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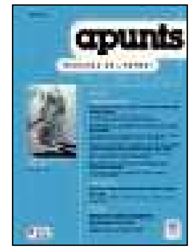

REVIEW

# On the application of stretching to healthy and injured sportsmen and women

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**KEYWORDS**
Stretching;
Sport;
Muscle injury

**Abstract**
Stretching is a technique that maintains or improves the range of movement in a joint or group of joints. It serves the muscle and sensory tissue due to an extended traction action. It is a technique that can be applied in the clinic or from a training perspective in health and injured athletes. The technique is indicated for the care, prevention and maintenance of the abilities of each individual or for their development. Not all stretches are done in the same way or seek the same objective.
On reviewing the literature, it is seen that there is no consensus on the classification or way in which to apply stretches. There is doubt on the beneficial effects of stretching during warming up. A study needs to be done to provide scientific support. The aim of the review is to recognise stretching, develop the classification, show five stretching methods and propose their application: in warming up, cooling down and training, in the healthy athlete and the athlete with muscle injuries.


**PALABRAS CLAVE**
Estiramiento;
Deporte;
Lesión muscular

**Sobre la aplicación de estiramientos en el deportista sano y lesionado**

**Resumen**
El estiramiento es una técnica que mantiene o mejora la amplitud de movimiento en una articulación o un conjunto de articulaciones. Solicita el tejido muscular y sensitivo gracias a una acción de tracción alargamiento. Supone una técnica que se puede aplicar en clínica o desde la perspectiva del entrenamiento en deportistas sanos o lesionados. Supone una técnica indicada para el cuidado, la prevención y el mantenimiento de las ca-

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pacidades de cada individuo o para su desarrollo. No todos los estiramientos se realizan de la misma manera o persiguen el mismo objetivo.
Al revisar la literatura, se observa que no hay consenso en la clasificación o en la manera de aplicar los estiramientos: se ponen en duda los efectos beneficiosos del estiramiento durante el calentamiento, y es necesario el estudio para dar respaldo científico.
El objetivo de la revisión es ubicar el estiramiento, desarrollar la clasificación, exponer cinco modalidades de estiramientos y hacer una propuesta de aplicación: en el calentamiento, vuelta a la calma y entrenamiento, en el deportista sano y en el deportista que padece lesiones musculares.


## Generalities

### Definition of stretching

If we look in the dictionary the definition of stretching that we find is: "To stretch, especially the limbs"[1].

We can classify the physical qualities into basic or conditional qualities and into complementary or facilitating qualities[2] (Figure 1).

Neiger asks: "Why do we stretch?", and concludes that we do it: "to be more flexible". It is certainly true that the stretching action forms part of the mobility-flexibility physical quality.

The *basic or conditional qualities* are also known as organic-functional qualities as they depend on the work of muscular contraction and on the energy necessary for this work. They are therefore based on the efficiency of the energy mechanisms and the application of the principles of training. They require an optimum adaptation by the organism to the load applied. They comprise: force, resistance and speed[2].

- *Force* is the ability to generate intramuscular tension, i.e. the ability that we have to overcome resistance. This sub-divides into *maximum force,* which is the main force that the neuromuscular system is capable of developing by means of voluntary contraction (for example a weight lifter), an *explosive or fast force,* the capacity of the neuromuscular system to overcome a resistance in the shortest time possible (for example, the jump in volleyball), and a *resistance force* or the ability to carry out continuous repetition i.e. the capacity of the organism to resist fatigue in efforts that last a long time (for example in rowing).
- *Resistance* is the ability to physically and psychologically resist a load for a specified period of time and the ability to recover rapidly. *Aerobic resistance* refers to long lasting, low intensity exercises. There is sufficient oxygen available for the oxidation of glycogen and fatty acids. *Anaerobic resistance* occurs in high intensity, short duration exercises where there is an insufficient supply of oxygen as an energy substrate resulting in the constant formation of lactic acid in the muscle.
- *Velocity* is a complex quality that concerns sportsmen and women's ability to react with maximum speed in response to a signal and to carry out a movement as quickly as possible within a determined time period.

Complementary or facilitating physical qualities concern the coordination and flexibility of movement. They are the qualities that make the preservation of the amplitude of movements and a major economy of movement possible. If they are developed to the optimum, then the learning, practising and performing of movements will be achieved earlier, with greater skill, confidence, elegance and ease of movement, in both sports and everyday activities.

- *Coordination* is the combined effect of the central nervous system and the skeletal musculature in carrying out a particular movement which influences the direction of a sequence of movements. Coordination concerns a quality determined by the processes involved in controlling and regulating movement. Its development involves increasing the repertoire of movements and motor skills.
- *Mobility-flexibility* refers to the mobilising, freedom of movement and, technically, the range of motion (ROM) of a joint or group of joints[3]. It depends on the biomechanical properties of the joints, specifically on the morphology of the articular surfaces and on the properties of the soft tissue around the joint, i.e. the capacity of the muscle, tendon, ligament and joint capsule to extend, as well as the muscular force necessary to generate the movement.

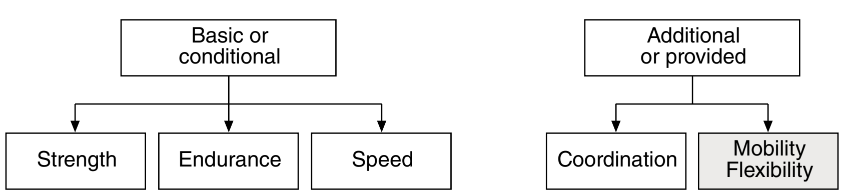


**Figure 1** Physical qualities.

## Types of flexibility

*Static flexibility* refers to the ROM of a joint produced by an external force, without the participation of voluntary muscle contraction. *Dynamic flexibility* is the ability to use the ROM of a joint by means of the voluntary contracting of muscles, during physical activity, both at normal and at accelerated speed. Good static flexibility does not necessarily guarantee good dynamic flexibility, but good dynamic flexibility does guarantee good static flexibility[4].

The *optimum level of flexibility* is the level that allows the efficient performance of movement and reduces the risk of being injured, adapted to the individual characteristics of each person and to the sport that has to be performed. It requires the use of the most appropriate stretching at all times, based on the physiological and methodological principles of flexibility. A higher degree of flexibility than required, apart from not being an improvement in physical development or in the prevention of injury, will produce an undesirable ROM. Instead, it is an expression of the excessive relaxation of the muscle fibres, joint capsule and ligaments, that increases the possibility of the sportsmen and women suffering joint instability[5].

Serra and Bagur[4], who refer to Matveiev, state that joint movement must be developed to the point of achieving optimum movement technique and the efficient use of the motor abilities required by particular sports. They distinguish between three different types of flexibility, according to their practical application: *absolute flexibility* or the maximum degree of mobility that can be obtained; *work flexibility,* or the maximum degree of ROM that can be obtained in a particular sport movement, and *residual flexibility*, which represents the safety margin needed to avoid injuries. This lies between absolute flexibility and work flexibility. Residual flexibility involves the safety margin that is essential for safe practice. It is especially important in group sports, where unexpected interactions and contact with others can require very high ROM.

**Table 1** Training versus prevention

| Flexibility training | Flexibility for prevention and performance improvement |
|---|---|
| Increase of the existing range of movement (ROM) | Working within the existing ROM |
| ROM increase | Performance optimization. Injury prevention |
| Flexibility exlusively training sessions | Preparation for the activity before the session (warming) and after (return to calm) |

ROM: range of motion.

## Flexibility training versus flexibility for injury prevention and performance improvement

The flexibility *training programme* is a programme of planned, intentional and regular exercises which, over a specific period of time, can fully and progressively increase the ROM of one or several joints.

The *flexibility programme that aims to improve performance and reduce the risk of injuries* is used in the warm-up phase and in the cool-down phase, i.e. the cooling down phase which follows physical activity.

Both have different objectives and involve different activities[6] that are summarised in Table 1.

### An approach to flexibility work during the season

According to Martín Dantas[6], referring to the work of Matveiev and Zacarov, the approach to flexibility work is modified according to the point in the season. This is sub-divided into periods or cycles: preparation, competition and transition.

- During the *preparation period* general or basic work is carried out in preparation for more specific work. The flexibility programme will be both active and passive, adapted to the particular sports played and the amplitudes required to help execute a movement while ensuring its stability. It must be individualised and consists of *a flexibility training programme*.
- During the *competition period* the qualities are adjusted so as to be able to perform the sport adequately. The sportsmen and women should not acquire more skills through the training but rather must maintain what was achieved during the previous period. The aim is to maintain the ROM and avoid injuries. During this period a *flexibility programme* is drawn up.
- In the *transition period,* the athlete is directed towards a state of active rest, with the aim of recovering for the next training cycle. During this period the aim is for the sportsmen and women to maintain the basic physical qualities obtained during the previous period of physical preparation, at the same time as recovering psychologically.

## Structures affected by stretching

To be able to understand how the application of one form of stretching or another has an effect, the muscle and tendon unit must be considered as a structure that has a *neurological* component on the one hand and a *mechanical* component on the other. Both influence[7,8] their behaviour (figure 2).

### The neurological component

In relation to the neurological component we describe below the neuromuscular spindles (NMS) and the Golgi tendon organ (GTO)[9,10].

The NMS are sensitive to changes of length and to the speed with which these changes are produced. If they are stimulated they inform:

- The alpha motoneuron situated in the medulla which activates the stretch myotatic reflex producing muscle contraction as the response.

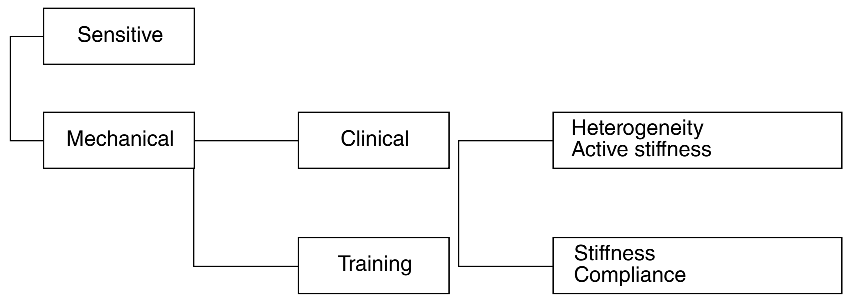


**Figure 2** Muscle components schema.

- At the same the relaxation of the antagonist muscle is brought about through the stimulation of an inhibitory interneuron. This depresses the alpha motor neuron of the antagonist muscle, producing an inverse myotatic reflex which relaxes the antagonist muscle.

This mechanoreceptor system regulates its perceptual threshold by means of motor innervations of the gamma fibres. The neuronal discharge modulates the minimum stimulation threshold for the intrafusal receptors (clusters of terminations and annulospiral terminations).

The GTO is stimulated if an increase in tension is produced at a muscle and tendon level. The GTO informs the alpha motor neuron and responds with an agonistic inhibition, i.e. a relaxation or termination of the contraction. This is the so called auto-inhibition or autogenic inhibition.

Regulation of muscle tone is produced at the medullary level, under the influence of suprasegmental centres. This is fundamentally a reticular system. There are two types of influences from the proprioceptors, those that cause a positive stimulus at a medullary level (contraction triggered by the NMS), and those that cause a negative stimulus at a medullary level (inhibition of tone through the activation of the GTO). This has an influence on muscle viscoelasticity through passive resistance to stretching[11].

## The mechanical component

When considering the mechanical component, we can differentiate two perspectives, the clinical perspective and the training related perspective. In clinic, Neiger introduces the heterogeneity perspective on the components that make up the muscle[12]. Esnault introduces the concept of pre-regulation as protective stiffness in anticipation of any action[13]. In relation to training, concepts have been developed related to *stiffness* and *compliance* and their effects on the stretching-shortening cycle to generate explosive force[14-17].

Neiger explains that the muscle-tendon unit is a heterogeneous structure in that the contractile part of the unit is in reality the muscle motor that produces the traction force in the tendon tissue situated at the end of the muscle. This acts as the transmitter of muscular force to the bone levers, which results in movement[12].

We can consider there to be two basic types of tissue in the organisation of the muscle-tendon complex, contractile tissue or muscle fibre and connective tissue. The connective tissue is structured in layers that enclose the tendon and muscle structures. From the outside inwards we have: the epimysium, the perimysium, the endomysium and the sarcolemma.

The function of the epimysium is basically protective. It is a denser structure of connective tissue. The perimysium organises groups of muscle fibres into fascicles which provide muscles with three dimensional action. The endomysium envelops each muscle fibre and the sarcolemma is a more lax connective membrane that envelops the myofibrils.

Myofibrils are composed of many sarcomeres which are the functional unit of the muscle. Sarcomeres contain the proteins actin (thin filament) and myosin (thick filament) that interact and support each other, thereby producing a contraction of the muscle. Sarcomeres contract longitudinally and contain structural proteins that help to maintain their integrity: titin (which connects the myosin with the Z line and is the elastic element of the sarcomere), the desmin (which connects the myofibrils to one another) and the nebulin (which is the structural protein of the actin)[9,18].

This heterogeneous organisation is represented in Hill's mechanical model, where contractile and connective elements are found.

These components have differing abilities to extend. We can rank them from the least to the most extendable: contractive elements (CE), the parallel elastic component (PEC) and the series elastic component (SEC).

The muscle connective tissue is organised in such a way that it establishes interconnections that converge in the tendon. Esnault maintains that, setting aside the contractile tissue or muscle fibre, we can talk of a "connective skeleton" able to be deformed both longitudinally and transversally[13,19]. This is composed of different related structures, with both contractile and non-contractile properties. It is covered by a viscous liquid, sarcoplasm, which gives the muscle its ability to behave in dynamic action like a viscoelastic material[3,12]. This property is expressed by internal resistance to stretching (also called passive tension). It is directly proportional to the speed with which the length of the tissue varies (the greater the speed the greater the resistance) and inversely proportional to temperature (the higher the temperature the less the viscosity and the less the resistance or passive tension).

The opposite property to extensibility is rigidity. In clinic, when we speak of *muscle rigidity* we differentiate between two types[13], passive and active. *Passive rigidity* is produced by the loss of extensibility in the connective tissue that is related to pathology of the soft tissue. *Active rigidity* is related to the increase in muscle tone that prepares the muscle for action, giving the muscle a greater reactive capacity. This latter concept is related to the proprioceptive modulation of the gamma loop at a medullary level.

The *myotendinous junction* (MTJ) is a very important element, given that it connects two tissues with different mechanical properties (extensibility). It consists of a transition zone that supports high intensity, tensile transmission loads. For the sarcomeres at the MTJ to adapt, they are more rigid and do not stretch as much as those in the centre of the muscle in response to an applied force. This less extendable area can be situated 1 mm from the MTJ[20]. Injuries as a result of an eccentric mechanism are produced in this transition zone. Stretching in active tension particularly uses these union areas and for this reason they are attributed with positive effects in the prevention of injury[13].

The tendon is a hierarchical structure, in which collagen forms fibrils and these form fascicles. The function of the tendon is to transmit the mechanical impulses originating from the muscle contraction to the skeleton. This makes it necessary for there to be a constant relationship between the force of the muscle contraction and the resistance of the tendon to the tension.

In the training field the terms *stiffness* and *compliance* are used. The former refers to the ability of the tissue to oppose stretching and the latter to the ease with which the muscle can stretch. They are opposing concepts[21].

In training, the mechanical model is extended to make the action of passive tension and the stretch-shortening cycle (SSC) more understandable. The objective of the SSC is to convert the elastic energy provided both by the weight of the body and by the force of gravity, during the eccentric phase, into an equal and opposite force during the concentric phase[21,22].

The sports that require explosive actions that start the SCC require a compliant muscle tendon unit that makes it possible to store elastic energy during the eccentric phase and release it during the concentric phase. Sports that use more concentric actions, that are of low intensity or limited SSC (such as swimming), need to generate concentric contractile work that transmits the energy from the contraction to the articulated bone levers to generate the movement. The muscle in this case has to be less *compliant* and have more *stiffness*[15].

If the muscle is *stiff* it transmits the energy from the concentric contraction more rapidly. If it is *compliant* it has a greater ability to store elastic energy and release it rapidly (SSC).

Witvrouw[15] cites Safran et al and Mc Hught et al, who state that if the tendon exhibits good compliance and the muscle exhibits good active contractile activation, elastic energy will be absorbed by the tendon thereby reducing traumas to the muscle fibre. If the muscle is not compliant (but instead is *stiff*), the elastic forces will be transferred to the contractile apparatus of the muscle, and there will be low energy absorption by the tendon. This mechanism helps to account for the fact that a low flexibility increases the risk of the development of muscle pain in *stiffer* individuals after eccentric training (Table 2).

Cometti[23], citing Proske and Morgan[24], analyses the structures involved when acute static stretching is performed. Stretching creates a passive tension that acts on three elements. In order of importance in recruitment they are the stable myosin-actin bridges, the titin as the elastic element of the sarcomere, and if we increase the amplitude the connective tissue and the tendon are involved.

At an acute level stretching reduces rigidity and viscoelasticity.

In the long term, the increase in ROM is produced by the *stretch tolerance*[14] (neurological adaptation to stretching, variation in the perception of pain and stretching through the phenomena of neurological accommodation, a decrease in the activation of NMB, a decrease in the excitability threshold of the GTO) and the Goldspink effect[23] (the addition of sarcomeres in series as a result of passive stretching and eccentric action: myogenic adaptation related to the force).

The *creeping* effect concerns the maintenance of the stretch[3,14,25]. In long, maintained stretches a plastic effect is produced and tissue reorganisation is provoked. A gain in ROM is produced, but this is accompanied by a decrease in the efficiency of the tendon to store energy. Therefore this type of stretching is not recommended in the warm-up as time is needed to adapt and recover (recommended in flexibility training).

**Table 2** Mechanical behavior of the muscle

| | Definition | Sports | Requirements | Observations |
|---|---|---|---|---|
| Stiffness | Tissue capacity to oppose the stretching | Concentric, contractions for the force transmission | Less compliant and more stiffness muscle | Easier to suffer muscle pain if eccentric training |
| Compliant | Facility with which a muscle can be stretched | Eccentric, reuse of the elastic energy related to the SSC | More compliant and less stiffness muscle | If there is a good active muscular contraction there is a high absorption of the elastic for the tendon, muscle structure will not suffer microtraumas and there will be greater tolerance to eccentric work with less DOMS incidence |

SSC: strecht-shortening cicle; DOMS: delayed onset muscular soreness.

When an external traction force is produced the tissue responds by getting longer. The tension-deformation curve explains the behaviour of the soft tissue when lengthening takes place[5,12]. There are different phases the elastic, the plastic and the tearing phases.

## Stretching for the improvement of performance and possible prevention of injury

### Stretching and warm-up

Sportsmen and women and professionals who work in the field of sport use the different forms of stretching before, during and after playing sport. On examining if there is a consensus regarding whether sportsmen and women should stretch and what stretching they should do in the warm up, it can be seen that some authors are critical of the process. They doubt the benefits of certain stretch exercises during the warm-up[15,23]. Regarding the form of stretching used, the studies focus on the Anglo-Saxon school and do not consider the forms of stretching proposed by the French school. Further research is therefore required to provide scientific weight to the discussions[8,11,13,26].

### Definition of the warm-up

The warm-up is a set of exercises, carried out before an activity that provides the body with a period of adjustment from being at rest to exercising. It aims to improve performance and reduce the possibility of injury through both physical movement and mental activity[3].

Physiologically it involves a period where the body is changing so that it reaches a point at which the tissues work with greater efficiency, because of the increase in the temperature of the soft tissues and joints and through facilitating nerve conduction. The individual thereby becomes capable of achieving maximum performance[27].

At a psychological level it stimulates performance. It involves a mental rehearsal of sporting movements and technical situations before putting them into practice.

We can differentiate between two types of warm-up: *general* (various movements not related to the activity to be undertaken, gentle calisthenics like jogging or exercise bike) and *formal* (movements that simulate the technical performance of the activity to be undertaken).

The "ideal" warm-up is one that is sufficiently intense to increase the body temperature, produce sweating, provide the articular amplitude necessary to carry out the technique and to do so without producing fatigue, thus preparing the body for the optimum execution of the specific actions. The duration of the warm-up varies from 10 to 15 minutes.

Esnault recommends the use of stretches that put the structure on alert without exhausting it[11,13]. He also stresses the importance of involving the soft tissues and protecting joint tissue. For this reason the muscle tendon system has to ensure an active protection or rigidity. The stretches are carried out through dynamically working the corresponding muscle group.

Geoffroy[28] recommends using static stretching with active tension followed by dynamically working the muscles in the muscle group one after the other (this is often considered as if it were a mobility exercise whereas in reality it is a dynamic activity) so as to then be able to carry out explosive elastic force exercises.

Cometti[23] recommends avoiding stretching during the warm-up for fast sports. Stretching is only permitted if these sports require a high ROM, with the aim of preparing the athlete to reach these amplitudes without risk. They should be low ROM stretches with a maximum of 1 or 2 repetitions. (He does not cite Esnaut but they agree in recommending the use of stretching with active tension.) He advises against PNF.

Cometti[23] and Prévost[29] recommend the use of the "Russian" warm-up. This consists of carrying out sub-maximum contractions of the muscles involved in the principal muscle groups to achieve optimum preparation for exertion.

### Current understanding of the use of stretches in the warm-up

In recent years there has been an increase in criticism of the immediate effectiveness of stretching (acute effects). The critical discussion concerns the following issues: the phenomena of the reaction and adaptation of muscles to training (the decrease in force, power and speed after a stretching session); the different types of immediate and long term effects of stretching, and the preventative role of stretching.

#### The reaction and adaptation of muscles to training

Some of the authors consulted agree that stretching has negative effects on the physical qualities of the muscles. Prévost[29] referring to Wilson et al[30] states that "all modification of the rigidity of the tendon muscle system will have repercussions on the physical form, affecting muscle force, speed and power". Prévost[29] argues that the variation in muscle rigidity can influence the speed with which the force is generated and transmitted to the articulated bone levers. The increase in rigidity of the tendon-muscle system accelerates the transmission speed and, therefore, the speed of movement, while if a variation in extensibility is produced with the system becoming more stretchable there is a delay in the transmission and, therefore, a slowing down of the transmission action.

To generate force it is important that the sarcomere is of optimum length. The active force (active tension) that a muscle can generate is a function of its initial length. When the muscle is at rest it is at its optimum length for generating force as there is maximum overlap between the actin and myosin bridges. The shortened or lengthened sarcomere loses its ability to generate force. The optimum length of the sarcomere is also related to the articular position or angle. The maximum force coincides with the optimum overlapping of the actin and myosin filaments (as the maximum number of bridges is useful). If this is evaluated in the elbow, the optimum length of the sarcomere in the biceps is found when the articular angle is 90 degrees. This is the angle at which the maximum active force is produced.

Passive tension is the force that opposes the lengthening produced by a stretch in the muscle at rest. This lengthening force acts on and modifies the elastic properties of the muscle, in a way that decreases after stretches have been held. It can therefore be seen that holding stretches results in less external force being required to produce the lengthening of a relaxed muscle and to achieve a specific articular angle. Resistance to stretching therefore appears later.

The length-tension curve differentiates between the tension that is produced in the contractile and non-contractile structures to preserve the structure of the sarcomere. The tension available in the contractile fibres reaches its maximum level around the rest position of the joint. By contrast, tension in the collagen fibres appears in the intermediate position and increases exponentially until complete extension is reached.

Therefore, the force that a stimulated muscle can generate is a function of its initial length. If this is less than its length at rest, it only acts on the contractile proteins. These, together with the elastic proteins are gradually mobilised when the stretching length differs from its resting length.

The relaxed muscle generates a passive force according to how much greater its stretched length is compared to its resting length. By passively stretching the muscle, the elastic structures (conectin, titin) become tense up to their elasticity limit[18,29,31,32].

Held stretches can alter the optimum length of the muscle and have a negative effect on the force generated. The maximum force (1RM)[31,33-37], the resistance force (the maximum repetitions test)[33,38] and the explosive jump test can all be affected[39-49].

**Increase in intramuscular temperature**

The increase in the temperature depends on vascularization. Some authors are not in favour of the use of stretching in the warm-up and its effect on the increase in intramuscular temperature.

Masterovoi (cited by Prévost[29], Alter[3], Wiemann and Klee[32,50]) argues that stretching creates ischemia and that it is best to obtain the muscle pump effect by using concentric contractions. According to Freiwald et al, cited by Prévost[29], static stretching produces an ischemic effect that does not help recuperation. For Schöber et al[29], held static stretching and PNF do not improve vascularization. On the contrary, intermittent dynamic stretches do. Masterovoi[29] believes that stretches do not improve blood drainage, and proposes pump contractions.

Cahors[26] and Esnault[13,19], by contrast, are in favour of the use of stretching in the warm-up. They defend well performed stretching in active tension during the warm-up, but they also warn that if it exceeds 6 seconds it can produce arterial ischemia and therefore can be harmful.

**Flexibility training: the effects of stretching over the long term**

Over the long term, regular stretching can have positive effects on the ability to recover elastic energy. Therefore it would be beneficial in exercises that involved muscle power[9,29,31,51,52]. Training with stretching modifies the viscoelastic properties of the tendon, in such a way that stretching improves the *compliance* of the tendons and reduces *stiffness*[16,17], which is very important in sports involving SSC[53]. This flexibility training has to be well organised over the season. It has to be directed and progressive, respecting the recuperation periods necessary for the muscle-tendon structure to be able to make the necessary adaptations.

**Stretching and the prevention of injury**

There are studies involving large numbers of participants, as well as several bibliographical reviews and meta-analyses none of which is able to demonstrate the effectiveness of stretching as a factor in the prevention of injury. The majority of the studies argue that the etiopathogeny of injuries is multifactorial. It is therefore difficult to state that stretching can be preventative or that, on the contrary, it is related to, or could have an effect on, the appearance of injuries[15,54-60].

Stiff participants are more prone to suffering myalgias after loads that involve eccentric work[15].

In relation to the acute effects of stretching, flexibility stretching increases tolerance to pain *(stretch tolerance)*. This analgesic effect can increase the risk of injury if particular stretching exercises are used during the warm-up. The type of stretching that probably has most effect on stretch tolerance is stretch-relaxation-contraction or PNF[58].

Coordination between agonistic and antagonistic muscles can be compromised if stretches that are predominantly passive and of long duration are used during the muscle warm-up.

Long, prolonged stretches elongate the tendon and causing a change in the arrangement organisation of the collagen[9,23]. Although there is an increase in length, the tendon loses its efficiency in storing elastic energy (compliance). This is a reversible process, with substantial latency and it is for this reason that there are authors who advise against using stretching in the warm-up.

## Stretching and the cool-down phase

Einsingbach et al[61] and Cos et al[62,63] refer to the Wolkow system to explain the preparation and recovery periods for sportsmen and women after exercise. Four different recovery phases are differentiated:

- *Synchronised or continued recovery.* Is recovery that takes place prior to and during effort. It consists of the warm-up and the sports activity. Mechanisms are used which concern the ability of the muscle to accumulate energy during effort and to transform the energy reserves.
- *Primary or rapid recovery.* Consists of the two hour period after finishing the activity. It requires a correct cool-down. The muscle congestion and hypertonia generated by the accumulation of metabolic waste substances must return to normal. It is very important to use a good "active cool-down" and "active-cleaning" by carrying out a predominantly aerobic, rhythmic activity that activates the muscle pump to improve the irrigation (cleaning) of the muscle, as well as applying the appropriate stretches designed for this purpose.
- *Secondary recovery or deep recovery.* Occurs 2 to 3 hours after the activity has finished and can last for

up to 72 hours after the effort. It aims to return the muscle and neurovegetative state to normal. Passive measures predominate.

- *Recovery from over-training and chronic exhaustion.* Is a situation in which recovery does not take place. There is an imbalance in the sympathetic and parasympathetic nervous systems and this requires a multi-disciplinary approach (Table 3).

## Stretching by sportsmen and women who suffer soft-tissue injuries

The application of stretching by sportsmen and women who suffer soft tissue injuries is described below, taking into account the classification of the injury, its location, the structure affected (mechanical or neurological) and justifying why one or the other form of stretching is used.

### Classification of the muscle injury

Muscle injuries are classified according to the injury mechanism into *extrinsic* injuries (caused by an external agent, through direct injury as a result of contact with an opponent or object) and *intrinsic* injuries (caused by individuals themselves)[63,64].

Intrinsic injuries can be caused by over-exertion or by indirect trauma. Muscle over-exertion can create metabolic modifications and changes at a neurological level (cramp) or a mechanical level (muscle contracture). In the case of indirect trauma, strain injuries and/or eccentric action on the muscle structure produce a loss of continuity that can vary from grade 0 microscopic injury with delayed onset muscular soreness (DOMS) to grade I (elongation) considered as slight or to grade II and III (complete tear) considered to be serious[63,64] (Figure 3).

### Cramp

Cramp is a brusque, painful and violent contraction that produces an uncontrollable muscle segment displacement. This is related to the accumulation of the waste substances deriving from the contraction in the core of the muscle fibre, usually secondary to excessive loads, particularly if anaerobic methods are used. This produces an alteration in the polarisation of the membrane (calcium, potassium, magnesium), local hydric imbalances (dehydration) and other factors such as excessive stress or over training[3,65]. In examining the cause of cramp, it is thought that an abnormal spinal reflex is triggered when the muscle is tired. The GTO stops modulating the inhibition of muscle tone, reaching a critical contraction point at which the cramp is set off[66].

Stretching acts by stopping and normalising this reflex arc. The most suitable stretches are passive, static and held stretches, carrying them out until the cramp stops. Afterwards gentle movements of the muscle segment are made and attempts are made to apply post effort active measures (see Synchronised or continued recovery).

The duration of the cramp varies. Generally it is a self-limiting, transitory phenomenon.

**Table 3** Periods of preparation and recovery of the athlete after the exercise

| Healthy athlete Period | Moment | Muscular state | Objectives | Strechting type | Comments |
|---|---|---|---|---|---|
| Synchronic restitution | During | Activation warming | Help and support (positive attitude) | Active in active tension. Dynamic ballistic | |
| Primary restitution | From 0 to 2 h after exercise | Fatigue, congestion, hypertonic | Cooperate to normalize the basal state. PNF with caution | Passive. Passive tension in decline | Active measures (jogging, stretch, ice, hydratation) |
| Secondary restitution | > 2 h to 72 h | Return to calm Hypertonic | Deep recuperation Decrease muscle, ↓tone, normalize | Passive analytic Neuromuscular techniques (PNF) | Passive measures (massage, stretch, warm) |

PNF: contraction-relaxation-stretch.

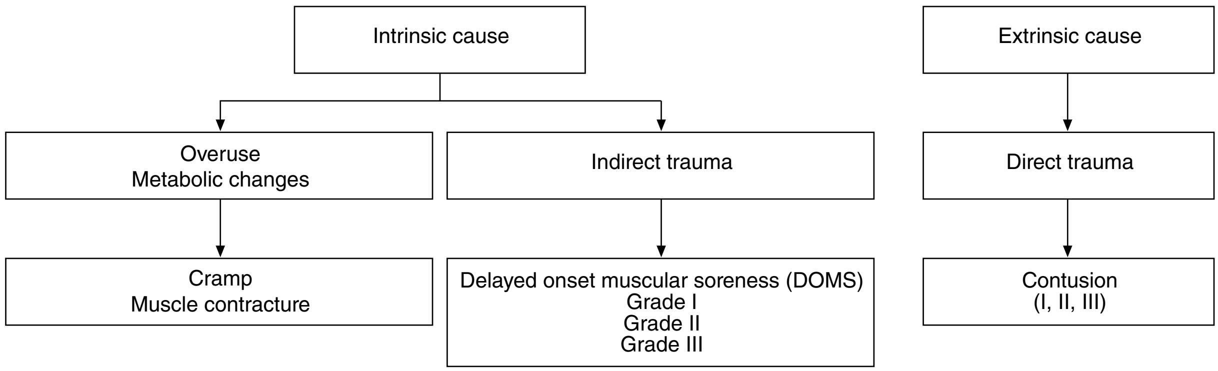


**Figura 3** Muscular injuries classification

**Muscle contracture**

Unlike "strain injury", contraction affects the muscle belly. The shortening of the myofibrils is prolonged in the absence of sarcolemma action potential[67]. This may be caused by the continued liberation of calcium by the sarcoplasmic reticulum together with a lack of relaxation, where the lack of cellular adenosine triphosphate (ATP) prevents the re-uptake of calcium during muscle relaxation. Clinically, pain appears in the affected muscle mass together with a degree of muscular impotence (Figure 4).

This can last for between 2 and 4 days. If it is prolonged, the muscle starts to modify and tends towards fibrosis and retraction, with the consequent loss of extensibility. The muscle will undergo metabolic changes that encourage the transformation of the contractile tissue in connective tissue[68].

Thermotherapy (heat or cold depending on prior evaluation and the area that is affected), massage and electrotherapy are used. Slow, progressive and held stretching is recommended, preferably using passive, analytical and neuromuscular techniques in PNF.

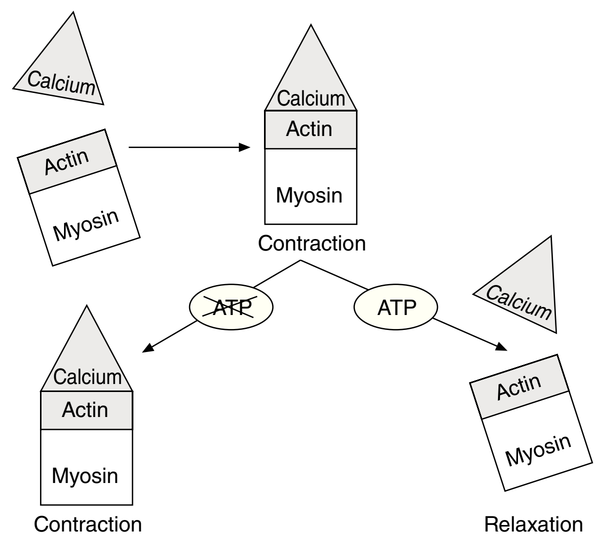


**Figure 4** Contracture mechanism[64].

**Injury through indirect trauma**

When the injury production mechanism caused by indirect trauma is analysed it can be seen that these injuries have many features in common as they are produced by an eccentric mechanism. Polyarticular muscles with a predominance of rapid fibres are affected, and the alterations (micro or macroscopic) are situated in the transition areas, i.e. the myotendinous junctions (MTJ). The MTJ plays an important role in the transmission of force. It is a transition zone between the connective tissue and the muscle tissue and is the area where the injury occurs[69]. Figure 5 shows the common features from least to most serious.

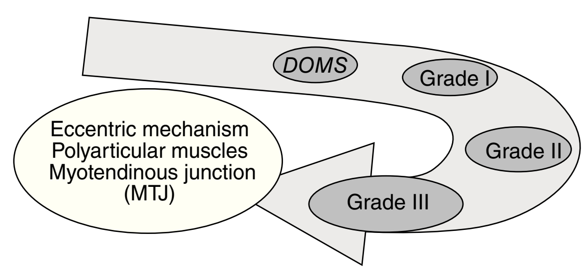


**Figure 5** Intrinsic muscle injury, common point between injury mechanism and severity from lowest to highest

**DOMS (delayed onset muscular soreness)**

This is late appearance myalgia that is produced after carrying out an activity over and above that to which we are accustomed. It is related to predominantly eccentric actions. The cause of the pain lies in the microlesions that are produced in the core of the muscle cell and connective axis (elastic elements of the sarcomere and between microfilaments). This phenomenon is accompanied by an inflammatory response after 24-72 hours which is responsible for the pain. This can last for 5 to 7 days, depending on the how serious the injury is. It is calculated that recovery of maximum force is achieved after two to three weeks in the most serious cases[3,7,8,65,70].

During the inflammatory phase cryotherapy, gentle massage, electrotherapy and prolonged aerobic work (for its drainage and cleaning effect) are used, increasing their intensity progressively according to patient tolerance. Initially stretches should be sub-painful, as we are working with inflamed tissue. We aim to achieve drainage by means of passive tension

**Table 4** Stretched acute injury

| Injured athlete Injury | Definition-classification | Production mechanism | Pain onset | Evolution |
|---|---|---|---|---|
| Grade I | Fibers requirements to the limit of their elastic possibilities, but maintaining its integrity | Is not aware of when the injury occurred | After sporting activity be aware of the presence of the muscle | Normally allows to continue the sporting activity (veteran athlete stops for prudence) |
| Grade II | Fiber disruption and injury<br>Haematoma formation | Symptoms starting in a sudden torn, kick on air or pace changing | Instantaneous, acute, falling due to the pain<br>Remains at rest and increases with any activity | Impossible to continue (lameness) |
| Grade III | Contraction altered by the injury | High intensity movement | Instantaneous, acute, falling due to the pain. Remains at rest | Severe functional disability. Support is not tolerated |

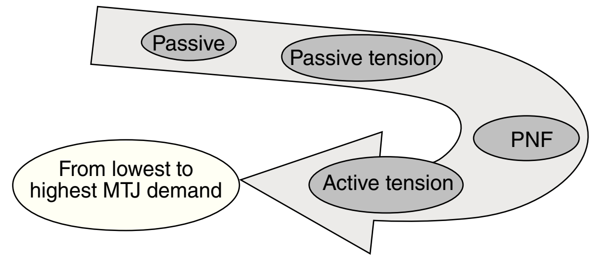


**Figure 6** Stretching gradation according to the myotendinous junction (JMT) demand. PNF: contraction-relaxation-stretch.

stretches in a downward sloping position, and normalisation of the ROM with low intensity and predominantly passive stretches, moving on progressively to active stretches with active tension to normalise the muscles.

Prevention, adequately planning the conditioning programmes and applying the appropriate protective measures both in the warm-up and in the cool-down are all very important (Table 4).

**Acute injury caused by stretching (strain injury)**

This is an intrinsic injury. The macroscopic affect on the MTJ is summarised in table 4.

Three phrases in muscle regeneration are differentiated[63,64,69,71-73]: the destruction or inflammatory phase; the proliferative or regeneration phase, and the final remodelling phase.

In the acute or inflammatory phase[73] it is very important to act correctly and quickly, with the application of RICE (rest, ice, external compression and elevation). It is very important to apply ice with compression to avoid the formation of a significant haematoma and to reduce the secondary hypoxic tissue injury as much as possible. Stretching is not advised. As the condition of the muscle improves, everyday activities should be recommenced so as to return to fitness. For injury of the lower limbs, it is advisable to support the injury by applying bandages and using crutches when walking. Pain indicates the limit of movement, bearable pain being the limit (analogue visual scale [AVS] between 5% and 10%)[64].

In the proliferative or regeneration phase, active use of the muscles is started. This early active movement encourages drainage and the regeneration of the tissue through mechanical action on the orientation and organisation of the regenerated tissue[9,28,63,71-74]. Work is progressive and adapted according to the degree of pain and discomfort. Stretching is usually started between the 3rd and 5th day, depending on how severe the injury is. Passive tension is used first and then the patient progresses to active tension, stretching in the maturation-remodelling phase. This phase coincides with the re-adaptation to sporting activity (Figures 6 and 7; Table 5).

## Classification of muscle stretches

Stretching maintains or improves the ROM though using traction on the chosen structures to lengthen the muscles. This is a technique that is suitable for the care, prevention and maintenance of each individual's abilities or for their maintenance and development. Not all stretching is carried out in the same way or has the same objectives. We obtain different results according to the way the stretching is performed[11,13,26]. Currently there is no internationally agreed classification of types of stretches. Consequently there are different classification systems that use different terminology.

**Figure 7** Passive tension stretching example in an injured hamstring.

What is considered to be the most suitable type or way of stretching has changed over time, such that there are a variety of different recommendations. Particularly significant are authors such as: Bob Anderson[75] who recommends passive stretching; Sölveborn[76] who transfers the neuromuscular technique consisting of contraction-relaxation-stretch (PNF), recommended by Kabbat[77], to sport; Pénninou and Tixa, who perfect and analyse *"les levées des tensions"*[78] or tension lifts; Moreau[11,13,79], and his "postural stretching", who introduced the concepts of tonic stretching ("tonic") and gentle stretching ("lourde"), and Esnault[11], who introduces the concept of active tension.

## The classification of muscle stretches proposed by different authors

### The classification system suggested by the Anglo-Saxon school (Table 6)[65]

- General classification: dynamic and static.
- This is based on the type of action on the ROM: passive (through the action of an external agent without the individual's participation); passive-active (passive stretching followed by the active maintenance of the position through isometric contraction of the antagonist muscle); active-assisted stretching (initial active contraction of the antagonist muscle, then when the limit is reached an external force is applied which increases the ROM of the agonist-antagonist relationship which improves the performance of the coordinated movement), and active stretching (stretching performed through contraction by the individual without any external help).

**Table 5** Summary of the application of stretching to injured athlete

| Injured athlete Injury | Affected structure | Objectives | Application time | Stretching type |
|---|---|---|---|---|
| Cramps | Sensitive component (abnormal spinal reflex when the muscle gets fatigued) | Normalize | Injury moment | Passive |
| Contracture | Mechanical component (contractile component, actin-myosin bridges) | ↓ Hypertonic | During the treatment, depending on the muscular state | Analytic passive<br>Neuromuscular techniques<br>PNF |
| DOMS | Mechanical component (microscopic lesion at the sarcomere) (desmin, titin) | Help in the inflammatory process resolution | According to clinical symptoms. After the inflammatory phase (3th to 5th day) | Passive<br>PT evolving to AT when pain goes better |
| Muscle rupture | Mechanical component (macroscopic lesion grade I, II, III, which affects myotendinous union) | Active progression with progressive demand of the myotendinous union | After the inflammatory phase (follow the rule "no pain if disconfort controlled") | PT<br>Passive<br>AT and dynamic stretching to the resolution phase |

PNF: passive analytic neuromuscular techniques; DOMS: delayed onset muscular soreness; AT: active tension stretching; PT: passive tension stretching.

**Table 6** Summary of the Anglo-saxon school proposal

| Anglo-saxon school proposal | | |
|---|---|---|
| General classification | Dynamic | Static |
| Classification by action responsible on the ROM | Passive | Action of an external agent without the participation of the athlete |
| | Passive-active | 1. Passive stretching<br>2. Active maintenance of the position in the isometric contraction of the antagonist |
| | Active-assisted | 1. Active contraction of the antagonist<br>2. When the limit is reached, apply an external force that increases the ROM |
| | Active stretching | Stretching performed by the athlete without any external aid |

ROM: range of motion.

## The classification system suggested by the French school

- Neiger[12] classifies the stretches according to their mode and character (Table 7).
- Esnault[11,13,19] (Figure 8):

  — Dynamic stretching (with ballistic type rebound or the slow dynamic stretching proposed by Kurtz).
  — Static stretching. This aims to achieve the maximum stretch and then maintain it.
  — Passive stretching (without contraction, maximum relaxation of the selected muscle).
  — Isometric stretching, static stretching (PNF).
  — Active stretching (adopting a stretch position and maintaining it through the action of the antagonistic muscle).
  — Stretching in active tension (the muscle or group of muscles going to be stretched are first contracted).
  — Stretching in passive tension (the muscle is not put under tension or given time to stretch beforehand). It is put under tension by the action of the antagonistic muscle.
  — Active isolated stretching, analytical stretching.
  — Postural stretching (Moreau[79]).

- Cahors[26] differentiates between dynamic and elastic stretching.
- In relation to static stretching:

  — Passive (Bob Anderson type[75]).
  — Neuromuscular (PNF, Sölveborn[76]).
  — Active stretching (Moreau[79], through co-contractions of deep and antagonistic muscles).
  — Rotating active stretching (muscle in contraction and a rotation component; Esnault type[11]).

**Table 7** Muscular stretching classification (Neiger)

| French school proposal | |
|---|---|
| Neiger | |
| Modalities | Passive (extreme force)<br>Active (antagonist internal contraction)<br>Active tension (agonist internal contraction) |
| Characters | Analytical<br>Global |

## Description of the types of stretches

### Dynamic stretches

These are stretches that are performed with extend and retract movements. The intensity depends on the amplitude and speed with which they are performed. Their objective is the activation of the stretch (myotatic) reflex and the contraction of the muscle that corresponds to this stretch without reaching the extremes of the joint's movement. It is a stretch that is used for warming up or preparing the structures as it has a friction effect and reduces the ability for elongation or the extensibility potential of the muscle. There is significant clinical controversy regarding the use of this stretch, with the majority of authors consulted advising against it[3,11,13,27,61,76,80], arguing that these stretches produce microtraumas and have a negative impact on the muscle's rigidity causing it to increase. They propose slow performance as an alternative to achieve the same objective. This would be the equivalent to active static flexibility actions.

In the sports field, the movements of rebound and balance are used in the sports warm-up with the aim of preparing the structures to rapidly and efficiently develop the contractions that are needed. They constitute a transition for explosive force work. They are not aimed at increasing ROM. Actions similar to movements used in the sport are made by those in training. They are used on tissues that can resist the tensions and absorb the tractions caused by this stretch[3,63]. For this reason they are not recommended in the initial phases of recovery from soft tissue injuries.

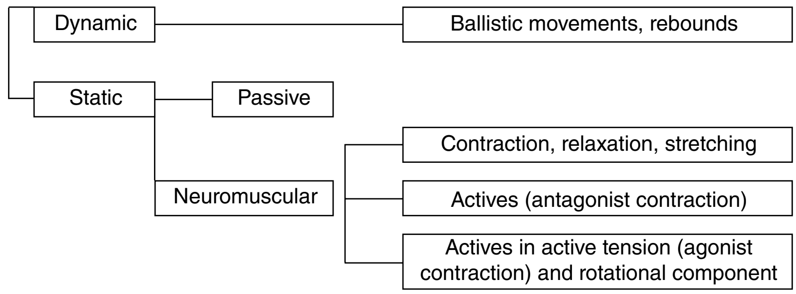


**Figure 8** French school stretching classification (Esnault, Cahors).

**Figure 9** Passive stretching on quadriceps application example: the player is placed in prone position, homolateral hand holding the ankle. The tension setting is achieved by increasing knee flexion, remains 30 seconds and repeat 2 times.

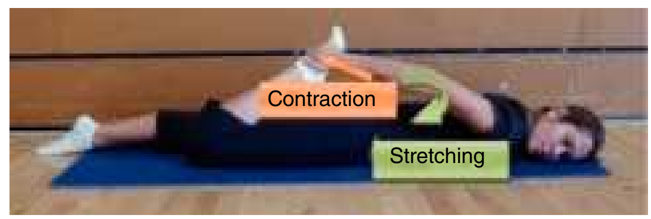


**Figure 10** PNF stretching, quadriceps: in the isometric contraction a force towards the extension of the knee is made (4 seconds). Then the muscle relaxes (4 seconds). In the next period we can take advantage of the state of post-isometric inhibition to stretch passively increasing knee flexion (15 seconds).

**Passive static stretches**

Passive static stretches put a muscle group under progressive, slow tension through assistance from an external force which can be the person's own weight, gravity, the assistance of a companion, or a physiotherapist[3].

The stretch is held for between 10 and 30 seconds (depending on the author):

- Anderson[75]: from 30 seconds to 1 minute.
- Geoffroy[28]: from 8 to 30 seconds.
- Esnault[11,13]: 12 seconds.

They are performed in a comfortable position.

They constitute a way of stretching recommended for improving or achieving articular movement (flexibility training). They are also used after physical activity with the objective of decreasing post-effort rigidity and helping to normalise the hypertonic muscles and muscle congestion. Combined with other techniques (manual therapy and massotherapy), they help to normalise amplitudes of movement in cases of articular rigidity and the loss of periarticular extensibility (Figure 9).

**Neuromuscular techniques in contraction-relaxation-stretch (PNF)**

In the pre-elongation state the muscle we want to stretch is contracted isometrically. In the period following the contraction the post-isometric inhibition state of the muscle is exploited so as to stretch it.

The length of time that the stretch should be maintained varies according to different authors:

- Geoffroy[28]: contraction (C) 10-15 seconds / relaxation (R) / stretch (S) 20 seconds.
- Sölveborn[76]: C 10-30 seconds / R / S 10-30 seconds.
- Janda[8]: C maximum 5-10 seconds / S 10-30 seconds.
- Esnault[11,13]: C 4 seconds / R 4 seconds / S 15 seconds.

This form of stretching is recommended for all situations (sport or clinical) in which the aim is to normalise the increase in muscle tone. After physical exercise (cool-down), to increase the ROM (flexibility training) and for the treatment of muscle pathology (muscle contractures or spasms)[81] (Figure 10).

**Active static stretches in passive tension**

Put under tension by means of contracting the antagonist muscle[11,13,26].

The stretch is held for between 6 and 10 seconds.

Their use depends on how long the stretch position is held:

- In the warm-up they are used to activate agonist-antagonist synergies, avoiding fatigue (they will be active and brief).
- Cool-down in a sloping position to help normalise hypertonic muscles and venous return.
- The increases in ROM will be active and larger, given that the appearance of the reciprocal inhibition reflex fosters an increase in amplitude in a muscle with spasms.

It is the first stretch that is introduced in physiotherapy once the acute phase of the torn muscle injury has passed[63] (Figure 11).


**Figure 11** Passive tension stretching, hamstring: supine position. A: The leg is fixed in hip flexion with the hands behind the thigh. B: The action of the quadriceps, increasing the active knee extension, puts tension on the hamstring. Stretching is maintained for a period of 6 seconds and repeated 2 times per muscle group.


**Figure 12** Active tension stretching. Hamstring. A: Standing, feet separated to the level of the hip, knees in slightly flexion, spine aligned in conjunction with mild transverse activation to maintain the lumbar curvature in a correct position. B: Anterior flexion of the upper body made by the hip. C: Managing the ischium to superior position. D: Setting tension. Stretching is maintained for 4 seconds and repeats 2 times per muscle group.

**Active static stretches in active tension**

The previously lengthened muscle is contracted and stretched simultaneously (put under tension by a prior eccentric activation). The stretch is performed in a position close to the effort, usually with the individual in a standing position. The stretch acts selectively on the muscle-tendon junction and the bone (myotendinous junctions and tendon-bone junctions)[11,13,19,26].

These stretches produce an increase in active rigidity, consisting of a modulation of muscle tone in preparation

**Table 8** Summary of the stretching modalities

| Type | Description | Finality | Action: mechanical component | Action: sensitive component | Time | Indications |
|---|---|---|---|---|---|---|
| Dynamic | Stretching performed with throwing or bouncing movements | Sporting warm up, activation | Elastic structures (in trained tissues) | NMS, activation of the myotatic reflex | Short | Warming to the sport activity |
| Static passive | Stress a muscle group gradually and slowly with the aid of an external force | Training flexibility increase ROM<br>ROM recovery after exercise<br>Normalize the ROM in cases of joint stiffness and loss of periarticular extensibility | The sarcomere. Connective tissue | GTO, autogenous inhibition to reduce tone | 8-30 s | Training flexibility increase ROM<br>Return to calm<br>Passive stiffness or loss of tissue extensibility |
| PNF | In pre-elongation state, isometric of the agonist, pause and passive stretching | Flexibility training. Return to calm. Normalization the ROM | Decrease of muscle rigidity and viscoelasticity | Post isometric inhibition (GTO and NMS) | According to authors | Normalize the increased muscle tone |
| Passive tension stretching | Stress for the antagonist muscle contraction | Sport warming to activate the agonist-antagonist synergies. Return to calm (longer and progressive). Increase ROM in a spastic muscle. Rupture muscle injury (subacute phase) | The sarcomere. Connective tissue | NMS (reciprocal inhibition reflex and synergies) | 6-10 s | Warming (short)<br>Return to calm (longer and progressive) |
| Active tension stretching | In pre-elongation state, the muscle contracts and stretches simultaneously (eccentric activation) | Increase active stiffness. Rehabilitation of muscle injuries due to rupture (correct answer against explosive actions) | Muscle-tendon and bone-tendon unions | NMS, activation of the myotatic reflex | 4-6 s | Warming |

PNF: contraction-relaxation-stretch; ROM: range of motion; NMS: neuromuscular spindles; GTO: Golgi tendon organ.

for the action that makes it possible to stimulate the muscle's reactive capacity. The stretches are linked with dynamic working of the corresponding group of muscles. For example, this can be seen if we stretch the peroneus longus muscles in active tension and dynamically flex the knees, heels-gluteus and then sprint[13].

The stretch is held for 4 to 6 seconds. It generates high intramuscular tension. For this reason, if the time indicated is exceeded the vascular and nervous structures can be irritated, producing cramp due to ischemia or paresthesia due to neurological irritation.

They are recommended principally in preparation for action (warm-up for physical or sports activity). They are attributed with the function of preventing muscle tendon injuries[5] (Figure 12 and Table 8).

## Conflict of interest

The authors declare they have no conflicts of interest.

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