INNOVATION

Absolute reliability and concurrent validity of a novel electromechanical pulley dynamometer for measuring shoulder rotation isometric strength in asymptomatic subjects. Study conducted at Pontificia Universidad Católica, Santiago, Chile

Claudio Chamorro[1], Carlos De la Fuente[2], Jose Rubio[3], Christian Campos[4], Luis Javier Chirosa[5]

Abstract

Objective: To estimate the test-retest reliability of measurements in shoulder internal and external rotators' isometric peak torque using a new dynamometer, and to compare it with isokinetic dynamometer.

Methods: The validity study was conducted in September-October 2016 at Pontificia Universidad Catolica de Chile and the Clinica Las Condes, Santiago, Chile. It comprised of asymptomatic university students who were randomly tested twice within a two-week period while in a supine position at 90° of shoulder abduction, using the novel functional electromechanical pulley dynamometer. Concurrent validity was assessed through comparing the values with the gold standard isokinetic dynamometer in the same position. SPSS 17 was used for data analysis.

Results: Of the 24 subjects, 5(21%) were males and 19(79%) were females. The overall mean age was 23.1±2.2 years, body mass index 23.6±2.13 kg/m^2 and Shoulder Pain and Disability Index score was 3.9±6.4. There was no statistically non-significant difference in terms of test-retest trials and between the devices ($p>0.05$). Absolute reliability was 24.3% for internal rotation and 27.9% for external rotation. Both dynamometer systems were very highly correlated for internal rotators peak torque (0.93) and highly correlated for external rotators peak torque (0.84).

Conclusions: Compared to the gold standard, the new device was found to be a valid instrument in measuring maximal voluntary isometric peak torque in internal and external rotation.

Keywords: Muscle strength dynamometer, Reliability of results, Rotator cuff. (JPMA 69: 1000; 2019)

Introduction

Muscle strength evaluation of the shoulder internal rotator (IR) and external rotator (ER) is often used by clinicians to assess muscle performance and to guide rehabilitation in the return-to-sports phase.[1] Isokinetic dynamometry (ID) assesses maximal muscle concentric, eccentric and isometric strength under constant velocities throughout the whole range of motion (ROM) of different joints[2,3] providing mechanically valid and reliable measures of torque, position and velocity for both clinical and research purposes.[4] Currently ID is considered the gold standard method for strength assessment[5] mainly because the results are not influenced by strength imbalance between the participant and the assessor. Moreover, it allows performing both isometric and isokinetic testing and despite the fact that no action in real life occurs at constant velocity, isokinetic testing provides a more natural movement condition due to its dynamic nature, whereby a maximal torque can be generated throughout the whole ROM.[6] However, its elevated cost limits its widespread use in clinical practice.[7] Hand-held dynamometers (HHDs) are usually used for strength assessment. The overall affordability of this device may justify further widespread clinical use, but reported reliability of HHD is low and is particularly imprecise with stronger patients.[5] An alternative to HHD is a novel functional electromechanical pulley dynamometer (FED) that transmits energy from an engine through a cable, thereby allowing strength assessments of different body parts.[8] This could be a practical and affordable alternative for use in clinical rehabilitation practice and in a research

[1,2]Departamento de Ciencias de la Salud, Carrera de Kinesiologia, Facultad de Medicina, Pontificia Universidad Catolica de Chile. [3]Servicio de Kinesiologia, Clínica las Condes. [4]Facultad Cs. de la Rehabilitacion, Universidad Andres Bello, Santiago, Chile. [5]Departamento de Educacion Fisica y Deportiva, Universidad de Granada, Granada, Espana.

Correspondence: Claudio Chamorro. e-mail: cchamorrol@uc.cl

setting. However, absolute test-retest reliability of measurements expressed as either the standard error of measurement (SEM) or minimal detectable change (MDC) and concurrent validity of this device compared with a gold-standard strength assessment tool expressed as Intra-class Correlation Coefficient (ICC) has not been reported in literature. Therefore, the current study was planned to examine the absolute reliability of FED and determine the concurrent validity compared with the gold-standard in measuring shoulder IR and ER isometric peak torque in asymptomatic subjects.

Subjects and Methods

The validity study was conducted in September-October 2016 at Pontificia Universidad Catolica de Chile (PUC) and the Clinica Las Condes (CLC), Santiago, Chile. It comprised asymptomatic university students who were randomly tested twice within a two-week period while in a supine position at 90° of shoulder abduction. FED (Haefni Health®, Ivolution R&D, Granada, Spain) and ID REV 7000 (TechnoGymSpA, Gambetola, Forli, Italy) were used as measurement tools. Shoulder strength assessments using FED were performed at the PUC Human Movement Analysis Laboratory, while ID assessments were done at the CLC Physical Therapy Department.

To estimate test-retest reliability for maximal voluntary isometric strength tests in shoulder IR and ER using FED, two identical test sessions were performed two weeks apart by the same trained tester. To estimate concurrent validity between ID and FED, tests were administered by separate trained physical therapists in identical sequence of exercises and setups with the same subjects. Each tester was blinded to the measurements taken with the other tool. Participants were assessed in a supine position with 90° of shoulder abduction. Test order (IR and ER) and device order (ID and FED) were randomly assigned by a computer programme.

The subjects were recruited through convenience sampling using advertisement in a local university. Hand dominance was determined by their throwing hand. Shoulder Pain and Disability Index (SPADI) was developed to measure current shoulder pain and disability in an outpatient setting. The SPADI contained 13 items that assessed two domains; a 5-item subscale that measured pain, and an 8-item subscale that measured disability. Each subscale was summed up and transformed to a score out of 100. A mean was taken of the two subscales to give a total score out of 100, with higher score indicating greater impairment or disability. The minimal clinically important difference has been reported to be 18 points.[9]

Those included were females and males aged 18 years or higher with SPADI ≤18 points who gave written informed consent. Those with shoulder or neck injury in the preceding six months, shoulder or neck pain at the time of assessment, history of shoulder or neck trauma, history of shoulder or neck surgery, orthopaedic alterations of the trunk, shoulder, neck or upper limbs, and any condition that would alter the assessed parameters were excluded. The study was approved by the ethics review committee of the School of Medicine, Pontificia Universidad Católica de Chile.

The sample size was calculated in line with literature.[10] Assuming the value for Intra-class Correlation Coefficient (ICC) to be 0.5 on the basis that any value lower than 0.5 might be considered clinically unacceptable; 80% power, two replicated measurements (one for each dynamometer) and a confidence interval (CI) of 95%, a minimum sample size of 15 was calculated.

FED is an electromechanical pulley dynamometer consisting of three primary aspects: mechanical, electronic, and informatic. Mechanically, this system consists of a column to which an adjustable-height pulley system is affixed, thus allowing adaptability for distinct positions, exercises and attachable devices. Electronically, the system is equipped with an inextensible cable, a 2.0 Kw linear actuator, and a gauge-strain system attached to a cable that, together with a strength sensor, controls tension, detects force, and relays corresponding signals to the control monitor. Regarding informatics, the system is fully integrated to control and monitor electronic and mechanical aspects, in addition to recording all data, providing web-cam capabilities, and offering 40 linked tables for viewing and interpreting results.[8] It can assess strength in analytical and functional movements.

The subjects received description of the instrument and how it works prior to testing. Body mass index (BMI) and height were measured and SPADI questionnaire was filled at the testing facility. Assessment of isometric muscle strength was performed in supine position with the dominant upper limb posture as follows: arm in the frontal plane at 90° of abduction, elbow flexed at 90º in the sagittal plane, and forearm in pronation. The pelvis and thorax were fixed with Velcro straps. Another strap controlled the anterior translation of the humeral head. Each test began with two submaximal 6 seconds isometric contractions for IR and ER to familiarise each participant with the device and type of movement required.[11] Participants then performed three maximal isometric shoulder rotator contractions for six seconds. The rest time between strength tests was one minute, and the time between contractions was 15 seconds. Participants were verbally encouraged to ensure a maximal effort in all trials. The same protocol was followed for both the IR and ER using FED and ID.

For setup, ID was brought to shoulder height and the shoulder-rotation attachment was installed. The arm rested in the rotation cuff pad, with the olecranon approximating the axis of the dynamometer and the participant's hand gripping the input shaft.[12] The machine axis was aligned with the longitudinal axis of the humerus and coincided with the centre of the glenohumeral joint. The arm was also fixed by straps. (Figure 1A). Torque magnitude is expressed as Newton-meter (Nm).

For FED setup, a custom stabiliser system was used to correctly position the shoulder girdle for rigid attachment to the dynamometer; an appropriate resistance against generated maximal forces and torques; and adequate participant comfort. Pulley system was placed at 90° between the dynamometer and participant forearm. (Figure 1B). Torque magnitude expressed in Nm was calculated from the cross-product between the lever arm of the forearm and force of the dynamometer using an automatised algorithm written in the Matlab 2014b software (MathWorks, Inc., Natick, MA, USA; Figure 2).

The maximum value of all sets of repetitions was retained and used for statistical analysis. Peak torque (PT) is expressed in Nm and is considered the outcome

IR and ER peak torque was used for absolute reliability and concurrent validity analysis. Data was expressed as the mean ± standard deviation. Normal data distribution was confirmed using the Shapiro-Wilk's test. Homogeneity of variance was confirmed using Bartlett test. Paired t-test was conducted to determine if significant differences existed for the mean measurement between sessions for both IR and ER peak torque assessed by FED. Paired t-test was also conducted to determine if significant differences existed between devices of IR and ER peak torque. Absolute reliability was evaluated to determine intra-participant variations during repeated measurements (i.e. level of variability between measurements over time). Absolute reliability was established by the standard error of the measurement (SEM) obtained as $SEM = SD/\sqrt{2}$, where SD is the standard deviation of differences between sessions.[13] Measurement error also was expressed as a percentage of the mean, which was defined as $SEM\% = SEM/\ mean \times 100$. The mean in this case is the mean for all of the measures for test and retest. Finally, sensitivity analysis was performed to determine the smallest amount of change needed to be considered statistically significant. For this, the minimum detectable change (MDC) was calculated at a 95% CI[14] as MDC = 1.96*SD. MDC was also expressed as a percentage, which was defined as $MDC(\%) = MDC/\ mean \times 100$. The mean here is the mean for all of the measures for test and retest. The unit of measurement error is Nm.[13] Concurrent validity was evaluated to determine inter-device measurement consistency using ICC2,1 with 95% CI.[13,14] ICC was based on a 2-way model, random effects, repeated measures analysis of variance (ANOVA) model with absolute agreement. ICCs were classified according to Munro,[15] where an ICC of 0.0-0.25 shows little correlation; 0.26-0.49 shows low correlation; 0.50-0.69 shows moderate correlation; 0.70-0.89 shows high correlation; and 0.90-1.0 shows very high correlation. The level of mean change between measurements was evaluated by Bland-Altman plots. All statistical analyses employed a probability of type I error equal to 0.05 and were performed using SPSS 17.

Results

Of the 24 subjects, 5(21%) were males and 19(79%) were females. The overall mean age was 23.1±2.2 years, BMI 23.6±2.13 kg/m2 and SPADI score was 3.9±6.4. Values for test-retest peak torque assessment using FED presented equal variance (p=0.06) and were normally distributed for IR (p=0.07) and ER peak torque differences at 90° (p=0.36) (Table 1).

Peak torque values obtained by FED and ID presented equal variance (p=0.49) and were normally distributed for IR (p=0.06) and ER (p=0.56) peak torque (Table 2). Bland Altman plots for concurrent validity showed non-significant IR (p=0.44) and ER (p=0.24) peak torque (Figure 3).

Table-1: Reliability results of novel electromechanical pulley dynamometry.

	Internal rotation, 90° of abduction	**External rotation, 90° of abduction**
Measurement Sessions		
Session 1, mean ± SD, Nm	30.9 ± 13.6	27.5 ± 12.0
Session 2, mean ± SD, Nm	32.1 ± 15.2	28.5 ± 12.3
Variability levels of measurements		
SEM, Nm	2.8	3.2
SEM%, %	8.8	10.1
Sensitivity levels off measurements		
MDC, Nm	7.7	8.8
MDC%, %	24.3	27.9

Non-statistical differences were found ($p < 0.05$). SD: Standard deviation; SEM: Standard error of mean; SEM%: Percentage of standard error; MDC: Minimum detectable change; MDC%: Percentage of minimum detectable change.

Table-2: Concurrent validity between novel electromechanical pulley dynamometer and gold standard isokinetic dynamometer.

	Peak torque	
	Internal rotation	**External rotation**
Shoulder rotator strength		
Haefni Health, mean ± SD, Nm	30.9 ± 13.6	27.5 ± 12.0
Technogym, mean ± SD, Nm	32.5 ± 11.1	23.9 ± 5.81
Concurrent Reliability		
ICC	0.93	0.84
95%ICC	0.82 to 0.97	0.60 to 0.93

Non-statistical differences were found ($p < 0.05$). SD: Standard deviation; ICC: Intra-class correlation coefficient.

Figure-1: Maximal isometric shoulder rotator tests. (A) Experimental setup using the traditional dynamometer. (B) Experimental setup using the functional electromechanical dynamometer.

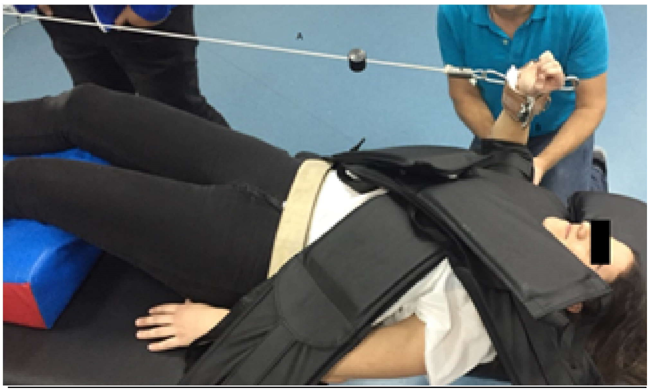
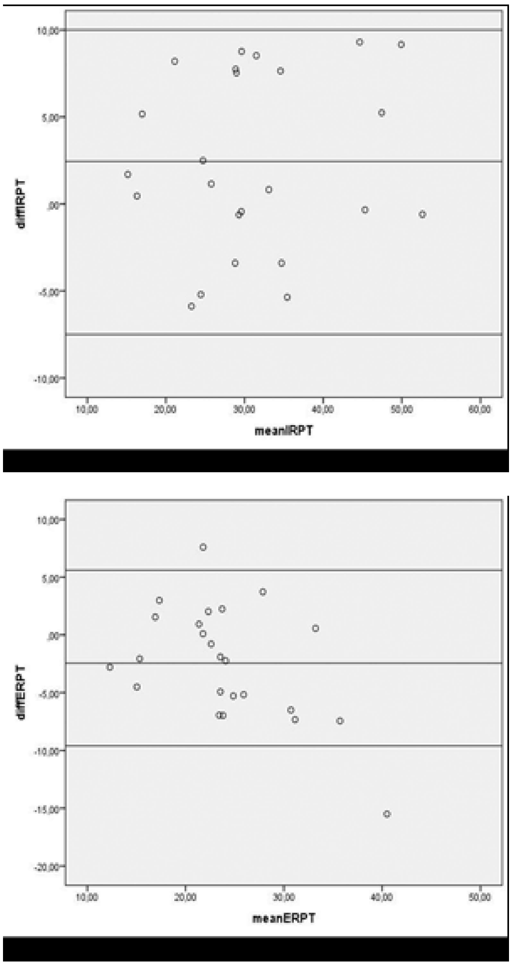


Figure-2: Torque calculation for FED (A) Lever arm of the forearm. (B) Force of the dynamometer measured by pulley system.



diffIRPT: Internal rotation peak torque difference, diffERPT: External rotation peak torque difference, MeanIRPT: Mean internal rotation peak torque, MeanERPT: Mean external rotation peak torque.

Figure-3: Bland-Altman plots. (A) Internal Rotator Peak Torque (p=0.44). (B) External Rotator Peak Torque (p=0.24). diffIRPT = internal rotation peak torque difference, diffERPT = external rotation peak torque difference, meanIRPT = mean internal rotation peak torque, and meanERPT = mean external rotation peak torque

Discussion

Similar MDC% values were found for IR (24.3%) and ER (27.9%) peak torque assessments at 90° of shoulder abduction in supine position using FED. Translated to a rehabilitation programme for ER shoulder strengthening, this means that to assure that a strengthening programme really improved the subject conditions, at least 27.9% improvement from the initial value should exist to be considered outside the FED random error. The MDC is a stringent decision limit for establishing improvement/deterioration in peak muscle force or torque following rehabilitation post-injury.[16] High heterogeneity between subjects exists for many measurements in sports medicine, as in the case of peak muscle force. Therefore, SEM and, consequently, MDC are high. In practice, one criterion for a return to sports is peak muscle strength deficits under 10% of the contralateral extremity.[16] At 90°, a study using a REV 9000 ID and another using a Cybex norm ID published MDC% results for the IR and ER within reported ranges (21-30%).[17,18] ER strength test-retest reliability has been studied previously,[11] obtaining an MDC% of 55.4% using a Kin-Com ID, and by a study[19] reporting an MDC% of 56.2% using a Cybex Norm ID. In turn, IR strength test-retest reliability studies have reported MDC% ranging 20-30%.[19-21]

Although MDC% values were similar to those established by other gold-standard IDs, this small but clinically relevant difference cannot be detected by either IDs or the currently-tested FED.

No existing literature has analysed the concurrent validity of novel pulley-system technology for measuring isometric strength in the shoulder rotators. This study compared the FED and ID, with findings supporting the validity of this dynamometer in measuring strength for IRs and ERs of the shoulder in a supine position with the arm elevated at 90°. Very high concurrent validity was found for IR peak torque between devices while high concurrent validity was found for ER peak torque. Further, the ICC CI between devices was more bounded for IR than ER. This similar behaviour, as demonstrated through high to very high correlation levels, supports the validity of the electromechanical dynamometry system compared to the gold standard dynamometry device.

Previously, according to a systematic review,[7] two studies[18,20] assessed concurrent validity with ID compared to HHDs in shoulder rotators. Lower ICC was obtained using HHDs compared to the ICC found in the present study. It seems that electromechanical pulley system has higher concurrent validity than HHDs in assessing shoulder rotators, but this hypothesis needs to be tested with a new study design.

Prior cadaveric shoulder rotator experiments showed that 90° of external shoulder rotator abduction creates instability due to a lack of participation by the biceps brachialis, coracobrachialis, anterior deltoid, major pectoral, and subscapularis, all of which could favour stabilisation of the glenohumeral girdle.[21] Furthermore, the ER are susceptible to major fatigue, which could be a source of variability during strength generation tests.[22] Stabilisation straps typically increases reliability in strength as shown in related studies.[23] FED does not have its own stabilisation straps. To avoid noise to the measurements that can alter the subject performance, the arm, thorax and pelvis were fixed with Velcro straps. To further control the anterior translation of the humeral head, another Velcro strap was added. Lower limb comfort was achieved with hip and knee flexion posturing. This stabilisation system could be a factor in obtaining high to very high concurrent validity, but still ER showed lower reliability scores. This suggest that shoulder IR maximal voluntary isometric strength test is more reliable than the shoulder ER test, but the effect of the stabilisation system needs to be studied in future studies with multifactor designs.

The main limitation of the current study was that the subjects were limited to isometric contraction and to one joint position. Only asymptomatic subjects were tested, so MDC% values obtained cannot be extrapolated to shoulder symptomatic population.

Future studies related to strength assessment in functional movements and in other joints will be of interest. Studies comparing MDC% in symptomatic and asymptomatic population are also recommended.

Conclusion

Absolute reliability of the FED pulley system was similar to those obtained by IDs and, thus, it was found to be a valid instrument in measuring maximal voluntary isometric peak torque in shoulder IRs and ERs.

Disclaimer: None.
Conflict of Interest: None.
Source of Funding: None.

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