1.2 Skeletal Muscle Functionality

Skeletal muscle is the most abundant tissue in the human body, with a total of 40-45% of body mass. The muscles play a key role in locomotion, heat production, soft tissue support and metabolism in general. Muscles have the ability to adapt to a wide variety of stimuli, including physical training, substratum availability, and detraining (release) conditions.

The architectural structure of the muscle will be a determining factor, both for the production of force in general and in the speed of contraction. Muscle architecture is the distribution of fibers in relation to the vectors or axes of force output. According to this arrangement of the fibers, muscles can be classified into **fusiform** (the muscle fibers are organized in parallel to the axis of force output, i.e. the tendon) or **pennate** (the distribution of the fibers is oblique in relation to the tendons). The latter can be **unipennate**, **bipennate** or **multipennate**, depending on the number of pennation angles that the fibers have in relation to the tendon.

As a result of the non-direct relationship that exists in the pennate muscles, between the force-producing vectors through tension in the muscle fibers and the tendon, not all of the force produced by the fibers will be transformed into such. In other words, the ability to transmit force is lost. However, pennate muscles are capable of generating large amounts of force. Even high-intensity strength training increases the angle of pennation of the fibers. This causes an increase in the physiological cross-sectional area of the muscle, which is responsible for the production of force and thus compensates for the lack of force transmission capacity, as a result of the angle of pennation. Another important factor in relation to fiber distribution and muscle architecture has to do with the length of the muscle and its fibers. Two muscles with a similar pennation angle and physiological cross-sectional area, but with different fiber lengths, will thus have different force output speeds, since it depends on these elements (Tricoli, 2011).

1.2.1 Skeletal muscles and their ability to generate strength. Serial and parallel sarcomere adaptations

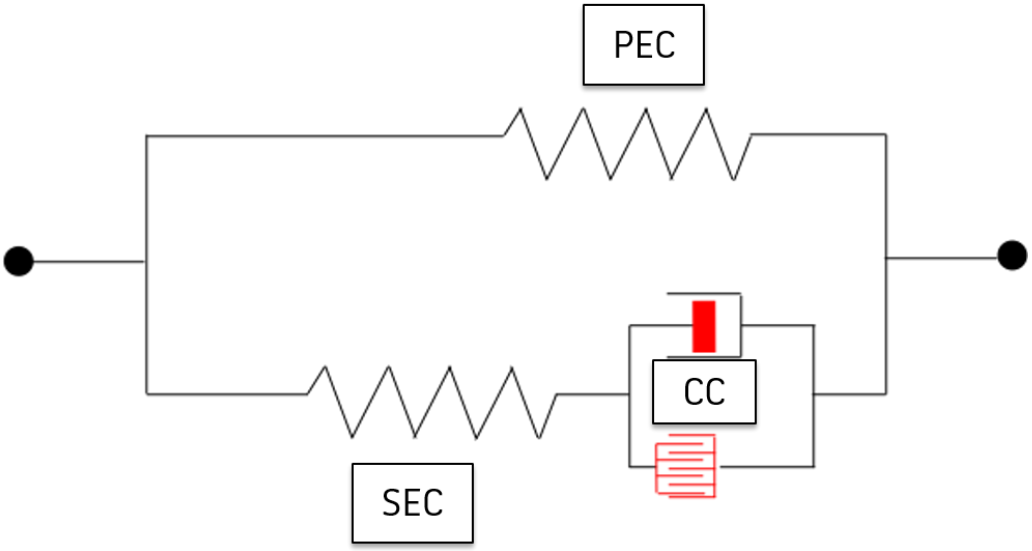
In the first two topics of this unit, we have examined the relationship between the central and peripheral components with the production of force; arriving at the excitation-contraction coupling, which finally allows for the existence of muscle tension. Once we understand this relationship, along with the most relevant aspects to take into account when developing a strength training program, we can focus on understanding how the capacity for strength can be increased within the muscle itself and its nerve connections.

The first aspect that must be taken into account is that the ability of skeletal muscles to generate force is provided by different components: the contractile, the elastic, the reactive and the reflex. These components can be seen in the book by Julio Tous (1999), focused on the concepts of strength and bodybuilding. We can see how different types of muscle tension introduce concepts such as "elastic" and "reactive".

In this regard, the elastic component enables force output, since the elastic properties of the muscle contractile component and the tendon component mean that these tissues, once elongated, tend to instantly recover their resting length. This means that it is important to produce strength in every SSC. On the other hand, the reactive component will depend on the energy use that usually occurs upon contact with the ground, so that short contact times enable the production of force, and long contact times dissipate the energy and do not use it. In relation to the reflex component is the well-known work of Sherrington and Lidell, who described the myotatic reflex nearly a century ago (Lidell and Sherrington, 1924; 1925). Specifically, these researchers studied how after a very short period of latency, stretching of the quadriceps muscle in cats led to an increase in strength of the muscle. On the contrary, when the nerve muscle was blocked, the stretching of that muscle produced only a small residual force, due to the elastic component of the fiber. The difference between the two tensions is the amount of force that these authors acknowledged in the reflex component (Clarac, 2005).

Finally, the contractile is among the components that produce muscle tension, which has been explained in the previous topic and is the most studied in the scientific literature. The well-known term hypertrophy is especially linked to this phenomenon. Despite this, in this topic we will examine the muscle's ability to provoke an increase in force through its growth; that is, by means of hypertrophy. This term refers to the increase in muscle size as a result of training, and is essentially due to the increase in size of individual fibers (Zatsiorsky and Kraemer, 2006). In relation to strength training, it important that we understand the concepts of hypertrophy in terms of the sarcomere growth. In Figure 7, we can see the different mechanical components of this muscle structure.

Figure 7: Schematic representation of the different components of a sarcomere

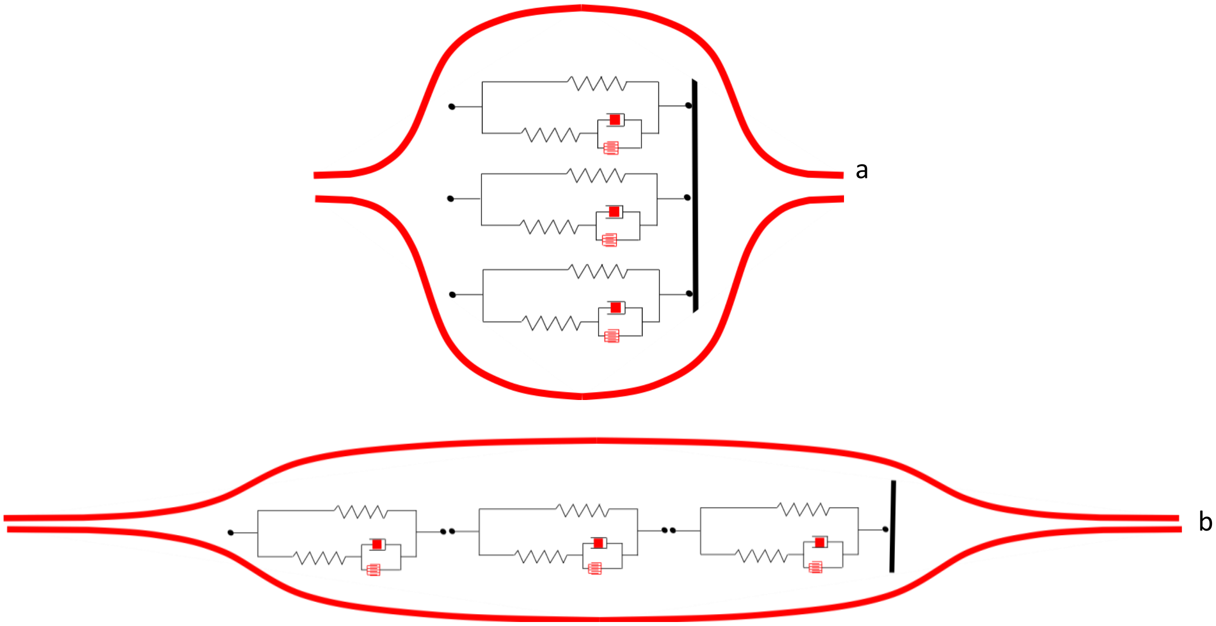


Source: Enoka, 1996, p. x. Parallel Elastic Component (PEC), Series Elastic Component (SEC) and Contractile Component (CC).

Depending on the type of arrangement adopted by the sarcomeres, with respect to their own muscular structure, the literature discusses the terms parallel hypertrophy and serial hypertrophy (Figure 8). These two types of adaptation will primarily depend on the type of training that we do. The parallel hypertrophy structure can be visualized by an increase in the diameter of muscle fibers, due to an increase in contractile material and a possible increase in the pennation angle of a muscle (Bompa and Haff, 2009). Essentially, the type of explosive training will have a greater impact on type II muscle fibers, which will enable the maximum power that can be developed. On the other hand, the type of exercise, with lower loads and performed at lower speeds, will lead to a priority stimulus of type I muscle fibers. Muscle fiber type will be discussed in the first topic of the following unit.

On the other hand, serial hypertrophy occurs through the creation of sarcomeres that are longitudinally aligned to the muscle. This may increase the rate of contraction or increase muscle length (Tous, 1999). From the perspective of team sports, where continuous accelerations, decelerations and movements occur at maximum intensity, it is important to achieve a muscular contractile ability in positions with greater elongation. This can be seen with the predominantly eccentric type of exercise, as indicated in studies such as those of Nelson and Bandy (2004), who observe an increase in range of joint motion in strength training.

Figure 8: Schematic representation of the arrangement of sarcomeres in parallel (a) and in series (b)



Source: Enoka (1996).

Regarding sarcomere distribution and elastic tissue characteristics, can be influenced by joint movement amplitude used during strength exercises.

Total Amplitude (T.A.): It contributes to a serial sarcomere distribution, increasing joint movement amplitude, given by the lengthening of the contractile tissue. Meaning that specific flexibility program will not be able, in order to maintain or recover joint movement amplitude.

External Amplitude (E.A.): It contributes to a serial sarcomere distribution, and elastic tissue (Tendons) adaptations. Desirable joint movement amplitude is maintained without needing a specific flexibility program.

Both types of workout protocols allow a bigger motor unit recruitment and a proper stretch shortening cycle stimuli. In addition, they contribute to a muscle structure built to endure sport specific demands, such as eccentric tensions. Tendons and elastic tissue functions should be developed and strengthened in order to sustain repeated explosive strength executions in sports. Given the fact that they are responsible for strength transmission and because of their elastic capacity.

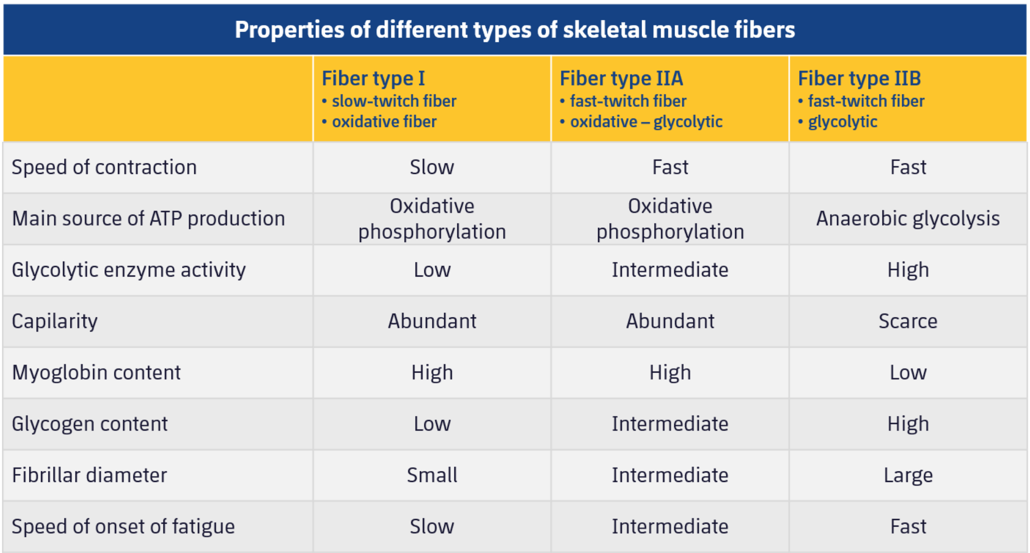
Internal Amplitude (I.A.) and Medial Amplitude (M.A.): Muscle total movement amplitude and length will suffer a slight reduction, because of a diminution of its contractile component. (Cos and Porta 1998).

1.2.2 Types of muscle fiber and their involvement in exercise

Skeletal muscle is a constantly changing tissue structure, in response to stimuli with both functional and metabolic demands. The mechanical, biomechanical and metabolic elements that characterize each muscle will depend on the distribution of the different types of muscle fibers. These muscle fibers differ fundamentally from one another in their contraction speeds, tension development and susceptibility to fatigue (Nordin and Frankel, 2001). Figure 9 shows the main characteristics of the muscle fibers according to their type, in relation to the aspects mentioned above.

The text by Nordin and Frankel (2001) describes a fourth type of muscle fiber, the IIC type. These are rare, characterized by being undifferentiated fibers and are generally seen before the 30th week of gestation. Type IIA fibers are called "intermediate" because, despite having a rapid contraction rate, they also have a moderately well-developed capacity for both oxidative and glycolytic metabolisms.

Figure 9: Properties of different types of muscle fiber



Properties of different types of skeletal muscle fibers

	Fiber type I • slow-twitch fiber • oxidative fiber	Fiber type IIA • fast-twitch fiber • oxidative – glycolytic	Fiber type IIB • fast-twitch fiber • glycolytic
Speed of contraction	Slow	Fast	Fast
Main source of ATP production	Oxidative phosphorylation	Oxidative phosphorylation	Anaerobic glycolysis
Glycolytic enzyme activity	Low	Intermediate	High
Capilarity	Abundant	Abundant	Scarce
Myoglobin content	High	High	Low
Glycogen content	Low	Intermediate	High
Fibrillar diameter	Small	Intermediate	Large
Speed of onset of fatigue	Slow	Intermediate	Fast

Source: Nordin and Frankel, 2001.

One of the main qualities of skeletal muscle is plasticity. This allows muscle fibers to acquire other types of attributes and become hybrids, by means of the appropriate stimuli. These stimuli can be the training or disuse and can affect the contractile, biomechanical and metabolic properties of fibers, which will also influence muscle ability. In relation to the adaptations triggered by training, greater hypertrophic adaptations have been found in type II fibers, as compared to type I fibers. As a result of the size principle, fast-twitch fibers are recruited less frequently, and their hypertrophy process is seen as an adaptive response to increase force output during periods of submaximal recruitment (such as strength training).

In order to expand on this concept, the total increase of the cross-cutting area of the muscle, as a result of the growth of type II fibers, is mostly determined by the effects of eccentric training (which is particularly responsible for serial hypertrophy). Thus, it is not surprising that performance in actions that involve strength, power and speed is dramatically increased through eccentric training (Douglas, Pearson, Ross and McGuigan, 2016). The exercise physiology treatise by McArdle, Katch and Katch (2001) details fibrillar conversion in both directions: from fibers I to fibers II and vice versa. Even the different studies cited by these authors explain that the daily increase in training time (a greater volume) increases the fibrillar conversion from rapid to slow in the phenotype of heavy myosin chains, as has been observed in animals. In this text, the authors argue that specific training can achieve specific adaptations in terms of fiber conversion.

In this regard, Siff and Verkhoshansky (2004) delve into the specificity of training, and the effects that different types of sessions can have on the proportion of each type of fiber. On the one hand, the training focused on the development of maximum and explosive force will center its hypertrophy on the so-called fast-twitch fibers (FT, according to the terminology of these authors). In relation to this, these authors observe that maximum muscle power and explosive movements will particularly depend on the percentage of FT fibers in the muscles recruited for this purpose. Contrary to this approach, if we design loads to work on the endurance of the cardiorespiratory system, we may find a decrease in explosive functional actions, such as jumping and speed. Despite the important role that the genetic factor plays in the distribution of the percentages of fiber types in each individual, training will have a determining role in sporting performance, i.e. the type, intensity and duration of training will influence the possible fibrillar development.

All of this knowledge is highly important when planning and scheduling training or post-injury readjustment processes.

Figure 10: Adaptive response of skeletal muscle to stimuli (strength and endurance)

	Endurance training	Strenght training
Muscular hyperthrophy	↔	↑↑
Muscle strenght	↔	↑↑
Size of muscular fibre	↔↑	↑↑
Synthesis of myofibrillar proteins	↑	↑↑
Satellite cell count	↑	↑↑
Myonuclei count	↔	↑↑
Lactate tolerance	↑↑	↔↑
Glycolytic function	↑	↑↑
Mitochondrial volume	↑↑	↑
Synthesis of mitochondrial proteins	↑↑	↔↑
Capillary density	↑↑	↔
Oxidative function	↑↑	↔↑
Endurance capacity	↑↑	↔↑

Source: Qaisar, Bhaskaran and Van Remmen, 2016.

1.2.3 Elastic properties of skeletal muscle: extensibility and elasticity

Extensibility is the ability of the muscle to stretch beyond its resting length (Marshall, Cashman and Cheema, 2011). In fact, extensibility is a physical property of any tissue, and we can therefore extend this concept to joint tissues. The extensibility of the different tissues of the musculoskeletal system, together with the property of force output, will be the main factors that determine the physical capacity of range of movement or flexibility, which are typically used synonymously (Moreno, 2018). Even today, the concept of flexibility is most commonly used as a physical attribute when we plan a training schedule. We are referring to an athlete with more or less flexibility, depending on whether he or she is able to produce movements of lesser or greater amplitude.

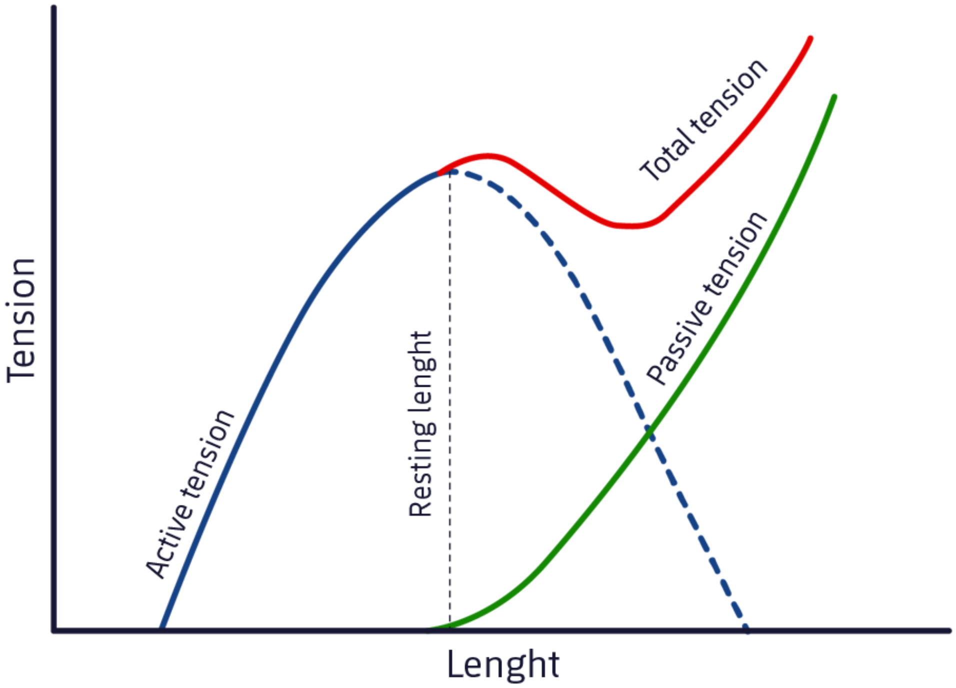
On the other hand, the elastic properties of a tissue refer to its ability to recover its original shape, once the forces that kept it distorted cease to be active. This means that the greater the elasticity of a tissue, the greater the force needed to distort it or, in the case of muscles, to stretch it. The concept of elasticity is usually related to the ability to generate tension (we have previously mentioned that elastic capacity is one of the muscle components to create strength) and with joint stability.

With regard to joint stability, it is important to keep in mind that an optimal stiffness capacity allows the musculature to react more quickly to situations that may lead to an injury of the joint structure. There is evidence that muscle fatigue is associated with an increase in electromechanical delay (EMD), leading to a decrease in muscle stiffness and an increase in elastic hysteresis (Gleeson, Reilly, Mercer, Rakowski and Rees, 1998). These events have also been described as triggers for an increase in electromechanical delay, which has been identified as a risk factor for injury, as described by Ristanis, et al. (2009). In the relationship between elasticity and range of movement, there is a necessity for a decrease in stiffness in order to obtain more articular degrees of mobility (Moras Feliu, 2003). However, in reality, the decrease in stiffness causes a decrease in muscle performance and a decrease in joint stability, as we have pointed out. It is evident that these facts do not interest us in terms of sports training and, to this end, we have methodologies that allow us to achieve more range of motion based on eccentric work, while simultaneously achieving an increase in stiffness of muscle and tendon tissue.

As for the component of elasticity as a producer of tension, we have already explained that Hill's model allows us to visualize the elastic role in this force output, as described by this author in 1939. This model differentiates between contractile elements (which ensure muscle contraction), serial-elastic components (passive elastic parts of the muscle which are the continuation of the contractile elements), and parallel elastic components (passive elastic parts which are parallel to the contractile elements).

The amount of passive tissue in a muscle can greatly vary. For example, the semimembranous and semitendinosus muscles have a number of passive components that are greater than the gluteus maximus, which has a percentage of the contractile component that is nearly equivalent to the totality of its tissue (Bosch, 2015). Despite being passive, the elastic components of the muscle have a great influence on its ability to produce force. The contraction produced by the contractile elements does not act directly on the muscular insertions, but through the absorption of forces that the serial-elastic components can achieve. This elastic tissue also enables a fluid and harmonious movement. Serial-elastic components have a high capacity to absorb forces; not only those produced by the contractile elements of the muscle itself, but also those produced from external forces. The main function of the elastic-serial components is the absorption and storage of tensions produced by opposing forces during muscle stretching (in an eccentric contraction, for example). This accumulated energy is used immediately afterwards in the production of force in opposite directions as the tension of the previous stretching, and contract the muscle. It should be noted that the elastic characteristics of the musculoskeletal system are based on **saving energy**, which is one of the premises of this system, in terms of the survival of the species (Bosch, 2015).

Figure 11: Adding the tension of passive tissues (passive tension) to the tension generated by the active elements (contractile tissue)



Source: prepared by the author, based on Nordin and Frankel, 2001.

The resulting total tension represents the amount quoted. It is illustrated how the contractile tissue can express its maximum tension, at a length that will be determined by the position that enables the greatest number of cross-bridge sarcomeres (known as resting length in the image). On the other hand, active tension will be higher in greater elongation positions.

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