STRENGTH AND POWER OF KNEE EXTENSOR MUSCLES

Abstract
In the studies of human neuromuscular function, the function of leg muscles has been most often measured, particularly the function of the knee extensors. Therefore, this review will be focused on knee extensors, methods for assessment of its function, the interdependence of strength and power, relations that describe these two abilities and the influence of various factors on their production (resistance training, stretching, movement tasks, age, etc.). Given that it consists of four separate muscles, the variability of their anatomical characteristics affects their participation in strength and power production, depending on the type of movement and motion that is performed. Since KE is active in a variety of activities it must be able to generate great strength in a large and diverse range of muscle lengths and high shortening velocities, in respect to different patterns of strength production, and thus different generation capacities within the muscle (Blazevich et al., 2006). It has been speculated that KE exerts its $P_{\text{max}}$ at workloads close to subject’s own body weight or lower (Rahmani et al., 2001), which is very close to the maximum dynamic output hypothesis (MDI) of Jaric and Markovic (2009). Changes under the influence of resistance training or biological age are variously manifested in muscle’s morphological, physiological and neural characteristics, and thus in strength and power. Understanding the issues related to strength and power as abilities of great importance for daily activities, is also important for sports and rehabilitation. Performances improvement in sports in which leg muscles strength and power are crucial, as well as recovery after the injuries, are largely dependent on the research results regarding KE function. Also, the appropriate strength balance between knee flexors and extensors is important for the knee joint stability, so that the presence of imbalance between these two muscle groups might be a risk factor for the occurrence of injuries.

Key words: MUSCLE STRUCTURE / MUSCLE ARCHITECTURE / NEUROMUSCULAR FUNCTION ASSESSMENT / STRENGTH TRAINING

INTRODUCTION
The motor abilities such as strength, power and their manifestations through functional tasks have an important role in daily activities, sports and related areas - sports medicine, physical education, physical therapy, rehabilitation, ergonomics (Wilson, 1996; Kadija, Knezevic, Milovanovic, Bumbasirevic, & Mirkov, 2010; Knezevic, & Mirkov, 2010). The research of neuromuscular function based on evaluation of force (strength) and power parameters has been the subject of numerous research studies. Nevertheless, there are a number of terminological problems related to the precise definition of certain terms used in this area. Therefore, basic terms used in this paper should be defined firstly.

The expression of muscular strength is a fundamental property of human performance. It could be defined as maximal force ($F_{\text{max}}$) exerted during the maximal voluntary contraction (MVC) under given conditions (Abernethy, Wilson, & Logan, 1995). Describing the same property, Jaric and Kukolj (1996) have used the term strength, defining it as a muscle’s ability to generate maximal force under isometric
conditions, or against large external loads at low shortening velocities. As this term has been widely accepted in the professional community, it will be used in the following text. Contrary, term force will be used to quantify the consequence of exerted muscular activity.

In some sports the speed at which force is developed (e.g. explosive strength) is of importance and it should be considered as an important functional property of the muscles (Mirkov, 2003; Andersen, et al., 2005; Knezevic, & Mirkov, 2010). Various terms are used to describe this ability, but for the purposes of this paper, Explosive Force Production (EFP) will be used.

In contrast to strength and EFP, power is a muscle’s ability to generate relatively large forces against small external loads at high shortening velocities (Jaric, & Kukolj, 1996). Power (P) is defined as amount of work (A) performed during a period of time (t), \( A = F/t \), or as the product of force (F) and velocity (V), \( P = F \times v \).

In the studies of human neuromuscular function, the function of leg muscles has been most often measured, particularly the function of the knee extensors. The vital role that knee extensors (KE) have in motion and their pronounced anti-gravity effect are some of the reasons why its function is the subject of research in sport and many other sciences.

Therefore, the topic of this paper will not be the muscle strength and power in general, but it will be more focused on knee extensors, methods for assessment of its function, the interdependence of strength and power, relations that describe these two skills and the influence of various factors on their production (resistance training, stretching, movement tasks, age, etc.).

### INFLUENCE OF ANATOMICAL FACTORS ON KNEE EXTENSORS STRENGTH AND POWER

The muscle strength depends on a variety of factors: biochemical, histological, biological, anatomical kinematics, etc. (Jaric, & Kukolj, 1996; Pincivero, Campy, & Karunakara., 2004). Anatomical factors relate to the structure, cross-sectional area and muscle architecture.

Given that knee extensor consists of four relatively distinct muscles (\( m.\text{rectus femoris RF, m.vastus lateralis VL, m.vastus medialis VM, m.vastus intermedius VI} \)) it is expected their structure to be different, but even the structure of the same muscles in different individuals is variable. The average structure of RF consists of approximately 45% of slow twitch fibers (ST) and 55% of fast twitch fibers (FT), while the proportion of FT fibers in the VL ranges from 35 to 60% (Jaric, & Kukolj, 1996; Blazevich, Gill, & Zhou, 2006; Blazevich, Cannavan, Coleman, & Horne, 2007).

The cross-sectional area (CSA) has a significant influence on muscle’s function, particularly on maximal isometric strength production. Knee extensors cross-sectional area differs between athletes trained in strength and untrained individuals, or those who are trained in endurance (Paasuke, Erelne, & Gapeyeva, 2001). However, even though there is no difference in relative strength of this muscle (expressed per unit of CSA) between athletes trained in strength and athletes trained in endurance, the former ones can generate greater strength at higher shortening velocities. Because of this difference between these two categories of athletes gets larger in the favour of the first group, and directly follows that they can also generate greater power (Jaric, & Kukolj, 1996; Paasuke et al., 2001). This stands for athletes, however, in several studies significant differences in relative strength were obtained between genders and between individuals of different age (Jaric, & Kukolj, 1996, Petrella, Kim, Tuggle, Hall, & Bamman, 2005). Izquierdo et al. (1999) found that muscle’s CSA significantly correlates with maximal isometric force (\( F_{\text{max}} \)), 1 repetition maximum (1RM) in squat and 1RM of leg extension in people at the age of 65, but not in those who were 40 years old. However, the interpretation and comparison of the results of different studies is difficult to a certain extent because of different methodologies applied. This, in addition to the applied tests, also refers to the methods used to normalize results of strength tests. Normalization of KE’s strength relative to the thigh lean body mass reduces the difference between younger and older subjects in the leg press and squat, but not in leg extension (Petrella et al., 2005).

The strength and power, as noted earlier, can be significantly affected by muscle’s architecture (Zhang, Wang, Nuber, Press, & Koh., 2003; Blazevich et al., 2006, Blazevich et al., 2007), i.e. relationship between muscle fiber length and CSA. Fiber
length has a significant impact on the range of motion that muscles can perform, on maximal shortening velocity and on the force-length relation.

Since KE is active in a variety of activities (walking, running, jumping, lifting, etc.) it must be able to generate great strength in a large and diverse range of muscle lengths, but also at high shortening velocities. In addition to this, the large variability of physical activity may require different patterns of strength production, and thus different generation capacities within the muscle (Blazevich et al., 2006). Muscle fibers length, muscle fiber pennation angles and muscle density can be directly estimated from the image using 2D and 3D ultrasound. (Izquierdo et al., 1999).

According to Blazevich et al. (2007) density of RF and VL reduces and density of VM increases in the proximal-distal direction, while the VI’s density is variable. The same pattern within these muscles is present when it comes to fiber pennation angles (Izquierdo et al., 1999; Blazevich et al., 2006). Based on previous, we could assume that the VM, VL and RF are similar to each other, while VI is structurally different with different potentials for strength production, and therefore probably has a different role in movement pattern. It is believed that muscle density and fiber pennation angles in VM best correlate with the architecture of whole knee extensor muscle (Blazevich et al., 2006), although this should not be generalized because the obtained results may depend on location where the sample was taken and on the methods used to assess muscle’s anatomical characteristics. Based on published data, it is expected men, compared to women, to have a higher KE density, the correlation between muscle density and fiber pennation angle to be positive and the pennation angle and fiber length to have weaker negative correlation (Narici, Roi, Landoni, Minetti, & Cerrettelli, 1989; Häkkinen et al., 1998, Blazevich et al., 2006; Blazevich et al., 2007).

The research on the influence of knee extensor’s muscle parts architecture on strength and power production indicates that individual contribution of each of its parts to the maximal isometric torque changes with the increase in contraction strength, so that the overall proportion of VI reduces, while of VL, VM and RF increases (Zhang et al., 2003). Similarly, studies involving EMG analysis showed a specific change in the activation level of each muscle part with the change in strength intensity level, joint angle (total muscle length), shortening velocity or contraction type (Naricci et al., 1996; Häkkinen et al., 2001, Pincivero et al., 2004). Such findings could possibly be explained through presence of variability in architecture of individual KE’s muscle parts.

**ASSESSMENT OF STRENGTH, POWER AND EXPLOSIVE FORCE PRODUCTION**

Different types of tests (performed in standardized conditions) are used for strength, power and EPF assessment. These tests are used to evaluate different functional properties of muscle, to obtain normative values for different groups of subjects, for selection in sports, evaluation of training or rehabilitation procedures, injury prevention, and evaluation of success capacities in sport or at workplace (Willson, 1996; Mirkov, 2003; Knezevic, & Mirkov, 2010).

**Methods for Knee Extensor’s Strength Evaluation**

Two different methods are used for strength assessment: direct and indirect, with direct methods based on use of different types of dynamometry where in the certain contraction mode (isometric, isoinertial or isokinetic) appropriate force is exerted against maximal loads (Abernethy et al., 1995).

The isometric strength assessment is based on a measurement of maximal force ($F_{max}$) exerted during maximal voluntary contraction (MVC) (against external load), in a specific knee (or other) joint angle. Selection of joint angle is very important because it can largely influence external validity of isometric strength tests (Markora, & Miller, 2000; Knežević, Pažin, Kadija, Milovanović, & Mirkov, 2010). You can read more about the influence of knee joint angle to strength production in the chapter which deals with knee extensor’s force-length relation.

The isokinetic strength assessment is based on a measurement of maximal force ($F_{max}$) exerted during maximal voluntary contraction (MVC) (against external load), in a specific range of motion with constant angular velocity, whereby it is possible to monitor various relations: angular velocity-joint angle; power-angular velocity and torque-joint angle (Kadija et al., 2010; Knežević, Pažin, Planić, & Mirkov, 2010). Depending on the...
selected testing protocol and by the selection of contraction combinations it is possible to estimate muscle strength and power in concentric-eccentric or eccentric-concentric mode, within various ranges of motion and angular velocities (from 15-300°/s).

The isoinertial strength assessment involves exertion of concentric, eccentric or concentric/eccentric contractions against constant external load. Unlike isometric strength tests, this type of strength assessment enables activation of stretch shortening cycle SSC (due to the presence of eccentric and concentric contractions), which is integral part of most athletic activities such as sprinting, jumping, hopping etc. (Abernethy et al., 1995; Wilson, 1996).

The muscle strength can also be indirectly estimated. Various equations, based on number of repetitions made against lighter external loads, are used to predict 1RM (Mirkov, 2003; Baechle, 2007). These formulas are based on the assumption that number of repetitions against loads lighter than a maximal (some % of 1RM) does not change under training. Squat and leg press are tests which are most commonly used to assess knee extensors 1RM.

Assessment of Explosive Force Production of Knee Extensors Muscles

The reason for evaluation of explosive force production comes from the fact that time to generate a certain level of force is limited in many sports. (Knežević, & Mirkov, 2010; Knežević et al., 2010). This implies to leg muscles’ ability to produce strength as fast as possible. Such a demand is very important in sprinting and jumping, ski jumps, weight lifting etc. In artistic gymnastics, during movements and positions, it takes 245ms for leg muscles to generate strength. In sprinting, ground contact lasts less than 100ms, while in various activities that include jumping it takes them about 300ms to produce strength (Abernethy et al., 1995).

Just like strength, EFP can be also estimated under different conditions: isometric, isoinertial and isokinetic. The most often used EFP test is called Rate of Force Development (RFD). Rate of Force Development represents a maximum slope of the force-time curve (Wilson, 1996; Passuke et al., 2001; Mirkov, 2003), but sometimes also the slope after a fixed time following the initiation of contraction (Mirkov, 2003 according to Aagaard et al, 2002).

Power assessment

The muscle power is very important physical ability, particularly responsible for the successful performance of rapid movements (jumping, running, accelerations, direction change, throwing, kicking, etc.) Two general approaches are used for the muscle power assessment. In the first approach, KE’s muscle power is directly estimated by measurement of Work (A) performed during the execution of certain movement, such as cycling (Wingate test), staircase running (Margaria test) or leg extensions on isokinetic dynamometer. Also, force plates are often used for time recordings of dependence of ground reaction force during vertical jumps with variable loads (Rahmani, Viale, Dalleau, & Lacour, 2001; Sleivert, & Taingahue, 2004). In another approach, power is estimated indirectly, with physical ability tests which include execution of rapid movements such as jumping (standing broad jump, triple jump, squat, series of continuous jumps, countermovement jump etc.), sprinting, or movements of extremities during throwing, kicking or hitting).

The external load and movement velocity need to be adjusted in order to enable leg muscles to produce maximal power in selected joint position. It is considered that maximal power is a product of optimal strength and optimal shortening velocity. For isoinertial power assessment, general recommendation is that optimal load should be 30% of maximal isometric strength and velocity 30%V_{max} (Mirkov, 2003 according to Hill, 1938 and Josephson, 1993). Other researchers quote that load should be 30-50% from maximal isoinertial strength (1R_{M}) (Pincivero et al., 2004; Sleivert, & Taingahue, 2004; Seynnes, de Boer, & Narici,, 2007). Comparing younger and older subjects of both genders, Petrella et al. (2005) found that KE of younger males generate maximal power at loads of 60%MVC, in younger females at 50% MVC, in older males at 40%MVC and in older females at 60%MVC. Other findings, on the other hand, showed that P_{max} could be produced under loads that ranges from 15 to 50% of maximal isometric strength (Stone, O’Bryant, McCoy, Coglianese, Lehmkuhl, & Schilling, 2003), and that KE generates it against loads of 45%F_{max} (Seynness et al., 2007). Re-
cent research of Stone et al. (2003) has shown that KE of trained athletes generate $P_{\text{max}}$ at loads of 40%1RM while in the beginners it is at 10%1RM. These differences could be attributed to different muscle lengths, which make maximal power assessment difficult, because it is dependent on shortening velocity that is associated with fiber length.

**FACTORS AFFECTING KNEE EXTENSOR’S STRENGTH, EPF AND POWER**

The motor ability test results may be affected by numerous factors (Cabri, 1999; Jaric, & Kukolj, 1996; Wilson, 1996). Strength production depends on number and size of activated motor units, motor neuron discharge rate, CSA, muscle length, muscle moment arm, external load, shortening velocity, antagonistic muscle groups etc. (Jaric, & Kukolj, 1996; Pincivero et al., 2004).

Of all the factors listed as important, it is strength’s dependency on shortening velocity (e.g. force-velocity relation $F-V$) that is of particular importance for this paper. This relation is represented by Hill’s equation according to which if muscle shortens faster, than the strength it generates will be lower than its isometric strength. As Jaric and Kukolj state (by Taylor et al. 1996) increase in shortening velocity results in reduction of KE’s strength, while power (by Taylor et al. 1996) increase in shortening velocity, than its isometric strength. As Jaric and Kukolj state faster, than the strength it generates will be lower than its isometric strength (by Taylor et al. 1996) increase in shortening velocity results in reduction of KE’s strength, while power (by Taylor et al. 1996) increase in shortening velocity results in reduction of KE’s strength, while power (by Taylor et al. 1996) increase in shortening velocity results in reduction of KE’s strength, while power (by Taylor et al. 1996) increase in shortening velocity results in reduction of KE’s strength, while power (by Taylor et al. 1996) increase in shortening velocity results in reduction of KE’s strength, while power (by Taylor et al. 1996) increase in shortening velocity results in reduction of KE’s strength, while power.

$P_{\text{max}}$ and $v_{\text{max}}$ were not reached. These results confirm that increase in workload leads to decline in muscle power and optimal interaction between shortening velocity and workload is necessary in order to generate $P_{\text{max}}$. Obviously, the effect of resistance training on the shape of the $F-V$ curve is associated with used load sizes and movement velocity.

Previous relation shows that the workload is one of the key factors which determines movement velocity, and thus produced strength and power. Rahmani et al. (2001) have speculated that KE exerts its $P_{\text{max}}$ at workloads close to subject’s own body weight or lower (no load or unloaded conditions). Such an assumption is very close to the hypothesis of maximum dynamic output (MDI) of Jaric and Markovic (2009), according to which leg muscles of physically active people are mainly designed to express their MDI in rapid movements such as jumping and running where load is own body weight and inertia.

In addition to $F-V$ relation, the exertion of maximal strength, as it could be seen in the foregoing regarding the muscle architecture, is also influenced by muscle length. Therefore, in the testing, particularly isometric, it is very important to define the knee joint angle at which the exertion of maximal strength is expected. It is stated that KE generates maximal torque at the angle which varies between 110° and 130° (Rahmani et al., 2001; Knezevic et al., 2010). Häkkinen et al. (1998) showed that during single joint leg extensions, KE’s strength increases until an angle of 120°, where reaches its maximum, regardless of the applied workload. Comparing the maximal isometric strength and RFD at angles of 90° or 120° and the jump height, Marcora and Miller (2000) noted that there are significant differences in $F_{\text{max}}$ and RFD between the two applied joint positions, and that results at the larger angle significantly correlate with the jump height, while the relationship between jump height and $F_{\text{max}}$ and RFD exerted at 90° was not significant. Although strength-joint angle (i.e. force-length relation) dependence is generally determined, there is not enough information how does the change the joint angle affects RFD. Since the exertion of maximal strength and power depends on the training modality, they should be evaluated in conditions similar to training or competition.

The force-length ($F-I$) relationship could be affected by stretching exercises and therefore potentially alter the results of strength and power assessment.
tests. According to Marek et al. (2005), a number of studies suggest that stretching before resistance exercise, or test, may temporarily compromise muscle’s ability to generate strength. Such a phenomenon can be useful in rehabilitation, but not during testing because the results would not be valid and reliable for the subsequent recommendation of training or recovery programs. Results of studies concerning the influence of stretching on the results of KE’s strength and power tests are different, but in general, it is said that static stretching reduces maximal isometric torque (opinions are conflicting about its impact to maximum power), while proprioceptive neuromuscular facilitation (PNF) has no such effect (Marek et al., 2005; Baechle, 2007).

The results suggest that static and ballistic stretching have caused the reduction in KE’s $F_{max}$ and 1RM, that partly might be consequence of reduced muscle activation (Nellson, & Kokkonen, 2001, Marek et al., 2005). Using EMG it is possible to examine the impact of stretching exercises on activity level of each of the KE muscle portions, and the reduction in maximal strength after stretching without any change in the activation level has been observed. However, there are allegations that both static and PNF stretching reduce strength and power, and the reduction of EMG amplitude of VL and RF during maximal isokinetic concentric contractions was observed at angular velocities of 60 and 300°/s (Marek et al., 2005), suggesting that the effect of these exercises does not depend on velocity. Comparison of the mean EMG amplitudes revealed that RF’s activity is sensitive to stretching, but it is not such a case with VL.

**INFLUENCE OF RESISTANCE TRAINING ON KNEE EXTENSOR’S STRENGTH AND POWER**

The resistance training is an inherent part of athletes’ training and recreational activities. Numerous studies have dealt with the assessment of the resistance training and subsequent detraining impact on KE’s muscle function, particularly on the $F-V$ and $P-V$ relations. In recent years, in addition to interest in monitoring the impact of such training on the athletes performance, considerable attention was also focused on the older population, particularly on the amount and degree of progress, changes at the molecular level and quality of life (Häkkinen et al., 2001; Thom, Morse, Birch, & Narici. 2007).

The resistance training aimed to develop KE’s strength and power, promotes hypertrophy and increase in muscle cross-sectional area (8-13% depending on the subjects age), increase in maximal isometric strength, 1RM, isokinetic strength (10-18% depending on the applied angular velocity), as well as changes in EMG activity amplitude, particularly in mm. vastii (Narrici et al., 1989, Andersen et al., 2005; Häkkinen et al., 1998; Häkkinen et al., 2001; Pincivero et al., 2004). Muscle hypertrophy timing is not uniform in all KE muscle portions. In addition to this, it is shown that compared to R, this process occurs at different rate in mm.vastii, there is no uniformity in terms of location within the muscle and distal parts of muscle react more quickly on training stimulus (Pincivero et al., 2004; Seyness et al., 2007).

The changes in the muscle architecture under the influence of training, detected with ultrasound, indicated that regardless of the contraction type (centric or eccentric), five weeks of exercise were needed in order an increase in length and pennation angle in VL fibers to occur, while no changes were observed in the VM (Blazevich et al., 2007). In addition to ultrasound monitoring of CSA and muscle structure, changes can be also observed on EMG. Earlier studies suggest that hypertrophy process starts simultaneously with the beginning of training process, but the “sudden” increase in growth occurs only after several weeks of training (Seyness et al., 2007). Naricci et al. (1989) have observed increased activity in VL eight weeks after the beginning of training, while Hakkinen et al. (1998) registered the same phenomenon ten weeks after the beginning of exercising. However, Pincivero et al. (2004) consider that due to development of increased opportunities for strength generation it can be expected someone to achieve the same level of the maximum strength as before training with a lower level of muscle activation. Their findings confirm this indicating that reduced activity of VM and VL was observed at the beginning of isometric contraction, which authors tried to explain by neuromuscular adaptations due to training.

The research on EFP, through monitoring of RFD, provided some contradictions. In the study of Hakkinen, Kraemer, Newton and Alen (2001) training has contributed to significant improvement in this
ability, while in another RFD remained the same as at the pre-test (Häkkinen et al., 1998). Training particularly increases the strength of slow movements, while it does not affect the observed characteristics during leg extension with no external load. However, results should not be generalized, because of training modality, particularly if isokinetic training was conducted at various angular velocities. This is in accordance with findings of Gruber and Gollhofer (2004) that applied sensorimotor training which did not affect maximal isometric strength in squat, but led to changes in RFD with significant differences in VM’s and VL’s EMG activity compared to the levels prior to training, indicating a change in neural component.

A process reversed from training, e.g. the complete cessation of exercise (detraining) also leads to a number of changes in muscle function: decrease in maximum strength and return to levels prior to training, decrease in muscle size, and changes in the neural control (Narici et al., 1989; Narici et al., 1996; Häkkinen et al., 1998; Häkkinen et al., 2001). In addition to that, changes were also observed in muscle fiber composition (Narici et al., 1989; Häkkinen et al., 2001; Andersen et al. 2005). However, the ability to produce maximal power was either reduced (Narici et al., 1989; Narici et al., 1996) or increased, but only when movement was performed with no external load, which is explained through improvement in EFP (RFD) whose underlying mechanism is increased contraction velocity (Andersen et al. 2005). Torstensson et al. (according to Andersen et al., 2005) got significant correlation between the percentage of type II muscle fibers and the maximal leg extension velocity, further suggesting the possibility of great power exertion in conditions of negligible external load.

**THE INFLUENCE OF BIOLOGICAL AGE ON KNEE EXTENSORS STRENGTH AND POWER**

As previously indicated, strength and especially power, are an important factor in sport and daily activities such as walking, stair climbing, standing up from the chair etc. During biological growth and maturation, due to increase of muscle mass, the improvement in these abilities occurs until the mid-

twenties for women and thirties for men, when power begins to decrease, while reduction in strength starts approaching sixth decade (Jaric, & Kukolj, 1996). In younger subjects, particularly children during sensitive periods of motor development and puberty, due to disturbance of intra and between muscular coordination there is possible lack of efficient exploitation of resources that would allow maximal strength and power production. Paasuke et al. (2001) compared results of strength, power and EFP tests in pre and post pubertal boys. They obtained significant differences among the obtained results in all applied tests with older boys performing better, where both groups were not able to use the positive effects of SSC during countermovement jump.

Age related loss and/or reduction in strength may increase the risk of falls and injuries. According to Petrella et al. (2005), age related sarcopenia leads to an accelerated reduction of muscle mass and strength (1-2% per year), particularly in the subjects who were 50 years old (Jaric, & Kukolj, 1996; Petrella et al. 2005), and that is why older population mostly has poor results in bilateral leg extension (Izquierdo et al., 1999), leg press (Izquierdo et al., 1999; Häkkinen et al., 2001; Petrella et al., 2005; Thom et al. 2005), jump height and jump distance. In addition to reduced capacity to produce maximal strength, capacities for EFP also get weaker to a greater extent compared to $F_{\text{max}}$ (Izquierdo et al., 1999).

$F-v$ relation is particularly affected by aging. Decline in power is more visible than in strength (3-4% vs. 1-2% per year). Decrease in specific power (normalized in respect to muscle mass or muscle size), may occur due to the gradual loss of α-motor neurons of fast motor units, which causes FT fibers to transform into ST fibers (Jaric, & Kukolj, 1996), and the related reduction in maximal contractile velocity. According to Thom et al. (2007) reduced ability for great torque production is associated with the muscle contraction type. Power of concentric and isometric contractions significantly decreases with age, while it remains almost intact in the eccentric. The decrease in isometric contraction strength primarily happens due to reduced CSA which is related to muscle atrophy. It is specifically quoted that difference between younger and older subject in concentric contraction torque increases with the increase in shortening velocity, due to age related changes in muscle structure (Thom et al., 2007). The significant differences in the
power were present even after obtained results were normalized in respect to thigh lean body mass.

Apart from the strength and power, muscle endurance is also important ability, and it is usually defined as a loss of strength during repeated or consecutive contractions. Knee extensor, along with other muscles, showed no muscle endurance dependence on age (Petrella et al., 2005; Petrella et al., 2007). However, age has a significant effect on muscle endurance during repeated leg extensions, but not during test of rising up from a chair (closed kinetic chain) (Petrella et al., 2005). In the elderly fatigue occurs during leg extensions, due to the decrease in concentric contraction velocity. EMG analysis showed that the elderly require a greater percentage of muscle’s maximal voluntary activation while rising up from a chair (concentric contraction), while during sit downs (eccentric contraction) gender has a significant role in such a way that women should have greater activation level to carry out movement in a controlled manner (Petrella et al., 2005).

In addition to these factors, strength and power production of KE is largely influenced by antagonistic muscle group activity. Thus, older subjects (65 years and older) had significantly higher hamstring activation when compared to younger subjects (mean age 40 years) (Izquierdo et al., 1999). High level of antagonistic muscle group activity can limit the full movement efficiency depending on the contraction type, test conditions, speed and rhythm of tasks execution, especially when it comes to older subjects.

CONCLUSIONS

Due to specificity of its anatomical characteristics and important role it has in locomotion, knee extensor is represented as a muscle of great interest in the studies of neuromuscular function. Given that it consists of four separate muscles, the variability of their anatomical characteristics affects their participation in strength and power production, depending on the type of movement and motion that is performed (and therefore training has different effects on mechanical and neural characteristics of each of the parts separately).

The maximal strength KE generates, regardless of contraction type, the fundamental quantity that affects its power, and that is in a hierarchical manner. It could be noticed that the impact of strength gets smaller as the external load decreases, until the moment when other factors, such as EPF (especially the initial and maximal RFD) become more important (Stone et al., 2003; Slievert et al., 2004). It follows that the maximum strength has the greatest impact on the maximum power at high loads, and to a lesser extent when loads are light. However, the strength of KE affects its own power production at different load levels and different shortening velocities. Although these two abilities are relatively independent, knee extensor’s power is still largely influenced by its maximal strength. Changes under the influence of resistance training or biological age are variously manifested in muscle’s morphological, physiological and neural characteristics, and thus in strength and power. This relative independence, and mutual dependence, in addition to the influence of different factors and relations and methods of their evaluation, is what causes correlation coefficients between results of strength and power tests to be different.

Understanding the issues related to strength and power as abilities of great importance for everyday life, is also important for practice, particularly sports and rehabilitation. Performances improvement in sports in which leg muscles strength and power are crucial, as well as recovery after the injuries, are largely dependent on the research results regarding KE function. Also, the appropriate strength balance between knee flexors and extensors is important for the knee joint stability, so that the presence of imbalance between these two muscle groups might be a risk factor for the occurrence of injuries.

Thus, knowledge of the basic strength and power characteristics makes easier to interpret results of tests which are used for the assessments of neuromuscular function after training and during the rehabilitation period. In addition, monitoring changes in strength and power contribute to a clearer understanding of the training effects and mechanisms of injury, thus providing opportunities to act preventive with appropriate training program and to prevent adverse strength deficit.
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