FIBER TYPE COMPOSITION AND CAPILLARY DENSITY IN RELATION TO SUBMAXIMAL NUMBER OF REPETITIONS IN RESISTANCE EXERCISE

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ABSTRACT
The purpose of this study was to investigate the relationship between skeletal muscle fiber type composition and the maximum number of repetitions performed during submaximal resistance exercise. Twelve young men performed a maximum repetitions test at 85% of 1 repetition maximum (1RM) in the leg press, which was repeated after 1 week. Seven days after the second 85% 1RM test, they performed a maximum repetitions test at 70% of 1RM in the leg press. This test, at 70% 1RM, was repeated 7 days later. One week before the initiation of the testing sessions, a biopsy sample was obtained from the vastus lateralis muscle and analyzed for fiber type distribution, fiber cross-sectional area, and capillary density (capillaries/mm²).

A low and nonsignificant relationship was found between the fiber type distribution or percent fiber type area and the number of repetitions performed at either 70% or 85% 1RM. Moreover, the number of repetitions performed at 70% or 85% of 1RM was not related significantly with 1RM strength. In contrast, the number of repetitions performed at 70% 1RM was significantly correlated with the number of capillaries per mm² of muscle cross-sectional area (r = 0.70; p = 0.01). These results suggest that fiber type composition is not the major biological variable regulating the number of repetitions performed in submaximal resistance exercise. Rather, it seems that submaximal strength performance depends on muscle capillary density, which is linked with the endurance capacity of the muscle tissue.

KEY WORDS skeletal muscle morphology, one repetition maximum, muscular endurance

INTRODUCTION
Muscular strength is an important biological variable both for athletic performance and for everyday activities. Resistance training is an effective way of increasing muscular strength. Various resistance training methods and techniques have been used to improve muscular strength in diverse populations (10). It is commonly accepted that after an initial period of resistance training (e.g., a few months), the training load should be set above a certain level (e.g., 75%) of 1 repetition maximum (1RM) in order to induce significant increases in muscular strength (10, 24). This suggests that the training load should be accurately determined so that the training stimulus is effective.

The accurate determination of training load requires the knowledge of the exact number of repetitions that can be performed at a certain percentage of 1RM. However, the number of repetitions that can be performed at a certain percentage of 1RM is not constant. It is influenced by a number of factors, such as the amount of muscle mass involved in a specific exercise (15) and the training level of the performer (19). For example, at 80% 1RM in the leg press, untrained men can perform 15 repetitions, while power lifters can perform 22 repetitions (19). Furthermore, in a certain group of subjects with more or less common training backgrounds, the number of repetitions that can be performed at 80% 1RM in the leg press can vary to a great extent (e.g., mean ± SD, 19 ± 9 (15)). With such a great variability, it is difficult to regulate the number of repetitions in order to meet the target percentage of 1RM in resistance training.

Human skeletal muscles contain 2 major groups of contracting cells: type I and type II muscle fibers. Type I fibers have mainly endurance characteristics, while type II muscle fibers have speed and power characteristics (25). Previous studies have suggested that the variability in the number of repetitions that can be performed at a certain percentage of 1RM is influenced by the fiber type composition of the protagonist muscles (6, 18). However, in these studies, fiber type composition was only indirectly...
Muscle Morphology and Performance in Resistance Exercise

estimated. Furthermore, it has been shown that endurance-trained athletes have greater capillary densities compared to untrained or strength-trained individuals (29). Moreover, strength training regimens emphasizing high number of sets and repetitions (e.g., bodybuilding training) result in greater capillary densities compared to strength training with a low number of sets and repetitions (28). This difference suggests that the submaximal performance in resistance exercise is linked to the muscular capillary density that is associated with local muscular endurance capacity.

The purpose of this study was to investigate the relationship between the fiber type composition and capillary density of the vastus lateralis muscle with the number of repetitions performed at a submaximal resistance load in the leg press exercise in young healthy individuals.

**METHODS**

**Experimental Approach to the Problem**

The leg press was chosen because the vastus lateralis is a protagonist muscle in this exercise (8) and there is a great variability regarding the number of repetitions that can be performed at a submaximal load in this exercise (15). The submaximal loads investigated were 70% and 85% 1RM. Both were selected because they represent a range of training intensities used by many athletes who aim for an increase in muscle strength, muscle hypertrophy, or muscular endurance. In addition, it was hypothesized that a submaximal load, such as 70% 1RM, would give a greater interindividual variability in the number of repetitions performed, which would uncover a possible correlation with fiber type composition and capillary density.

**Subjects**

Twelve male physical education students (22 ± 1 years) participated in the study after being thoroughly informed about the experimental procedures and the possible hazards of the biopsy procedure. Their physiological characteristics are presented in Table 1. All subjects had right-leg dominance and were well familiarized with the leg press machine through their previous participation in relevant research studies. Subjects participated in this study had diverse training backgrounds; 6 were physical education students with various levels of physical activity, and the remaining 6 were also physical education students who also participated in strength training, sailing, basketball, kayaking, rowing, or fencing. Subjects were instructed to refrain from any strenuous physical activity at least 72 hours before each strength testing session. Strength tests were performed during the morning hours, and the subjects were allowed to consume food and water ad libitum until 2 hours before the testing sessions. All procedures were approved by the local ethical committee.

**Procedures**

**One Repetition Maximum and Maximum Repetitions Testing.**

Subjects reported to the laboratory on the first day of the measurements to perform the 1RM strength test in the leg press. Briefly, after a 10-minute submaximal warm-up period on a static bicycle, subjects passively stretched the large leg muscle groups, 2 × 20 seconds for each muscle group. Subsequently, they performed incremental submaximal efforts until they were unable to lift a larger weight. During the initial lifts, the range of motion was determined so that knee angle varied between 180° and 90°. In all subsequent lifts, knee bending of more than 90° was not allowed by means of a metal lock, which did not allow further lowering of the weight rack of the leg press machine.

After a 10-minute rest, subjects performed a maximum repetitions test at 85% 1RM. The range of motion was the same as during the 1RM measurement. The duration of each repetition was 2 seconds (i.e., 1 second of lowering and 1 second of lifting). During all efforts, subjects were vocally encouraged by 2 experimenters. The same procedure (i.e., 1RM and maximum repetitions test at 85% 1RM) was performed 5 to 7 days later. The best of the 2 performances (i.e., number of repetitions at 85% 1RM) was used in further analysis. One week later, the subjects followed the same procedure for the determination of 1RM and the number of repetitions performed at 70% 1RM. Finally, 1 week later, this testing session was repeated (i.e., 1RM and maximum repetitions test at 70% 1RM). The best of the 2 performances at 70% 1RM was used in further analysis. None of the subjects complained of muscular discomfort during the measurements.

**Muscle Biopsies and Histochemistry.** Muscle samples (2) were obtained from the vastus lateralis of the right (dominant) leg.
20 cm from the patella. Two samples at opposite directions were obtained by using suction (9) from the same incision site (27). The biopsy samples weighed between 100 and 150 mg. Samples were quickly removed from the needle, aligned, placed in embedding compound, and immediately frozen in isopentane precooled to its freezing point. They were kept at −80°C until the day of analysis. Cryostat transverse sections 10 μm thick (12 μm for the capillary staining) were cut at −20°C and were stained for myofibrillar adenosine triphosphatase after preincubation at pH 4.3, 4.6, and 10.3 (3,4). A mean of 489 ± 32 muscle fibers were classified as type I, IIa, or IIx in each slice (26). Alpha-amylase periodic acid–Schiff staining was used for capillary density measurement. The cross-sectional area of all the classified fibers (21) was measured in each of the samples with an image analysis system (ImagePro; Media Cybernetics, Inc., Bethesda, Md.) at a known and calibrated magnification. Measurement of the capillary density (capillaries·mm⁻²) was performed with the same image analysis system.

Statistical Analyses
Mean and SEM were used to describe each variable. The Pearson product moment correlation coefficient (r) was used to explore the relationship between different variables. Differences in capillary density and performance between the 2 subgroups of subjects were analyzed with a t-test. Differences in 1RM and the number of repetitions performed at different testing sessions were analyzed with a repeated-measures analysis of variance. A 2-tailed level of significance was set at p ≤ 0.05.

RESULTS
The physiological and performance characteristics of the subjects are presented in Table 1. There was no significant difference in 1RM among the 4 testing sessions. The mean number of repetitions performed at 85% 1RM was 9 ± 1, and there was no difference between the 2 different testing sessions. The mean number of repetitions performed at 70% 1RM was 17 ± 1. Again, no difference was found between the 2 different testing sessions.

The correlation coefficient between the percentage of type I fibers and the number of repetitions performed at either 70% or 85% of 1RM leg press was low and nonsignificant (Figure 1). When subjects were divided into 2 equal groups regarding their muscle fiber type composition (i.e., type I fibers greater than or less than 50%), there was no significant difference between the groups in the number of repetitions performed at either 75% or 80% of 1RM (Figure 2). In contrast, a significant relationship was found between the number of capillaries per mm² of muscle cross-sectional area and the number of repetitions performed at 70% of 1RM (r = 0.70; p = 0.01) (Figure 3). The subgroup of subjects who participated in systematic athletic training (n = 6) performed...
more repetitions at 70% 1RM (19.7 ± 1 vs. 13.7 ± 1; \( p = 0.003 \)) and had a higher capillary density (363 ± 13 capillaries-mm\(^{-2}\) vs. 327 ± 10 capillaries-mm\(^{-2}\); \( p < 0.05 \)).

**DISCUSSION**

The main finding of this study was that the maximum number of repetitions that can be performed during the leg press at 70% 1RM is significantly correlated with vastus lateralis capillary density. Capillary density is closely associated with the oxygen and metabolic demand of skeletal muscles (14,20). Participation in sport activities that require increased oxygen and nutrient delivery to the muscles, such as endurance running, induces an increase in muscle capillary density (16). In contrast, training for maximum strength induces a decrease in muscle capillary density because of parallel increases in muscle fiber cross-sectional area (29). However, resistance training with high volume, moderate intensity, and limited rest between sets leads to a greater capillary density compared to resistance training aiming for maximum strength (28). In the current study, 6 of the subjects were involved in sport activities with increased local muscular endurance demands. These subjects had a higher capillary density and performed better at 70% 1RM. Thus, it seems that muscular endurance capacity (i.e., the number of repetitions performed at 70% 1RM) was enhanced in these subjects. Unfortunately, it was not possible to analyze other biological parameters of the muscle tissue besides capillarity, such as energy-related enzymes, which might have provided a further insight into the explanation of such human performance.

The main research hypothesis of the current study was that there would be a close coupling between the fiber type composition and the maximum number of repetitions performed at a submaximal load in resistance exercise. However, it was found that the correlation coefficient between the number of repetitions performed at either 85% or 70% 1RM in the leg press and fiber type composition of the vastus lateralis was low and nonsignificant. This finding is in accordance with the results of a previous study that revealed that in a small group of people, the fatigue index after 2 minutes of intermittent electrical stimulation was not related to the vastus lateralis myosin heavy chain composition (11). The current results are also in agreement with data from Patton et al. (23), who revealed that endurance time during isokinetic cycling at 36%, 55%, and 73% of maximum power was not related with fiber type composition of the vastus lateralis. Type I muscle fibers are known to be more resistant to continuous fatigue contractions than type II fibers (5). However, this difference is linked to the higher concentration of mitochondria, aerobic enzyme activities, and capillary density of type I fibers. These biological parameters can readily change in response to activity alterations (25). For example, the activity of cytochrome oxidase can almost double in response to aerobic training in just a few weeks of aerobic training (13). Muscle capillaries can rapidly grow between muscle fibers in response to increased aerobic activity (1). In support of this notion, the percentage of type I muscle fibers of the subjects who participated in the study was not correlated significantly with the capillary density (data not shown). This is in agreement with previous reports that revealed that it is the oxygen demand and not the fiber type composition that mainly determines the capillary density in skeletal muscles (20,31). Thus, it seems that the critical biological parameter in submaximal resistance exercise performance (e.g., 70% 1RM) is the metabolic capacity of the muscles and not the fiber type composition per se. However, it should be emphasized that a correlation between 2 parameters does not imply a cause-and-effect relationship.

Alternatively, the recruitment pattern of different muscle fibers could have influenced the results of the current study. The size principle for the recruitment of muscle fibers indicates that at a submaximal level of force production (e.g., 70% 1RM), lower threshold motor units (i.e., usually type I muscle fibers) are recruited (12). Thus, a close correlation should be revealed between the percentage of type I area and the number of repetitions performed at 70% 1RM. However, this relationship was low and nonsignificant. Muscle fiber type recruitment during resistance exercise seems to be complicated. Tesch et al. (30) showed that at 60% of 1RM in leg extension, glycogen is reduced from all types of muscle fibers (i.e., type I, IIA, and IIB). This suggests that in the current study all types of muscle fibers were activated to some extent at 85% and 70%. Moreover, Nardone et al. (22) revealed that during slow eccentric contractions, a large fraction of fast-twitch motor units are selectively active. This suggests that during lowering of the weight in the leg press, type II muscle fibers may be selectively recruited. Such a phenomenon would have an impact on the relationship between the number of repetitions performed at 70% 1RM and the fiber type composition in the respective muscles. Furthermore, it is worth noting that an alternative...
recruitment of muscle fibers during resistance exercise has been proposed previously (14). In contrast, the number of capillaries per muscle area seems to be a more independent factor during the performance of a resistance training set at 70% 1RM, since capillaries supply all types of muscle fibers. However, because of the strong association between the neural and muscular function, the current results suggest only a minor role of fiber type composition in submaximal resistance training performance.

The correlation coefficient between the performance at 85% 1RM and both the fiber type composition and muscle capillary supply was low and nonsignificant. At this high intensity, all types of muscles fibers may be activated, at some point, during the performance of the set of repetitions. This may confuse the relationship between the fiber type composition and the number of repetitions performed. Moreover, the number of repetitions performed at 85% 1RM is relatively low. This suggests that biological parameters other than the capillary supply (e.g., local muscular endurance) are probably more important (e.g., energy status of the cells, [H+]') during such performance.

To the authors’ knowledge, this is the first study that determined the relationship between the number of repetitions performed during resistance exercise with submaximal load and the fiber type composition of a protagonist muscle. It was recently reported that type I muscle fiber percentage, as estimated by an indirect method, is moderately (r = 0.48) related to the number of repetitions performed at 70% 1RM (6), which is in contrast to the results of the current study. It should be noted that in this previous study, the subjects were women and the performance was determined on a leg extension machine. The difference in these variables might have influenced the discrepancy of the results between the 2 studies. Another factor that might have influenced the current results is the methodological error inherent in the muscle biopsy technique. It has been suggested that at least 2 muscular sites should be sampled in order to gain a reliable estimation of the fiber type composition of the vastus lateralis (7). In the current study, 2 muscle samples were obtained in opposite directions from the same incision point in order to increase the accuracy of the fiber type composition determination. An additional factor that might have influenced the current results is the recruitment of other muscles during the leg press exercise. Indeed, a number of other muscles with different fiber type composition (17) are also involved in this exercise, such as the gluteus and rectus femoris. However, biopsy sampling from all of these muscles was not feasible.

In a pilot study, it was found that 1RM leg press varied by only 1% to 3% in consecutive measurements separated by 1 week in subjects with the same training history, such as the subjects who participated in the current study. However, it was also found that subjects were unable to perform their best when the maximum number of repetitions was tested for 2 submaximal loads (i.e., 85% and 70% 1RM) in the same session. For this reason, the maximum number of repetitions of each submaximal load was measured in different sessions separated by 5 to 7 days. Moreover, each submaximal performance was measured in 2 different sessions again separated by 5 to 7 days in order to ensure the reliability of the measurement. In addition, all the subjects were familiar with the measurement device, and they had used the same leg press machine for strength training previously.

In conclusion, the current results suggest that the number of repetitions performed at 70% 1RM in leg press is moderately influenced by the fiber type composition of the vastus lateralis. A significant relationship found between this submaximal performance and the capillary density of the vastus lateralis may reflect an association with local muscle endurance capacity.

**PRACTICAL APPLICATIONS**

The results of the current study suggest that the interindividual variability in the number of repetitions performed at 70% 1RM in the leg press is influenced by the local muscular endurance, which is expressed herein as the capillary density of the muscle and is a trainable parameter. This provides the coach with basic knowledge of the physiological function of the neuromuscular unit during resistance training with submaximal loads. In practice, the current results may suggest that the estimation of 1RM from submaximal training loads should be done carefully, and for this purpose, the training loads that should be used are certainly higher than 70% 1RM. Furthermore, in sport events that require elevated local muscular endurance (e.g., rowing), the number of repetitions performed at 70% 1RM can be readily altered in the course of the training. This suggests that this type of performance should be evaluated frequently during the training season in order to adjust the training parameters (e.g., interval between sets) and enhance the effectiveness of the training program.

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Muscle Morphology and Performance in Resistance Exercise


