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Assessment of resistance torque and resultant muscular force during Pilates hip extension exercise and its implications to prescription and progression

Análise do torque de resistência e da força muscular resultante durante exercício de extensão de quadril no Pilates e suas implicações na prescrição e progressão

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Abstract

Background: The understanding of the external mechanics of Pilates exercises and the biomechanics of the joints may guide the prescription of rehabilitation exercises. **Objectives:** To evaluate the resistance torque (Γ_R) during hip extension (HE) exercises performed on the Pilates Cadillac. To perform a biomechanic analysis of the Γ_R and the weighted mean moment arm (WMMA) in order to calculate the resultant muscle force (FM_R) of the hip extensors and flexors. To present a mechanical criteria for progression of HE exercise on the Pilates Cadillac. **Methods:** Fourteen participants performed HE exercises on the Cadillac in four randomly assigned situations – using two springs (blue and red), which were attached in two positions (high and low). Angular positions were measured using an electrogoniometer. In order to calculate Γ_R, the muscle torque (Γ_M) and FM_R, free-body diagrams and movement equations were used. The WMMA of the hip extensors and flexors were estimated from the literature. **Results:** The Γ_R and FM_R presented a similar behavior during all situations; however, the maximum Γ_R values did not occur at the same joint position as the FM_R maximum values. The WMMA of the hip flexors presented an increased- decreased behavior with greatest values around 55° of flexion, while the hip extensors presented a similar behavior with greatest values around 25° of flexion. **Conclusion:** Biomechanic analysis of HE exercises and the evaluation of mechanical features in relation to the hip joint may be used as an objective criteria for the prescription and progression of HE exercise in Pilates.

Key words: hip extension; Pilates; torque; moment arm.

Resumo

Contextualização: A análise da mecânica externa dos exercícios de Pilates e da biomecânica das articulações pode subsidiar a prescrição de exercícios na reabilitação. **Objetivos:** Avaliar o comportamento do torque de resistência (Γ_R) do exercício de extensão de quadril (EQ) realizado no Cadillac; realizar uma análise biomecânica a partir do comportamento do Γ_R e das distâncias perpendiculares médias ponderadas (DPMPs) para estimar a força muscular resultante (FM_R) dos extensores e flexores e propor critérios mecânicos para progressão do exercício de EQ realizado no Cadillac. **Métodos:** Catorze praticantes de Pilates realizaram EQ no aparelho Cadillac em quatro situações em ordem aleatorizada – usando duas molas (vermelha e azul) fixadas em duas posições (alta e baixa). As posições angulares foram coletadas por meio de eletrogoniometria. Para o cálculo do Γ_R, torque muscular (Γ_M) e da FM_R foram usados diagramas de corpo livre e equações de movimento. Os valores de DPMP dos músculos flexores e extensores do quadril foram quantificados usando dados da literatura. **Resultados:** O Γ_R e a FM_R apresentaram comportamentos semelhantes em todas as situações, entretanto os valores máximos de Γ_R não ocorrem na mesma posição articular que a FM_R máxima. A DPMP dos flexores de quadril apresentou um comportamento crescente-decrescente, com máximo próximo aos 55° de flexão, enquanto os extensores de quadril apresentaram comportamento semelhante, com máximo próximo aos 25° de flexão. **Conclusão:** A análise biomecânica do exercício e a avaliação das características mecânicas associadas à articulação do quadril podem ser usadas como critérios objetivos de prescrição e progressão do exercício de EQ no Pilates.

Palavras-chave: extensão do quadril; Pilates; torque; braço de momento.

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Introduction

Developed by Joseph Pilates (1880-1967), the Pilates method has a general purpose to develop the *power house* muscles (anterior abdominals, spinal extensors, hip extensors, hip flexors and the deep pelvis muscles)[1,2]. In physical therapy, the Pilates method has been used for several purposes, such as: restoration of joint function[3,4], lumbar-pelvic stabilization[1,5], fibromyalgia control[6] and the treatment of low back pain[3,7]. To reach these objectives, therapists can count on land based exercises and exercises perfomed on special equipments, such as the *Reformer,* the *Barrel* and the *Cadillac*. On the tradicional Cadillac, one of the movements commonly used to promote trunk stabilization and the recovery of functional and anatomic integrity of the hip joint is the hip extension (HE) with extended knees[3,8,9]. When HE is performed with the subjects positioned in supine on the equipment, the external load is obtained mainly from the external springs with different constants of strain and from the variation of the equipment's spring vertical regulation (fixed height)[10].

In genneral, it has been recommended that rehabilitation programs use the exercises with progressive intensities according to the necessities of each patient[11-12]. However, when Pilates' exercises are used in clinical practice, it is observed that the external loads are chosen based on subjective information, such as the substitution of a less resistent spring to another with higher resistance, without noticing the amount of resistance offered in both situations[10]. Therefore, when the process is performed this way, the definition of intensity used in the exercise is almost exclusively based on patient's feedback and on professional experience. Aiming to enrich the prescription of Pilates exercises, Silva et al.[10] showed that for the HE exercise performed on the Cadillac, it is possible to combine the constant of the spring's strain and its positioning on the equipment as an objective criteria for the selection of the intensities of the exercises. The reason for this is that the sping's strength (given by the constant of strain and the variation of its length) in addition to its respective perpendicular distance (directly determined by the fixation site of the spring) compose the resistance torque (T_R) offered by this exercise, during the exercise range of motion (ROM). Thus, in clinical practice, Γ_R assessment (which considers the variations in the constant of strain and the fixation height of the spring) may provide useful quantitative data for progressing the intensity of the program over the course of the treatment and also indicate in which joint position the external load is maximum[11,13-15], allowing clinicians to prioritize strength gains in specific ranges of motion.

In spite of the importance of determining the Γ_R offered by the exercises, its quantification alone is not enough to indicate the level of muscle effort resulting from the exercises. Another important factor is the mechanical characteristic of the muscles involved in the exercise (perpendicular distance of the muscle), which composes the muscle torque (T_M) which then counteracts the Γ_R[13-16]. The muscle perpendicular distance or muscle moment arm is the distance between the action line of the muscle (on tendon insertion) and the joint rotation center[15,16]. The size of the perpendicular distance of a muscle represents a "mechanical advantage" of the muscle in a joint, and its measurement can assist in the understanding of muscle function[17]. Thus, considering that the T_M does not always increase in the same proportion of Γ_R and that the Γ_R offered by an equipment may not comply with the mechanical characteristics of the involved muscles, it is believed that the combined analysis of these factors can avoid the risk of excessive overload of human structures and/or enhance the specificity of the effort planned.

In spite of the popularity of the exercises performed on the Cadillac equipment, in physical therapy, there is a lack of scientific research focusing on biomechanical analysis (T_R analysis) of the equipment and its relation to the mechanical characteristics of joints (perpendicular distance)[8,10,18,19]. In this context, the purposes of the present study were: a) to assess the behavior of the T_R offered by HE exercises on the Cadillac, using springs with different constants of strain and fixed heights; b) to perform a biomechanical analysis of the Γ_R behavior and the weighted mean moment arm (WMMA) of the muscles in order to estimate the resultant muscle force (FM_R) of the hip extensors and flexors during the exercise and c) to propose a mechanical criteria for the progression of HE exercises on the Cadillac.

Methods

Sample

The sample was composed of 14 female subjects (30,9±8,6 years-old; 1,60±0,04 m; 55,5±4,3 kg). The inclusion criteria were the current practice of Pilates, for at least six months, and the absence of musculoskeletal injuries (current or treated), which were informed by the participants. All participants signed a consent form. This study was approved by the Research Ethics Committee of the Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil, under the protocol nº 2007903, approved in the meeting nº 43, registration protocol nº 123 of January 22th of 2009.

Data acquisition and analysis

Assessment Protocol

The Cadillac allows the use of springs of different colors. Each color represents a level of resistance or the spring's constant of strain. In the present study, the springs were calibrated before data collection[20]. The constant of strain found were 0,30 kg/cm for the blue spring and 0,39 kg/cm for the red spring. Since the springs can be positioned in several heights, for the exercise of interest, two heights were chosen: high (86 cm in relation to the subject's level) and low (20 cm in relation to the subject's level) (Figure 1). Each series of the HE exercises were performed with one spring and one height randomly selected. Data acquisition consisted of the execution of four series of five trials of HE exercises on the Cadillac, initiating from a angle of hip flexion of 90° degrees until 0° degrees, after a stretch session of the trunk and lower limbs performed on the same device.

Electrogoniometry

The angular positions of the hip during data collection were recorded by an electronic goniometer (Miotec Biomedical Equipments Ltda, POA, Brazil), with a sampling rate of 2000 Hz. The signals of electrogoniometry were filtered by a band-pass digital filter *butterworth*, third order, with a cutoff rate of 3 Hz, with the support of the software SAD32, version 2,61. 07mp, previously used by Loss and Candotti[13].

Resistance and muscle torques

The analysis of Γ_R and Γ_M were conducted according to recommendations from Loss e Candotti[13], based on the construction of free-body diagrams (FBD) from the body segments during movement. Figure 2a illustrates the FBD in an intermediate position of the ROM, designed in the plane of execution of the exercise. The weight is represented in the center of mass of the lower limb[21]; the springs' strength is represented acting in the distal extremity of the segment; the resulting joint strength, acting on hip joint axis and the resultant muscle torque, acting on hip joint. Casual movements of the pelvis or even the lumbar spine were considered to be irrelevant, limiting the analysis to the hip, both at the joint and the muscle levels. Although this simplification may be considered a limitation of this model, the low load chosen for the exercises associated to the level of training and to the healthy condition of the participants are mitigating factors that support this approach.

Based on the FBD, the following equations of translation, (Equation 1) and rotation (Equation 2) that governs the movements were written:

$$\sum \vec{F} = m\,\vec{a}_{CM} \quad ==> \quad \vec{F}_{MO} + \vec{P} + \vec{F}_{AR} = m\,\vec{a}_{CM} \qquad (1)$$

$$\sum \vec{\Gamma} = I\vec{\alpha} \quad ==> \quad \vec{\Gamma}_M + \vec{\Gamma}_P + \vec{\Gamma}_{MO} = I\vec{\alpha} \qquad (2)$$

in which, on equation 1, $\sum \vec{F}$ represents the sum of all the forces ($\vec{F}_{MO}$ - spring strength; $\vec{P}$ - weight of the segment; $\vec{F}_{AR}$ - resultant joint strength) that act on the mass (m) leading to an acceleration $\vec{a}_{CM}$ of the center of mass. On equation 2, $\sum \vec{\Gamma}$ represents the sum of all the torques ($\vec{\Gamma}_M$ - muscle torque; $\vec{\Gamma}_P$ - torque of the segment weight; $\vec{\Gamma}_{MO}$ - torque of spring strength) which equal to the inertial moment (I) of the segment, generating an angular acceleration $\vec{\alpha}$.

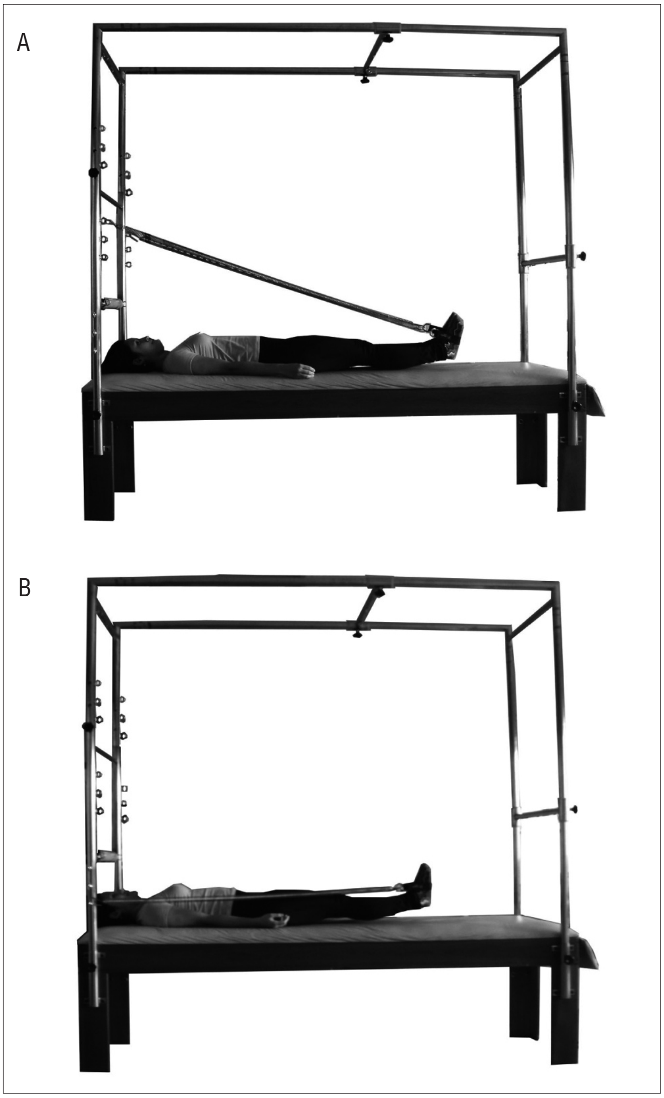

Figure 1. Hip extension exercise on the Cadillac at final position. (a) Spring at high position; (b) Spring at low position.

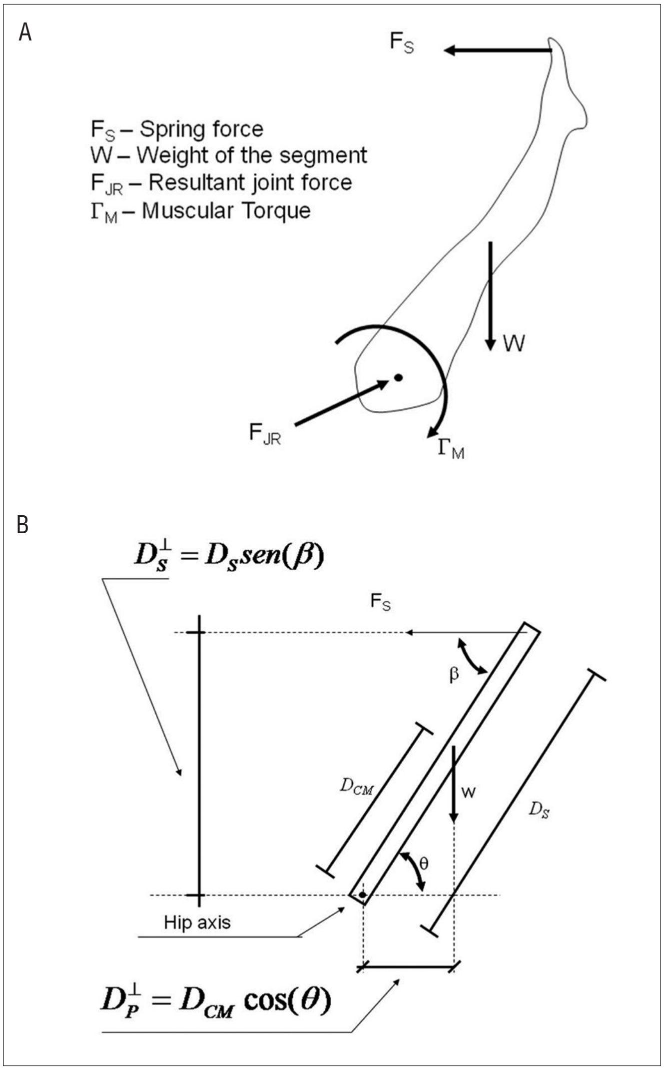

Figure 2. (a) Free-body diagram of the thigh-leg-foot segment. (b) Trigonometric deduction used for calculating of the moment arm of weight force and of spring force.

According to Loss and Candotti[13], when the exercise is executed slowly (<30º/s), the inertial effects can be irrelevant. Considering the extension torque as positive, the equation 2 can be rewrite in its scalar form, as equation 3:

$$\Gamma_M + \Gamma_P - \Gamma_{MO} = 0 \qquad \text{or} \qquad \Gamma_M = \Gamma_{MO} - \Gamma_P \tag{3}$$

where the difference between the Γ_{MO} and the Γ_P is the Γ_R[10]. According to Winter[21], when the movement is performed at low velocities without reaching the extremes of the joint range of motion, the effects of the passive structures, such as ligaments or tendons, under the Γ_M can be disregarded. However, in situations when the co-contraction of antagonist muscle groups happens, the Γ_M represents the net effect of muscle activity. In this perspective, and according to the convention adopted, when Γ_M is positive, there will be a predominance of extensors activity and, when negative, a predominance of flexors activity.

The perpendicular distances of the spring strength ($D_{MO}^{\perp}$) and of the segment weight ($D_P^{\perp}$) were obtained from trigonometric relationships (Figure 2b) by the direct measurement of the hip angle through the entire ROM and the measurement of the angle between the spring and the human segment and of the corresponding distances at the begining and at the end of the movement. To assess the F_{MO} through the entire ROM, trigonometric relationships associated to the coefficients of sprain from the springs determined by the calibration were used. The inertial parameters used (weight and position of the center of mass of the segments involved in the segments thigh-leg-foot segment) were estimated through anthropometric tables obtained in the literature[21].

Resultant muscular force and weighted mean moment arm

The WMMA is the result from the sum of the products between the perpendicular distance of each muscle ($d^{\perp}$) and its respective physiological cross-sectional area (PCSA) divided by the sum of the cross-sectional areas of the muscles[13,14] (Equation 4). In the present study, HE muscles included: biceps femoris, semitendinosus, semimembranosus and gluteus maximus and flexor muscles included: rectus femoris, psoas, iliacus, sartorius and tensor fasciae latae. The WMMA and the PCSA were determined from the literature[22-25]:

$$DPMP = \frac{\sum_{i=1}^{n} d_i^{\perp} ASTF_i}{\sum_{i=1}^{n} ASTF_i} \tag{4}$$

where:

$d_M^{\perp}$ = weighted mean of the muscle perpendicular distance
$d_i^{\perp}$ = perpendicular distance of the muscle i
$ASTF_i$ = physiological transverse section área of the muscle i
n = number of muscles included

Since the Γ_R is equal to the Γ_M, the FM_R was determined dividing the Γ_R by the WMMA of the muscular group involved, for example, when the Γ_M was extensor, the Γ_R was divided by the WMMA of the hip flexors (Equation 5). The calculation necessary for the quantification of the Γ_R and the FM_R were developed using Excel (version 2007, Microsoft Windows). For further statistical analysis, the mean of the values corresponding to each 10° of the assessed ROM were calculated.

$$FM_R = \frac{\Gamma_R}{DPMP} \tag{5}$$

Statistical analysis

The equivalence of the variances (Levene Test) and the normality of data (Shapiro-Wilk) were both verified and confirmed. Analysis of variance (ANOVA) of the three factors (spring, spring height and angle) were performed to verify differences for the results of Γ_R and FM_R. The main effects were examined by the *post hoc* Bonferroni test. For all analysis performed, the level of significance adopted was 0,05.

Results

Since the exercise of interest starts at an angle of 90° degrees of hip flexion and goes until 0° degrees, all graphs must be observed from right to left. Figure 3 shows the average behavior of the Γ_R along the angle of hip flexion for both springs used (blue and red), at high and low heights. Considering equation 3, Γ_M is equal to Γ_R, but with opposite signals (negative). The WMMA was calculated using equation 4, and values presented along the hip flexion angles are shown on Figure 3c. Figure 3b shows the average behavior of the FM_R along the angles of hip flexion for both the springs, at high and low heights.

Table 1 presents mean and standard-deviation values of Γ_R for each 10 degrees of ROM assessed and the result of the comparisons. Table 2 presents mean and standard-deviation values of the FM_R for each 10 degrees of ROM assessed and the result of the comparisons.

Discussion

The methodological approach used in the present study aimed to identify the external demand imposed on the muscles from a mechanical point of view and to estimate the resultant muscle effort, based on the theoretical information associated to WMMA from the most important muscles acting on the movement studied. In spite of the limitations from this approach, described on the methodological section of the present study, previous studies, not related to Pilates, showed that a mechanical analysis of the external demand offered by an exercises and the estimative of the resultant muscle effort made from biomechanical techniques, as a representation of the acting strengths through FBD and the use of movement equations, can be used objectively for the prescription of exercises during training and rehabilitation programs[11-16].

The analysis and investigation of the biomechanics of Pilates exercises gained great value, given the wide spread of this modality in clinical practice. From a physical therapy point of view, the evaluation of the behavior of external loads along the ROM and the mechanical conditions of muscle response, are extremely important for the success of a treatment program. Although the method proposed in the present study does not allow an objective analysis with regards to the individual contribution of each muscle and not even from the total strength of the muscles, it allows to assess in which position the external load is higher or lower and if its combination favors or not the mechanical condition of the muscle, enabling a more secure and controlled choice of exercise.

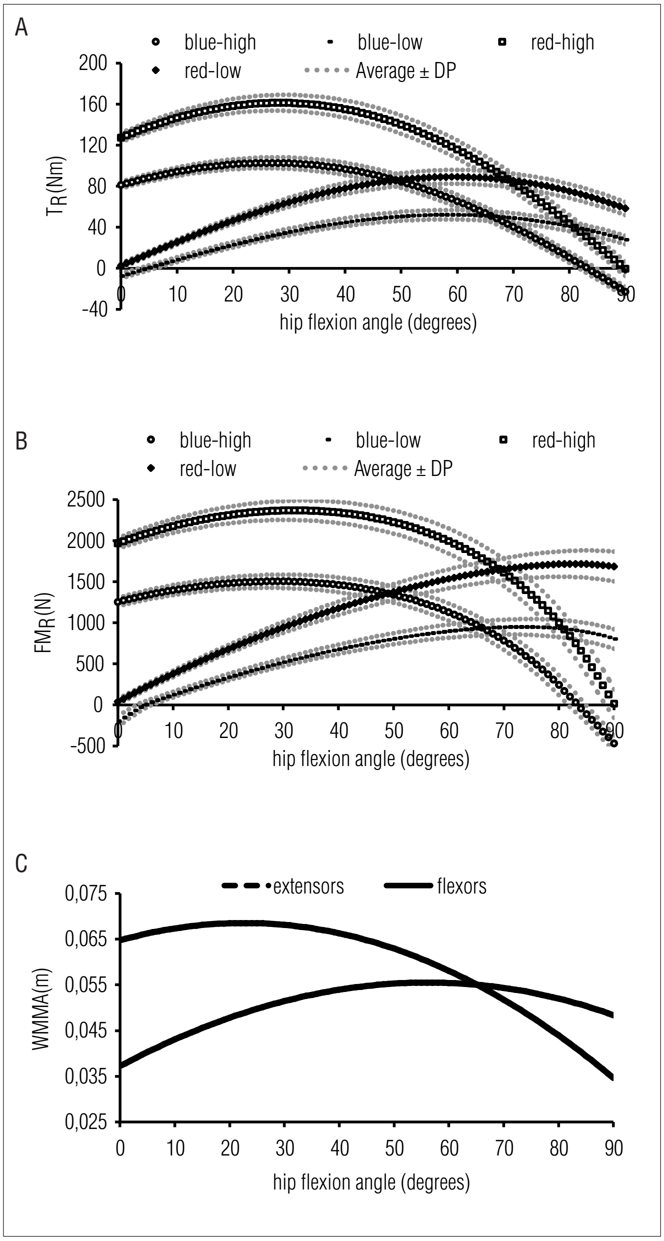

Figure 3. (a) Behaviour of the Γ_R in relation to hip flexion angles obtained with blue and red springs at low and high positions. (b) Behaviour of the FM_R in relation to hip flexion angles obtained with blue and red springs at low and high positions. (c) Behavior of the WMMA of the hip extensors and flexors in relation to hip flexion angles. The exercise starts when the hip flexion angle is 90°, while 0° refers to maximum extension of the hip.

Table 1. Average and standard deviation of resistance torque (Γ_R), in Nm, during all evaluated situations (different springs and positions) and the results of statistic comparisons.

Angles(degrees)	Blue Spring		Red spring	
	High position	Low position	High position	Low position
10	^{I}87.68 (±4.50)^{a}	^{II}0.02 (±3.83)^{a}	^{III}130.93 (±23.66)^{a}	^{IV}14.17 (±2.36)^{a}
20	^{I}101.92 (±6.25)^{b}	^{II}15.94 (±2.47)^{b}	^{III}154.09 (±6.28)^{b}	^{IV}36.24 (±2.99)^{b}
30	^{I}100.22 (±5.77)^{b}	^{II}29.51 (±2.94)^{c}	^{III}160.44 (±7.36)^{b}	^{IV}55.72 (±3.98)^{c}
40	^{I} 97.63 (±5.77)^{c}	^{II}40.50 (±3.52)^{d}	^{III}158.99 (±8.17)^{c}	^{IV}71.51 (±4.98)^{d}
50	^{I}91.26(±6.10)^{d}	^{II}48.13 (±4.06)^{e}	^{III}148.39 (±8.67)^{d}	^{IV}82.65 (±5.85)^{e}
60	^{I}75.59 (±51.78)^{e}	^{II}51.78 (±4.46)^{e}	^{III}128.67 (±8.84)^{e}	^{IV}88.31 (±6.48)^{e}
70	^{I}53.58 (±6.04)^{f}	^{I}50.96 (±4.67)^{e}	^{II}100.28 (±8.68)^{f}	^{III}87.88 (±6.83)^{e}
80	^{I}25.98 (±5.67)^{g}	^{II}45.34 (±4.65)^{f}	^{III}64.17 (±8.19)^{g}	^{IV}80.95 (±6.85)^{f}
90	^{I}-5.86 (±5.11)^{h}	^{II}34.74 (±4.39)^{g}	^{III}22.06 (±7.42)^{h}	^{IV}67.34 (±6.53)^{g}

Different letters indicate significant differences between the angles for each condition (same column); Different Roman numerals indicate significant differences between different conditions of exercise for the same angle (same row).

Table 2. Average and standard deviation of resultant muscle force (FM_R), in N, during all evaluated situations (different springs and positions) and the results of statisticc comparisons.

Angles (degrees)	Blue Spring		Red spring	
	High position	Low position	High position	Low position
10	^{I}1326.68 (±63.83)^{a}	^{II}-13.58 (±107.48)^{a}	^{III}1978.73 (±356.05)^{a}	^{IV}212.89 (±35.62)^{a}
20	^{I}1437.53 (±78.94)^{b}	^{II}234.03 (±36.30)^{b}	^{III}2250.13 (±92.39)^{b}	^{IV}532.20 (±44.01)^{b}
30	^{I}1491.65 (±87.46)^{c}	^{II}431.59 (±43.07)^{c}	^{III}2345.2 (±814.66)^{c}	^{IV}814.66 (±58.22)^{c}
40	^{I}1489.04 (±85.79)^{c}	^{II}602.19 (±52.42)^{d}	^{III}2362.33 (±121.47)^{c}	^{IV}1063.27 (±74.15)^{d}
50	^{I}1409.85 (±94.32)^{d}	^{II}744.60 (±62.83)^{e}	^{III}2292.93 (±134.17)^{d}	^{IV}1278.46 (±134.17)^{e}
60	^{I}1245.53 (±102.23)^{e}	^{II}855.18 (±73.72)^{f}	^{III}2121.11 (±146.08)^{e}	^{IV}1458.39 (±107.16)^{f}
70	^{I}969.78 (±109.96)^{f}	^{I}926.76 (±85.08)^{g}	^{II}1817.88 (±157.88)^{f}	^{III}159.45 (±124.42)^{g}
80	^{I}532.90 (±5.67)^{g}	^{II}945.17 (±97.36)^{g}	^{III}1328.29 (±171.05)^{g}	^{IV}1689.08 (±143.36)^{h}
90	^{I}-111.87 (±235.14)^{h}	^{II}878.89 (±111.95)^{h}	^{III}539.60 (±329.07)^{h}	^{IV}1708.77 (±166.45)^{h}

Different letters indicate significant differences between the angles for each condition (same column); Different Roman numerals indicate significant differences between different conditions of exercise for the same angle (same row).

In general, the results from the present study corroborate the literature, since the maximum FM_R were not always reached when the Γ_R reached maximum values during HE exercises on the Cadillac[11,12,14,15]. The explanation for this finding is that by definition, the Γ_M also depends on the behavior and size of the WMMA involved in the analysis. According to Chaffin, Anderson and Martin[26], during dynamic situations, as the joint angle changes, the perpendicular distance from the muscle also changes.

In the present study, it was observed that when the exercise was performed with the springs (red and blue) in the high position, the Γ_R increased sharply, reaching a plateau next to the angles of 20º and 30º (Figure 3a), and then decreased until the end of HE; whereas the FM_R seemed to present a plateau at the angles of 30º and 40º (Figure 3b). This behavior was confirmed with statistical significance in the comparison that was performed for each 10 degrees (Tables 1 and 2). These differences observed between joint position and occurrence of peak values of Γ_R and FM_R probably happened because of the behavior of the WMMA from the extensors, which is crescent from the start of the extension and reaches its maximum value at the same range observed for the Γ_R, which can lead to a lower necessity of muscle effort in this region. However, it is still important to note that the HE exercises performed with the high spring will not always be easiest in the ranges where the WMMA is maximal, since the Γ_M will also depends on the capacity of muscle strength production. Among other factors, muscle strength production will depend on the relation strength-length[27,28], which states that the production of muscle strength depends on the length of the muscle fibers and their constituting sarcomeres. Thus, although this relationship was not assessed experimentally in the present study, it is reasonable to suggest that, close to complete extension, because of the contraposition of thin filaments in shortened muscle regions, there is lower capacity to produce strength[29,30], which can or not be compensated by an advantage in WMMA.

When the exercise is performed with the spring fixed at low height, it is observed that the Γ_R increases a little at the begin of the movement until an angle close to 60° and, then, decreases in a sharper form. In this situation, the statistical analysis also revealed a plateau between the angles of 50º, 60º and 70º (Table 1). As the crescent behavior of the WMMA is determinant in the production of Γ_M, the maximum values of FM$_R$ occurred in longer muscle lengths than those of the Γ_R, near 70-80º for the blue spring and 80-90º for the red spring (Table 2), sites where in theory there is a higher contribution of the elastic components of the musculoskeletal system for the production of muscle strength[29]. On the other hand, at the end of the ROM (close to complete extension), the WMMA increased and reached a significant plateau, whereas the Γ_R and the FM$_R$ decreased (Figure 3). In the situation, in which the external demand at the end of the ROM is low (reduction of the $\Gamma_{R)}$, there is an apparent reduction in the external load over the muscles and joints. However, in clinical practice, it is not known how far the WMMA will compensate for a possible lower capacity of strength due to the smaller muscle lengths at this ROM.

Typically, the recovery of ROM and muscle strength are rehabilitation goals, derived from muscle weakness from joint degenerative and chronic processes, or even from the recovery after a surgery[31,32]. Irrespective of the condition, exercises must have progressive loads and respect joint mechanics. Considering the hip case, it is important to use knowledge of the capacity of production of FM$_R$ and WMMA, which, together, execute the movement of extension (hamstrings and gluteus maximums), as criteria for the prescription and progression of exercises. The administration of resistance in ranges with higher mechanical advantages can promote a lower overload of musculoskeletal structure. On the other hand, if the peak of resistance is administered in ranges where the perpendicular distance is disadvantaged, there will be a higher overload. In addition to the evaluation of the WMMA, the present study suggest therapists to also consider the capacity of torque production associated to the joint ranges involved, considering the theoretical assumptions in which the relationship strength-length is based[27-30]. However, these analysis shall be done cautiously, since the relation strength-length is a static and discrete property of the muscles and shall be used only to support the comprehension of muscle strength during dynamic tasks[33].

In general, when performing HE exercise on the Cadillac, therapist can vary the spring heights with the purpose to focus the work at the angular patch in which the higher external demand occurs and, posteriorly, vary the spring colors to modulate the intensities in specific joint amplitude. Thus, for example, if the objective is ROM recovery and the patient has little flexion ROM (about 60□), it is recommended to initiate the treatment with the high spring, using the blue color at first , and then change the color to red, a variation that promotes a gradual increase of FM$_R$ (Table 2). The option for the high spring presents an advantage to generate a higher load on patient's available ROM and also to act on the muscles in a more stretched position, which may stimulate the addition of sarcomeres in serie[34]. This change on the structure of the muscle tissue has been pointed out as an imported factor for the increase in ROM and the higher capacity of force production in longer muscle lengths[35]. In the next phase of treatment, when the patient reaches ranges of motion close to 80º degrees, it would be possible to choose the spring at lower positions, since these positions loads to a higher resistance to extension.

Another possibility for the use of the present results can be illustrated in situations of rehabilitation of athletes with specific demands according to the sports modalities. In this perspective, at the final stages of rehabilitation of muscle injuries , such as muscle strain or muscle spasms, it is possible to prescribe exercises that aim to prioritize the gain of strength in specific ROM[31,32]. Thus, athletes that by the imposition of their sport require a higher effort close to extreme angles of hip flexion, such as in cycling[36], could exercise with low spring heights, initiating with the blue spring and, posteriorly, changing to the red spring. In the case where the sport required activities at higher HE angles, such as for runners, the proposal would be to perform the exercises with the spring in higher positions[36].

Conclusion

Within the methodology of this study, the results demonstrated that the same movement of Pilates presented different sizes and behaviors of Γ_R and FM$_R$. In addition, the maximum values of Γ_R did not always occur in the joint amplitudes in which the maximum values of FM$_R$ were observed. This information associated to the theoretical knowledge of WMMA can be used as mechanical parameters for the prescription and progression of rehabilitation programs with the purpose to identify the joint position in which the external load is higher or lower, and which is the mechanical condition of muscle response to this load. Depending on the height and type of spring used, HE exercises on the Cadillac can be more often indicated to a clinical purpose than to others.

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