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Originales

Validity and Reliability of a Low-Cost Load Cell for Isometric Knee Extension and Flexion in Professional Soccer Players

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ABSTRACT

Purpose: Muscle strength is essential for sport performance, but gold-standard assessment tools are costly. We evaluated the validity and reliability of a very low-cost load cell (LC) for measuring isometric knee extension and flexion strength compared with an isokinetic dynamometer (ID). **Methods:** Thirty-one professional male soccer players (17.8 ± 1.3 y; 71.2 ± 6.3 kg; 177 ± 0.1 cm) completed two testing sessions. Peak isometric force at of knee flexion was measured with both the load cell LC and ID. Reliability was assessed using intraclass correlation coefficients (ICC), coefficients of variation (CV), and Bland–Altman plots. Validity was examined by comparing peak force between devices using repeated-measures ANOVA. **Results:** Both devices showed excellent test–retest reliability for knee extension (LC ICC = 0.91; ID ICC = 0.94) and knee flexion (LC ICC = 0.93; ID ICC = 0.99). CVs ≤ 7.2% indicated acceptable to high reliability. The LC consistently overestimated peak force relative to the ID in both movements (p < 0.001). Trial-to-trial differences were also found for knee flexion with the LC (p = 0.010). **Conclusion:** The low-cost LC demonstrated excellent reliability but poor validity versus the ID. It may be useful in applied settings, but systematic overestimation warrants caution.

Keywords: muscle strength; isometric assessment; load cell; reliability; validity; soccer.

Validade e confiabilidade de uma célula de carga de baixo custo para a extensão e a flexão isométricas do joelho em jogadores profissionais de futebol

RESUMO

Objetivo: A força muscular é essencial para o desempenho esportivo, mas os instrumentos considerados padrão-ouro para sua avaliação apresentam custos elevados. O objetivo deste estudo foi avaliar a validade e a confiabilidade de uma célula de carga de muito baixo custo (LC) para medir a força isométrica de extensão e flexão do joelho, em comparação com um dinamômetro isocinético (DI). **Métodos:** Trinta e um jogadores profissionais de futebol do sexo masculino (17,8 ± 1,3 anos; 71,2 ± 6,3 kg; 177 ± 0,1 cm) participaram de duas sessões de avaliação. A força isométrica máxima durante a extensão e a flexão do joelho foi medida por meio da célula de carga LC e do DI. A confiabilidade foi avaliada por meio do coeficiente de correlação intraclasse (CCI), do coeficiente de variação (CV) e dos gráficos de Bland–Altman. A validade foi analisada mediante a comparação da força máxima entre os dispositivos por meio de análise de variância para medidas repetidas. **Resultados:** Ambos os dispositivos apresentaram excelente confiabilidade teste–reteste para a extensão do joelho (LC: CCI = 0,91; DI: CCI = 0,94) e para a flexão do joelho (LC: CCI = 0,93; DI: CCI = 0,99). Valores de CV ≤ 7,2% indicaram confiabilidade aceitável a elevada. A LC superestimou sistematicamente a força máxima em comparação com o DI em ambos os movimentos (p < 0,001). Também foram observadas diferenças entre as tentativas para a flexão do joelho avaliada com a LC (p = 0,010). **Conclusão:** A célula de carga de baixo custo apresentou excelente confiabilidade, mas baixa validade em comparação com o dinamômetro isocinético. Esse dispositivo pode ser útil em contextos aplicados, embora a superestimação sistemática dos valores de força exija cautela na interpretação dos resultados.

Palavras-chave: força muscular; avaliação isométrica; célula de carga; confiabilidade; validade; futebol.

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Validez y fiabilidad de una célula de carga de bajo coste para la extensión y la flexión isométricas de rodilla en futbolistas profesionales

RESUMEN

Objetivo: La fuerza muscular es esencial para el rendimiento deportivo, pero las herramientas consideradas de referencia para su evaluación tienen un coste elevado. El objetivo de este estudio fue evaluar la validez y la fiabilidad de una célula de carga de muy bajo coste (LC) para medir la fuerza isométrica de extensión y flexión de rodilla, en comparación con un dinamómetro isocinético (DI). **Métodos:** Treinta y un futbolistas profesionales de sexo masculino (17,8 ± 1,3 años; 71,2 ± 6,3 kg; 177 ± 0,1 cm) realizaron dos sesiones de evaluación. La fuerza isométrica máxima durante la extensión y la flexión de rodilla se midió mediante la célula de carga LC y el DI. La fiabilidad se evaluó mediante el coeficiente de correlación intraclase (CCI), el coeficiente de variación (CV) y los gráficos de Bland–Altman. La validez se examinó comparando la fuerza máxima entre ambos dispositivos mediante un análisis de la varianza de medidas repetidas. **Resultados:** Ambos dispositivos mostraron una excelente fiabilidad test–retest para la extensión de rodilla (LC: CCI = 0,91; DI: CCI = 0,94) y la flexión de rodilla (LC: CCI = 0,93; DI: CCI = 0,99). Los valores de CV ≤ 7,2% indicaron una fiabilidad aceptable o elevada. La LC sobreestimó sistemáticamente la fuerza máxima respecto al DI en ambos movimientos (p < 0,001). También se encontraron diferencias entre intentos en la flexión de rodilla evaluada con la LC (p = 0,010). **Conclusión:** La célula de carga de bajo coste mostró una excelente fiabilidad, pero una validez deficiente en comparación con el dinamómetro isocinético. Puede resultar útil en contextos aplicados, aunque la sobreestimación sistemática de los valores de fuerza exige cautela en la interpretación de los resultados.

Palabras clave: fuerza muscular; evaluación isométrica; célula de carga; fiabilidad; validez; fútbol.

INTRODUCTION

Strength is a physical capability which is considered an essential aspect for a good sport performance. Greater muscular strength has been associated with enhanced force-time characteristics (e.g. rate of force development [RFD]), general sport skill performance (e.g. jumping, sprinting and change of direction [COD]) and specific sport skill performance as well as decreased injury rates and enhanced potentiation effects [1]. On the order hand, bad physical preparation, as low level of strength and flexibility showed a significantly higher injury rate [2]. For example, the imbalance of muscular strength with a low hamstring to quadriceps ratio (H:Q ratio) is a risk factor for hamstrings injuries in sports involving sprinting and jumping [3]. As the hamstring and groin strains together with the ankle and knee sprains account for more than 50% of all injuries in soccer [4], good levels of strength and a balanced muscular strength between agonist and antagonist muscles groups in lower limbs are needed for these athletes.

The level of muscular strength can be assessed isometrically or dynamically. Suchomel and colleagues [1] argued that isometric strength tests have displayed notable relationships with dynamic strength performance in addition to being time efficient, particularly with large groups, and may provide a truer measure of "maximum" strength compared to dynamic strength testing in which the final load attempted may be overestimated. However, the isometric level of muscular strength as well as the imbalance of muscular strength between agonist-antagonist muscle groups are generally assessed by the isokinetic dynamometer (ID). Although ID is the gold standard device to assess the isometric muscular strength [5], its limitations such as the usage in laboratory environments, the spending time in large samples and the high cost hinder the utilization. In this way, cheaper procedures employing more versatile devices with good validity and reliability would be of great value.

An interesting device to be used in the field due to its easy transportation and reasonable costs is the load cell (LC). There are a lot of LC brands available in the market. In the scientific literature, there are studies which have assessed the validity and/or reliability of different brands of LCs for knee extension and/or flexion [5-9]. Although LCs are much cheaper than ID, the price variation is wide with some LC devices costing ~$1000 [6] or more and others with price <$500 [10]. Nevertheless, even prices around 500 dollars may be a considerable expenditure in some situations. For instance, teams and staffs with no sponsorship and low income may have some difficulties to purchase a LC with price around that. Fortunately, alternative LCs costing around $20 or less can also be bought and may be an option for those with low purchasing power. Notwithstanding, the great part of these LCs, if not all, have no proof of the validity and reliability. Because of the potential for universal utilization of these LCs due to the very low expenditure, the validity and reliability of some these devices deserve to be analysed.

Thus, the aim of this study is to assess the validity and reliability of a very cheap LC (~$10) through the comparison of knee extension-flexion peak force with the data obtained in an ID test in professional soccer players. We hypothesized that the LC will get validity and reliability in the comparisons with the ID test.

METHODS

Experimental Approach to the problem

This cross-sectional validation and reliability study with a repeated-measures design was conducted during the mid-season of the 2025 Brazilian U-20 National Soccer Championship. Testing sessions were conducted at two time points separated by a minimum of 48 hours and no longer than 72 hours apart (mean = 50 ± 1.0 h). During this period, the subjects were instructed to refrain from strenuous physical exercise, the utilization of supplements that would impact their performance and alcohol for 48 hours before each session. Also, they were instructed to maintain the routine diet as usual (not recorded). Subjects completed the testing sessions in a randomized, counterbalanced order, performing both the criterion (isokinetic dynamometer) and experimental (low-cost load cell) conditions.

Subjects

Sample size estimation was performed using G*Power software (F-tests ANOVA: Repeated measures within factors family), assuming an alpha level of 0.01, statistical power of 0.90, and a conservative effect size of 0.7. The analysis indicated that a minimum of 7 subjects is required to achieve a power of 0.91. Thirty-one professional male soccer players (17.8 ± 1.3 y; 71.2 ± 6.3 kg; 177 ± 0.1 cm) were enrolled in this study. The subjects had ≥ 2 years of experience in federated soccer championships (e.g., national championship). All subjects read and signed the informed consent exposing the benefits and risks associated with participation in this investigation. This study was approved by the University's Human Research Ethics Committee in accordance with the Declaration of Helsinki (CAAE nº: 89797725.4.0000.0423).

Procedures

The dominant leg was tested on the LC and ID protocols on the same day in a counterbalanced order. Dominant leg was defined as the preferred leg used to kick a soccer ball. Measurements of knee flexion-extension strength were tested isometrically at 90º of knee flexion. Joint position was quantified through a goniometric measurement.

Session began with a warm-up of 5 minutes of moderate cycling (Borg RPE scale 3–4/10) followed by dynamic stretching (~5 minutes) targeting the lower limbs. Then, a submaximal warm-up consisting of two 5-second isometric contractions at 50% and 70% of perceived effort preceded the maximal tests. A familiarization was performed 48 h before the tests began involving 2 submaximal following the described warm-up. The movements performed were the knee flexion and knee extension with the LC and ID during each testing session.

The knee extension-flexion test in LC and ID required the subjects to sit in a stabilization chair during the testing (Digital Crane Scale, Weiheng, 500 kg capacity, Wuxi JI, China; Biodex System 4 Pro, Biodex Medical Systems®, NY, USA, respectively). During the testing with the LC, one end of the LC was attached to a stabilization strap fixed to the subject's ankle while the other end was fixed to the examination table. For ID test, subjects were attached to the seat of the dynamometer (seat tilt: 85º) so that the axis of their knee aligned with the axis of the dynamometer. The seat orientation and ID orientation were 90º and the free extremity of the lever arm attached to the ID was strapped around the volunteer´s ankle.

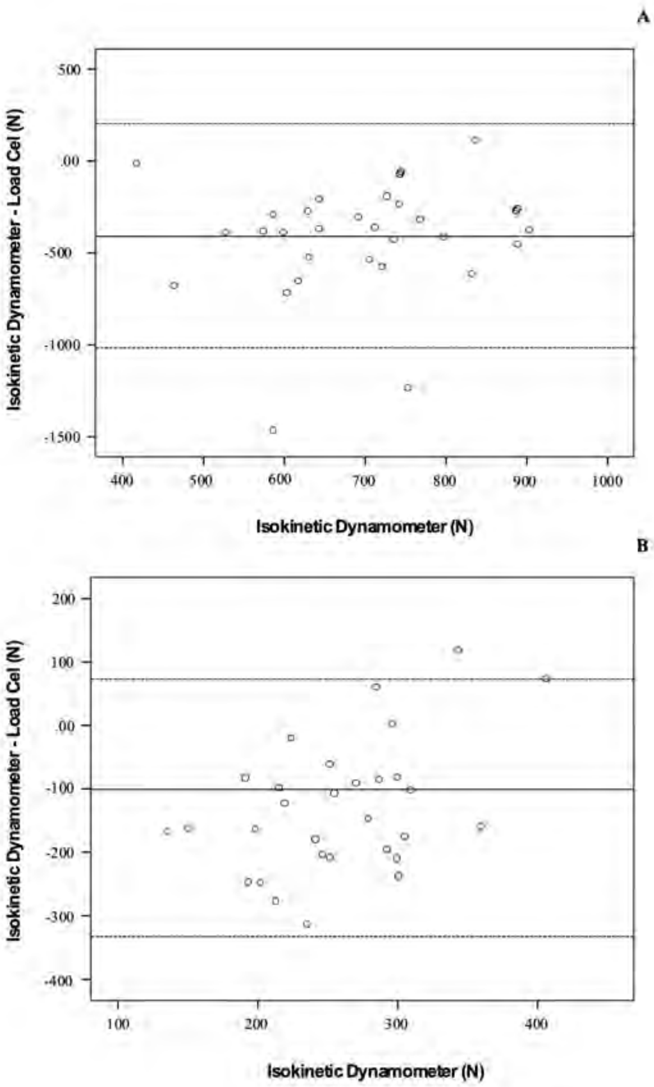
The protocol consisted of three maximal voluntary isometric contractions (MVIC) lasting five seconds each on every device, with one minute of rest between trials. A five-minute rest was provided between testing devices. The peak force (N) from the three trials for each movement was recorded.

Statistical Analysis

Data normality was assessed using the Shapiro–Wilk test. Reliability and validity for each variable were evaluated using intraclass correlation coefficients (ICC), coefficient of variation (CV), and Bland–Altman plots, each accompanied by their 95% confidence intervals (CI). A two-way random-effects model with absolute agreement was used to calculate ICCs. ICC values ≥ 0.80 were considered acceptable, and values ≥ 0.90 were considered excellent [11]. For the CV, values ≤ 10% were deemed acceptable, while values ≤ 5% indicated high reliability [12]. Validity analyses were performed using the mean values from test and retest for each condition. Repeated measures of ANOVA was used to compare the two methods of assessing peak force between days. Sphericity was verified and a post hoc analysis with Bonferroni correction was employed for multiple comparisons between methods (0.05 / 4 = 0.0125). All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS, version 21; IBM Corp., Armonk, NY, USA). Results are reported as mean ± standard deviation (SD), and statistical significance was set at $p \leq 0.05$.

RESULTS

Figure 1 showing the agreement between the ID and the LC for peak force during (A) knee extension and (B) knee flexion. The plots present the difference between paired ID and LC values (y-axis) against the corresponding ID values (x-axis). Across both movements, the LC consistently overestimated muscle strength compared with the ID.



Note: Y-axis, Representation (A) comparison between difference of mean of ID and LC in knee extension condition; (B) difference of mean of ID and LC in knee flexion condition. X-axis, isometric knee extension (fig. A) and flexion (fig. B) forces obtained from the isokinetic dynamometer. The dotted lines present upper and lower limit. LC, low-cost load cell; ID, isokinetic dynamometer; N, Newtons.
Figure 1. Bland-Altman plot of the isometric knee extension and flexion force and the difference between low-cost load cell and isokinetic dynamometer.

The CV indicated acceptable reliability for knee extension in both LC and ID, and high reliability for knee flexion (7.2% and 6% for extension; 1.4% and 1.2% for flexion, respectively). The reliability of the LC was assessed using ICC. We used a two-way random effect model with absolute agreement [ICC (2,1)]. For knee extension, the single measures ICC was 0.91 (95% CI: 0.817 - 0.955; $p < 0.001$), and for knee flexion, the single measures ICC was 0.93 (95% CI: 0.868 – 0.968; $p < 0.001$), indicating excellent reliability. The reliability of the ID followed the same design as the LC. For knee extension, the single measures ICC was 0.94 (95% CI: 0.883 - 0.972; $p < 0.001$), and for knee flexion, the single measures ICC was 0.99 (95% CI: 0.992 – 0.998; $p < 0.001$), indicating excellent reliability. Table 1 shows the test-rest reliability values.

For knee extension, there were no significant differences in peak force between Trial 1 and Trial 2 within the same condition, either the LC or the ID ($p = 0.615$ and $p = 0.333$, respectively).

Table 1. Test-Retest Reliability Values

Condition	Muscle Group	ICC	SEM (N)	95% MDC (N)
Load Cell	Knee extensors	.91	93.9	260.1
	Knee flexors	.93	23.2	426.3
Isokinetic Dynamometer	Knee extensors	.94	30.1	653.7
	Knee flexors	.99	5.6	81.3

Note ICC, Intraclass correlation coefficient; SEM, standard error of measurement; MDC: minimal detectable change.

Table 2. Knee-Extension and -Flexion Peak-Force Values

	Condition	Peak Force (N)	SD	95% CI
Knee extension				
Trial 1	Load cell	1055.3	317.9	936.552 – 1173.975
	Isokinetic Dynamometer	699.9	123.9	653.635 – 746.184
Trial 2	Load cell	1097.5	323	976.861 – 1218.071
	Isokinetic Dynamometer	684.5	125.4	637.698 – 731.341
Knee flexion				
Trial 1	Load cell	385.4	95	349.952 – 420.915
	Isokinetic Dynamometer	258.9	55.2	238.300 – 279.519
Trial 2	Load cell	365.1	83	334.132 – 396.121
	Isokinetic Dynamometer	257.6	56.2	236.648 – 278.585

Note N, newton; SD, standard deviation; 95% CI, 95% confidence interval.

However, significant differences in peak force were observed between the methods for both Trial 1 and Trial 2 ($p < 0.001$).

For knee flexion, a significant difference in peak force was found between trials in the LC condition ($p = 0.010$), but not in the ID condition ($p = 0.898$). Similar to the extension data, between-method comparisons for both Trial 1 and Trial 2 revealed significant differences in peak force ($p < 0.001$). Table 2 shows the knee-extension and -flexion peak force values.

DISCUSSION

The aim of the present study was to evaluate the validity and reliability of a low-cost load cell by comparing knee extension–flexion peak force values with those obtained from an isokinetic dynamometer test in professional soccer players. The results contradict partially our initial hypothesis which speculated that LC would be a valid and reliable device compared to the “gold standard” apparatus (ID). The data demonstrated that both LC and ID presented excellent reliability for both movements (knee flexion and extension) in a test-retest design. Moreover, the peak force was different between LC and ID in trials 1 and 2 for both knee extension and flexion and in peak force between trials in the LC only for knee flexion. Despite the low cost and ease of transportation, these results suggest that LC presents a poor validity even though the excellent reliability.

During knee extension movement, LC reached a test-retest ICC value of 0.91 while ID obtained a value of 0.94 in this parameter. These values are greater than 0.90 which allow us to infer that both devices present excellent reliability. Juneau et al. [8] reported that a different brand of LC showed excellent intrasession reliability (ICC > 0.90) for peak force in the seated knee extension. Likewise, Kollock et al. [7] described good (0.80 < ICC < 0.90) to excellent (ICC > 0.90) intrasession ICC values for another LC during the same movement pattern in 3 different sessions. However, in the present study, we focused exclusively on intersession reliability, as this approach better reflects the reproducibility of measurements across different testing days, a critical aspect for both longitudinal monitoring and practical application in research and clinical settings. In this way, Kollock et al. [7] demonstrated poor to fair intersession reliability (ICC: 0.43–0.76) for knee and hip strength evaluated by different movement patterns including seated knee extension. This difference from our findings may be due to inherent aspects of the LCs used in the Kollock's study [7] and in the present study and also by the ability of athletes to consistently produce high strength values across different days, likely as a result of years of training.

For knee flexion, the ICC values obtained by LC and ID was 0.93 and 0.99, respectively. Similar to the findings for knee extension, both devices demonstrated excellent reliability. Kollock et al. [7] reported high intrasession reliability of a portable fixed dynamometer in assessing hip and knee musculature strength (0.85 to 0.99). Notwithstanding, the intersession ICC value for knee flexion was the lowest (ICC: 0.43, poor reliability) among all measurements. Again, despite the difference related to the distinct devices used in the present study and that in the Kollock's study [7], the different characteristics of the sample needs to be taken into account. Our subjects were professional soccer players, who place high demands on the hamstring muscles [4], whereas Kollock et al. [7] examined non-athlete individuals.

The peak force values between LC and ID were different for both movements (knee extension and flexion) in both trials (Trials 1 and 2). This data indicates that the peak force reached by LC in these movements did not match the values obtained by ID. As ID is considered the gold standard, or the criterion measure for isometric muscle strength [5, 6], would be expected that LC got values for this parameter similar to that for ID test if the tested LC in the present study was a valid device. In other words, the validity of the LC used in this investigation was not confirmed for both seated knee flexion and extension. Moreover, while peak force registers between trials were not different in both conditions (LC and ID) for knee extension, only LC showed significant difference between Trials 1 and 2 for knee flexion. This suggests that although the ranking of subjects remained consistent, absolute scores varied across trials, potentially due to learning effects, fatigue, or instrument bias.

The findings of the present study demonstrated a low CV for both instruments (ID and LC), supporting their measurement reliability. In summary, the low-cost load cell (LC) evaluated in the present study demonstrated excellent reliability for both knee extension and knee flexion; however, its validity could not be confirmed. Difference was observed between trials for knee flexion, and the absolute peak force values for both knee extension and flexion differed significantly from those obtained with the isokinetic dynamometer (ID). Therefore, these findings should be interpreted with caution. The applicability of the present results cannot be generalized to other populations, nor can conclusions be extended to different movement patterns. Future research should investigate the use of the LC in diverse populations (e.g., athletes from other sports) and across various movement tasks to further establish its reliability and potential applications.

In certain contexts, such as team sports, the use of an LC may be attractive due to these advantages, but the device tested in the present study may yield inaccurate values for knee extension and flexion. Although this result, this device may be useful to day-a-day application as much as the reliability is excellent.

The LC demonstrated excellent reliability when compared with the gold-standard ID; however, its validity could not be confirmed. While the LC presents advantages over the ID, such as portability and, in this case, very low cost, the results obtained should be interpreted with caution. Furthermore, its validity and reliability for other movement patterns remain unknown.

Award id

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Conflicts of interest

The authors have declared no conflicts of interest.

Author Contributions

All authors contributed to the study conception and design.

Ethics Approval

This study was approved by the University's Human Research Ethics Committee in accordance with the Declaration of Helsinki (CAEE).

Consent to participate

Informed consent was obtained from all individual participants included in the study.