sitting stability in individuals with paraplegia[2] or elderly adults.[32,33] Balance is a multifaceted skill requiring, but not limited to, appropriate muscle endurance, sensory and vestibular information processing, force control, multijoint coordination, and motor control. Static balance refers to the ability to maintain the body's center of mass over the available BOS[34] and is most frequently documented as the amount of time that an individual can maintain a given position.[35,36] In this sense, static balance requires muscle endurance. Dynamic balance requires the ability to sense when the center of mass moves toward the limits of one's BOS and to perform appropriate postural responses or equilibrium reactions.[37,38] Protective reactions or change-in-support strategies are observed when individuals exceed their limits of stability and change their BOS by reaching out with an arm or stepping to prevent a fall.[39–41] Thus, dynamic balance and protective reactions rely on appropriate sensory and vestibular processing, force control,[42–44] multijoint coordination, and motor control.[45] Despite the fact that postural muscle strength is not a direct measure of sitting balance, it is likely that individuals with neuropathologies need to attain a minimum threshold postural muscle strength in sitting to successfully accomplish the wide variety of functional activities typically performed in the sitting position.

Based on the results of this study, we cannot specify the minimum postural muscle strength required to achieve functional milestones or how much change in postural muscle strength is clinically meaningful. It can be speculated that incremental, functional milestones, such as achieving the ability to maintain static upright sitting (1) without UE support (hands slightly lifted from the support surface), (2) with one UE, or (3) both UEs reaching to a target within arm's length, would require corresponding increases in postural muscle strength in sitting. When reaching with one arm and pointing to or grasping a target or object within 60% to 100% of arm's length, the trunk acts as a postural stabilizer; whereas when reaching beyond arm's length (100%–140%), the trunk and arm transport the hand to the target or object location.[46,47] Although a more systematic study would be needed to identify the minimum postural muscle strength that is required to achieve identified functional milestones in sitting, this study can suggest that an estimated, minimum force-generating capacity range of 3.5 to 5.3 kg (7.8–11.7 lb) is required to maintain upright sitting for five to 15 seconds without UE support.

Regarding the issue of how much change in postural muscle strength is clinically meaningful, for participants sitting without UE support, changes in peak force of ~3 to 4 kg (7–9 lb) were associated with changes in participants' sitting balance (poor to fair to good) abilities. In a study that examined elbow flexion and extension strength using an HHD, maximum force variability was 3.5 kg for individuals with tetraplegia.[29] Others reported that strength changes of $<1\%$ are within measurement error, whereas strength changes $>3.5\%$ represent true changes in muscle strength.[17]

Limitations

Although the authors attempted to control for sources of error, some limitations have been recognized. A relatively small number of individuals with SCI participated in this study. We assessed reliability only because it relates to repeatability within and between raters because we did not assess test-retest reliability over time. Because the participants were concurrently engaged in an outpatient rehabilitation program, it was possible that the participants improved between test 1 and 2; however, examination of the data did not reveal a consistent, positive trend in strength over this period. Participants' body weight was not recorded. Although testing reliability is not affected, it is more appropriate that peak force be normalized for body weight and height particularly when comparing postural muscle strength in sitting among individuals[1,2,6] and when determining the strength threshold corresponding to functional milestone achievement. Finally, the study assessed only postural muscle strength used to maintain an upright seated posture, and the relationship of this measure to postural control and seated balance is not known. Accordingly, it can be argued that application of the HHD provided some stabilization and assisted the participant in maintaining the upright sitting position.

Future Research

Future research should be conducted to further assess the reliability of testing postural muscle strength in sitting using a larger sample size. Reference or normative strength values should be determined for healthy adults and children without any disabilities. Most importantly, minimum criterion strength required to achieve functional milestones or clinically meaningful change in strength must be systematically explored. Initial findings concerning these interrelationships may be forthcoming as a result of ongoing research using a constellation of outcome measures designed to document change across the body structure and function, activity, and participation levels for individuals with SCI participating in an intense rehabilitation program.

CONCLUSIONS

Muscle weakness frequently impairs the ability to maintain upright sitting posture in individuals who have sustained an SCI. Because intrarater and interrater reliability was good to excellent, HHD can be used among different raters to objectively quantify postural muscle strength in sitting for individuals with SCI. Future research is needed to identify the minimum strength required to achieve identified functional milestones and clinically meaningful change in postural muscle strength in sitting. Studies are also needed characterize the relationship between postural muscle strength and sitting balance.

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