Revision article

What is the most effective protocol to induce fatigue in knee joint muscles? a systematic review

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Abstract

The aim of this study was to review the literature to see how the protocols are designed to induce knee joint muscles fatigue using an isokinetic dynamometer. Materials and Methods: This study consisted of a systematic review and the search for the theoretical composition was performed in the PubMed database using as descriptors the words muscle fatigue, knee, and isokinetic, and as filters the words Abstract available, Humans, Randomized Controlled Trial, and English language. It was not set limits for year of publications. Results: twenty nine studies were found, from which, seventeen were excluded due to exclusion criteria. Conclusion: It became evident in the present review that the greatest reduction in the peak torque occurs in protocols that use series of trials without determining the number of repetitions, requiring that the movement be executed until attaining exhaustion. However, if there is a need to determine a number of repetitions to decrease the the knee joint torque to the levels close to the one attained in the exhaustion protocol, the protocol that most reduced the knee joint flexor and extensor torque was the one that used five series of 30 repetitions with interval of one minute between series, independent of the angular speed and the type of contraction, concentric or excentric.

Keywords: knee flexion, knee extension and isokinetic dynamometer.

1 Introduction

Muscle fatigue (MF) takes place when a muscle group cannot maintain neither sustain the contraction levels for a certain period of time (ENOKA, 1992). This occurs when the musculature is raised to extreme effort levels, which may happen when practicing physical exercises, physical activity, daily life activities, sports or carrying out a laboring task.

Conditions that may lead to muscle fatigue, recovery methods and how to avoid muscle fatigue when practicing sports are subjects frequently addressed in the literature (GIOFTSIDOU, MALLIOU, PAFIS et al., 2006; KOUTEDAKIS and SHARP, 2004; MERCER, GLEESON and WREN, 2003). Understanding how these conditions arise and mainly how muscle fatigue takes place is highly important in practicing exercises, whereby they can be prescribed in a way to avoid muscle fatigue and, consequently, movement alterations owing to fatigue. Changes in amplitude, frequency, and intensity of movements provoked by muscle fatigue are potentially harmful to the musculoskeletal system and impair the performance and skills in the exercised task (DERAVE, OZDEMIR, HARRIS et al., 2007; RAASTAD, RISOY, BENESTAD et al., 2003). Aiming a better understanding of the phenomenon, experimental studies are performed. However, it is basically necessary the dominion of muscle fatigue induction techniques and corresponding protocols used for such purpose.

The different types of protocols presented in the literature consist on modulation of velocity and type of movement (CARREGALO, GENTIL, BROWN et al., 2011), the number of repetitions, series and interval between series of trials (ASTORINO, TERZI, ROBERSON et al., 2010; RAWSON, 2010) besides the characteristics of the populations, plus how to differentiate the protocol according to the volunteers gender (DIPLA, TSIRINI, ZAFERIDIS et al., 2009), level of physical activity (DERAVE, OZDEMIR, HARRIS et al., 2007; TIGGELEN, COOREVITS and WITVROUW, 2007; MOLINARI, KNAFLITZ, BONATO et al., 2006; GABRIEL, PROCTOR, ENGLE et al., 2002).

The most used instruments to allow application of protocols to induce muscle fatigue are connected with strength training that use the principle of weight lifting (RAASTAD, RISOY, BENESTAD et al., 2003), and cycle ergometer (KRAEMER, GARDINER, GORDON et al., 2001). However, the use of isokinetic dynamometer for muscle fatigue induction enables the control of angular velocity besides permitting that torque values, angular joint, muscular strength and coactivation between agonistic and antagonistic muscles be measured and monitored during all the procedure of muscle fatigue induction (ARROYO-MORALES, FERNANDEZ-LAO, ARIZA-GARCIA et al., 2011; CARREGALO, GENTIL, BROWN et al., 2011;

BLACKER, FALLOWFIELD, BILZON et al., 2010). Although the use of isokinetic dynamometer allows monitoring of important biomechanical parameters involved on muscle fatigue, there is no consensus in the scientific literature as to the protocol to be applied. The protocols of muscle fatigue induction vary basically according to the demanded angular velocity, number of series, number of repetitions by series, and interval between series. The values applied found in the literature vary respectively between 30 to 180°/sec, 1to 10 series, 5 to 40 repetitions, with intervals of 15 seconds to ten minutes. The fatigue monitoring occurs by comparing the performed torque before and after applying the muscle fatigue induction protocol. The literature presents values between 6% Carregalo, Gentil, Brown et al. (2011) and 50% Kellis (2003) of angular torque reduction.

The present study aims, based on literature review, 1) to display the different protocols that use an isokinetic dynamometer to induce muscle fatigue on knee extensors, and 2) to present the most efficient combination of isokinetic dynamometer parameters used to induce muscle fatigue on knee extensors.

2 Materials and Methods

The present study consists of a systematic review. The PubMed (www.pubmed.nl), Scielo, and Sports Discus database were used to conduct a literature search using the following keywords: muscle fatigue, knee and isokinetic. Twenty-nine articles were found that met these pre-requirements, however, seventeen were excluded, two for not having used theisokinetic equipment to induce muscle fatigue and fifteen for not presenting muscle fatigue indexes.

From the muscle fatigue induction protocols, gender, age, as well as number of series and trials, interval between series, angular velocity, and knee torque were analyzed.

3 Results

In Table 1, it is summarized the main findings (% of pre-fatigue knee torque) and the muscle fatigue experimental protocol applied.

4 Discussion

Muscle fatigue is defined as the inability of the muscle to sustain a target force level for a certain time (ENOKA, 1992). Taking into consideration the concept of muscle fatigue presented above, all the protocols displayed in Table 1 reached the objective of inducing fatigue, as maximum voluntary torque levels were decreased after applying the protocols.

In this review it is necessary to understand which muscle fatigue induction protocol is the most effective. As such, the significant discussion will have regard to the results obtained, considering the number of series,repetitions, angular velocity and time interval between sets.

In a study conducted by Carregalo, Gentil, Brown et al. (2011), adult males were submitted to three fatigue protocols. The first protocol applied consisted on inducing fatigue by means of three seriesof ten contractions (knee joint concentrically extensions, followed by concentrically flexions), with an interval of one minute between series. The second protocol consisted of an accomplishment of three series of ten maximum concentrically extensions, with interval of one minute between series, and thethird protocol demanded 20 alternated flexion and extension movements with the maximum concentrically action in the muscle.

All three protocols were achieved in the angular velocities of 60°/s and180°/s and in both there was fatigue induction. However, Astorino, Terzi, Roberson et al. (2010) did not observe influence in the angular velocities, but yesin the number of repetitions for larger reduction on the knee joint peak torque.

Astorino, Terzi, Roberson et al. (2010) submitted adult males to a knee joint extension protocol using the angular velocity of 180°/s, however, applying greater number of repetitions (40+40 = 80 repetitions), lower number of series (two series), and larger interval between series (three minutes). In Carregalo, Gentil, Brown et al. (2011) study it is evident that there was greater reduction of the peak torque in the tested angular velocity. However, Astorino, Terzi, Roberson et al. (2010) did not observe influence on angular velocities but yes in the number of repetitions for larger reduction on knee joint peak torque.

Rawson's study (2010), achieved with adult males, corroborates with the above mentioned assertion, emphasizing the increase of repetitions with the larger reduction on the peak torque, because in the study, 150 repetitions were performed (five series of 30 repetitions), considering the interval of one minute in the angular velocity of 180°/s. From this information, it is evident that the number of repetitions and the interval between series are key factors for the reduction in the peak torque. Besides adults, elderly people participated in the study and were submitted to the same protocol (RAWSON, 2010). In this group there was no reduction in peak torque as sharp as in the adult group. This finding can be partially explained by the sarcopenia that takes place in elderly people inducing muscle atrophy, besides the fact that the aging process causes slow metabolism, which makes muscles less prepared to the requirements of the contraction. It is also important to consider that glycogen is stored in a greater proportion in skeletal muscle. Elderly people have decreased glycogen supply and, conversely, there is increased fat stock which explains the non-reduction on torque peak during induction of muscle fatigue. Dipla, Tsirini, Zaferidis et al. (2009) employed a protocol to induce muscle fatigue in an angular velocity of 120°/s, with four sets of 18 repetitions of knee joint flexion-extension. The interval between series has not been informed. Based on the above cited studies, it can be concluded that with the same total number of repetitions in a given angular velocity,the smaller the number of sets, the greater impact in reducing peak torque.

According to Dipla, Tsirini, Zaferidis et al. (2009) adult women, compared with adult men, present lower peak torque reduction in both knee flexors and extensors. Possibly, this phenomenon is partially explained by male hormone influence (testosterone) in the cell composition. Testosterone increases the protein synthesis in the muscles allowing that men store more glycogen in the cells and, consequently, have more capacity to generate power while there is glycogen to be immediately used. During execution of intense and endurance exercises, glycogen is the first source of power to be metabolized, therefore, men tend to decrease more intensely the peak torque starting from

Table 1. Summary of scientific studies' main findings and the experimental protocol applied to induce fatigue on the knee muscles.

Author	Gender	Age (Years)	Joint velocity (°/s)	Numberof series	Numberoftrials	Joint Movement	Intervalbetween series (minutes)	% ofpre fatigue torque
Carregalo, Gentil, Brown et al. (2011)	Male	30±6.1	60	3	10/10 *	Flx/Ext	1	82.8
			60	3	10	Flex	1	89.9
			60	3	10	Ext/Flex	1	79.2
			180	3	10/10 **	Flx-Ext	1	90.3
			180	3	10	Flex	1	94.2
			180	3	10	Ext/Flex	1	86.7
Astorino, Terzi, Roberson et al. (2010)	Male	27±3.9	180	2	40	Ext	3	64.4
Rawson (2010)	Male	66±6	180	5	30	Ext	1	75
	Male	21±2	180	5	30	Ext	1	55
Dipla, Tsirini, Zaferidis et al. (2009)	Male	11±0.5	120	4	18	Flex		107
	Male	14±0.6	120	4	18	Flex		85
	Male	24±2.1	120	4	18	Flex		75
	Female	11±0.6	120	4	18	Flex		100
	Female	14±0.7	120	4	18	Flex		82
	Female	25±1.4	120	4	18	Flex		83
	Male	11±0.5	120	4	18	Ext		82
	Male	14±0.6	120	4	18	Ext		85
	Female	24±2.1	120	4	18	Ext		71
	Female	11±0.6	120	4	18	Ext		89
	Female	14±0.7	120	4	18	Ext		82
	Female	25±1.4	120	4	18	Ext		73
Theou, Gareth and Brown (2008)	Female	22±1.7		3	08	Flex	0.25	85
	Female	70±4.3		3	08	Flex	0.25	88
	Female	22±1.7		3	08	Ext	0.25	87
	Female	70±4.3		3	08	Ext	0.25	84
Tiggelen, Coorevits and Witvrouw (2008)	Males/ Female	23±3.4	120	1	150s	Ext	0.50	50
Derave, Ozdemir, Harris et al. (2007)	Male		180	5	30	Ext	1	75-86
Molinari, Knaflitz, Bonato et al. (2006)	Males/ Female	29±8	180	4	10	Ext (conc.)	10	72.9
			30	4	10	Flex (ecc.)	10	75.8
			60	4	15	Flex(conc.)	10	75
			60	4	15	Ext (ecc.)	10	76.7
Kellis (2003)	Males/ Female	14±0.5	60	1	34	Ext		50
Mercer, Gleeson and Wren (2003)	Male		60	1	5	Ext		77.7
	Female		60	1	5	Ext		77.7
Michaut, Pousson, Millet et al. (2003)	Female		60	10	10	Ext	1,30	90
Gabriel, Proctor, Engle et al. (2002)	Male	20 a 60		1	Exhaustion	Ext		50

Flex=Flexion Ext=Extension Conc=Concentric Exc=Eccentric M=Male F=Female. *twenty alternated concentric knee flexion/extension movements. **ten concentric knee extension movements followed by ten concentric knee flexion movements.

the moment glycogen is missing. Thus, it is justified the reason why men present more reductions in the peak torque compared with women.

In a study performed by Theou, Gareth and Brown (2008), muscle fatigue was induced through execution of three series of eight repetitions of isokinetic knee flexion and extension. In this study, the time interval between series was only 15 seconds, aiming to optimize the fatigue induction. However, if compared to Dipla, Tsirini, Zaferidis et al. (2009) study, the reduced interval between series seems less important in relation to the volume of exercises. The protocol applied by Dipla, Tsirini, Zaferidis et al. (2009), in which the interval between series was one minute and the volume of 72 repetitions (four series of 18 repetitions) showed to be more specific in reducing the peak torque.

The study presented by Tiggelen, Coorevits and Witvrouw (2007) considered one single group including male and female adults in the sample. In such study, the volunteers performed one series of knee extension movements for 150 seconds (with no time interval between trials), at the speed of 120°/s. The study does not present the specific results as obtained with males and females. However, the average result showed higher reduction of the peak torque in relation to the above mentioned studies. In this study, one series of 150 seconds was performed, allowing the volunteers to do as many trials as possible at a fixed speed. Thus, Tiggelen, Coorevits and Witvrouw (2007) increased exponentially the volume of the knee flexion and extension movement, which resulted in a reduction of 50% of the peak torque, corroborating with the previously cited authors who observed that the volume (number of repetitions) is more efficient in the reduction of thejoint torque.

Dealing with number of series, repetitions, angular velocity, and interval between series to reduce the knee joint peak torque, the protocols for athletes must be differentiate. In a study performed by Derave, Ozdemir, Harris et al. (2007), male athletes were induced to the same protocol proposed by Rawson (2010) and it was observed that athletes, probably due to fitness level, suffer low reductions in the peak of torque.

Similarly to the study carried out by Tiggelen, Coorevits and Witvrouw (2007) and Molinari, Knaflitz, Bonato et al. (2006) performed a study with a single group of males and females volunteers. The study attempted to use different angular velocities (30, 60, and 180°/s), with a volume of 40 repetitions (four series of ten repetitions) of the concentric action of the knee extension. Compared with studies already achieved and analyzed, pertinent to peak torque reduction, we can affirm that it is not the best protocol to be used for muscle fatigue induction, probably because fixing the number of repetitions does not allow some of the volunteers to reach the fatigued state.

Molinari, Knaflitz, Bonato et al. (2006) applied another protocol for the same group. The protocol consisted of four series of 15 repetitions, at the angular velocities of 30, 60 and 180°/s, totaling 60 repetitions, with interval of ten minutes between series, which consisted of concentric knee flexion and eccentric knee extension. The greatest reduction in the peak torque occurred at the highest speed, contradicting the findings of Carregalo, Gentil, Brown et al. (2011).

In a study proposed by Michaut, Pousson, Millet et al. (2003), adult females performed the largest number of series of all studies analyzed in the present review. The protocol was composed of ten series of ten knee extension movements at 60°/s, totaling a volume of 100 repetitions. There was an interval of 90 seconds between series.The peak torque reduction was minimal in relation with other studies. Even the protocol being applied at low speed, high volume, and reduced interval between series, the number of series and decrease in the number of repetitions did not make a good combination as the peak torque reduction was irrelevant.

Gabriel, Proctor, Engle et al. (2002) applied a protocol for male volunteers ranging in age from 20 to 60 years old. Angular speed was not presented, the number of series was restricted to only one, and the repetitions were performed until reaching exhaustion. The peak torque attained was the same found in the study of Tiggelen, Coorevits and Witvrouw (2008), being considered the greatest reduction found in all the studies analyzed in the present review, as both do not propose exact numbers of repetitions and recommended execution running to exhaustion.

5 Conclusion

It became evident in the present review that the greatest reduction in the peak torque occurs in protocols that use series of trials without determining the number of repetitions, requiring that the movement be executed until attaining exhaustion. However, if there is a need to determine a number of repetitions to decrease the knee joint torque to the levels close to the one attained in the exhaustion protocol, the protocol that most reduced the knee joint flexor and extensor torque was the one that used five series of 30 repetitions with interval of one minute between series, independent of the angular speed and the type of contraction, concentric or eccentric.

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