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TECHNICAL REPORT

Portable, One-Dimensional, Trunk-Flexor Muscle Strength Measurement System

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Trunk-flexor muscle strength plays a fundamental role in athletic performance, but objective measurements are usually obtained using expensive and nonportable equipment, such as isokinetic dynamometers. The aim of this study was to assess the concurrent validity of a portable, one-dimensional, trunk-flexor muscle strength measurement system (Measurement System) that uses calibrated barbells and the reliability of the measurements obtained using the Measurement System, by conducting test–retests. As a complementary assessment, the measurements obtained during a maximum contraction test performed by a group of 15 subjects were also recorded. Four conditions were assessed: repeatability, time reproducibility, position reproducibility, and subject reproducibility. The results demonstrate that both the concurrent validity and the measured reliability (intraclass correlation coefficient > .98) of the Measurement System are acceptable. The Measurement System provides valid and reliable measures of trunk-flexor muscle strength.

Keywords*:* dynamometer, reliability, concurrent validity

Trunk-flexor muscle strength plays a fundamental role in athletic performance,[1–3] health of children and adolescents,[4,5] posture, and rehabilitation. It is also vital for core stability[6,7] and situations such as urinary incontinence and athletes' rehabilitation.[8] Therefore, accurate and objective assessment of trunk-flexor muscle strength is essential in follow-up assessments of general physical activities, rehabilitation, and optimal performance in sports.

Isokinetic dynamometers can be used to directly measure trunk-flexor muscle strength,[9] but their high cost and lack of portability limit their use. Thus, several alternative methods and instruments have been adopted.[10,11] Endurance tests,[10] which do not require specific equipment, are easy to apply for this purpose. However, endurance tests do not provide a direct measurement of strength and are more useful when assessing the resistance and functionality of the trunk-flexor muscles.

Handheld dynamometers have also been adapted to measure trunk-flexor muscle strength.[11] However, while they provide direct measurement of strength, they are dependent on several factors, such as dynamometer position, the direction of the force applied by the rater, and even the rater's experience.[12] Moreover, a handheld dynamometer in this situation cannot evaluate the strength used to support the trunk weight. Hence, to the best of the authors' knowledge, no specific portable instrument has been developed for this purpose.

The aim of this study was to assess (1) the concurrent validity of the Measurement System using calibrated barbells and (2) the reliability of the measurements obtained using the Measurement System by conducting test–retests. We hypothesized that concurrent validity and measurement reliability will obtain high indexes of approval.

Methodology

The BIOMEC research group[13] has developed a low-cost device capable of isometrically assessing trunk-flexor muscle strength: the portable, one-dimensional, trunk-flexor muscle strength measurement system (Measurement System). The subject to be assessed lies in a supine position with knees and hips flexed (Figure 1A), then performs an isometric trunk flexion against a bar positioned on his/her chest (Figure 1B).

The Measurement System consists of a base that supports the apparatus and upon which the subject is positioned, an articulated metal bar to which the forces will be applied, and a load cell that measures the forces applied to the bar (Figure 2A). To accommodate individuals of different sizes, the Measurement System has a height adjustment that allows the bar to be positioned on the subject's chest (at the level of axilla). The Measurement System was assessed in 4 different conditions, the first 3 involving only calibrated barbells: (1) repeatability (ie, consecutive test–retest); (2) time reproducibility (ie, 24-h-interval test–retest); (3) position reproducibility (ie, tests in 3 different bar positions); and (4) subject repeatability, as a complementary assessment, in which the forces applied to the bar by individual subjects were measured. During the first 3 conditions assessed, the apparatus was positioned upside down, so that the force bar remained horizontal (Figure 2B). A rope and a hook were used to suspend the barbells, thus applying force perpendicularly to the bar.

The number of times known forces were applied to the bar (ie, the sample size) was calculated according to specific literature for reliability studies.[14,15] This assumes the value of the null hypothesis of the intraclass correlation coefficient (ICC) is .40 (ie, any value less than .40 would be considered unacceptable),

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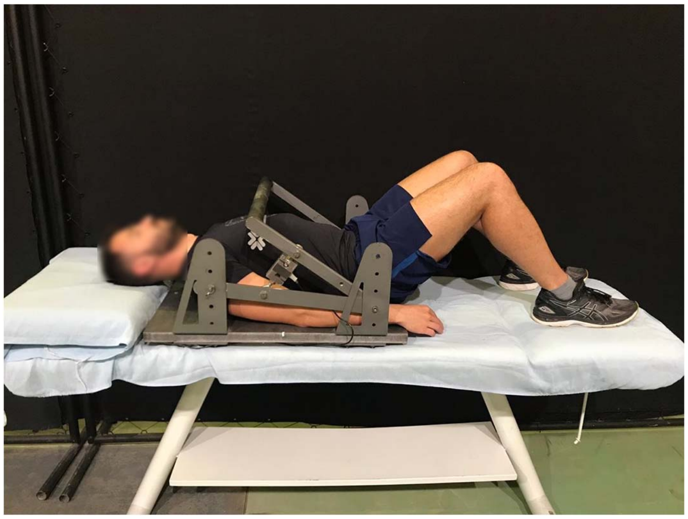

Figure 1 — The portable, one-dimensional, trunk flexor muscle strength measurement system (Measurement System). (A) The subject is assessed in a supine position with knees and hips flexed. (B) The subject is performing an isometric trunk flexion against a bar positioned on his/her chest.

Figure 2 — Measurement System schema. (A) Main parts and dimensions. (B) The apparatus was positioned upside down during the assessment with barbells.

80% of power, and a significance level of 95% to detect an ICC value of at least .80. For situations involving 2 repetitions, immediate test–retest (repeatability), and 24-hour-interval test–retest (time reproducibility), a minimum of 15.1 situations were found. For situations involving 3 repetitions, with measurements at different bar positions (position reproducibility), a minimum of 9.6 situations were found.

Five sets of measurements with barbells were carried out, as described below:

- Set 1: 15 loads were applied to the center of the bar (day 1)
- Set 2: 15 loads were applied to the center of the bar, immediately after set 1 (day 1)
- Set 3: 10 loads were applied 15 cm to the left of the center of the bar (day 1)
- Set 4: 10 loads were applied 15 cm to the right of the center of the bar (day 1)
- Set 5: 15 loads were applied to the center of the bar (day 2)

In the sets with 15 situations (ie, sets 1, 2, and 5), the loads were applied at 49.05 N (5 kg) increments (from 0 to 686.7 N [70 kg]) with the barbells attached to the center of the bar. In the sets with 10 situations (ie, sets 3 and 4), the loads were applied from 49.05 N to 490.5 N (50 kg), with the barbells attached 15 cm to the left and to the right of center of the bar, respectively.

In addition to the assessments conducted with barbells, 15 healthy women, aged 27.7 years (±7.1), body mass 59.8 kg (±8.2), and height 1.66 m (±0.01) performed 2 consecutive maximum force tests, with a 2-minute interval to minimize any variations resulting from fatigue.

Statistical Analysis

The Shapiro–Wilk test was used to check the data's normality. When assessing repeatability and time reproducibility, the Student *t* test was used to analyze the concurrent validity, comparing the difference between the barbell weights and the values obtained using the system with the zero value. When assessing position reproducibility, 1-way ANOVA was used to compare the differences between positions. Effect sizes (*d* for *t* test and *f* for ANOVA) were quantified using standardized differences in means (the mean difference divided by the between-subject SD), where effect sizes of 0.20, 0.60, 1.20, 2.0, and 4.0 represented small, moderate, large, very large, and extremely large effects, respectively.[16]

The ICC was used to assess reliability. The $ICC_{1,2}$ (1-way random, 2 situations) was adopted for the repeatability, time reproducibility, and subject-repeatability conditions. The $ICC_{1,3}$ (1-way random, 3 situations) was adopted for the position-reproducibility condition. Munro's classification was assumed to interpret the ICC values of the reliability coefficients, in which .26 to .49 indicates low correlation, .50 to .69 indicates moderate correlation, .70 to .89 indicates high correlation, and .90 to 1.00 indicates very high correlation.[17]

Besides the ICC, the SEM and minimal detectable change (MDC) were adopted to assess the reliability of the measurements. The SEM quantifies the precision of individual scores on a test, thus providing an absolute index of reliability. The SEM was estimated using the SD of the measurements, $\text{SEM} = \text{SD}\sqrt{1 - \text{ICC}}$. The MDC estimates the minimal amount of change needed to exceed the measurement error. The MDC for each situation was estimated based on a 95% confidence interval, $\text{MDC} = 1.96 \times \text{SEM}$.

In all the tests, the level of significance adopted was $\alpha \leq .05$. All procedures were performed with the aid of IBM® SPSS Statistics® software (version 20; Chicago, IL).

Results

No significant differences were found when comparing the values obtained with the Measurement System and those from the barbells weight for any set of measurements (Table 1), indicating that the forces applied to the bar were correctly measured. When the test–retest procedures were carried out with barbells, the ICCs were always higher than .999 (Table 2), demonstrating high levels of reliability for all tested conditions.

In the reliability tests conducted with the barbells (Table 2), a maximal SEM value of 0.5 N was found, indicating a very small error throughout the range of the measurements. In the same tests,

Table 1 Concurrent Validity

Assessment	Statistical test	P	Effect size
Set 1 × set 2	$t_{14} = -1.849$	.11	$d = 0.006$
Set 1 × set 5	$t_{14} = 0.830$	.44	$d = 0.008$
Set 1 × set 3 × set 4	$F_{2,44} = 0.001$	.10	$f = 0.012$

Table 2 Reliability Results

Assessment	ICC	SEM, N	MDC, N
Repeatability (set 1 × set 2)	.9999	.1	0.3
Time reproducibility (set 1 × set 5)	.9997	.3	0.7
Position reproducibility (set 1 × set 3 × set 4)	.9994	.5	0.9
Subject repeatability	.9805	1.6	3.1

Abbreviations: ICC, intraclass correlation coefficient; MDC, minimal detectable change.

the MDC values were lower at 1 N, indicating the maximum differences between measurements, which can be attributed to random error. Regarding the test–retest procedure conducted with the subjects, the ICC was also very high and an MDC of 3.1 N was found, indicating the minimum difference between measurements from the same subject required to identify any real difference (Table 2).

Discussion

The purpose of this study was to assess both the concurrent validity and the reliability of the measurements obtained using the Measurement System by conducting test–retests. Our hypotheses were confirmed, as both the concurrent validity and the reliability obtained high indexes of approval. Regarding the concurrent validity, the absence of difference ($P > .05$) and trivial effect sizes (<0.1) indicate high levels of accuracy (Table 1). In relation to reliability, the results show nearly perfect correlations and very low SEM and MDC values for all tested conditions (Table 2). Together, these findings demonstrate that the Measurement System can be used to objectively assess the strength of the trunk-flexor muscles.

To the best of our knowledge, this is the first portable dynamometer specifically designed to measure the strength of the trunk-flexor muscles. It can also evaluate the effect of the weight of the HAT (head, arms, and trunk) on the measurements. As with isokinetic dynamometers, it is necessary to previously measure the body segment by suspending it while completely relaxed,[18] thus evaluating the effect of HAT. For example, if someone's HAT offers a resistance of 40 N and the Measurement System identifies a force of 10 N, the total force attributed to muscle effort is in fact 50 N. The combined values of the forces measured during the maximum contraction test and HAT evaluation, although not equal to the abdominal muscular force itself (which could only be measured just by an invasive sensor connected directed to the muscles), can be used as an objective indicator of the capacity of the trunk-flexor muscles.

The MDC values establish a confidence interval to consider the difference between the measurements as real and not by chance. Thus, the MDC values lower than 1 N reveal the high level of reliability of the equipment, and 1 N can be considered the sensibility of the equipment. When the subjects performed the test–retest, the reliability was reduced compared with the barbell conditions, represented by a small decrease in the ICC and a slight increase in the SEM and MDC values (Table 2). When someone is required to repeat a maximal effort, factors such as motivation, disposition, learning effect, and fatigue may affect the results. Even so, the MDC obtained during the subject-repeatability condition indicates that differences greater than 3 N between measurements in the same subject cannot be attributed to chance. It is important to highlight that when applying force to the bar, the subject does not necessarily apply that force exactly in the exact center of the bar, as represented in sets 1, 2, and 5 with barbells. Due to factors such as motor coordination, asymmetric trunk-flexor muscle capacity, or a condition such as scoliosis, the center of pressure of resultant force may not be applied to the center of the bar. For example, when the oblique muscles are recruited bilaterally, they can perform a trunk flexion. However, when only one side is recruited, a trunk rotation will also occur. In the same way, if there are any asymmetries in these muscle strengths, a tendency of rotation could occur and the resultant force would not be considered applied at the center of the bar. Given this possibility, we also conducted assessments in which known forces were applied to the left and right of the center of the bar, and the results for both the concurrent validity and reliability tests were compatible with those obtained at the center of the bar. Therefore, when a human being performs the test, it does not matter where he/she will apply the force because the result will be the same. As a limitation, it should be noted that reproducibility evaluations were performed with dumbbells alone. It is necessary to evaluate the SEM and MDC when subjects perform the test on distinct days.

In conclusion, the portable, one-dimensional, trunk-flexor muscle force measurement system provides valid and reliable measures of trunk-flexor muscle strength. Thus, practitioners can use this relatively inexpensive portable force system to record accurate measures of trunk-flexor muscle strength.

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