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Original Article

10-RM TEST OF UPPER AND LOWER LIMBS USING A MACHINE AND ELASTIC BANDS: IS THERE AGREEMENT BETWEEN DEVICES?

TESTE DE 10-RM DOS MEMBROS SUPERIORES E INFERIORES UTILIZANDO MÁQUINA E FAIXAS DE ELÁSTICO: EXISTE ACORDO ENTRE OS DISPOSITIVOS?

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RESUMO

Máquinas e pesos livres são comumente usados para aumentar a força muscular e o desempenho. No entanto, o uso de dispositivos elásticos necessita de investigações científicas quanto à sua concordância com os métodos padrão-ouro de força muscular. Objetivo: Verificar a concordância do teste de 10-RM entre a musculação e a resistência elástica em exercícios de membros superiores e inferiores, e a confiabilidade intra-dispositivo, concordância e alterações mínimas detectáveis do teste de 10-RM. Métodos: Vinte e três adultos saudáveis e não treinados, de ambos os sexos (idade 22,43 ± 2,55), realizaram o teste de supino reto de 10-RM e extensão de joelho com aparelhos de musculação e tubos elásticos, de forma aleatória. Resultados: A comparação do teste de 10-RM entre os instrumentos, pela utilização do índice ICC, demonstrou confiabilidade muito alta e alta para membros inferiores (ICC = 0,87) e superiores (ICC = 0,80), respectivamente. A análise de concordância de Bland Altman mostrou que o teste de 10-RM usando resistência elástica produziu cargas menores (Kgf) na extensão do joelho (34,16 ± 6,81 [elástico]; 36,22 ± 9,45 [máquina]; diferença média = 2,05 kgf ± 5,32) e cargas maiores (Kgf) no supino vertical (31,61 ± 7,81 [elástico]; 24,96 ± 10,11 [máquina]; Diferença média = 6,65 kgf ± 4,93) quando comparado aos aparelhos de musculação. A confiabilidade intra-dispositivo também demonstrou um índice ICC muito alto para membros superiores e inferiores em ambos os dispositivos. Conclusão: A utilização de 10-RM com resistência elástica apresenta alta confiabilidade e concordância quando comparada a aparelhos de musculação para exercícios de supino horizontal ou extensão de joelhos.

Palavras-chave: Reprodutibilidade de resultados. Força muscular. Theraband. Supino. Questionário de prontidão para atividade física.

ABSTRACT

Machines and free weights are commonly used to increase muscle strength and performance. However, the use of elastic devices needs scientific investigations regarding its agreement against gold standards methods muscle strength. Aim: To determine the agreement of the 10-RM test between weight machine and elastic resistance in upper and lower limb exercises, and the intra-device reliability, agreement, and minimal detectable changes of the 10-RM test. Methods: Twenty-three healthy and untrained adults, of both sexes (age 22.43 ± 2.55), performed the 10-RM bench press and knee extension test with weight machines and elastic tubes, randomly. Results: The comparison of the 10-RM test between instruments, by the use of ICC index, demonstrated very high and high reliability for lower (ICC = 0.87) and upper (ICC = 0.80) limbs, respectively. The Bland Altman agreement analysis showed that the 10-RM test using elastic resistance produced lower loads (Kgf) on knee extension (34.16 ± 6.81 [elastic]; 36.22 ± 9.45 [machine]; Mean difference = 2.05 kgf ± 5.32) and higher loads (Kgf) on the vertical bench press (31.61 ± 7.81 [elastic]; 24.96 ± 10.11 [machine]; Mean difference = 6.65 kgf ± 4.93) when compared to the weight machines. Intra-device reliability also demonstrated a very high ICC index for upper and lower limbs on both devices. Conclusion: The use of 10-RM with elastic resistance presents high reliability and agreement when compared to weight machines for bench press or knee extension exercises.

Keywords: Reproducibility of results. Muscle Strength. Theraband. Bench Press. Physical Activity Readiness Questionnaire.

Introduction

The 1-repetitions maximum test (1RM) test is considered the gold standard for assessing muscle strength. However, it may require a long execution time and several day attempts for stabilizing the measurements and consequently determining the load prescription[1]. Another way to determine muscle strength is to increase the maximal repetitions on the 1RM tests, such as the 10-repetitions maximum test (10RM), which is widely used to monitor the intensity used in resistance training in different populations[2–5].

Traditionally, the assessment of muscle strength using 10RM has been focused on its application by the use of free weights or weights machines. Another device that could be performed using the 10RM test is elastic tubes. The use of elastic tubes has increased in recent years in training and rehabilitation programs. Clinical trials performed with elastic resistance exercises demonstrated similar improvements in muscle strength, power, balance, and joint mobility compared to the use of machines[2,5–7].

Despite the widespread use, the load prescription in elastic resistance programs remains questionable and the lack of standardization protocols is still a problem to be solved. More recently, different acute studies have been designed to demonstrate the muscle activity during strengthening exercises using free weights and elastic resistance, and the method proposed and used to standardize the loads in exercises with elastic bands is the multiple-RM test[1,3,6–11]. For example, a prescription of 10 repetitions maximum (10RM) may be described as an endurance training goal[4,11].

Considering that this alternative method has demonstrated similar evidence in different populations and outcomes when compared to traditional tools, a new study developed to analyze the agreement between devices regarding the results of a strength test could be useful to better explain why the effects are similar between devices in acute and longitudinal neuromuscular adaptations. In this line, for example, the use of elastic resistance exercises has presented validity when compared to maximal concentric isokinetic test for knee extensors and flexors in adult females and males in a previous study[12]. Despite the evidence of this study, the agreement of strength tests between devices is scarce.

Therefore, this study aimed to determine the agreement of the 10-RM test between weight machine and elastic resistance on the bench press and knee extension exercises. Secondary, it was investigated the intra-device reliability, agreement, and minimal detectable changes of the 10-RM test in the investigated exercises.

Methods

Study Overview

This is an agreement study to compare the results of the 10-RM test between devices (weight machines and elastic) performed in two exercises (vertical bench press and unilateral knee extensor).

The data collection occurred on five days. On the first day, participants answered the Physical Activity Readiness Questionnaire (PAR-Q), International Physical Activity Questionnaire (IPAQ), and performed the anthropometric measurements. On the second to the fourth day of the experiment, the participants performed the 10-RM in two random orders. The first random order definition was the type of device to be used (for intra-device assessment). After the establishment of device orders, the exercise random order was defined (vertical bench press and unilateral knee extensor). The experimental approach is shown in figure 1. The order of the tests (machine or elastic) and exercises (vertical bench press or unilateral knee extensor) was determined by a random sequence generation. The interval between assessments was chosen to decrease the possibility of any facilitating stimulus, which could create a bias in the research[5].

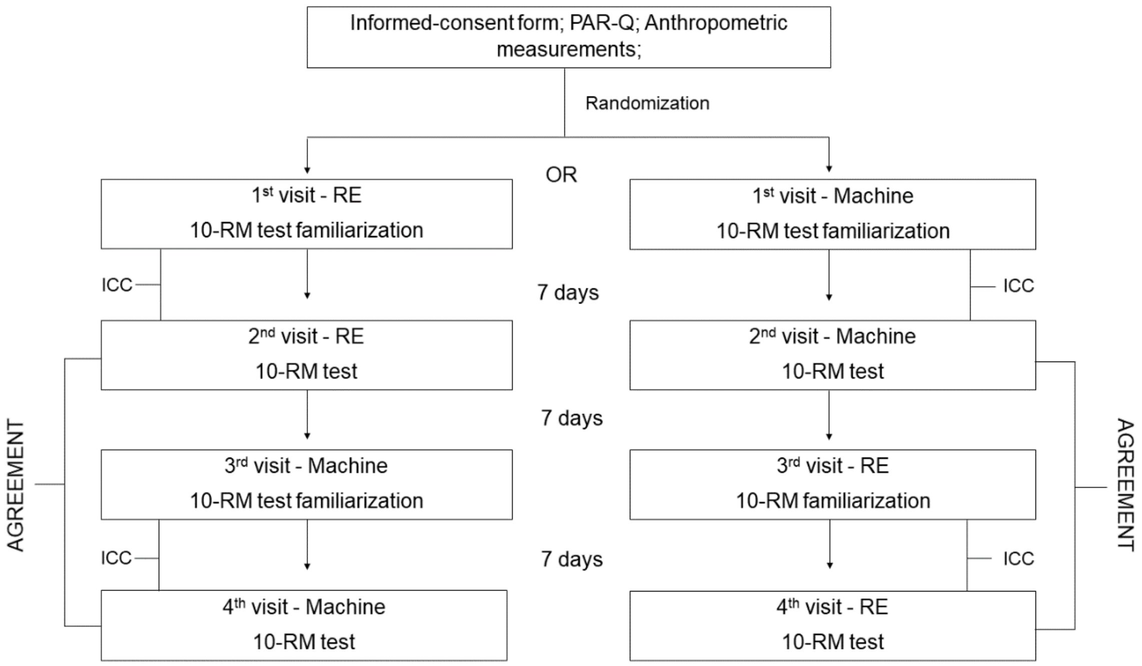

Figure 1. Experimental design – PAR-Q: Physical Activity Readiness Questionnaire; RE: elastic resistance; RM: repetition maximum; ICC: Intraclass Correlation Coefficient
Source: Authors

Ethical Aspects

The Ethics and Human Research Committee of the University of Brasilia approved this study on November 14st 2017, under protocol 2.380.445, according to resolution 196/96 of the National Health Council. Participation in the study was voluntary and, after clarification of the study's objectives and procedures, the participants were invited to sign the Informed Consent Form.

Participants

The sample size calculation was performed considering a correlation coefficient of at least 0.70 between measurements of the same instrument as well as between the two different types of equipment. A sample size of 21 participants was required considering a significance level of 0.05 and a power of 0.80[6]. The sample size calculation was performed using G Power* (version 3.1.9.2). Twenty-three sedentary healthy adults, degree students of the Faculty of Ceilândia (University of Brasília, Brazil) were recruited by non-probabilistic sampling. The extra participants were recruited considering to account for a 20% dropout rate.

We considered as eligibility criteria for the research the following characteristics: the presence of orthopedic-trauma; neurological, rheumatological, metabolic or cardiovascular pathologies; acute or chronic musculoskeletal pain in the limbs; traumatic orthopedic surgery in the previous six months; bone fracture or muscle injury in the previous six months;

reporting the need for a clinical and medical evaluation before exercise in the Physical Activity Readiness Questionnaire (PAR-Q); and classified as non-sedentary in the short version of the International Physical Activity Questionnaire (IPAQ).

1*0-Repetitions Maximum test (10-RM)*

The 10-RM test, adapted from Fleck and Kraeme[13], was performed according to the following procedures:

•A warm-up with the specific exercise, composed of 10 repetitions with a submaximal load considered a "little easier" by the participant. An interval of 2 minutes was given between the warm-up and the start of the 10-RM test;
•To establish the specific 10RM load, the participant was required to mobilize a load that would prevent them from performing more than 10 repetitions in a regime of concentric muscular failure[14];
•The exercises were performed with constant guidance to control the repetition speed in 4 seconds (2 seconds for eccentric phase and 2 seconds for concentric phase)[5];
•A maximum of 6 attempts to establish the 10RM load of each participant, with an interval of 5 minutes between attempts.
•An interval of 20 minutes was used to change exercises, that is, from vertical bench press for unilateral knee extensor, and vice versa.
Moreover, we suggested that the individual routine was maintained during the collection period, to avoid changes in the performance of test[15].

Instruments

In the 10-RM test with a weight machine, was used the vertical bench press (Gervasport®, Fitness Equipment, Spain) and the extension chair (Gervasport®, Fitness Equipment, Spain), both with ranging from 5kg to 100kg and gradually increase by 5kg.

As for the 10-RM test with elastics, was used elastic tubes (Elastos®, Brazil) with 7 levels of resistance represented by the colors yellow, red, green, blue, black, purple, and gold (weakest to strongest). Also, a load cell (AEPH do Brazil, model TS 50kg for the bench press and TS 100kg for the knee extension) was used to measure the load produced during the tests. The load cell allowed the obtention of values in kilogram-force (Kgf) from the tension force produced by the elastic resistance. The values were obtained at the point of the total extension of both movements (knee extension and vertical bench press).

Exercise technique

Weight machine

In the exercise, with the lower limb, the participant performed a unilateral knee extension with a dominant leg. For this, the participant was positioned in an extensor chair with the lever arm of the machine was fixed 1 cm above the medial malleolus. For perform tests, it was defined as an initial position that the participants should be with the knee and hip at 90º of flexion, and after that, the participants should perform a total knee extension and return to the initial position (Figure 2A).

In the exercise with the upper limbs, the participants performed the horizontal bench press exercise with the two limbs simultaneously. For performing the test, it was defined as an initial position that the participants should be with elbows at 90º flexion and shoulders at 90º abduction, and after that, the participants should perform total shoulder adduction, until reaching total elbow extension and then returned to the initial position (Figure 2B).

Figure 2. exercise techniques; A – machine knee extension; B – machine vertical bench press; C –elastic resistance knee extension; D –elastic resistance vertical bench press
Source: Authors

Elastic resistance

The lower limb exercise was performed unilaterally, using the dominant leg. The participant was positioned sitting in a high chair, with their back to the fixation point of the elastic (located 10 cm above the floor and at a horizontal distance sufficient to generate tension in the elastic from 90° of knee flexion). The elastic resistance was placed 1 cm above the medial malleolus on the side to be assessed and the other end of the resistance was connected to the load cell associated with a fixed foothold. For perform tests, it was defined as an initial position that the participants should be with the knee and hip at 90º of flexion, and after that, the participants should perform a total knee extension and return to the initial position (Figure 2C).

The upper limb exercise was performed with the 2 limbs simultaneously, with the dominant limb connected to the load cell. The participant was placed with their back to a wall (elastic fixation point), at a distance sufficient to generate tension in the elastic 90º of elbow flexion. The elastic tube was fixed to hooks on the wall at a similar height to the machine, and at the other end, the participants held handles. For performing the test, it was defined as an initial position that the participants should be with elbows at 90º flexion and shoulders at 90º abduction, and after that, the participants should perform total shoulder adduction, until reaching total elbow extension and then returned to the initial position (Figure 2D).

Furthermore, during the tests with elastic resistance, participants were supervised to maintain a similar posture to that used on weight machines.

Statistical analysis

Means and standard deviations (SD) were used to describe participant characteristics and strength values according to the devices and exercises investigated.

To the primary analysis, between devices responses (10RM machines vs 10RM elastic), the following statistical approaches were used: (a) intraclass correlation coefficient ([ICC]; model: two-way mixed effects, average measures, with absolute agreement); (b) the standard error of measurement ([SEM]; SEM = SD of the test scores multiplied by the square root of 1 – ICC; and SEM%); (c) the Bland-Altman plots to evaluate the agreement between devices (mean differences within 95% of the differences).

To the secondary intra-device responses (test-rest of machines for two exercises; test-retest of elastic tubes for two exercises), the following statistical approaches were used: (a) ICC (model two-way mixed effects, average measures, with absolute agreement), (b) SEM (SEM%); (c) minimal detectable change ([MDC]; MDC = 1.96 x the square root of 2 x SEM).

Munro´s classification of reliability was used to interpret the ICC coefficients: 0.50 to 0.69 reflects moderate correlation, 0.70 to 0.89 reflects high correlation, and 0.90 to 1.00 indicates a very high correlation[16]. Statistical analysis was performed using MedCalc Software (version 18.6) and R studio. The statistically significant level was set at 5% for all analyses.

Results

The characterization of the 23 participants (4 men and 19 women) is presented in Table 1. The comparison between instruments demonstrated a high ICC index for both exercises. The results of agreement between instruments are presented in Table 2. The agreement analysis showed that the 10-RM test using elastic resistance produced lower loads on knee extension and higher loads on the vertical bench press when compared to the weight machines (Table 2).

For the bench press exercise, the absolute difference between the devices was estimated at 6.7 Kg (Bland-Altman limits of agreement of 3 Kg [lower] and 16.3 kg [upper]) and 3.63 Kg (SEM; SEM%=14.94%). For the knee extension exercise, the absolute difference between devices was of 2.1Kg (Bland-Altman limits of agreement of 12.5Kg [lower] and 8.4Kg [upper]) and 3.98Kg (SEM; SEM% = 6.23%). The differences between the devices can be seen in the Bland-Altman graphic representations (Figure 3).

Table 1. Characteristics of participants

	Men (Mean ± SD)	Women (Mean ± SD)	Total (Mean ± SD)
Sample (n)	4	19	23
Age (years)	20.25 ± 0.95	22.89 ± 2.55	22.43 ± 2.55
Height (cm)	1.70 ± 0.09	1.61 ± 0.06	1.62 ± 0.07
Body mass (Kg)	70.10 ± 15.03	58.84 ± 11.54	60.80 ± 12.60
Body mass index (BMI)	24.06 ± 4.54	22.75 ± 3.29	22.98 ± 3.45

Note: SD: standard deviation
Source: Authors

Table 2. The primary analysis of agreement for the 10RM between elastics and machines devices

	Upper Limb (Kg)	Lower Limb (Kg)
10RM elastic	31.61 ± 7.81	34.16 ± 6.81
10RM machine	24.96 ± 10.11	36.22 ± 9.45
Difference	6.65 ± 4.93	2.05 ± 5.32
ICC (95% CI)	0.80 (0.18 – 0.95)	0.87 (0.69 – 0.95)
SEM (SEM%)	4.22 (14.94)	2.93 (6.23)
Systematic Bias	6.7	2.1
LOALB	3.0	12.5
LOAUB	16.3	8.4

Note: Kg: kilogram-force; ICC: Intraclass Correlation Coefficient; SEM: standard errors of measurement; LOALB: limits of agreement lower boundary; LOAUB: limits of agreement upper boundary; CI: confidence interval
Source: Authors

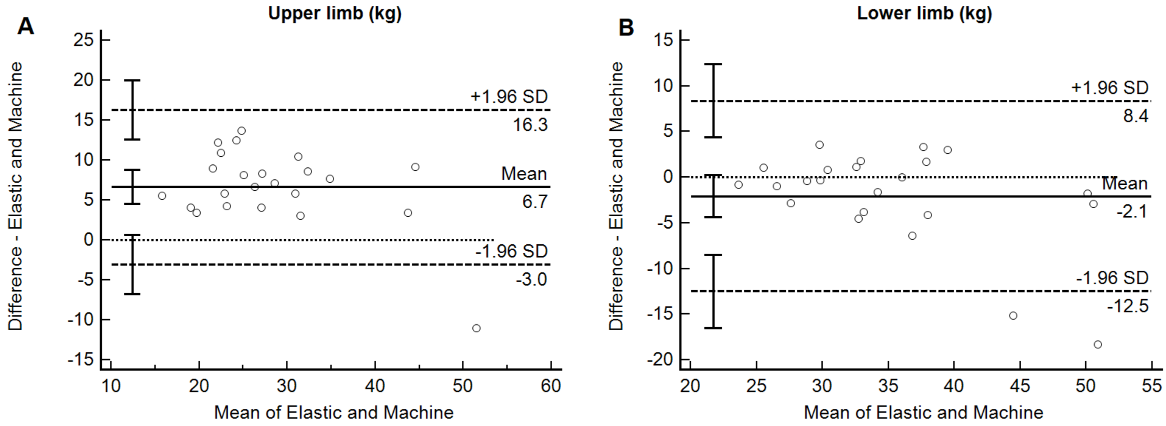

Figure 3 –Bland-Altman graphical representation of the comparison between the elastics and machines in the upper and lower limbs
Note: A and B represent the agreement between the elastic resistance and the machine for the bench press and knee extensor, respectively. The solid line determines the mean of the differences between the devices and the dashed line determines the 95% confidence interval of the differences between measurements
Source: Authors

The intra-device reliability demonstrated high and very high ICCs (Table 3). Regarding the absolute differences for the same device, both presented little difference between the test-retest, in both exercises. In the vertical bench press using a weight machine, the difference was: 1.57 Kgf (± 1.31) (Bland Altman analysis); absolute SEM of 1.73 Kgf; absolute MDC of 4.79 Kgf. In the vertical bench press using elastic resistance, the difference was: 3.02 Kgf (± 3.16) (Bland Altman analysis), absolute SEM of 2.19 Kgf, and absolute MDC of 6.08 Kgf. For knee extensors with a weight machine, the difference was 1.96 Kgf (± 2.48) (Bland Altman analysis), absolute SEM of 1.55 Kgf; and absolute MDC of 4.30 Kgf. Already with the elastic resistance, the difference was: 1.69 kgf (± 3.69 Kg) (Bland Altman analysis), absolute SEM 2.06 of Kgf, and absolute MDC 5.71 Kg (Table 3).

Table 3. Secondary analysis of reliability for the 10RM test in elastics and machines devices

	First 10RM test (mean ± SD)	Second 10RM test (mean ± SD)	Difference (mean ± SD)	ICC (95% CI)	SEM (SEM%)	MDC (MDC%)
Elastic						
UL	28.58 ± 6.24	31.61 ± 7.81	3.02 ± 3.16	0.91 (0.42-0.97)	2.19 (7.29)	6.08 (2.48)
LL	32.47 ± 6.23	34.16 ± 6.81	1.69 ± 3.69	0.90 (0.74-0.96)	2.06 (6.18)	5.71 (17.13)
Machine						
UL	23.39 ± 10.37	24.96 ± 10.11	1.57 ± 1.31	0.99 (0.85-0.99)	1.73 (7.15)	4.79 (19.83)
LL	34.26 ± 8.88	36.22 ± 9.45	1.96 ± 2.48	0.97 (0.85-0.99)	1.55 (4.91)	4.30 (12.21)

Note: All values are expressed in kilogram-force. UL: upper limb; LL: Lower limb; ICC: Intraclass Correlation Coefficient; SEM: standard errors of measurement; MDC: Minimal Detectable Change; SD: standard deviation; CI: confidence interval
Source: Authors

Discussion

This study aimed to analyze whether there is an agreement between the 10 RM test in the bench press and knee extension exercises performed with weight machines and elastic tubes in healthy young adults not practicing resistance training. The results demonstrated a high linear association between the devices for the 10RM test performed in the bench press and knee extension exercises. The agreement analysis showed that the differences in the values obtained in the 10RM test between the devices were considered small and acceptable in the two exercises investigated. The intra-device reliability also demonstrated high linear association and small standard error of the measure and minimal detectable difference.

To achieve adequate resistance training stimuli the choice of exercise device is considered a critical factor, which implies specific results associated with training[11]. Although the literature supports the positive effects of elastic training on muscle strength in adults and older adults[7,11,17,18], some authors have reported that elastic resistance is not as effective as traditional devices because it provides a linear increase in resistance as the device is elongated, leading to an increase in the resistance at the end of the range of motion[19,20]. To clarify this discussion and add new perspectives, a recent meta-analysis[21] provided results concerning the quantitative comparison of muscle activation (EMG activity) between elastic and isoinertial resistance. The results demonstrated the lack of significant differences in the prime mover, antagonist, stabilizer, and assistant mover EMG activity when comparing elastic resistance and isoinertial exercises, suggesting that equal muscle adaptation could be expected following these two exercises devices. To compare muscle activity between elastic and isoinertial exercises in this review, 2 studies performed the 8-RM test and 1 study performed the 6-RM test, and considering the exercise intensity was similar between conditions, the muscle activation was not different between devices.

We believe this to be the first parallel reliability study of the 10-RM test using elastic resistance and weight machines. Guex and collaborators[12] attempted to validate the use of elastic resistance to evaluate the maximum force compared to the isokinetic dynamometer. The authors performed the 10-RM test and estimated 1-RM in the knee flexors and extensors and compared them with the isokinetic peak torque. In the relative reliability between test and retest for knee flexors and extensors using elastic resistance, the results revealed high reproducibility of the measurement (ICC 0.98 and 0.99 for knee flexor and extensor, respectively), Coefficients of Variation (CV) less than 10%, and SEM in the scope of 2 Kg[12]. However, to attempt to validate the measure of elastic resistance for maximum strength evaluation by the isokinetic dynamometer, the authors used only the Pearson's linear correlation coefficient (r = 0.93) and did not show absolute reliability between the methods/devices. In the present study, the mean value of the differences (systematic error) found between elastic resistance and machines for the knee extension was 2.1 Kg, that is, the lever arms were similarly stabilized and supported during the movement of the two resistance tools, which reproduced the small difference (variation), however with smaller values reached by the elastic resistance. Thus, it seems that the use of elastic resistance presents good reproducibility to evaluate muscle strength, although greater differences between elastic resistance and an isokinetic dynamometer may occur.

Another form of parallel reliability reported in previous studies was the comparison between elastic resistance and maximum voluntary isometric contraction (MVIC) for upper limbs[19]. Andersen and collaborators[22] found a high linear association (ICC = 0.96) and a relative SEM of 8.1% between elastic resistance and a force transducer (load cell) in lateral shoulder abduction at 90°, although elastic resistance produced systematically lower torque values (1.02 Kg). Differently from our study, the vertical bench press presented a systematic error of 6.7 Kg and a relative SEM of 14.94% in favor of the elastic resistance compared to the machine.

The higher value found for the vertical bench press for elastic resistance can be explained in part by the difference between the sticking points of the exercises, since different exercises may have different sticking points[20]. This is possibly due to the characteristics of the elastic which provides progressive resistance, increasing tension with the progression of movement, so higher resistance is applied at the end of the movement, i.e., at the moment of mechanical advantage. In other words, lower tension is applied at the beginning of the movement at the moment of mechanical disadvantage, and higher tension at the end of the movement would be the moment of mechanical advantage. With machines the reverse probably occurs, greater force production must be employed to shift the load at the beginning of the movement precisely at the moment of mechanical disadvantage. These factors could impact different points of fatigue.

In light of all the above, we assume that the 10 RM test performed with elastic resistance was shown to be a reliable device to evaluate the training load of the muscle groups in question, as well as the test performed with a weight machine, and in this way can be used in clinical practice. Although the elastic resistance and weight machines are different resistance devices, one of variable resistance and the other of constant resistance, they can present similar behaviors in the evaluation of load in the 10 RM test. In addition, elastic resistance is an instrument that is easy to use and inexpensive, and being more practical than a weight machine, presents itself as another alternative in the evaluation of training load, as well as allowing it to be performed more evenly during rehabilitation processes.

The limitations of the study include biological factors (hormonal, sleep-wake, anxiety) that could not be controlled and may have influenced the performance of the participants during the collection period, as well as which the exercise performed in the upper limbs was not performed independently, that is, the dominant side was collected together with the contralateral side. Another limiting factor to be reported regarding the upper limb exercise is that when it was performed with elastic resistance, as it does not provide guided movements like the machine, there may have been greater muscle activation of internal rotators from the shoulders to stabilize the limbs and perform the correct movement, similar to the machine, which may explain the greater reproduction of load with elastic resistance in the two measurements. However, although the total load is affected, it is believed that these factors did not significantly affect the standard error.

Conclusion

The use of 10-RM with elastic resistance presents high reliability and agreement when compared to weight machines for bench press or knee extension exercises. According to these results, elastic tubes are useful and reliable devices for evaluation, prescription, and load control in resistance exercise programs.

Conflicts of Interest Statement

The authors declare no conflict of interest.

Funding/Support Statement

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