Analysis of the relation between flexibility and passive stiffness of the hamstrings

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ABSTRACT

Introduction: The terms stiffness and flexibility, which refer to muscle properties, are frequently used as synonyms in the literature. However, these two muscle properties have distinct definitions. Objective: To investigate the contribution of the measure of flexibility to the passive stiffness of the hamstrings. Methods: Stiffness and flexibility were measured in 33 healthy individuals. An isokinetic dynamometer registered the resistance torque offered by the hamstrings during knee passive extension at 59.6°. Muscle activity was monitored during the tests to guarantee electromyographic silence. The slope of the torque-angle curve was used to determine the hamstrings passive stiffness. The range of the test was divided into three portions to calculate the stiffness of the 1st, 2nd and 3rd thirds of knee movement. Flexibility was assessed by having the examiner move the lever of the dynamometer in the direction of knee extension. The final measure was determined as the angle at which movement was interrupted because the examiner perceived a resistance to further movement and the volunteer reported a sensation of discomfort. Simple regressions were used for statistical analysis. Results: The regression analysis demonstrated correlation values of \( r = -0.48 \) \((R^2 = 0.23; p = 0.005)\), \( r = -0.54 \) \((R^2 = 0.29; p = 0.001)\), \( r = -0.46 \) \((R^2 = 0.21; p = 0.007)\) and \( r = -0.45 \) \((R^2 = 0.20; p = 0.008)\) between flexibility and total, 1st, 2nd and 3rd third stiffness, respectively. Conclusion: Despite significant associations between the analyzed variables, flexibility explains only a low percentage of the variability of the stiffness measure. Stiffness and flexibility are not equivalent and should be analyzed independently.

INTRODUCTION

The passive stiffness and flexibility muscular properties are frequently investigated in rehabilitation and sports studies fields¹-², being considered synonyms and indistinctly used by many authors of these fields³. However, these properties present differences in relation to their definitions found in the literature. Passive muscular stiffness is defined as the reason between the change in the muscle tension by change unit in its length, when it is elongated without contraction activity⁴. On the other hand, flexibility is defined as the ability of the muscular tissue to elongate, allowing that the articulation moves through the whole movement’s breadth⁵. These conceptual definitions of stiffness and flexibility guide the investigations about the contribution of these muscular properties to the functional and sports performance.

Muscular stiffness is a mechanical property of the muscle related to the resistance of this tissue to deformation, being graphically represented by the slope of the stress-strain curve⁶. The area below this curve represents the amount of energy absorbed by the muscle when it is elongated, either in rest or contracted⁷. Thus, the stiffness contributes to the muscle’s ability to absorb energy under mechanical forces⁸-⁹. The amount of energy applied on the musculoskeletal structures during the sports and functional activities seems to determine the occurrence of lesion of these structures⁴-¹⁰. Therefore, the bigger the stiffness of the muscular tissue, the bigger its ability to absorb energy and the lower its susceptibility to lesion. Moreover, the absorbed energy by the muscular tissue can be stored and, then, reused in the subsequent movement in order to trigger the muscular action¹¹-¹². Thus, the stiffness and the energy absorption ability of the muscle can help not only in the prevention of muscular lesions, but also in the performance improvement during the movement.

Flexibility property is frequently used as a means of inference over the muscular length¹²-¹⁳. Although the maximum excursion of the muscle is not usually necessary in routine activities¹⁴, significant losses of this property may compromise the suitable execution of the movement¹²-¹⁴. Despite some authors’ suggestion that the flexibility reduction would be associated to a higher musculoskeletal lesions frequency¹⁵-¹⁷, it is not proved that the flexibility gain has influence on these lesions prevention¹⁸-¹⁹. The lack of demonstration of this effect may be explained by the use of different evaluation methods of the flexibility¹⁷, varied criteria to determine muscular shortening¹⁹, besides the lack of standardization in the definition of the term lesion¹⁷. Therefore, the real impact of the flexibility as means of the muscular length, in the occurrence of lesions and in the functional performance, needs to be better investigated.

Clinical and research data suggest that the stiffness is inversely related to the muscular flexibility, that is, more rigid muscles would invariably be less flexible and, on the contrary, less passively rigid muscles would have more flexibility¹⁵-¹⁷,²⁰. These data are based on the mathematical formula that defines stiffness, expressed as the force variation \((\Delta F)\) divided by the length variation \((\Delta L)\). Once this length variation can be considered as a flexibility measurement, the presence of this common denominator would imply in an inversely proportional relation between these two properties. Some authors also consider the passive stiffness as being a flexibility component, using similar operational ways to measure both properties¹⁶-²². The flexibility usually functions as the movement’s breadth of an articulation for a determined force capable of promoting the muscle’s elongation which goes through it²². On the
other hand, due to the direct measurement impossibility, the muscle’s passive stiffness in humans is quantified through the relation between the resistance torque offered by the articulation and the breadth of movement during the passive articulator dislocation[23]. Thus, the operational definitions of stiffness and flexibility demonstrate that the investigation of these properties contribution for the functional and sports performance should consider the existing conceptual differences between these properties and use measurement procedures corresponding to such differences.

Further studies which precisely determine the existing relation between flexibility and muscular stiffness, using operational means compatible with the definition of each property are still needed. Thus, the aim of the present study was to investigate the contribution of the measurement of the hamstrings flexibility for the passive stiffness of this muscular group.

METHODS

Sample

The sample of this study consisted of 33 healthy university students, of both sexes (6 males and 27 females), with age range between 18 and 26 years (average of 21.7 ± 1.8). The volunteers could not present lumbar pain history or lesion of the lower limbs. This research was approved by the Ethics Committee in Research from the Universidade Federal de Minas Gerais, having all participants signed a free and clarified consent form, agreeing to participate in the study.

Procedures

After the study’s procedures explanation and consent form’s signature, the determination of the volunteer’s dominant lower limb was done, since the measurements were done only in the non-dominant limb, as a means of standardizing the measures among the volunteers. The limb considered dominant was that chosen by the participant to kick a ball[17]. After that, the participants were submitted to the measurement of the body mass and the leg and foot segments length of this side. The anatomic references used for the measurement of the lengths of the segments were according to the descriptions of the anthropometrical table by Dempster[24].

Evaluation of the passive stiffness

Pairs of surface active electrodes (Biopac System Inc., Goleta, CA), with diameter of 11.4 mm and inter-electrodes distance of 20 mm, were placed over the area of the biggest muscular part of the lateral vast (LV) and femoral biceps (FB) of the non-dominant limb, following the fibers orientation. Before the electrodes placement, the trichotomy and cleansing of the skin with alcohol was done. A land electrode was placed on the acromio.

During the passive stiffness test, the electromyographic activity of the LV and FB was simultaneously collected, which allowed the monitoring of the muscular activity and guaranteed that the test was passively conducted. A MP 150WSW electromyographic was used (Biopac System Inc., Goleta, CA) connected to a computer, with collection frequency of 1000 Hz, entrance avoidance of 2 mega ohms (MΩ) and Rejection of the Common Mode potency of 1000 MΩ. Only the measures in which the activity of both muscles did not exceed the average activity registered in resting increased in two standard-deviations above the average were accepted for analysis[25]. A computer program was developed in order to compare the muscular activity presented during the test with resting electromyographic signal, in intervals of 50 ms. The program was applied right after each measurement, in the interval between the repetitions, hence allowing or rejecting the test.

The passive stiffness was evaluated through a isokinetic dynamometer (Biodex Medical System Inc., Shirley, NY). Such device has a passive mode of operation, which moves the desired articulation at a constant velocity, in predetermined breadths, register-
Data reduction

The total stiffness calculation and of the 1st, 2nd and 3rd thirds were performed from the isokinetic dynamometer software data obtained during the passive stiffness test, collected at a 100 Hz frequency. The articular angle was measured in degrees and the resistance torque was measured in Newton-meters (Nm), without gravity's effects correction. The torque values and angles registered by the dynamometer were transferred to a computer for data analysis. The hamstrings stiffness was determined through a program specially developed for this reason. The data were filtered with an ordinary Butterworth filter of 4th order and a cut-off of 0.025 Hz. The program calculated the torques produced by the leg's and foot's weight and by the foot's weight over the leg for the whole breadth, from the data related to the body mass and the segments' length, according to the anthropometrical table by Dempster[24]. The values of these torques and of the torque produced by the weight of the lever in the whole breadth of the movement were subtracted from the passive torque provided by the dynamometer, with the resulting torques being used for the calculation of the passive stiffness of the hamstrings. The measure of the angle was changed to radians (rad) and the passive torque offered by the hamstrings was plotted in relation to the angular dislocation. The stiffness was defined as the torque variation (Nm) divided by the angle variation (rad) and was calculated through an analysis of simple linear regression between the test angles and the passive torque of the hamstrings. The slope of the torque angle curve resulting from the analysis of regression was used in order to determine the passive stiffness of the hamstrings, being expressed in Nm/rad. The test breadth was divided in three equal portions and a calculation of the total stiffness and of the slope of the curves in the 1st, 2nd and 3rd thirds of the angular movement was done (figure 1).

The dynamometer software provided the value of the knee articular angle in which the lever movement was interrupted, used to evaluate the hamstrings flexibility. The angulation in which the movement was interrupted, determined in degrees, and correspondent to the flexibility value, was determined from the figure provided by the software.

Statistical analysis

Simple regression analyses were used to determine the contribution of the flexibility measure for the passive stiffness measures of the hamstrings in the total breadth of the test (total stiffness) and in the 1st, 2nd and 3rd portions of the angular movement (stiffness of the 1st, 2nd and 3rd thirds). The significance level was established in $\alpha = 0.05$.

RESULTS

The simple regression analyses revealed corre-
TABLE 1

<table>
<thead>
<tr>
<th>Variáveis</th>
<th>Médias</th>
<th>Desvio-padrão</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibilidade</td>
<td>8,15</td>
<td>3,98</td>
</tr>
<tr>
<td>Rigidez passiva total</td>
<td>11,99</td>
<td>3,92</td>
</tr>
<tr>
<td>Rigidez passiva 1º terço</td>
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<td>2,48</td>
</tr>
<tr>
<td>Rigidez passiva 2º terço</td>
<td>10,28</td>
<td>3,57</td>
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<tr>
<td>Rigidez passiva 3º terço</td>
<td>21,53</td>
<td>7,04</td>
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**DISCUSSION**

The present study was conducted with the aim to investigate the relation between the flexibility and passive stiffness relation of the hamstrings. According to the obtained results, a percentage relatively small of the total passive stiffness variability measures, of the 1st, 2nd and 3rd thirds (23%, 29%, 21% and 20%, respectively) may be explained by the flexibility measure of this muscular group, despite the associations between these variables being significant.

The R² values found in this study suggest the existence of other variables as predicting factors of the passive muscular stiffness. Among these variables, the transversal section area of the muscle [27] and the passive articular structures should be considered [28]. Chelboun et al. (1997) demonstrated that the muscular volume is responsible for 84% of the stiffness measure variation of the elbow flexion muscles [27]. Moreover, Blackburn et al. (2004) suggest that muscles with bigger tropism would have a greater number of crossing bridges between the actin and miosine filaments, which would contribute for the muscle resistance to deformation [41]. On the other hand, there is evidence that the muscular atrophy observed after a period of immobilization is associated to a decrease of the muscular stiffness [29]. These findings reinforce the lack of strong association between flexibility and stiffness; once the flexibility, evaluated through the breadth of the articulation’s movement changes, may occur in the absence of modification of the passive stiffness.

A proposal of an inverse relation between flexibility and stiffness is based on the mathematical formula that defines stiffness (ΔF/ΔL), which shows that less flexible muscles that is, which present a low value in the formula’s denominator, are stiffer, and would be more prone to lesions [3,15,17,32]. However, one should consider that the formula for the stiffness definition characterizes a relation between strength and length. Therefore, an increase of the AL may be observed, which would characterize an increase in flexibility, accompanied by a simultaneous increase in the AF. In this case, even if the muscle presented a variation in its length, the stiffness would not alter, which would justify the findings in the study which evaluate changes in flexibility without modification in stiffness. Thus, contrary to what has been reported in the literature [39], the flexibility and passive stiffness properties are not synonyms and should be independently analyzed.

The found values in this study are similar to the ones reported by Wilson et al, who investigated the association between flexibility and stiffness of the muscles of the shoulder articulation, obtaining a R² value of 0.30 [30]. Blackburn et al (2004) reported values of moderate and positive correlation between flexibility and passive stiffness of the hamstrings [31]. Although a discrepancy between the studies in relation to the correlations direction due to differences in the measurement techniques is found, the interpretation of these results is similar. However, differently from the studies mentioned before, the present study has chosen to analyze the total curve of the stiffness and the three parts of the curve divided according to the articulation angle, once the stiffness behavior is non-linear during the movement [22,21,27]. In the first third of the curve, the torque values were low and the variation coefficients were high. The second third consisted of a transition zone and the third third represented the linear portion of the curve. Hence, there was the possibility that the correlation values between flexibility and passive stiffness would be different according to the portion of the curve analyzed. However, the determination coefficients were similar, with the analysis considering the whole stiffness curve and each one of its three portions. Consequently, even considering the methodological differences in the studies, the results of the present investigation are according to the other findings in the literature.

A possible limitation of this study is related to the method used in order to measure the flexibility. The obtained measure with the use of such method is influenced by the individual’s tolerance to stretching and also by variations in the muscle’s resistance [21,32]. Another possible limitation refers to the passive stiffness measure of the hamstrings, which as mentioned before, was used as synonym to the knee articulation stiffness, being able to suffer influence from other passive structures. Moreover, the findings of the present study may have been influenced by the higher number of female individuals present in the sample, which limits the generalization of the results. Despite the mentioned limitations in relation to the measurement of the stiffness and flexibility variables and the sample’s composition, a factor which contributes to guarantee these measures validation was the monitoring of the electromyographic activity of the muscles which could have influenced in the measure during the tests. Trials in which the electromyo-
graphic activity was higher than the one registered in resting, according to criteria established in the literature, were not analyzed\(^\text{20}\). Therefore, the stiffness and flexibility properties evaluated represent properties intrinsic to the muscle in resting, and not a function of the contraction or reflex muscle activity.

The results of the present study show that other variables, different from the flexibility, may be used in order to predict the muscular stiffness. The low correlation values found between flexibility and passive stiffness possibly justify the absence of evidence in the literature in relation to the effects of the flexibility gain in the prevention of musculoskeletal lesions\(^\text{18,19}\). Thus, changes in the tropism and muscular length, more than changes in flexibility, evaluated through the maximum breadth of the articulation movement, should lead future studies with the aim to modify the muscular stiffness trying to optimize the sports performance and decrease the number of musculoskeletal lesions. Little stiff muscles present greater deformation in response to an applied strength\(^\text{13}\), which can absorb bigger amounts of energy, decreasing the susceptibility of the musculoskeletal structures to lesion\(^\text{8,9}\). Therefore, studies that investigate the impact of intervention programs, such as the muscular strengthening and stretching, in the passive stiffness and their potential benefits in the lesions prevention are needed.

## CONCLUSION

Although the associations between the variables have been significant, a relatively small percentage of the variability of the total, 1\(^{\text{st}}\), 2\(^{\text{nd}}\) and 3\(^{\text{rd}}\) thirds of the passive stiffness measures (23\%, 29\%, 21\% and 20\%, respectively) can be explained through the measure of the flexibility of this muscular group. Such result indicates the possibility of influence of other variables, such as transversal section area and consequently greater stiffness, can absorb bigger amounts of energy, decreasing the susceptibility of the musculoskeletal structures to lesion\(^{18,19}\). Therefore, studies which investigate the impact of intervention programs, such as the muscular strengthening and stretching, in the passive stiffness and their potential benefits in the lesions prevention are needed.

All the authors declared there is not any potential conflict of interests regarding this article.

### REFERENCES