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Original Research

Estimation of Muscle Fiber Types Using Force-Time Curves During Submaximal Leg Press Task

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ABSTRACT

In the field of sports sciences and especially sports physiology, one of the most important and interesting topics is the estimation of the composition of the muscle fiber types, especially among the athletes, so the main approach of this research was to find out the relationship between the number of repetitions and the parameters obtained from the force-time curves in a sub-maximal repetitive task with the leg press machine until exhaustion to estimate the dominant type of muscle fibers. The research was a semi-experimental study. The statistical sample in this research was included 19 university students. The test process was carried out in two days for each subject with an interval of 48 hours to prevent muscle soreness. The first day included recording data related to anthropometry and the One Repetition Maximum Test (1RM) on leg press machine. The second day consisted of a repetitive exercise until 70% 1RM until exhaustion. Using the Visual FoxPro software, the raw force-time data was processed in the repetitive test and applied information was extracted. The Shapiro-Wilk test was used to determine the normality of the data distribution. Pearson's or Spearman's correlation test was used to check the relationship between the parameters with a significance level of $p<0.05$. There was a correlation between the number of repetitions and the sub area under the force-time curve in the first group (low repetitions) ($r=-0.828$, $p<0.001$), and in the third group (high number of repetitions) ($r=-0.636$, $p<0.001$). This research showed that there is an inverse relationship between the number of repetitions and the level of the force-time sub-curve in a submaximal task. The results of this study contribute to the development of a field test that can be used to predict muscle fiber composition, as well as to demonstrate the dynamic and physiological mechanism responsible for variability in the number of repetitions in a submaximal task.

Keywords: Slow-Twitch Muscle Fiber, Fast-Twitch Muscle Fiber, One Repetition Maximum (1RM), Leg-Press Machine

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INTRODUCTION

In the field of sports sciences and especially sports physiology, one of the most important and popular topics is the estimation of the composition of muscle fibers of a person, especially among the athletes [1]. The proportion of human skeletal muscles in type I fibers (slow-twitch fibers) and type II fibers (fast-twitch fibers) show a great variety in muscles [2]. Types of muscle fibers can be described using histochemical, biochemical, morphological, or physiological characteristics [3]. However, the classification of muscle fibers with different techniques is not always the same [3]. To understand muscle fiber classification techniques, a basic understanding of muscle structure and physiology is necessary. In humans, skeletal muscle fibers are characterized by the presence of myosin heavy chain (MHC) isoforms as type I, IIa and IIx. but there are also combined I/IIa, and IIa/IIx fibers [4]. Training load and repetitions are the most important aspects of a resistance training program [5]. Maximum one repetition (1RM) is one of the methods of estimating muscle fiber composition [6]. Each subject's 1RM is defined as the maximum weight that can be moved in the entire range of motion in only one repetition and is considered the gold standard for evaluating muscle strength in non-laboratory situations [2, 7]. On the other hand, the estimation of a maximum repetition is done in different percentages of the maximum weight lifted, and the number of repetitions in different percentages of 1RM depends to a large extent on the dominant type of muscle fibers involved in the movement [7]. Researchers have confirmed the variation of repetitions with different percentages of 1RM in trained and untrained individuals [5, 8]. The composition of muscle fiber type has been proposed as the physiological mechanism responsible for this variety of repetitions [5, 9-11]. As a result, researchers consider fiber type distribution to be an important factor in determining the level of performance in various physical activities [12, 13].

Researchers have well accepted that type II and type I fibers have different mechanical properties [2]. Type I or slow-twitch muscle fibers are characterized by slow contraction speed, low power output, high endurance, and high density of aerobic enzymes, and type II muscle fibers, or fast-twitch, with fast contraction speed, high power output, low endurance, and high concentration of anaerobic enzymes are defined [6]. Type II muscle fibers are superior at producing force but are inefficient at sustaining it for long periods [13-15]. This makes type II muscle fibers very susceptible to fatigue [5]. Assuming complete neural activation, the main determinant of maximal contraction force in human skeletal muscle is the physiological cross-sectional area of the muscle [16]. However, other parameters also appear to play an important role in the mechanical contraction properties of skeletal muscle, for example, a close relationship between myosin heavy chain (MHC) composition and maximal unloaded shortening velocity of isolated human muscle fibers [17-19]. The fiber composition of some skeletal muscles is effective for successful performance in sports competitions [12, 13], however, muscle fiber composition is not the only factor determining the superior performance of athletes [20]. There is good logical evidence to support the position that the fiber composition of a muscle is the result of a genetic endowment [20].

Athletes with a high percentage of type I fibers are more successful in long-term endurance events, while athletes with predominant type II fibers can be more successful in short-term high-intensity explosive activities [20, 21]. There are limited methods to determine an athlete's fiber type, which are either expensive and invasive, or indirect methods that provide only an approximate value of the fiber ratio [11]. Athletes who wish to know their exact fiber type ratio can undergo a muscle biopsy, in which a small piece of a person's muscle is removed for examination under a microscope [11]. In this method, the number of slow-twitch versus fast-twitch fibers can be seen and counted, which provides the possibility of measuring the approximate ratio for the sample muscle [11]. To measure this ratio in other muscles, multiple biopsy samples from each muscle group of interest are required [11]. On the other hand, there are also non-invasive methods that show a good estimate of muscle fiber ratio, for example, Mechanomyography [8, 22], Tensiomyography [23, 24], MRI [25] and other techniques, which are among the advantages of these methods. We can point out that these methods are non-invasive, unlike the biopsy method where the muscle is damaged, therefore, a non-invasive method to evaluate the composition of muscle fiber type can be an important diagnostic tool in athletes and non-athletes [26].

Previous research has aimed to help develop a non-invasive method to estimate muscle fiber composition. By reviewing previous research and using their results, we can see that in a sub-maximal method until exhaustion, the number of repetitions is related to the percentage of muscle fiber type [5, 7, 9, 10]. Also, using force-velocity curves [27-30] or power-velocity [26-28] relationships, it can be understood that there is a relationship between the percentage of muscle fiber type and the physiological structure of the fibers and their reaction to a stimulus (training load) it will be different. Among the non-invasive methods, the use of 1RM is an acceptable method for evaluating muscle composition, but in previous research, only the correlation between the number of repetitions or the time to perform the task with the number of muscle fibers counted through biopsy has been considered [5, 9, 10]. One of the things that previous researchers have neglected to investigate is movement dynamics during maximal or submaximal performance tests in the 1RM method. We know that different types of muscle fibers have different mechanical characteristics [2], so we can see variations in the number of repetitions and probably changes in the force-time curve recorded from sub-maximal tests until exhaustion in different people and quantify these values.

Based on the mentioned cases, the main approach of this research is to discover the relationship between the number of repetitions and the parameters obtained from the force-time curves in a sub-maximum repetitive task until exhaustion. We hypothesized that at a submaximal load (70% 1RM), we would observe interindividual variation in the number of repetitions, and a possible correlation between the number of repetitions, fiber type composition, and other parameters derived from force-time curves discovered.

METHODS

Subjects

The research was of an applied, semi-experimental method in a laboratory setting. The statistical sample of this research included 19 university students, which was determined using G*power software and based on the statistical method with a power of 0.9 and at the significance level of 0.05. The subjects were voluntarily participated in the research. The physiological and anthropometric characteristics of the subjects are listed in Table 1. All subjects signed informed consent to participate in this study after being informed about the purpose of the study as well as the possible benefits and risks associated with the experiments. The experimental protocol of this research was approved by the Ethics Committee in Biomedical Research at the University of Mohaghegh Ardabili (IR.UMA.REC.1400.071). The criteria for entering the study were no history of diseases such as cardio-respiratory, neuro-muscular problems, no history of injuries in knee and ankle joints, no professional training in any sport for at least two years. People who met the mentioned conditions were excluded from the study. Also, each person was left out if he did not want to continue cooperation in any stage of the research.

Table 1: Physiological and anthropometric characteristics of the subjects

Subjects (n=19)	**Mean**	**Standard deviation**
Age (year)	22.43	2.69
Height (cm)	175.6	6.8
Weight (kg)	80.2	14.93
Mid-thigh circumference (cm)	58.56	11.93
Thigh skinfold (mm)	23.11	10.36
Quadriceps cross sectional area (mm^2)	73.55	26.42

Protocol

The test process was carried out in two days with a 48-hour break for each subject. The first day included recording data related to anthropometry and maximal isometric tests. To measure the weight and height of the subjects, a combination device of SECA (Vogel & Halke) was used, this device shows a person's weight with an accuracy of 0.1 kg and a person's height with an accuracy of 1 cm. In this study, the Leg-press machine was chosen to perform the frequency test task, because the leg press machine is an isolated machine for the lower body muscles strength evaluation [31] and the 70% 1RM training load was also chosen because there is a variation in the number of repetitions in the 70% 1RM training load. [5, 9, 32]. To estimate the anatomical cross-sectional area of muscles (CSA), the circumference of the thigh was measured by a tape measure, and to determine the thickness of the skinfold in the thigh area, a skin fold Caliper (Pooya Caliper, Pooya Armaghan Company, Mashhad, Iran) was used with thickness measurement was up to 80 mm and the measurement accuracy was 0.5 mm. Equation 1, was used to calculate the cross-sectional area of effective muscles in leg press movement (quadriceps muscles) [33].

Equation 1: $Quadriceps\ CSA = (2.52 * MT) - (1.25 * SF) - 45.13$

In equation 1, MT is the circumference of the middle of the thigh and SF is the thickness of the skinfold in the middle and front of the thigh.

A four-channel computer dynamometer (manufactured by the corresponding author) was used to measure the maximum isometric force of the quadriceps muscle. To measure the leg-press forces, two load cells manufactured by Zemic Company in China, model H3, class C3, with a capacity of 500 kg were used. The sensors were installed between the moving plate of the leg press machine and the pedals for positioning the legs. Before performing the tests, the sensors were calibrated with a 10 kg weight. All the methods were done that after 10 minutes of warming up with stretching exercise, then familiarization exercises to the task, and warming up with light weights on the machine with few repetitions were performed.

The maximum voluntary contraction strength of the quadriceps muscle was measured in such a way that the subject was placed on the leg press machine while his legs were bent at the knee joint (90 degrees) and the thigh, while the leg press machine, with a fixator, moving part was fixed. By declaring the word "ready", the subject puts his feet on the pedals connected to the force sensors, and by declaring the word "start", each subject applies the maximum isometric force and after 5 seconds, the software ends with a beep sound after 5 seconds. Dynamometer software was displayed a real-time force-time curve on the Labtop monitor for values of the right and left leg forces, and at the same time, these results were saved in the laptop for each subject as a file in CSV format. Each subject made five attempts to record the maximum force with a break of 2-3 minutes. At the end, the best result for each individual was recorded as maximum isometric strength. To have the same way of rest, they were asked to sit on a chair during the rest period. Maximum force in each of the five attempts, was recorded as the person's 1RM. Two days after recording the data related to the first stage, the repetitive test until exhaustion was taken for each subject. This test was performed with weights equal to 70% of the person's best isometric effort, and the value of each weight was calculated according to equation 2 and installed on the leg press machine:

Equation 2: $W = m.g.sin45^{\circ}$

Then the calculated weights were installed and after 5 minutes of warm-up and preparation, the subject placed his feet on the pedals after hearing the word "Ready" and immediately after hearing the command "Go" was recorded. Force measurement tests were started in the laptop software and during the test, the subject was encouraged to do his maximum effort until exhaustion and inability to continue the work. At the end of the test, real-time forces measured by the software were recorded and stored in the laptop.

Data analysis

The raw data recorded by the dynamometer was computed by Visual Fox Pro version 6 software after being converted into a readable format by the software using software programming to evaluate different parameters such as maximum force, repetition frequency, slope of force-time curve changes, loading rate in each repetition, loading rate at 75% of the maximum force of each repetition, the area under the force-time curve, the area under the force-time curve 75% to the maximum. All data for each test transformed, computed and then statistically evaluated to obtain the slope of changes and regression of functional parameters during successive repetitions of a subject and finally exported in MS Excel Format. Then, to do more comparison, the results, were normalized on the cross-sectional area of the quadriceps muscles [16].

The area under the force-time curve was calculated by the trapezoid method:

$$(Force1 + Force2)/2 \times (Time(msec)/1000)$$

For the calculations of parameters in each forward push, only the push-up step data classified by the software were considered.

SPSS software version 22 was used in this research. The Shapiro-Wilk test was used to determine the normality of data distribution. Pearson's or Spearman's correlation test with a significance level of $p<0.05$ was used to check the relationship between the data and the parameters respectively for parameters and non-parametric variables.

RESULTS

In this research, all the subjects were non-athletes. Based on the literature review of the background of the research with the criterion of the number of correct repetitions, the people present in the research were divided into three groups, the highest number of repetitions which was 37 and the lowest was 7. The average number of repetitions in this study was 22.16 with a standard deviation of 7.01. By examining the distribution of the number of repetitions, it was found that more people are in the average range, and by calculating percentiles (Table 2) and using the normal distribution, the people of this study were placed in three groups for statistical analysis. Also, in the past research, there was a correlation between the number of repetitions and muscle fibers counted through biopsy, the results of which are listed in Table 3. Table 4 shows how to group people based on the number of repetitions. By calculating the ratio between the number of repetitions at 80% 1RM and 20 repetitions performed at 70% 1RM, it can be concluded that this value represents an equal proportion of fiber types, more than 20 repetitions performed means more than 50% Type I muscle fibers and less than 20 repetitions performed represent more than 50% of type II fibers for the quadriceps [5, 10]. In the research (Terzis et al., 2008) based on the average repetitions, the people in the research were divided into two groups, and the statistical analysis of the research was done in one and two groups.

Table 2: Percentage of the number of repetitions

Percentiles	5	10	25	50	75	90	95
Number of repetitions	7	15	17	22	27	34	-

Table 3: Research results related to the present study

Researcher Methods	Subject	Number of subjects	Mean	Standard deviation	Minimum repetition	Maximum repetition	Regression line formula
Douris	Non-athletic women	22	10.68	2.50	7	15	$y = -1.43x + 77.6$
Elliott	Active men	20	10.26	2.86	5	15	$y = -2.18x + 72.78$

Table 4: Classification of subjects into three groups based on percentage of repetitions

Number of repetitions of the first group (n=4)		**Number of repetitions of the second group (n=11)**		**Number of repetitions of the third group (n=4)**	
Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
7	16	17	27	28	37

According to the results obtained when the data analysis was examined in one group, no significant correlation was found between the number of repetitions and the parameters of the force-time curve and there was only a correlation between the number of repetitions and the area under curve (r=-0.148, p=0.002). However, when data were dividing into three groups based on the percentage of repetitions, a correlation was observed between the number of repetitions and the cross-sectional area of the quadriceps muscles in all three groups (Table 5).

The results of the present study showed that in the first group, there was a high correlation (r=-0.921, p<0.001) between the number of repetitions and the maximum isometric force (the results of the first day). In the first group, there was a negative correlation (r=-0.572, p<0.001) between the number of repetitions and isotonic force (second-day results). In the first group, there was a negative correlation (r=-0.457, p<0.001) between the number of repetitions and the slope of force changes in leg press frequency. On the other hand, in the first group, there was a positive correlation between the number of repetitions and the frequency (r=0.526, p<0.001). Also, in the third group, there was a negative correlation between the number of repetitions and the repetition frequency (r=-0.321, p<0.001). Examining the results, a high negative correlation was observed between the number of repetitions and the area under the curve in the first group (r=-0.828, p<0.001), and the second group, there was a positive correlation (r=0.353, p<0.001), but in the third group had a negative correlation (r=-0.636, p<0.001). There was a negative correlation between the number of repetitions and the level under the curve of 75% of the maximum in the first group (r=-0.684, p<0.001), and in the third group, there was almost the same negative correlation (r=-0.639, p<0.001).

Table 5: The results of the correlation test of the number of repetitions with parameters in three groups

Parameters	Group 1 (n=4)		Group 2 (n=11)		Group 3 (n=4)	
	Correlation (R)	Significance level (P)	Correlation (R)	Significance level (P)	Correlation (R)	Significance level (P)
Cross-sectional area of the quadriceps muscles	0.551	p<0.001*	-0.335	p<0.001*	0.319	p<0.001*
Maximum isometric force	-0.921	p<0.001*	0.144	0.032*	-0.287	0.001*
Isotonic force	-0.572	p<0.001*	0.455	p<0.001*	-0.535	p<0.001*
Loading rate	0.233	0.050	0.305	p<0.001*	-0.356	p<0.001*
Loading rate of 75% to the maximum	0.279	0.019*	0.303	p<0.001*	0.354	p<0.001*
The slope of force changes	0.457	p<0.001*	0.158	0.019*	0.169	0.056
Repetition frequency	0.526	p<0.001*	0.103	0.125	0.321-	p<0.001*
area under the curve	-0.828	p<0.001*	0.353	p<0.001*	-0.636	p<0.001*
The area under the curve is 75% to the maximum	-0.684	p<0.001*	0.163	*0.015	-0.639	p<0.001*

*Significance level p<0.05, correlation between the number of repetitions and the parameters derived from the force-time curve

DISCUSSION

The main purpose of this research is to discover the relationship between the number of repetitions and the parameters obtained from the force-time curve in a sub-maximal task up to exhaustion. We hypothesized that at a submaximal load (70% 1RM), inter-individual changes in the number of repetitions can be observed and a possible correlation between the number of repetitions, fiber type composition, and kinetic parameters derived from the force-time curve is discovered. For this purpose, goals were pursued in this research that were not examined or neglected in previous research.

The main finding of this research is the existence of a significant negative correlation between the number of repetitions and the level of the force-time sub-curve in the first group with low repetitions and the third group with high repetitions in a submaximal task. In other words, in the first group, despite the low number of repetitions, the area under the force-time curve is high, and in the third group, the area under the curve decreased with the increase in the number of repetitions. The normalized force level on the cross-sectional area of the effective muscle in the leg press is a better representative of the dynamic performance of the muscle fibers. Also, a relatively high correlation was found in the first group with the low number of repetitions and other parameters mentioned in (Table 5). This pattern is also confirmed by the value and intensity of the correlation between the number of repetitions and the maximum isometric force in the first group ($r=-0.921$, $p<0.001$). In addition to the mentioned correlation, the average isometric force in this group shows a higher value than the third group which had more repetitions. We can conclude that these people had more fast-twitch fibers in their quadriceps muscles.

Isotonic force in this research is the amount of force exerted by the person while pushing the weight upwards, which was recorded by the right & left leg dynamometer sensors, connected to the leg press machine. First, it was assumed that the amount of isotonic force recorded could be a good indicator for clarifying the mechanism of variability of repetitions and its relationship with the productive force of muscles, and as a result, estimating the dominant type of muscle fibers. Although a relatively good correlation value has also been found, it seems that the parameter of the level under the curve of isotonic force is a better indicator for evaluating the applied force in each push. Also, in all three groups, the value and intensity of the relationship between isotonic force and the number of repetitions is the same as the relationship between the number of repetitions and the sub-curve level, but this value is higher for the sub-curve level and the number of repetitions.

It was expected that the parameter of the slope of force changes during a sub-maximal action to the fatigue limit would show a decrease in each person, which is a sign of exhaustion and a decrease in force production in each push of the weight. This is relatively visible in the first group because there is a positive correlation between the number of repetitions and the slope of force changes, but the correlation value found in the second and third groups is very low (it was expected that this amount would become negative in the third group).

The field test proposed by Karp expresses the number of repetitions performed at 80% 1RM in such a way that the number of repetitions greater than 12 indicates a greater percentage of slow-twitch fibers and the number of repetitions 8-12 indicates an equal percentage of each Two types of fibers and the number of repetitions less than 8 indicates a higher percentage of fast-twitch fibers [7]. Also, Douris, using Karp's suggestion, deduced that 20 repetitions performed at 70% 1RM represents an equal proportion of fiber types, more than 20 repetitions mean more than 50% of slow-twitch muscle fibers and less than 20 repetitions represent more than 50% of fast-twitch fibers for quadriceps muscles [5]. In the current study, the average number of repetitions was 22.16, which confirms the findings of Douris's research and the field test proposed by Karp.

One of the limitations of this research is the lack of examination of two groups of sprinter/strength and endurance athletes. The impossibility of using biopsy to compare the parameters obtained from the force-time curve and the number of fibers counted through it was another limitation of this research. Another limitation of this research was the lack of kinematic data recording. Also, in this research, only male subjects were used and female subjects were not used and their differences were not compared with male subjects.

The main finding of this research is the inverse and significant relationship between the number of repetitions and the area under the curve (integral) of the force-time in a submaximal task in non-athlete people with dominant fast and slow twitch muscle fibers. Our results were in line with the findings of previous studies, in which people with the dominant type of fast-twitch muscle fibers perform fewer repetitions than people with the dominant type of slow-twitch muscle fibers. Although further studies in larger cohorts are needed to support our findings, the present study highlights the potential of this approach as an accessible and cost-effective alternative for estimating muscle fiber composition.

CONCLUSION

We concluded that the findings of the present study show the potential of developing a non-invasive and cost-effective method for estimating muscle fiber composition, which after further verification, can help design training programs to improve the strength or endurance capacity of effective skeletal muscles. The results of this study contribute to the development of a field test that can be used to predict muscle fiber composition, as well as to elucidate the dynamic and physiological mechanism responsible for variability in the number of repetitions in a submaximal task and provide original data and documented the number of repetitions performed in 70% 1RM.

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Authors' contributions

All authors contributed equally to the preparation of this article.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

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تخمین نوع غالب تارهای عضلات با استفاده از منحنی های نیرو-زمان در یک تکلیف زیر بیشینه تواتری با دستگاه پرس‌پا

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چکیده:

در حوزه علوم ورزشـی و مخصـوصـا فیزیولوژی ورزشی یکی از موضوعات مهم و مورد علاقه برآورد ترکیب تارهای عضلانی یک فرد بالاخص در بین جامعه ورزشـکار اسـت، بنابراین رویکرد اصـلی این پژوهش کشـف ارتباط بین تعداد تکرار و پارامترهای حاصـله از منحنی های نیرو-زمان در یک تکلیف زیر بیشـینه تواتری با دستگاه پرس پا تا مرز خستگی برای تخمین نوع غالب تارهای عضلانی بود. پژوهش از نوع کاربردی (نیمه تجربی) با نحوه اجرای آزمایشـگاهی بود. نمونه آماری این پژوهش شـامل ۱۹ نفر از دانشـجویان محقق اردبیلی بود. فرآیند آزمون در دو روز برای هر آزمودنی و با فاصـله ۴۸ ساعت برای جلوگیری از ایجاد کوفتگی عضلانی انجام شـد. روز اول شامل ثبت داده‌های آنتروپومتری و تست ایزومتریک بیشینه (1RM) بود. روز دوم شامل تست خستگی ۷۰٪ 1RM بود. با نرم‌افزار ویژوال فاکس‌پرو اطلاعات خام نیرو-زمان در آزمون تواتری پردازش و اطلاعات کاربردی استخراج گردید. برای تعیین طبیعی بودن توزیع داده‌ها از آزمون شـاپیروویلک اسـتفاده شـد. جهت بررسـی ارتباط بین پارامترهای موجود، آزمون همبسـتگی پیرسـون و اسـپیرمن با سـطح معنی‌داری p<۰/۰۵ استفاده شد. بین تعداد تکرار و سطح زیرمنحنی در گروه اول (تعداد تکرار کم) همبسـتگی (r=-۰/۸۲۸، p<۰/۰۰۱) و در گروه سـوم (تعداد تکرار بالا) همبسـتگی (r=-۰/۶۳۶، p<۰/۰۰۱) وجود داشـت. این پژوهش نشـان داد که رابطه معکوس بین تعداد تکرار و سطح زیرمنحنی نیرو-زمان در یک تکلیف زیر بیشینه وجود دارد. نتایج این مطالعه به ابداع یک تست میدانی کمک می‌کند که می‌تواند برای پیش‌بینی ترکیب فیبر عضلانی استفاده شود و همچنین مکانیسم دینامیکی و فیزیولوژیکی مسئول تغییرپذیری تعداد تکرار را در یک تکلیف زیر بیشینه نشان دهد.

واژگان کلیدی: فیبر عضلانی کند انقباض، فیبر عضلانی تند انقباض، یک تکرار بیشینه، دستگاه پرس پا