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Effects of an active eccentric stretching program for the knee flexor muscles on range of motion and torque

Efeitos do alongamento ativo excêntrico dos músculos flexores do joelho na amplitude de movimento e torque

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Abstract

Objective: To evaluate the changes in knee range of motion (ROM) and torque of knee flexor and extensor muscles after an active eccentric stretching program for the knee flexor muscles. **Methods:** Thirty-four volunteers (23 women and 11 men), aged 34.42±9.3 years, performed an active eccentric stretching program for the knee flexor muscles in the standing posture, consisting of seven repetitions of one minute each, with 30 seconds of resting between them. The stretching program was performed twice a week, for four weeks. Knee extension ROM and the torque of the knee flexor and extensor muscles were evaluated using an isokinetic dynamometer before and after the stretching program. The torque was evaluated in the isometric, isokinetic concentric and eccentric modes at 30°/s and 60°/s. **Results:** There was an increase in ROM from 53.7±13° to 30.1±16° (p=0.0001), in isometric torque of the flexors from 89±32Nm to 93±33Nm (p=0.01) and of the extensors from 178±67Nm to 187±73Nm (p=0.006). The concentric and eccentric torque of the flexors at 30°/s increased from 90±31Nm to 96±31Nm (p=0.001) and from 100±34Nm to 105±35Nm (p=0.01), respectively. The concentric torque of the extensors at 60°/s increased from 144±51Nm to 151±58Nm (p=0.02), and the eccentric torque at 30°/s increased from 175±71Nm to 189±73Nm (p=0.01). **Conclusions:** The stretching program proposed was effective for increasing the flexibility of the stretched muscles and the torque of the agonist (stretched) muscle groups and their antagonists.

Key words: active eccentric stretching; flexibility; torque; ROM; knee flexors.

Resumo

Objetivo: Avaliar a amplitude de movimento (ADM) e o torque flexor e extensor do joelho após a realização de um programa de alongamento ativo excêntrico dos músculos flexores do joelho. **Materiais e métodos:** Trinta e quatro voluntários (23 mulheres e 11 homens), 34,42±9,3 anos, realizaram um programa de alongamento ativo excêntrico dos músculos flexores do joelho na postura em pé, que consistiu de sete repetições de um minuto com 30 segundos de descanso entre as repetições. O programa de alongamento foi realizado duas vezes por semana, durante quatro semanas. A ADM de extensão e o torque flexor e extensor do joelho foram avaliados no dinamômetro isocinético pré e pós-programa de alongamento. O torque foi avaliado nos modos isométrico e isocinético concêntrico e excêntrico a 30°/s e 60°/s. **Resultados:** Houve aumento na ADM de 53,7±13° para 30,1±16° (p=0,0001), no torque isométrico flexor de 89±32Nm para 93±33Nm (p=0,01) e extensor de 178±67Nm para 187±73Nm (p=0,006). O torque flexor concêntrico e excêntrico a 30°/s aumentou de 90±31Nm para 96±31Nm (p=0,001) e de 100±34Nm para 105±35Nm (p=0,01), respectivamente. O torque extensor concêntrico a 60°/s aumentou de 144±51Nm para 151±58Nm (p=0,02) e o excêntrico a 30°/s de 175±71Nm para 189±73Nm (p=0,01). **Conclusões:** O programa de alongamento proposto foi efetivo para aumentar a flexibilidade dos músculos alongados e torque dos grupos musculares agonistas (alongados) e seus antagonistas.

Palavras-chave: alongamento ativo excêntrico; flexibilidade; torque; ADM; flexores do joelho.

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Introduction

The immobilization of muscles in a stretched position promotes an increase of their length because of increments in the number of sarcomeres in series of the muscular fibrils[1]. This adaptation happens in an attempt to re-establish the ideal physiological superposition of actin and myosin filaments, that make the muscle able to generate higher levels of strength in this new functional length[2]. Therefore, stretching can increase muscular flexibility, and in addition, could cause changes in the development of maximum strength.

In the measurement of the range of motion of knee extension and hip flexion, many studies have reported increases of knee flexor muscle flexibility, subsequent to the application of various stretching programs[3-5]. However, few studies considered the correlations between changes in flexibility and muscular torque. Many of these studies analysed acute post-stretching[6-8] muscle responses, even though, there is a lack of data related to long-term stretching effects[9,10].

Worrell, Smith and Winegardner[9] submitted knee flexor muscles to two kinds of stretching: static and proprioceptive neuromuscular facilitation (PNF). The authors verified that the amplitude of knee extension did not suffer any changes after stretching, although an increase occurred of the eccentric and concentric torque of the muscular group that were stretched. Hortobágy et al.[10] noticed an increase in the flexibility of the knee flexor agonist muscles subsequent to a static stretching program performed with this muscle group. Although the performance of this muscle group was not analysed, the authors demonstrated improvements in the performance of the knee extensor muscles in the antagonist group. Consequently, according to the authors, it is possible that the stretched agonist muscles could have influenced the mechanical properties of the antagonist group. Similarly, Winters et al.[11] defend the view that active stretching of the agonist muscular group can improve the performance of its antagonist group. Even so, the authors suggest that other studies should investigate these correlations more closely. The results of the studies regarding the changes in flexibility of the stretched muscles and their antagonists are still a controversial subject in the scientific literature.

Analysing the above mentioned studies, some characteristics were verified: a) the various kinds of knee flexors stretched, in the standing position, were not performed with unloading of the weight on the member that was stretched, but this was superficially supported[4,5]; b) the improvement of knee flexor muscle flexibility was greater when they remained under tension during stretching[3,4], as is characterized by active stretching.

It is important to point out that the majority of authors who carried out research on humans showed the efficiency of static, passive, dynamic or PNF stretching techniques[5], however, active static stretching has not been frequently studied[11]. Published studies which have shown, the majority performed with animals, demonstrated that active eccentric stretching is highly suggested for promoting muscular stretching, since it stimulates faster adaptations in length of the muscles, and consequently, increases muscle flexibility, that could also cause changes in the levels of strength development[12].

Thus, greater knowledge of the changes in flexibility and muscular torque of agonist and antagonist muscle groups, performed in a clinic or during the practice of sports, could provide scientific evidence of the efficiency of active eccentric stretching applied in humans. For this reason, this study aimed to evaluate the effects of an active eccentric stretching program applied to knee flexors, performed in a standing position, with unloading of weight on the stretched member, with flexibility evaluated by measuring the amplitude of the knee extension, flexor torque and knee extension.

Materials and methods

Subjects

Thirty-four subjects participated in this study (23 women and 11 men) aged 34.42±9.3 years old. The subjects should demonstrate the following characteristics: a) have a sedentary lifestyle; b) and a minimum of 20° amplitude of the dominant member knee extension[13], which was measured using an isokinetic dynamometer and c) be in good health. In this case, subjects who participated in the study showed no inflammatory or osteomioarticular disturbances, as well as, no cognitive or cardiovascular problems of the lower limbs and/or spine which could prevent them from performing the study procedures.

All subjects were informed of the objectives and the procedures of the study and signed an informed consent form in accordance with the resolution 196/96 of the National Health Council. The study was approved by the Ethics Committee of the Universidade Federal de São Carlos (UFSCar), number 179/2007, and was in accordance with the demands of the Helsinki declaration for studies performed with humans.

Procedures

All procedures were performed by the same evaluator. The procedures included; in week 1, an introduction; week 2, measurements of the range of motion and knee flexor and extensor torque; weeks 3 to 6, stretching; and in week 7, a re-evaluation of the range of motion and torque. The range of motion and torque were evaluated using isokinetic dynamometer (Biodex Multi-joint System 3), using only the dominant member.

Evaluations

a) Measurement of the amplitude of knee extension
Position on the equipment: a quilt accessory was created to be placed on the back of the dynamometer chair (Figure 1) to maintain the subject's hips inflected approximately 90°. This procedure maintained the pelvis closest to the neutral position during the evaluations. Afterwards, the subject was positioned and stabilized on the dynamometer chair using diagonal and pelvic belts and the dynamometer's axis was aligned with the lateral condyle of the femur. The subjects were advised to close their eyes and remain relaxed during the test;
Measurements: the subject could operate the dynamometer using a device (Figure 1), so that the resistance arm of the equipment would passively start to extend the knee up to 90° of knee flexion, at a speed of 2°/s. They were also advised to stop the dynamometer resistance arm using the device as soon as they felt the beginning of knee flexor muscular tension in stretching, which occurred normally between 90° and 20° of knee extension for the subjects who were selected, could not perform total knee extension (0°). The measurements were taken three times and the mean value was used for the statistical analysis[14]. No warm-up was performed before the measurement of the amplitude of movement.

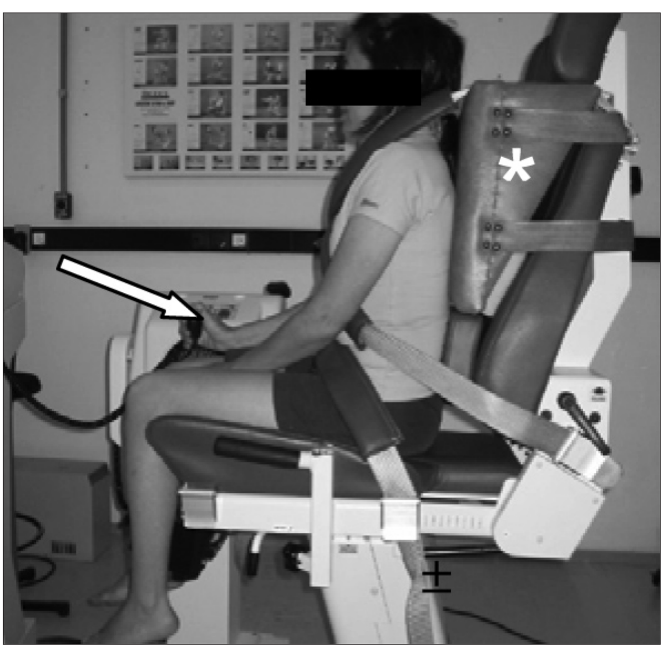

Figure 1. Positioning of the volunteer in the seat of the dynamometer: device (arrow) that was used to start or stop the passive evaluation, and accessory (*) to keep the hip joint at 90° of flexion, respectively.

b) Measurement of the isometric torque of the knee flexor and extensor muscles: after the range of motion was measured, the subject would warm-up on a stationary bicycle for five minutes at a speed of 20km/h and performed self-stretching of the knee flexor and extensor muscles. Afterwards, they would once again be positioned on the dynamometer chair, this time without the support of the quilt. The maximum isometric torque of the knee extension was evaluated using maximum voluntary isometric contraction (MVIC) at 80° of knee flexion, as suggested by Marginson and Eston[15]. Three MVICs were performed and the highest peak torque reached was maintained. Each contraction was maintained for five seconds, with a rest interval of 90 seconds. The same procedure was used for the evaluation of the knee flexor torque, except that the flexor torque was evaluated with knee flexed at 30°, in agreement with Murray et al.[16].

c) Measurement of the isokinetic torque of the knee flexor and extensor muscles: the concentric and eccentric isokinetic torque of the knee flexor and extensor muscles were evaluated using an range of motion of 60º[17], starting from 90º of knee flexion. It is important to indicate that the concentric-eccentric program was used to analyse the maximum contractions of the knee extensor muscles, whereas the eccentric-concentric program was used to evaluate the knee flexor muscles. These evaluations were performed at a speed of 30º/s and 60º/s for both muscular groups. Five consecutive movements of knee extension and flexion were performed at each speed, with a rest interval of two minutes. The evaluation always started at a speed of 30°/s. It is also important to state that five sub-maximum contractions were performed before the maximum tests in order for the subjects to get used to the equipment. All tests were carried out by the same therapist.

Stretching

Knee flexor stretching program: first, the subjects were advised to stand in front of a stretcher, being sufficiently distant to it so they could support both hands on the stretcher. Afterwards, the therapist aligned the subjects' spine using a bar to help straighten it. Then, the subjects were instructed to bend the knee slowly and incline the trunk backwards until they could touch the stretcher using their hands, however they should support their body weight on the stretcher (Figure 2). Subsequently, they should have extended the knee slowly and performed an ante-version of the pelvis[4] until they stated that they felt maximum supportable knee flexor stretching, without pain. As soon as this maximum tension was achieved, the stretching should be maintained for one minute. At the end, the subjects returned to the initial position and remained still for 30 seconds. Then they would repeat the procedure.

The same procedure was performed seven times, two times a week (with an interval of two days in between each session), for a period of four weeks. It is important to indicate that a bar remained over the subject's spine during all of stretching time in an attempt to prevent possible compensations.

Statistical analyses

Paired Student t-tests and the Wilcoxon test were used to evaluate the knee extension amplitude and knee flexors and extensors torque, before and after the stretching program. The first was used to evaluate parametric data and the later was used to evaluate non-parametric data. A significance level of $p<0.05$ was considered at the conclusion of the analysis.

Results

- Evaluation of the amplitude of movement: there was an increase of approximately 23.6° in the knee extension amplitude (p=0.0001t), when comparing the previous data and after the stretching program (Table 1).
- Knee extensor concentric and eccentric isometric and isokinetic torque: the knee extensor torque peak increased after the stretching program in all evaluated modules: isometric (p=0.006); concentric isokinetic at the speed of 60°/s (p=0.02) and eccentric at the speed of 30°/s (p=0.01), as shown in Table 1.
- Knee flexor concentric and eccentric isometric and isokinetic torque: as specified in Table 1, the peak knee flexor torque also increased after the stretching program in the evaluated modules: isometric (p=0.01); concentric isokinetic at the speed of 30°/s (p=0.001, Wilcoxon) and eccentric at the speed of 30°/s (p=0.01, Wilcoxon).

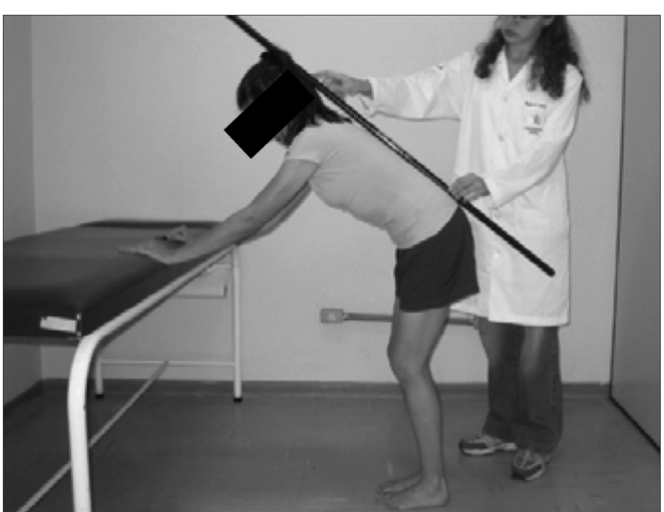

Figure 2. Posture used for the active eccentric stretching of the knee flexor muscles. Note the knee and trunk flexion, alignment of the spine and support of the hands on the stretcher.

Discussion

The results of this study showed that the knee flexor stretching program, eccentrically and actively performed, with unloading of the body weight over the stretched member, was effective in increasing knee extension range of motion and in increasing the knee extensors and flexors torque.

Many studies have analysed changes in the flexibility of the knee flexor muscles, evaluating the joint range of motion, after submitting them to various stretching protocols[5,17]. However, the stretching programs used were usually passive and performed with the participant sitting or standing, without unloading of the weight of the leg which was stretched[5,18,19]. In these studies, the range of motion increased an average of 10°[5], 10°[17], 4°[18] whereas in the present study, carried out using an eccentric active stretching program with the participant standing and unloading of the body weight on the leg which was stretched,

Table 1. Knee extension range of motion (ROM) and torque of the flexors and extensors of the knee evaluated in the isometric mode at 80 and 30° of flexion, respectively, and in the concentric and eccentric modes at 30°/s and 60°/s, pre- and post-intervention.

	Pre-intervention	Post-intervention
Extension ROM (°)	53.7±13.0	30.1±16.0*
Extensor torque (Nm)		
Isometric	178.6±67.8	187.5±73.5*
30°/s		
Eccentric	175.4±71.6	189.9±73.8 *
Concentric	155.3±59.5	161.6±65.1
60°/s		
Eccentric	177.8±74.1	183.1±68.0
Concentric	144.4±51.6	151.57±58.2*
Flexor torque (Nm)		
Isometric	89.6±32.62	93.8±33.1*
30°/s		
Eccentric	100.3±34.2	105.6±35 *
Concentric	90.7±31.7	96.7±31.8*
60°/s		
Eccentric	102.9±35.2	103.9±33.4
Concentric	99.4±34.9	100.7±31.5

Results are mean±standard deviation. *p<0.05 when compared to the pre-intervention period.

the range of motion increased 23.6°. This indicated that the procedure used in the present study showed better advantages for gains in the range of motion.

Nelson and Bandy[20] did not observe any differences in gains of amplitude of knee extension after eccentric active and passive stretching. In both stretching programs, the average of gains in range of motion was 12°. This difference was perhaps due to better positioning of the pelvis, which was maintained in ante-version position during the performance of the stretching of the knee extensors and flexors that was not mentioned in other studies[5]. Although Sullivan, Dejulia and Worrell[4] found an increase of just 11° in the amplitude of the knee extension, after completing the stretching programs, they have indicated the relevance of pelvis positioning during the performance of stretching of the knee flexors. Thus, the maintenance of the pelvic positioning guaranteed muscular tension of the knee flexors during the performance of the exercises. Taylor, Brooks and Ryan[21], carrying out research using animals, noticed that the combination of stretching and contraction in an exercise program can be more effective than a program just consisted of stretching, since the application of higher levels of tension on the musculotendinous unit causes more viscoelastic stress. The results of this study point to a necessity of future studies in which different stretching postures should be taken, unloading the weight on the stretched leg, demanding simultaneous contractions of different groups of muscles to better stabilize the knee[3].

The gains in the knee extension amplitude might have been caused by changes in muscular length due to increases in the number of sarcomeres in series[1,2]. However, it is important to point out that many of these changes were not observed with human muscles[22]. Studies which have been carried out on animals[23] and humans[24] show that increases in muscular length can also occur due to changes in the conjunctive tissues.

Peak knee extensor and flexor isometric torque increased after the performance of the stretching program. Since the subjects showed shortening of the knee flexor muscles, they could not inflect the trunk and extend the knees at the same time during the performance of the stretching. Because of this, the exercises were performed with semi-flexed knees. This increased the activity of the quadriceps and the knee flexors by co-contraction, to maintain the posture[25]. Considering the principle of specificity[26,27], a training program produces physiological adaptations in the muscles, which are being trained in response to the stimuli of the exercise that has been performed. Accordingly, the specificity of a stretching program is related to increases of the knee extensor and flexor isometric torques.

The peak concentric and eccentric isokinetic extensor torques also increased after the performance of the stretching program. Hortobágyi et al.[10] defend the viewpoint that increases in the flexibility of the knee flexors may influence the intrinsic extensor mechanical properties. They showed that there were increases in the strength of the knee extensors after passive flexor stretching. As previously stated and in accordance with Winters et al.[11], when a muscular group is stretched, the antagonists contract. Therefore, the standing active stretching performed might have caused neural adaptations which controlled the level of tension of the muscle, the number of active motor units, the frequency and synchrony of activation between them[26]. The peak isokinetic flexor torque increased likewise during the eccentric and concentric contractions, at a speed of 30º/s. One of the reasons for this increase in the torque of the flexors would be a reduction of neural stability levels. According to Hamill and Knutzen[28], active stretching induces a more pronounced response of the Golgi tendon organs and can attenuate their response by permitting higher levels of tension of the muscles that received active stretching.

Worrell, Smith and Winegardner[9], also observed increases in concentric knee flexor torque after the performance of stretching programs. They attributed these increases to a greater ability of the stretched muscle to store elastic potential energy absorbed during the eccentric contractions. This would improve the later strength of the concentric contractions. The phenomena of the improvements in strength of the concentric contractions subsequent to the eccentric pre-stretching contractions of the same muscles is well accepted in the scientific community. Most of the improvements in strength after stretching is due to the passive components as well as the contractible and active components of the muscles[29]. Taylor, Brooks and Ryan[21] related that, after stretching, some viscoelastic properties of the muscular conjunctive tissue change, the resistance tension diminishes and the muscle becomes more complacent. Thus, it would be able to store more potential elastic energy during eccentric contractions. Analysing this present data, the increases in peak knee flexor concentric torque that was observed in this study, might have been caused by increases of the elastic components, since there were increases in the flexibility of the knee flexors.

As was stated by Hortobagyi and Katch[30], concentric torque diminishes with increases of speed, because of the reduction of cross bridges at the highest speeds of muscular shortening, while initially, the opposite occurs during eccentric contractions. In the present study, the increases in eccentric extensor torque were achieved during the performance of the isokinetic test at the lowest speed (30°/s), whereas, during the concentric contractions, the highest extensor speeds were achieved at the speed of 60°/s. In contrast to the results found by the above mentioned authors, only the concentric test resulted in higher peak torque of the knee flexors at the lowest speed. The results found in the present study differed from the results in the scientific literature, except for the results found for concentric contractions of the knee flexors. That indicates that more studies should be carried out to elucidate the changes in torque for the various muscular groups (agonists and antagonists) when submitted to eccentric active stretching programs. These studies might be more useful if they used faster speeds than the speeds used in this study. It is also important to state that the large differences found in the results of the isokinetic tests, in this study, may have occurred because of the difficulty the subjects showed when performing them. The subjects showed some difficulty especially to start the eccentric tests of both muscular groups. These difficulties might had been eased if the knee flexor eccentric test began with a lower angle of knee flexion (between 80 and 70°), and in the meantime, the stretching would be performed using an amplitude of 60°. In addition, the subjects could have been more familiarized with the equipment, which might have influenced the knee extensor tests.

Conclusion

The results of this study show that the stretching program for the knee flexor muscles, actively and eccentrically performed with unloading of body weight, were effective in increasing the amplitude of knee extension, as well as torque of the knee flexors and extensors.

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