Physical Therapy in Sport 16 (2015) 59–65

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original research

Inter-machine reliability of the Biodex and Cybex isokinetic dynamometers for knee flexor/extensor isometric, concentric and eccentric tests

João Breno de Araujo Ribeiro Alvares, Rodrigo Rodrigues, Rodrigo de Azevedo Franke, Bruna Gonçalves Cordeiro da Silva, Ronei Silveira Pinto, Marco Aurélio Vaz, Bruno Manfredini Baroni*

Exercise Research Laboratory (LAPEX), Federal University of Rio Grande do Sul (UFRGS), Rua Felizardo, 750, Bairro Jardim Botânico, CEP: 90690-200 Porto Alegre, RS, Brazil

ARTICLE INFO

Article history:
Received 7 September 2013
Received in revised form
15 April 2014
Accepted 24 April 2014

Keywords:
Isokinetic dynamometry
Test–retest
Quadriceps
Hamstring

ABSTRACT

Objectives: To assess the inter-machine reliability of the Biodex System 3 Pro and Cybex Humac Norm Model 770 dynamometers for knee extensor and knee flexor peak torque measurements in isometric, concentric and eccentric tests.
Design: Randomized/crossover.
Setting: Exercise Research Laboratory, Federal University of Rio Grande do Sul (Brazil).
Participants: 25 healthy male subjects.
Main outcome measures: Isometric, concentric and eccentric knee extensor and knee flexor peak torques recorded in the same test procedure performed on both isokinetic dynamometers. One-way ANOVA, intraclass correlation coefficient (ICC), standard error of measurement (SEM) and coefficient of variation (CV) were used to verify significant differences, relative and absolute reliability between devices.
Results: No significant differences were found between tests performed on Biodex and Cybex ($p > 0.05$). ICC values indicated a high to very high reproducibility for isometric, concentric and eccentric peak torques (0.88–0.92), and moderate to high reliability for agonist-antagonist strength ratios (0.62–0.73). Peak torque did not show great difference between dynamometers for SEM (3.72–11.27 Nm) and CV (5.27–7.77%). Strength ratios presented CV values of 8.57–10.72%.
Conclusion: Maximal knee extensor and knee flexor tests performed in isometric (60° of knee flexion), concentric and eccentric modes at 60°/s in Biodex and Cybex dynamometers present similar values.

1. Introduction

Strength generated by muscles is responsible for joint torque production, which contributes to the development of human body movements and assists in joint stability and posture maintenance (Hamill & Knutzen, 2009). Therefore, skeletal muscle capacity is a requirement of regular functionality of the human body (Anderson, Madigan, & Nussbaum, 2007), and muscle strength measurements are used to assess physical conditioning, to identify weakness related to aging or disease, and to monitor the progress in training/rehabilitation programs (Dwyer & Davis, 2008). Isometric tests using load cells (Pinto, Liedtke, Alberton, Da Silva, Cadore, & Kruel, 2010), dynamic tests using free weights or fitness machines (Correa et al., 2013), as well as isometric and dynamic tests using isokinetic dynamometers (Baroni, Rodrigues, Franke, Geremia, Rassier, & Vaz, 2013b) are commonly used in both clinical and academic activity.

Isokinetic dynamometry was introduced in the 1960s in order to quantify the moment of force, or torque, generated by the contraction of a muscle group in a circular motion. Isokinetic dynamometers allow for the execution of a dynamic exercise with a specific angular velocity and accommodating resistance, enabling subjects to perform maximum contraction throughout the full range of motion (Brown, 2000). The potential for safe maximal effort in a controlled environment added to the fact it has become the gold standard method in the literature (Lund et al., 2005) and encouraged the use of

* Corresponding author. Tel.: +55 51 33085859.
E-mail address: bmbaroni@yahoo.com.br (B.M. Baroni).

http://dx.doi.org/10.1016/j.ptsp.2014.04.004
1466-853X/

isokinetic dynamometers in training, rehabilitation and evaluation of musculoskeletal function (Kannus, 1994). Therefore, there are studies involving isokinetic dynamometry focusing in distinct groups: healthy men (Baroni, Leal Junior, Geremia, Diefenthaeler, & Vaz, 2010); women (Pinto et al., 2014); children (Tsiros et al., 2012); elderly (Baroni et al., 2013a); athletes (Borges, Vaz, De La Rocha Freitas, & Rassier, 2003); and subjects with musculoskeletal (Vaz et al., 2013), neurological (Pierce, Barbe, Barr, Shewokis, & Lauer, 2008) and cardiopulmonary diseases (Quittan et al., 2001).

The consumer market for isokinetic dynamometers (which includes universities, private research laboratories, sports clubs, rehabilitation centers and other facilities) has been dynamic in recent years with the availability of an increasing number of models from established and new manufacturers (Dirnberger, Kösters, & Müller, 2012). These dynamometers should be able to produce reliable assessments of the musculoskeletal system, independently of manufacturer or model. Reliability refers to the confidence that results will be consistent when the test is performed multiple times under similar conditions (Atkinson & Nevill, 1998; Emery, Maitland, & Meeuwisse, 1999; Hopkins, 2000). Using a reliable instrument ensures that changes observed between measurements are due to differences in performance rather than because of inconsistencies in the measuring capacity of a device (Drouin, Valovich-mcLeod, Shultz, Gansneder, & Perrin, 2004). The test–retest reliability studies usually reported relative reliability, where statistics indicate the degree to which individuals maintain their position in a sample over two or more measures, but do not provide clinical guidance for assessing real changes (Sole, Hamrén, Milosavljevic, Nicholson, & Sullivan, 2007). On the other hand, absolute reliability tests determine the degree to which repeated measurements vary for individuals, i.e. the smaller the variation, the higher the reliability (Dvir, 2003).

A considerable number of studies have demonstrated high between-test reliability scores performed using the same isokinetic dynamometer (intra-machine reliability) (Almosnino, Stevenson, Bardana, Diaconescu, & Dvir, 2012; Ayala, Croix, Baranda & Santoja, 2012; Bandy & Mclaughlin, 1993; Drouin et al., 2004; Dirnberger et al., 2012; Emery et al., 1999; Impellizzeri, Bizzini, Rampinini, Cereda, & Maffiuletti, 2008; Li, Wu, Maffulli, Chan, & Chan, 1996; Sole et al., 2007). These findings suggest, for example, that clinicians can have confidence in measurements to check patients' evolution throughout a rehabilitation program. However, there are fewer studies in the literature assessing the reliability of measurements between different isokinetic dynamometers (inter-machine reliability), and their results are inconsistent (Bandy & Mclaughlin, 1993; Cotte & Ferret, 2003; Francis & Hoobler, 1987; Gross et al., 1991; Keilani et al., 2007; Lund et al., 2005; Thompson, Shingleton, & Kegerreis, 1989).

If different isokinetic dynamometers express different data for a subject performing the same test, scientists would not be able to compare studies from different laboratories, physiotherapists could not verify if the muscular capacity of their patients agrees with the literature and coaches could not check if results from their athletes are above or below those reported by other teams, for example. Therefore, the aim of this study was to assess the inter-machine reliability of two of the most used isokinetic dynamometers (Biodex System 3 Pro and Cybex Humac Norm Model 770) for knee extensor and knee flexor peak torque measurements in isometric, concentric and eccentric tests.

2. Methods

2.1. Experimental design

Two isokinetic dynamometers were used in this study: a Biodex System 3 (Biodex Medical Systems, Shirley, NY, USA) and a Cybex Norm (Cybex, division of Lumex Inc., Ronkonkoma, NY, USA). The inter-machine reliability was assessed through isometric, concentric and eccentric maximal tests of knee flexor and extensor muscles. Volunteers performed two visits to the laboratory with a minimal interval of seven days to reduce both the possibility of learning effect and the deleterious effects of fatigue caused by eccentric efforts (Lund et al., 2005). In each visit, they performed the test protocol using one isokinetic dynamometer. The order of devices (Biodex–Cybex or Cybex–Biodex) usage was randomized between subjects: 13 subjects started the protocol with the Biodex dynamometer and 12 started with the Cybex dynamometer.

2.2. Subjects

The recruitment of volunteers was made through the dissemination of the study between the undergraduate and graduate students of the Federal University of Rio Grande do Sul, Porto Alegre, Brazil. Healthy male, physically active subjects, ranging from 20 to 35 years old, were invited to participate. Subjects were carefully informed about the study design and procedures during an interview session when eligible subjects were selected. Exclusion criteria included: (1) history of lower limb musculoskeletal disorders that could recur or interfere with a process of multiple maximal tests (e.g., patellar tendinitis, knee surgery, ruptured but not operated knee ligaments, recent muscle strains or joint sprains); and (2) respiratory or cardiovascular diseases considered a risk or a limiting factor for maximal tests. Ethical approval was obtained from the University's Research Ethics Committee (Project number 20412).

Twenty five subjects (23.72 ± 3.19 years old; 175.68 ± 7.84 cm in height; 75.00 ± 9.08 kg of body mass) signed an informed consent form to participate in the study. Subjects were instructed to maintain their daily routines, but were asked not to perform any vigorous physical activity in the 48 h preceding each testing day.

2.3. Procedures

Prior to data collection both isokinetic dynamometers were calibrated according to the manufacturer's instructions. After calibration, subjects were positioned on the Biodex and Cybex isokinetic dynamometers for the assessment of the right lower limb maximal strength according to the manufacturer's recommendations. Subjects were seated with the hip joint at 85° of flexion and attached to the dynamometer chair with velcro straps in order to provide stability during maximal contractions. The position of straps is specific and predetermined for each apparatus (for example, trunk straps cross the subject's chest on Biodex and are parallel to the trunk on Cybex). However, the dynamometer's lever arm was fixed in a similar length for both devices (pad positioned 2 cm above the lateral malleolus).

Tests were conducted by researchers experienced in dynamometer evaluations. Two researchers were assigned to drive the subject positioning and the hardware and software operation. Another researcher was responsible for the guidelines and verbal stimuli. The test protocol was adapted from a previous study of our research group (Baroni et al., 2013b). After a warm-up, consisting of 10 knee extension/flexion repetitions at an angular velocity of 90°/s with a submaximal effort level, subjects performed isometric, concentric and eccentric maximal tests.

Three maximum 5-s knee extensor isometric contractions and three maximum 5-s knee flexor isometric contractions were executed alternately at 60° of knee flexion (0° = full extension). A 2-min interval was observed between contractions of the same muscle group. Peak torque values from each contraction were checked during data collection and an additional test was performed when torque variation was higher than 10% between the first three tests.

For concentric torque evaluation, three consecutive maximum contractions were executed in the concentric–concentric mode. Movements were performed at an angular velocity of 60°/s and a range of motion between 90° and 10° of knee flexion. The test was repeated twice with a 2-min resting period between tests.

For eccentric torque evaluation, three consecutive maximal contractions were executed in the eccentric–eccentric mode. Movements were performed at an angular velocity of 60°/s and a range of motion between 30° and 90° of knee flexion. The test was repeated twice with a 2-min resting period between tests.

Aiming to avoid the influence of the order of the tests on the results, tests on Cybex and Biodex dynamometers were executed in the same order. During all attempts, subjects were verbally encouraged to do their best. Both dynamometers allow real-time visual feedback from a computer screen. The highest peak torque value reached in each dynamometer for each contraction type was considered for statistical analysis.

The strength ratio between hamstrings and quadriceps is commonly referred as *H*:*Q* ratio, and is used to evaluate the balance between the agonist and antagonist muscles at the knee joint (Aagaard, Simonsen, Magusson, Larsson, & Dyhre-Poulsen, 1998). In this study, “conventional ratio” was assessed through the division of the concentric peak torque of knee flexors by the concentric peak torque of knee extensors, while we called “functional ratio” the result of the knee flexor eccentric peak torque divided by the knee extensor concentric peak torque, as firstly described by Dvir, Eger, Halperin, and Shklar (1989) with the term “dynamic control ratio”.

2.4. Statistical analysis

Knee extensor and knee flexor peak torques, obtained in either isometric, concentric and eccentric modes were recorded and compared between Biodex and Cybex devices, as well as muscle strength ratios (conventional and functional), were also assessed. A one-way ANOVA was run in order to verify significant differences between tests performed on Biodex and Cybex dynamometers with a significance level of 5% ($\alpha < 0.05$). The relative reliability was assessed through the intraclass correlation coefficient (ICC). Since no universally accepted correlation values have been established for reliability studies (Bandy & Mclaughlin, 1993; Emery et al., 1999), we adopt the classification suggested by Sole et al. (2007), in which correlations of 0.50–0.69 are “moderate, 70–0.90 are “high”, and higher than 0.90 are “very high”. Absolute reliability was assessed through the standard error of measurement (SEM) and the coefficient of variation (CV), calculated according Dvir (2003). The SEM was not assessed for muscle strength ratios because they are not expressed in Newton-meters (Nm), as all other measures of the study, and thereby a comparison with them would be inadequate.

3. Results

No significant differences were observed between tests performed at the Biodex and Cybex devices ($p > 0.05$ for all comparisons; Table 1). In addition, correlations involving measures of knee extensors and knee flexors isometric, concentric and eccentric peak torques were close to 0.90, indicating a high to very high reproducibility (Table 1). ICC values of muscle strength ratios were 0.73 and 0.62, for conventional and functional ratios, respectively, indicating a moderate to high reliability (Table 1). Peak torque of knee flexors and extensors did not show great difference between dynamometers, according to SEM (3.72–11.27 Nm) and CV (5.27–7.77%) assessments (Table 1). Agonist–antagonist strength ratios presented CV values of 8.57–10.72% (Table 1).

We observed a random relationship between the individual difference for Biodex and Cybex measurements, as illustrated in the Bland–Altman plots for isometric (Fig. 1), concentric (Fig. 2) and eccentric (Fig. 3) tests, as well for strength ratios (Fig. 4). Mean peak torque values measured with the Biodex were higher than Cybex for knee extensors in concentric (3.2 Nm) and eccentric (4.0 Nm) tests, and for knee flexors in isometric tests (6.4 Nm). Biodex mean values were smaller than those measured with the Cybex dynamometer for knee extensor isometric peak torque (−10.4 Nm), knee flexor concentric (−1.5 Nm) and eccentric (−5.9 Nm) peak torques, and conventional (−0.03) and functional (−0.01) strength ratios. In addition, lines of equality between Biodex and Cybex measurements for each test (Figs. 1–4; right side) further demonstrated the similarity of results obtained across the two dynamometers.

4. Discussion

We were able to find three previous studies that compared torque values obtained through isokinetic tests performed with the Biodex and Cybex dynamometers (Thompson et al., 1989; Gross et al., 1991; Keilani et al., 2007). Although the equipment models tested in these studies are different from ours, these are the only investigations that enable a closer comparison with the present study. Thompson et al. (1989) and Keilani et al. (2007) reported knee extensor and knee flexor concentric peak torque data performed at angular velocities of 60°/s, 180°/s and 240°/s, while Gross et al. (1991) tested only the first two angular velocities.

These previous studies (Gross et al., 1991; Keilani et al., 2007; Thompson et al., 1989) have found reliable values between Biodex and Cybex dynamometers for knee extensor and knee flexor concentric tests, with relative reliability ranging between 0.71 and 0.96, consistent with our results. However, unlike our findings, these studies found significant differences when comparing the two

Table 1
Means and standard deviations of peak torque (Nm) for all variables, as well as *p*-values, relative (ICC) and absolute (CV and SEM) reproducibility statistics.

		Biodex	Cybex	*p*-value	ICC (95%CI)	CV	SEM
KE	Iso	290.20 ± 54.40	300.56 ± 60.44	0.527	0.88 (0.73–0.94)	7.19	9.98
	Con	244.84 ± 40.27	241.60 ± 38.17	0.772	0.89 (0.77–0.95)	5.27	5.95
	Ecc	317.92 ± 75.63	313.92 ± 61.92	0.838	0.89 (0.74–0.94)	7.62	11.27
KF	Iso	154.52 ± 32.92	149.46 ± 29.72	0.473	0.90 (0.78–0.95)	7.18	4.47
	Con	146.16 ± 26.05	147.64 ± 32.14	0.859	0.91 (0.78–0.95)	6.22	3.72
	Ecc	182.24 ± 38.12	188.12 ± 42.09	0.607	0.88 (0.74–0.94)	7.77	6.83
R_{conv}		0.60 ± 0.08	0.61 ± 0.11	0.408	0.73 (0.42–0.85)	8.57	–
Rf_{unc}		0.75 ± 0.12	0.78 ± 0.14	0.174	0.62 (0.30–0.81)	10.72	–

KE = knee extensors; KF = knee flexors; Iso = isometric; Con = concentric; Ecc = eccentric; R_{conv} = conventional ratio (Hcon:Qcon); R_{func} = functional ratio (Hecc:Qcon); *p*-value = one-way ANOVA; ICC = intraclass correlation coefficient; CI = confidence interval; CV = coefficient of variation (in %); SEM = standard error of measurement (in Nm).

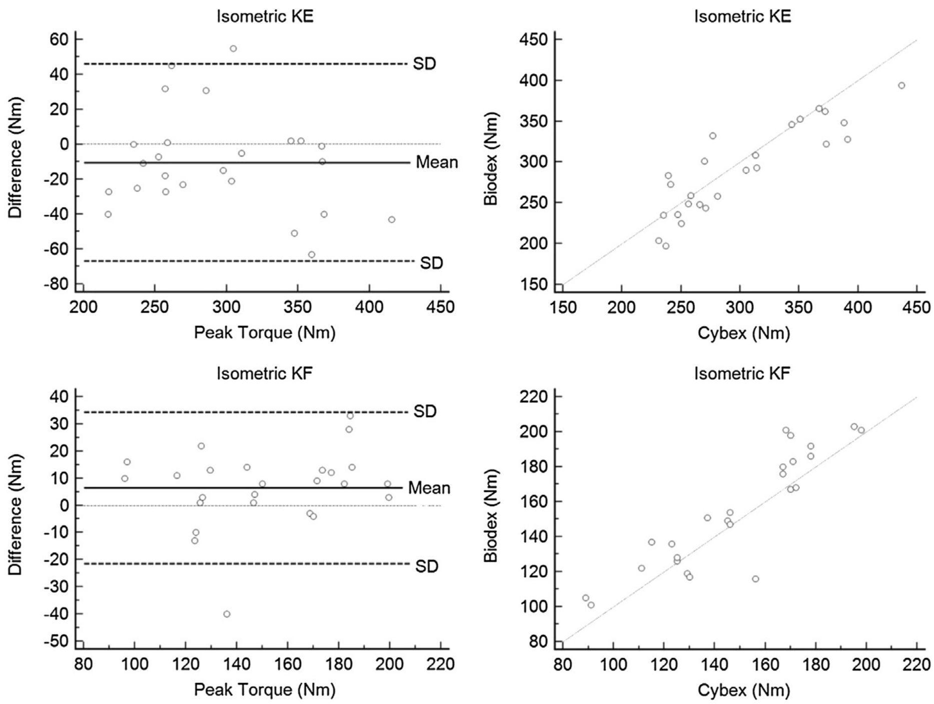

Fig. 1. Differences in isometric peak torque between test sessions: Biodex test − Cybex test (left side); and line of equality between the two dynamometers' measurements (right side), for knee extensors (KE) and knee extensors (KF).

devices. Keilani et al. (2007) observed higher peak torque values for knee flexion and knee extension measured with the Biodex compared to those performed on the Cybex. Thompson et al. (1989) and Gross et al. (1991) also found peak torque values of knee extension significantly higher with the Biodex. However, while results from Thompson et al. (1989) suggested no difference between machines for the knee flexors, Gross et al. (1991) demonstrated that knee flexion tests performed on the Cybex reached higher peak torque values.

Studies comparing tests performed with the Biodex and Cybex machines (Gross et al., 1991; Keilani et al., 2007; Thompson et al., 1989) and also those of inter-machine reliability using other devices (Bandy & Mclaughlin, 1993; Cotte & Ferret, 2003; Francis & Hoobler, 1987; Lund et al., 2005) did not assess isometric and

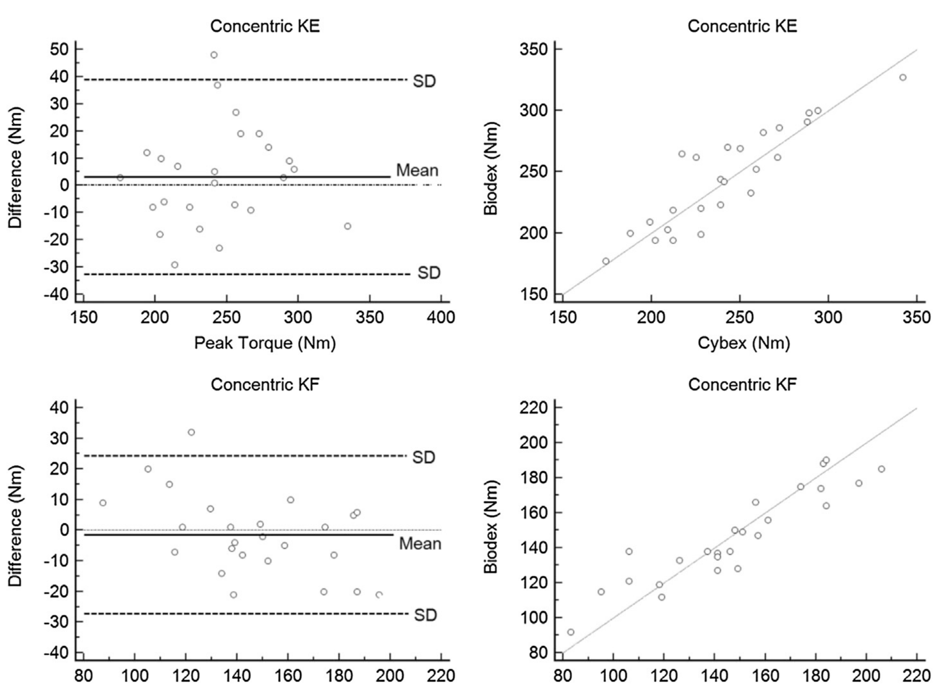

Fig. 2. Differences in concentric peak torque between test sessions: Biodex test − Cybex test (left side); and line of equality between the two dynamometers' measurements (right side), for knee extensors (KE) and knee extensors (KF).

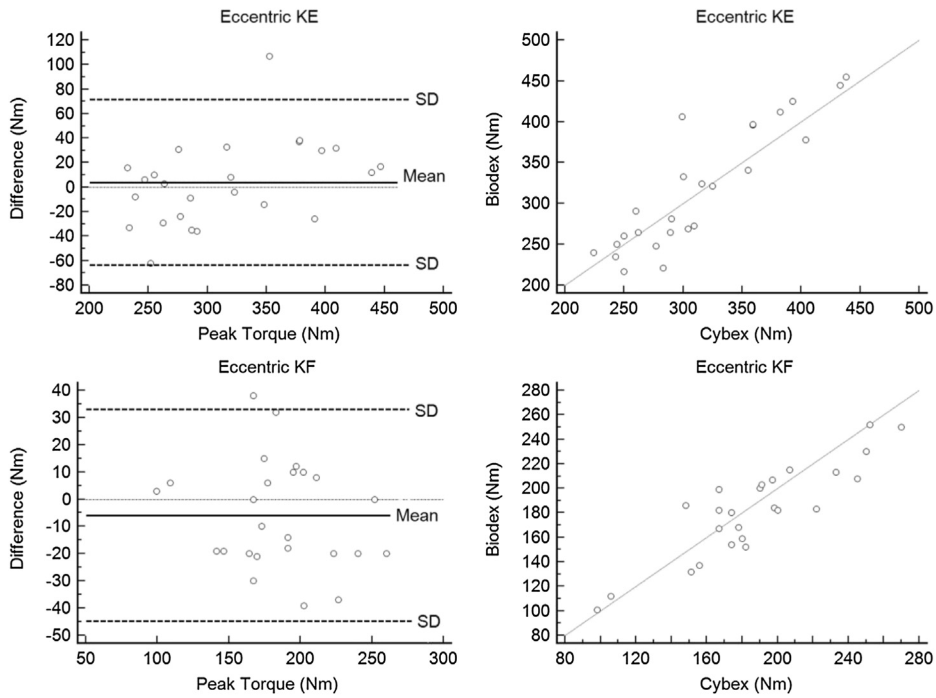

Fig. 3. Differences in eccentric peak torque between test sessions: Biodex test − Cybex test (left side); and line of equality between the two dynamometers' measurements (right side), for knee extensors (KE) and knee extensors (KF).

eccentric tests. It is known that isometric tests may exhibit low association with functionality improvements resulting from a training or rehabilitation program (Murphy & Wilson, 1997), but these measures seem to have good test-retest reproducibility and are commonly used in clinical evaluation. In addition, although eccentric tests are the less frequently used, their application is growing as a result of a reported relationship between eccentric strength production and sports performance (Aagaard, 2010), injury prevention (Petersen, Thorborg, Nielsen, Budtz-Jørgensen, & Hölmich, 2011) and musculoskeletal rehabilitation (Lorenz & Reiman, 2011). Thus, isometric and eccentric tests are important data in the dynamometry field, and this study seems to be the first to compare inter-machine reliability of isokinetic dynamometers for these types of test.

Absolute indices of reliability used in the present study corroborate the inter-machine reliability for knee flexor and

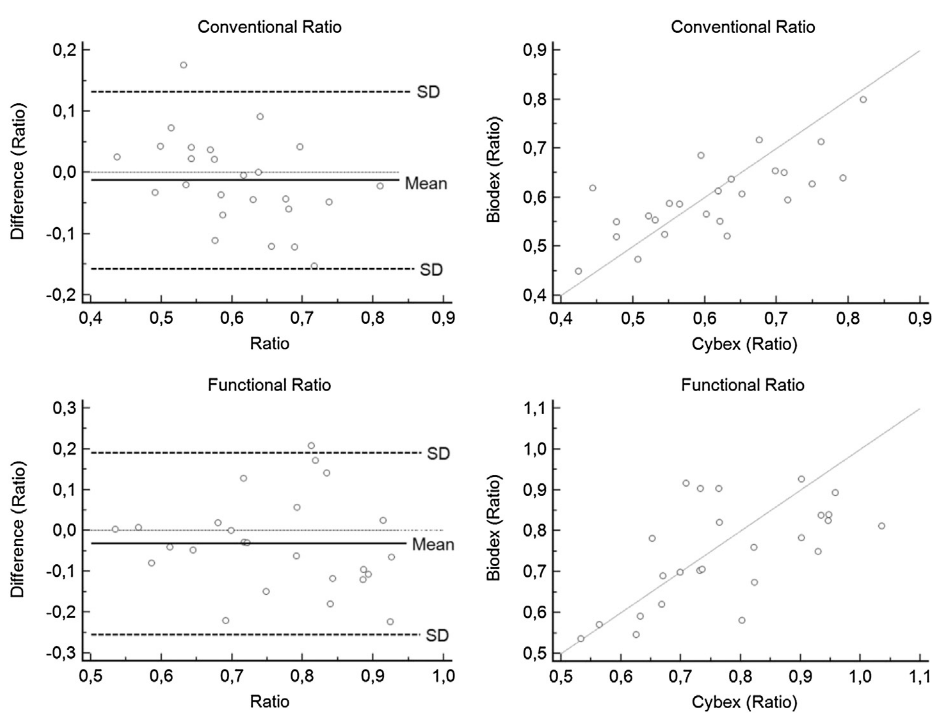

Fig. 4. Differences in strength ratios between test sessions: Biodex test − Cybex test (left side); and line of equality between the two dynamometers' measurements (right side).

extensor tests. CV and SEM reflect the magnitude of the differences between two measures (Sole et al., 2007). Since they are expressed in units that are readily interpretable, extrapolation to new individuals as well as comparison between different measurement tools is possible (Dvir, 2003). CV was below 7.8% for all peak torque measures, while SEM presented acceptable values ranged from 3.77 Nm (concentric knee flexors) to 11.27 Nm (eccentric knee extensors). In addition, there was a good agreement between the different equipment, without any identifiable trend; because Bland–Altman plots showed no systematic biases and most of the points are very close to the line of equality.

Interestingly, conventional and functional ratios presented moderate to high ICC scores and the worse CV values compared to peak torque measurements. Although no significant differences have been found, the values measured in the Biodex were on average 2–5% lower than those reported for the Cybex. These findings are consistent with those reported by Thompson et al. (1989), which showed significantly higher values of conventional ratio obtained from the Cybex compared to those of the Biodex. Similarly, Francis and Hoobler (1987) also found significant differences and moderate reliability in the H:Q ratio measurements by Lido and Cybex devices. Furthermore, our results suggest a smaller degree of reliability for functional ratio compared to the conventional ratio, corroborating findings of Ayala, De Ste Croix, Sainz de Baranda, and Santonja (2012). Nevertheless, muscle strength ratios are formed by the division of two measures with potential measurement error, and thereby a lower consistency is expected in the values of test and retest evaluations. Together, these findings suggest *H*:*Q* ratios evaluated using different dynamometers present an acceptable level of reliability, but this kind of comparison requires a higher level of caution than comparisons involving single contractions of knee flexor or extensor muscles.

As in most clinical trials, the impossibility of guaranteeing that the subject performs the exact same amount of force in tests performed with both dynamometers is present in our study. Despite our concern in trying to minimize this intervening variable through standardized instructions prior to testing and the continuous verbal encouragement during testing, there is no guarantee that volunteers have identical performance in the two evaluation sessions. The variation comes from several sources, and the main source is usually biological. An individual's maximum power output changes between trials because of changes in mental or physical state. Equipment may also contribute noise to the measurements (Hopkins, 2000) that can alter the subject's performance, such as: the straps system of each device for body fixation, the deformation suffered by the material of the seat cushion and the pad lever arm attached to the subject's leg, and the comfort provided by the equipment itself to the subject being tested. These and other factors are present in the isokinetic assessment performed at research laboratories, sports clubs and rehabilitation clinics. Therefore, we believe that our findings depict the real situation that professionals involved in the human movement sciences experience in their daily practice.

5. Conclusion

In conclusion, the results of this study suggest that maximal knee extensor and knee flexor tests performed with the isometric at 60° of knee flexion, concentric and eccentric at 60°/s modes in Biodex and Cybex dynamometers present similar peak torque values. Therefore, our data suggest that it is possible to extrapolate individual values from one machine to the other; researchers may compare results from studies performed using these two different dynamometers with relative safety and clinicians may use reference values derived from one isokinetic device and apply them to data obtained from the other isokinetic device.

Conflict of interest

None declared.

Ethical approval

Ethical approval was obtained from the University's Research Ethics Committee (Project number 20412).

Funding

None declared.

Acknowledgments

The authors would like to thank CAPES-Brazil and CNPq-Brazil for financial support, and all volunteers for their participation in this project.

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