

# The Effect Of An Eccentric Training Program On The Change Of The Architectural Structure On Knee Extensor Muscles

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## Abstract

Background: Muscle strength is a key factor to the performance in all sports. Thus, it is important to correctly implement training programmes to improve it. Eccentric training programmes increase muscle strength and causes hypertrophy. However, the effectiveness of eccentric exercise in changing the architectural structure of muscles, using multi-joint isokinetic dynamometer at high intensity, has not been studied. The purpose of this study was to investigate the effects of eccentric isokinetic training of high loads on the architectural structure of amateur soccer players' rectus femoris, utilizing a multi-joint dynamometer.

Methods: Sixteen subjects (18-26 years) without musculoskeletal problems took part in this study. Eight of them were amateur soccer players and 8 non-trained individuals. The equipment utilized was the following: a) a multi-joint isokinetic dynamometer (MID - Hydrodynamic AF), b) a force plate (Kistler, 9281 - CA), a computer and a video projector in order to provide feedback regarding the characteristics of the power-time curve during training and c) an ultrasound device used to record the architectural structure of the RF (General Electric, model: LOGIQ 400).

Results: The experimental group demonstrated statistically significant differences regarding all the tested variables: Xapon,  $t(7)=-4,288$   $p=,004$ , Lfiber,  $t(7)=-4,209$   $p=,004$  and  $\Delta$ pterosi,  $t(7)= -3,418$   $p=,011$ , while the control group did not.

Conclusion: The multi-joint isokinetic dynamometer is a tool that leads to the maximization the eccentric strength.

## INTRODUCTION

Muscles are able to produce strength by specific ways:

a) isometric contractions (same distance or not moving), b) isokinetic contraction (same speed), and c) isotonic contractions (same tension). The last one is distinguished in two different types: 1) concentric and 2) eccentric contraction. The eccentric contraction is responsible for the muscle's length increase.

During an eccentric contraction, larger strength is produced, as compared to concentric contraction, proving that the eccentric training is easier for a relatively weak person (Kues & Mayhew, 1996; Enoka, 1996). It is well-documented that the muscle strength can be enhanced either by increasing the muscle hypertrophy or neuromuscular adaptations (Schmidtbleicher, 1992). Previous studies report that the characteristics of the chronic eccentric training are the following: energy absorption, development of

considerable muscle strength and small metabolic requirements. These characteristics cause increased muscle stiffness, power and hypertrophy.

(Lindstedt et al. 2001). The eccentric contractions are characterized as energy cheaper: less Adenosine triphosphate (ATP) consumption and greater output voltage, which causes damage to the muscle-tendon complex (Clarkson et al. 1995). Therefore, the eccentric training programmes are suggested to be incorporated into a training plan in order to ameliorate the muscle strength in parallel with the neuromuscular performance. It is well established that the eccentric isokinetic training enhances the muscle volume and the nervous activity of motor neurons (Higbie et al. 1996; Norrbrand et al. 2008). As a result, the repetitive eccentric training increases the number of sarcomeres in rats by reducing the muscle tension, thus, the joint angle, in which the maximal muscle strength is produced, changes (Proske et al. 2004).

Despite the fact that the eccentric training is a promising programme, the increased muscle strain during the programme is responsible for muscle damage, muscle pain, increased blood levels of creatine phosphokinase (CPK), oedema, reduction of the range of motion (ROM) and muscular functionality (contraction capacity) (Twist & Easton, 2005; Paschalis et al. 2008). However, an eccentric training can be a protective factor to avoid the muscle damage during exercise. This protective action is characterized by faster recovery of muscle strength, ROM, a smaller increase muscle protein in the blood and statistically significant smaller increase in muscle pain and oedema (Nosaka et al. 2001; Clarkson et al. 1992; McHugh et al. 1999). These mechanisms are often referred to as "repeated bout effect", and are not completely understood yet. This protective action is possibly explained due to the reduction of susceptible to tension muscle fibers, the restructuring of the existing myofibrils, the changes in the connective tissue and neural adaptations (McHugh et al., 1999). Also, the repetitive eccentric exercises minimize the risk of muscle injury and stabilize the response angle of the knee ligaments and generally of the lower limbs (Paschalis et al. 2005).

The eccentric training is a passive motion under resistance training combined with power output while elongating the muscle (Mahieu et al. 2008). Hence, the eccentric training increases the maximum force and additionally the maximum produced power, demonstrating that the eccentric power is related mainly to force and not to speed (Demura & Yamaji, 2006). In particular, the eccentric training at higher loads developed during contractions is remarkable (Roig et al. 2008).

Throughout the literature, there are a variety of studies examining specific training programmes or their combinations in order to increase the lower extremities' muscle strength. However, the literature lacks studies that include an ultrasound device to investigate the effectiveness of isokinetic eccentric training programmes at high loads, exerted by a multi-joint dynamometer, on the architectural structure of the RF muscle. Few studies, including isokinetic eccentric exercises, embody assessment intervals of the maximal eccentric power.

The goal of the present study was to explore the effectiveness of an isokinetic eccentric training programme at high loads, by the means of a multi-joint dynamometer, on the architectural structure of the RF muscles of amateur soccer players. More specifically, it aims to examine the

effectiveness of the particular training programme on the pennation angle, the cross-sectional area and the fascicle length of the RF. This examination took place by utilizing an ultrasound device during the resting period of the muscle.

The importance of this study lies firstly, on the use of the multi-joint dynamometer; secondly, on the exertion of high loads (80-90% of 1 Repetition Maximum-RM) while the range of motion of the knee is 160-130%. Finally, the real-time illustration of the athletes' performance on a video projector and the assessment intervals of the Fecc-max contribute to the significance of the present study.

We hypothesised that the isokinetic eccentric training at high loads would affect the architectural structure (i.e. pennation angle, cross-sectional area and fascicle length) of the extensor muscles of the knee and more specifically, of the RF.

## **MATERIALS AND METHODS**

### **Subjects**

Sixteen subjects (18-26 years) without injuries participated in this study, which took place in the Sports Biomechanics Laboratory of the Department of Physical Education and Sports at Serres. The participants were assigned in two groups; the experimental group (n=8 amateur soccer players without injuries) and the control group (n=8 untrained individuals). All the participants gave their written consent for taking part in this study.

### **Experimental Procedure and Equipment**

By using an ultrasound device, both groups were assessed in terms of the architectural structure of the RF muscle at baseline and 8 weeks later, during which the experimental group received a training programme. The data obtained were the following: the cross-sectional area, the pennation angle and the fascicle length of the RF muscle. During the measurement of the architectural structures, the pre-decided position of the lower extremities' joints was: 90° hip angle, 120° knee angle and 90° ankle angle.

The following devices were used, in the present study: a) an isokinetic multi-joint dynamometer (Hydrodynamic AF), b) a force plate (Kistler, 9281 – CA), a computer and a video projector for providing feedback regarding the power-time curve during training and c) an ultrasound device (General Electric, model: LOGIQ 400) with scanning head 3.5-7.5 MHz.

## The Effect Of An Eccentric Training Program On The Change Of The Architectural Structure On Knee Extensor Muscles

The participants were constantly receiving feedback on the level of the produced force, through a computer connected to the force platform. The goal was to maintain the force level at 70% -90% of the Fecc-max. In case any participants either did not reach or exceeded the required level, were encouraged to increase or decrease the produced force, respectively.

### Training Protocol

The experimental group followed an eccentric training programme lasting 8 weeks, with 2 training sessions per week. Between sessions there was always an interval of at least 48 hours. Every training session would start with a warming up session of 5-6 minutes on a Stationary bicycle at low load, followed by another 5 minutes of stretching the quadriceps, plantar flexors and hamstrings. For every muscle, the participants were performing 4 types of stretching exercises, lasting 5-7 seconds each. The reason for carrying out the warming up is that it provides protection against muscle injuries (Nosaka & Clarkson, 1997).

Afterward, the participants conducted an eccentric training programme on the isokinetic multi-joint dynamometer with velocity set at 0.35 m/s and a starting angle of the knee of 160°. The participants were sitting comfortably on the isokinetic device and were strapped tightly around their chest and hips, whilst their arms were hanging loosely. They put their feet onto the force plate and adjusted the knee angle at 160°, as it was predetermined during the baseline measurements. A goniometer was also used to measure the knee angle, in order to avoid mistakes. The participants were able to watch, during the training session, the increase of their strength through a projector, connected to the same computer as the force plate. The dynamometer resistance (load) was set up beforehand via computer, according to a predetermined value, which was a percentage of the Fecc-max for every individual. Therefore, all participants were able to control and adjust the resistance level, through the bioanalysis software of the Ariel Performance Analysis System (APAS). The participants did not take part in any other training programme until the end of the particular project.

### Training programme

The programme contained 3-5 sets of eccentric contractions of 6-10 repetitions per set, setting the load at 70-90% of the Fecc-max. In the first 2 sessions, the participants familiarised themselves with the isokinetic dynamometer

(sitting position, resistance and force application). Therefore, the load was set at 70% of the baseline Fecc-max (3 sets of 10 repetitions/set with 5-minute intervals). At the end of the second session, the Fecc-max was re-evaluated. The sessions of the next 2 weeks (i.e. 4 sessions) started with a load of 80% of the new Fecc-max. Every 2 weeks, the Fecc-max was evaluated again and the load was re-adjusted. The training programme, in detail, is illustrated in Table 1:

**Table 1**

The eccentric training programme on the isokinetic

WEEK	No of SETS	No of REPETITIONS	% Fecc-max	Break INTERVAL	No of SESSIONS
1 <sup>st</sup>	3	10	70	5min	2
Fecc-max evaluation					
2 <sup>nd</sup>	5	8	80	3min	2
3 <sup>rd</sup>	5	8	80	3min	2
Fecc-max evaluation					
4 <sup>th</sup>	4	5	90	5min	2
5 <sup>th</sup>	4	5	90	5min	2
Fecc-max evaluation					
6 <sup>th</sup>	5	6	90	6min	2
7 <sup>th</sup>	5	6	90	6min	2
Fecc-max evaluation					
8 <sup>th</sup>	6	6	90	7min	2

Two days after the end of the training programme, the final assessments were conducted with kinematic and electromyographic recordings from the multi-joint isokinetic dynamometer. The maximal isometric, eccentric and concentric strength was measured as well as the performance of 30 cm drop jump (DJ30) and of countermovement jumps (CMJ). The conditions, under which the baseline and the final measurements were conducted, were the same regarding the time, the training protocols and the utilised equipment.

## STATISTICAL ANALYSIS

The data obtained were analysed using a Multivariate Analysis of Variance (MANOVA) with repeated measures. Additionally, independent and paired t-tests were carried out for the analysis of interactions (Table 2).

**Table 2**

Variables analysed

Variable	Name
X <sub>apon</sub>	Distance between the aponeuroses
L <sub>fiber</sub>	Fascicle length
Φ <sub>pterosi</sub>	Pennation angle

**RESULTS**

The interaction between the groups and the repeated measurements of the experimental group and the control group as well as the variation of the time was statistically significant  $X_{apon} F(1,14) = 18,380, p = ,001$ ,  $L_{fiber} F(1,14) = 17,797, p = ,001$  and  $\phi_{pterosi} F(1,14) = 11,055, p = ,005$ .

The difference between the two groups prior to the intervention was examined with independent t-tests. The averages of the dependent variables between the two groups before the experimental procedure did not demonstrate statistically significant differences ( $p > .05$ ). The averages of the dependent variables, regarding the experimental group, after the experimental procedure demonstrated statistically significant differences ( $p < .05$ ), and more specifically:  $X_{apon}, t(14) = 11,008, p = ,046$ ,  $L_{fiber}, t(14) = 10,223, p = ,005$  and  $\phi_{pterosi}, t(14) = 8,405, p = ,002$ , whilst, in terms of the control group the averages did not show statistically significant differences ( $p > .05$ ).

Paired t-tests between the two repeated measurements were carried out for both groups in order to investigate if there are statistically significant differences between the dependent variables (Bonferroni adjusted). Concerning the experimental group, there were statistically significant differences in all the variables:  $X_{apon}, t(7) = -4,288, p = ,004$ ,  $L_{fiber}, t(7) = -4,209, p = ,004$  and  $\phi_{pterosi}, t(7) = -3,418, p = ,011$ . On the other hand, in terms of the control group, the variables did not reach a level of significance (Table 3).

**Table 3**

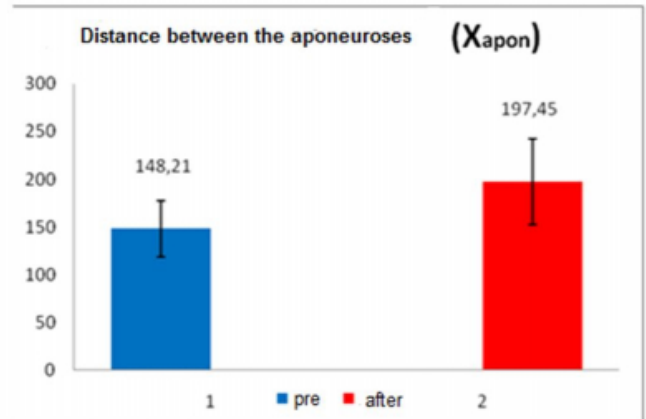
Mean and standard deviations at baseline and after the end of the project

	Baseline		Final	
	Mean	St. deviation	mean	St. deviation
$X_{apon}$	148,21	29,48	197,45	45,36
$L_{fiber}$	470,20	74,47	584,91	47,50
$\phi_{pterosi}$	19,70	3,48	22,91	3,00

After the end of the specific training programme, there was statistically significant difference concerning the distance between the aponeuroses ( $X_{apon}$ ) (Table 4) and the fascicle length ( $L_{fiber}$ ) (Table 5), with  $t(7) = -4,288, p = ,004$  and  $t(7) = -4,209, p = ,004$ , respectively.

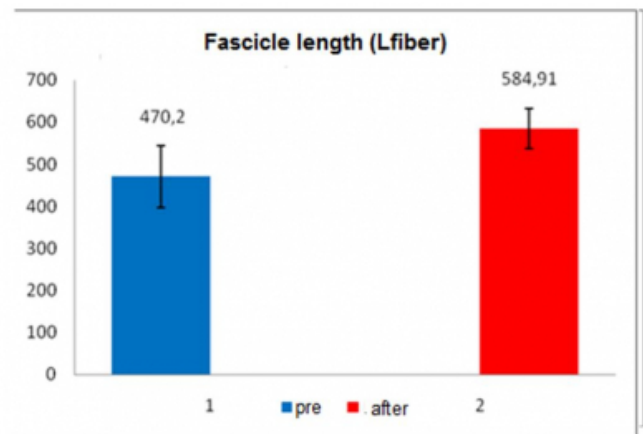
**Table 4**

Distance between the aponeuroses



**Table 5**

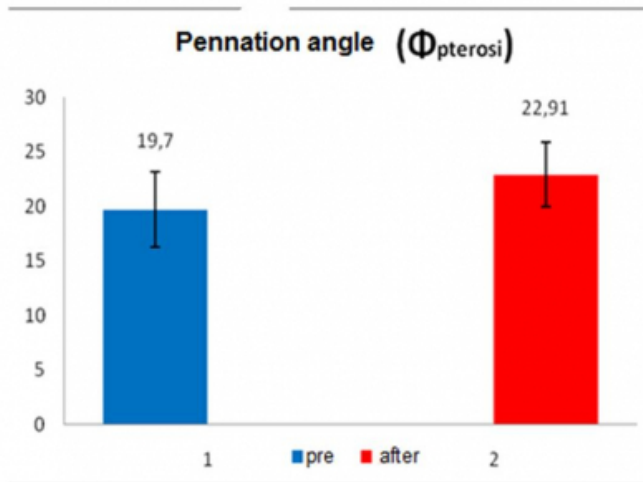
Fascicle length modification



Additionally, after the end of the training programme, the pennation angle ( $\phi_{pterosi}$ ) was increased at a statistically significant level,  $t(7) = -3,418, p = ,011$ , as it is shown on Table 6.

**Table 6**

Alteration of the pennation angle



## DISCUSSION

The purpose of this study was to investigate the effects of an isokinetic eccentric training programme, at high intensity, on the architectural structure (i.e. pennation angle, cross-sectional area and fascicle length) of the RF muscle of amateur soccer players. For the assessment, a multi-joint dynamometer was used as well as an ultrasound device.

In the present project, a novel eccentric training protocol was employed. The significance of this study lies, firstly, on the fact that it included a multi-joint isokinetic dynamometer. Secondly, there was real-time illustration of the participants' performance via a video projector. Finally, the Fecc-max was assessed at various time points during the 8-week period therefore, the resistance, expressed as percentages of the Fecc-max, could be frequently re-adjusted.

According to the results, the hypothesis tested in this study is verified. To elaborate, the eccentric training programme received by the experimental group had a statistically significant effect on the set variables; this is in line with other similar studies (Enoka, 1996; Higbie et al. 1996; Blazevich et al. 2007).

More specifically, the pennation angle was statistically significantly increased from 19.70° to 22.91°. This finding, according to the literature, is caused by training with resistance and, more specifically, by the subsequent muscle hypertrophy (Binzoni et al., 2001; Kawakami et al., 1993). Aagaard et al. 2001 found a difference of 7.9° in the pennation angle of the vastus lateralis, after a training programme with high loads. Furthermore, other similar

studies, also, found differences in the pennation angle (18° Fukunaga et al. 1997; 17.1° Narici et al. 1992; 11–23° Henriksson-Larsen et al. 1992).

The fascicle length of the muscle fibres ( $L_{fiber}$ ) was, also, statistically significantly increased from 470.20 to 584.21. This is, more likely, attributed to the external stimuli (i.e. training with resistance) (Abe et al., 2000).

The muscle fibres length and the pennation angle have a significant effect on the functionality of the muscle (e.g. maximum shortening velocity, maximum strain etc.) and the composition of the fibres (Sacks & Roy, 1982; Burkholder et al., 1994). The distribution of the muscle fibres and the cross-sectional area of a muscle are two of the most important biological parameters, which designate one's sport performance (Saltin and Golnick 1983).

In the present study, a statistically significant difference was found in terms of the distance between the aponeuroses of the RF. This finding could be attributed to the elongation of the muscle fibres in combination with the increased pennation angle.

## LIMITATIONS

There are also some limitations in this study. Firstly, the assessment regarding the modification of the architectural structure of the RF was conducted in rest. Secondly, the sample size was small and the participants were amateur soccer players and untrained individuals. These limitations could possibly impede the generalisation of the results.

## CONCLUSION

According to the aforementioned, the multi-joint isokinetic dynamometer is a tool that leads to the maximization the eccentric strength. Thus, it is a useful tool for improving the performance of athletes in general and more specifically, of soccer players.

In summary, the architectural structure of the extensor muscles of the knee is affected by an isokinetic eccentric training programme. Of course, the training programme is not the unique factor that plays an important role in the performance of a muscle. Other factors are the type of muscle fibre, the neuromuscular function and the training background of the athletes.

It is recommended that future studies investigate the effectiveness of an isokinetic eccentric training programme in professional soccer players. Additionally, forthcoming studies would examine the architectural structure, of each

knee extensor muscle individually, not only during the resting period but also during their contraction. The present study adds new information to the characteristics of the architectural structure of the RF of athletes and more specifically of amateur soccer players; it also indicates a training method that aims at improving the athletes' performance.

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