Validity of an Inexpensive Hanging Scale During Isometric Shoulder Movements

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Context: Strength assessment is essential to prescribe exercise in sports and rehabilitation. Low-cost valid equipment may allow continuous monitoring of training. **Objective:** To examine the validity of a very low-cost hanging scale by comparing differences in the measures of peak force to a laboratory grade load cell during shoulder abduction, flexion, extension, and internal and external rotations. **Design:** Analytical study. **Participants:** Thirty-two healthy subjects (18 women, age 26 [10] y, height 172 [8] cm, mass 69 [13] kg, body mass index 23 [4] kg/m²). **Main Outcome Measures:** The dependent variable was the maximal peak force (in kilogram-force). The independent variable was the instrument (laboratory grade load cell and hanging scale). **Results:** No differences were observed while comparing the results. The intraclass correlation coefficients_{1,1} ranged from .96 to .99, showing excellent results. The Cronbach alpha test also returned >.99 for all comparisons. The SEM ranged from 0.02 to 0.04 kgf, with an averaged SD from 0.24 to 0.38 kgf. The correlation was classified as high for all tested movements ($r > .99$; $P < .001$), with excellent adjusted coefficients of determination ($.96 < r^2 < .99$). Bland-Altman results showed high levels of agreement with bias ranging from 0.27 to 0.48. **Conclusions:** Hanging scale provides valid measures of isometric strength with similar output measures as laboratory grade load cell.

Keywords: muscle strength, upper-extremity, isometric contraction

Shoulder weakness and muscle imbalances are both associated with shoulder pain in athletes performing overhead sports.¹ Pre-season shoulder external-rotation weakness is associated with supraspinatus strength deficits and in-season throwing-related injuries.² Differences in strength between the agonist and antagonist muscle groups in the shoulder and decreased eccentric muscle strength of the external rotators are associated with the rate of injury on the shoulder girdle.² Studies showed that muscle weakness leads to increased direct costs, placing a burden on health care system.^{3,4}

Objective measures of muscle function provide valid information to implement effective treatment and exercise training.⁵ Equipments are available for measuring muscle strength, such as hand-held dynamometers and load cells. The isokinetic dynamometer (IKD) is often referred as the gold standard to which all other measures are compared.⁵ However, the IKD is very expensive, not portable, requires extensive staff training, and it is often restricted to laboratory environment. The laboratory grade load cell (LLC) is the optimal alternative to IKD, showing excellent results for both validity and reliability.^{5,6} The LLC is often used for research purposes and requires an analog-to-digital converter, with a dedicated software to interpret the results. Despite its portability and validity, the LLC can also be expensive, and the software is usually not user friendly, requiring training and experience to avoid any assessment biases.

The hanging scale (HS) may be a cost-effective alternative to ensure accurate and safe performance for muscle strength assessments. The battery operated equipment is used for weighting in a suspended manner, with good precision and wide weight ranges. It is very portable, with an easy-to-read display. The HS uses a

transducer principle (with a load cell), which is essentially a metallic sturdy element, yet elastic enough for a load to deform it. The transducer has an attached strain gauge, which reads the electrical resistance change when a load is placed on the transducer. The change in electrical resistance is converted to a digital signal by the strain gauge, which is readable on the display.⁷

While LLC has demonstrated high validity, we are unaware of any studies comparing it with HS to assess shoulder muscle strength. Therefore, the purpose of this study was to examine the validity of a very low-cost HS by comparing differences in the measures of peak force to an LLC during shoulder abduction, flexion, extension, and internal and external rotations.

Methods

A convenience sample of 32 subjects (18 women, age 26 [10] y, height 172 [8] cm, mass 69 [13] kg, body mass index 23 [4] kg/m²) participated in the study. Exclusion criteria included history of injury to the upper-extremity during the past 6 months, a history of neck pain, previous shoulder or neck surgery, diagnosed neurologic disorder (eg, stroke, head trauma), or current symptoms related to the neck and shoulder area. The dependent variable was the peak force (in kilogram-force). The independent variable was the instrument (LLC and HS).

Data were collected using an LLC (Miotec™; Biomedical Equipments, Porto Alegre, RS, Brazil; maximum tension-compression = 200 kgf, precision of 0.1 kgf, maximum error of measurement = 0.33%) attached to an acquisition module with 8 analog channels (Miotec™, Biomedical Equipments). The conversion from analog-to-digital (A/D) signals was performed by an A/D board with 16-bit resolution input range, the sampling frequency of 2 kHz, common rejection module of >100 dB, signal-to-noise ratio of <03 μ V root mean square, and impedance of 109 Ω .

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The collected data were windowed at 125 ms and analyzed offline using the Miotec™ Suite Software. The windowing is a preprocessing technique for smoothening/filtering the signal. The size of the window is predefined in the A/D system (hardware/software) and varies between 100 and 300 ms, according to the International Society of Electrophysiology and Kinesiology (<https://isek.org>). The LLC was calibrated using 10% of the maximum tension–compression load, following the manufacturer recommendations. A new calibrated HS (model MNCS-M; Bode Technical Services, Denver, CO; maximum tension–compression = 200 kgf, precision of 0.1 kgf, 5 digits display) was used as a testing equipment.

Procedures

All testing was performed in the musculoskeletal lab at the School Clinic of Federal University of Juiz de Fora. The UFJF ethics committee for human investigation approved the procedures employed in the study. The objectives of the study were explained to the subjects, and they were notified of the benefits and potential risks involved before signing an informed consent form prior to participation. Data including height, weight, and body mass index were measured and recorded for each participant. The dominant upper limb was tested 3 times (with 5 s of rest; first trial was considered as familiarization) using the HS attached to the LLC, which was fixed to the wall with a chain (Figure 1). Dominant arm was defined as the arm used to write. Flexion and abduction were tested at 90° of shoulder flexion and abduction, respectively. Extension was tested at 40° of shoulder extension. The elbow was kept at full extension for the previous movement testing. Internal and external rotations were tested with the arm along to the body, elbow flexed at 90°, and neutral positioned (Figure 2). All angles were quantified through goniometric measurement.

Statistical Analysis

All trials were used for analysis, comprising a total of 64 measures. Data were presented as mean (SD). The Mann–Whitney test was used to compare differences between measures. Significance was set at $P < .05$. One-way random effects, absolute agreement, single-rater/measurement intraclass correlation coefficients ($ICC_{1,1}$) were calculated to assess the reliability between results from both equipments. The Cronbach alpha test was used to assess the

expected correlation of both equipments measuring the same construct. SEM was also calculated to provide an estimate of measurement error. Linear regression estimated the coefficient of correlation (R) and the adjusted coefficient of determination (R^2). Bland–Altman method estimated the measurement bias, with lower and upper limits of agreement between results. All statistics were done using the Jamovi software.⁸

Results

No differences were observed while comparing the isometric peak forces between LLC and HS ($P > .05$). The $ICC_{1,1}$ ranged from .96 to .99, showing excellent results. The Cronbach alpha test also returned $>.99$ for all comparisons. The SEM returned a range of 0.02 to 0.04 kgf, with an averaged SD ranging from 0.24 to 0.38 kgf. The correlation was classified as high for all tested movements ($R > .99$; $P < .001$), with excellent adjusted coefficients of determination ($.96 < R^2 < .99$). Bland–Altman results showed high levels of agreement with bias ranging from 0.27 to 0.48. All results are described in detail in Table 1.

Discussion

The results of this study demonstrated that the peak force recorded for shoulder movements were similar (almost the same) between the LLC and HS. These findings support the primary hypothesis, which contended that isometric peak force for the HS would reach acceptable levels of validity. To our knowledge, this is the first study in which validity has been established for HS. A previous study showed no significant differences in peak torque values between an LLC system and IKD for knee flexion and extension, proposing the LLC as the practical standard device to assess muscle strength.⁵ Another study showed acceptable validity to measure the isometric peak force ($ICC = .88$) using an LLC attached to a fixed plate tested against a force platform while performing midhigh clean pull.⁹

Monitoring improvements on strength along training is essential for fitting the exercise to the subject's needs. The validation of the HS would help health professionals and coaches to objectively monitor strength without technical (as rater experience, previous training to use equipment/software) or financial issues (expensive equipment). The maximal isometric contraction improvements reflect combination of central and peripheral adaptations in muscle strength.¹⁰ Thus, isometric tests are available options to assess the muscle force output as they are easily standardized, requiring minimal familiarization.¹¹ Other characteristics also reinforce the importance of maximal isometric measures. Studies showed that torque production measured at a constant angle is more sensitive to influences produced by muscle fiber type rather than angle independent peak torque during dynamic contractions.^{10,11}

Valid and fast strength assessment could potentially reduce the risk for shoulder injuries by fitting the resistance exercise to subjects' immediate and/or future needs. Considering its portability and the very lower cost, the HS might also be considered as a valid standard equipment for shoulder muscle strength assessment. The LLC full system is around USD 2000.00, while the HS used in this study was bought for USD 37.00.

There are some limitations of this study. Intrarater and interrater reliability were not assessed. The sample included only healthy participants, and testing was conducted on the dominant

Figure 1 — Equipment's setup. (A) Analog-to-digital converter, (B) hanging scale, and (C) laboratory grade load cell.

Figure 2 — Shoulder movements. (A) Abduction, (B) extension, (C) internal rotation, (D) external rotation, and (E) flexion.

Table 1 Outcome Variables With Significant Differences

Outcome	Abduction	Extension	Internal rotation	External rotation	Flexion
LLC, kgf	7.24 (2.8)	8.67 (4.64)	9.94 (4.14)	7.47 (2.62)	7.38 (2.75)
HS, kgf	6.97 (2.81)	8.29 (4.59)	9.47 (4)	7.06 (2.55)	7.1 (2.69)
<i>P</i> value (difference)	.44	.44	.33	.22	.38
Mean difference	0.26	0.34	0.41	0.39	0.3
95% CI					
Lower bound	−1.02	−1.3	−1.28	−1	−1.05
Upper bound	0.52	0.65	0.43	0.25	0.44
ICC _{1,1}	.985	.988	.983	.969	.986
Cronbach α	.995	.999	.997	.994	.997
<i>R</i>	.993	.998	.995	.989	.994
Adjusted <i>R</i> ²	.986	.996	.989	.978	.988
<i>P</i> value (correlation)	.001	.001	.001	.001	.001

(continued)

Table 1 (continued)

Outcome	Abduction	Extension	Internal rotation	External rotation	Flexion
Bland–Altman					
Bias	0.268	0.377	0.461	0.41	0.276
LLA	−0.412	−0.192	−0.408	−0.34	−0.32
ULA	0.948	0.945	1.331	1.161	0.872
SEM	0.03	0.03	0.04	0.03	0.02

Abbreviations: CI, confidence interval; HS, hanging scale; ICC_{1,1}, intraclass correlation coefficient; LLA, lower level of agreement; LLC, laboratory grade load cell; R, correlation coefficient; R², determination coefficient; ULA, upper level of agreement. Note: Descriptive data are presented in mean (SD).

limb. It is unknown whether similar results could be found in a pathological population or whether the opposite side differences exist.

The HS appears to be a valid method of assessing isometric shoulder strength. The portability, cost effectiveness, and user-friendly system provide an effective means of measuring shoulder isometric strength.

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