Review article

The eccentric intervention for prevention: muscle and tendon aspects

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ABSTRACT

The muscle-tendon pathologies remain very common in sport as well as to manual workers. An action of primary and secondary prevention is crucial if we are to prevent the occurrence of these pathologies and prevent recurrence. The eccentric contractions marked by the removal of muscle insertions, gives them certain preventive and rehabilitative characteristics. It is now clearly shown that the eccentric work applied to the muscle-tendon complex, leads to progressive structural changes. These adaptations allow the muscles and tendons to better suit external stresses under which they are subjected and thereby reduce the lesion risk but also to prevent recurrence. Finally, it is also accepted that only the sub maximal eccentric exercise gradually increased helped protect (up to 1 year) of Delayed Onset Muscle Soreness in case of severe and unusual eccentric work.

Keywords: eccentric, prevention, muscle injuries, DOMS, tendinopathy

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INTRODUCTION

The non-traumatic muscle-tendon pathologies remain very frequent and are often associated with a repetitive and/or intensive professional or sporting activity.[1-3] If tendon lesions correspond essentially to tendinopathy, the muscle damage can be classified into two categories: acute injuries of intrinsic nature for which one of the risk factors corresponds to the lack of eccentric force, and the slow appearance stiffness type of pain associated with deleterious nature of unusual eccentric exercises. A work of primary and secondary prevention is on one hand essential to prevent the occurrence of these pathologies and on the other, prevent recurrence. The specificities of eccentric contractions, corresponding to the controlled elongation movement of the trained muscle and tendon, characterized by the elongation of muscle insertions, give them some preventive and rehabilitative features.[4] These can be achieved manually by the therapist or usefully supported and controlled by an isokinetic dynamometer.[4]

MUSCLE ASPECTS

Primary prevention

It is widely agreed that the muscles working eccentrically, that is, in external trail, will be driven in a stretched position of the same and limits of viscoelasticity will be stretched with a shift of the length tension to the right.[6,7] Thus, an increase in number of serial sarcomeres will enable the muscle to develop its maximum tension in the most applied position (Goldspink theory[8,9]), the muscle fibers are larger and the pennation angle is more closed, thus giving way to an optimal architectural configuration.[7] Furthermore, the muscle architecture alters during the eccentric stiffening by lengthening of the sections, which may lead to an increase in range of motion.[10] These alterations do not seem to differ even though the eccentric exercise is isotonic or isokinetic.[11] Finally, these eccentric stresses help apply preferentially the fibers of type II, mainly injured within the framework of acute muscle lesions.[7]

Regarding acute injuries of the hamstrings during eccentric stress, various non-exclusive risk factors have been proposed: an age over 25 years; a previous injury healed badly and causing a reduction in eccentric strength particularly due to an atrophy; the melanoderm sportspersons, muscle imbalance between hamstrings and knee extensors, bilateral asymmetry of the hamstrings and ratios between extensors and flexors of the lower knee; a certain degree of inflexibility, a muscle and/or general fatigue.[12] The footrace biomechanical studies have shown that the hamstrings are active during the entire cycle of walking or running, with activation peaks from the earliest phases to terminal swing.[12] Particularly during this latter, the hamstrings that are in stretched position must contract significantly to help limit the knee extension and hip flexion.[12] The biomechanical findings suggest that the eccentric contraction is a necessary condition to the hamstrings injury during the footrace; this is reinforced by the absence of concentric strain injury in sports such as swimming and cycling.[12] In addition, the elongation of the hamstrings predispose to acute muscle lesions when the stretch exceeds the mechanical limits of the latter.[12]

Clinical studies have shown that eccentric muscle work could help prevent intrinsically traumatic acute muscle injuries among sportspersons, mainly on "suppressive oriented muscles" such as the hamstrings.[13-15] These results were confirmed by a level 1 randomized and controlled study with professional and amateur football players. In fact, they observed that eccentric hamstring exercises were leading to a decrease in muscle injuries, whether new or recurrent.[16] This very simple procedure involves making repeated sessions of "Nordic Hamstring Exercise" protocol over a period of 10 weeks and this protective effect would continue up to one year.[16] This exercise requires no equipment except a cushion to put below the knees. The aim is, while the subject is on his knees

and ankles fastened to the ground by a team-mate, to lean forward by slowing the fall with hamstrings (eccentric work) while locking the hips until his hands touch the ground. The subject returns to the starting position by propelling himself on his hands to straighten up while allowing hamstrings regain control during their concentric contraction. Even though this program seems to be very intense for hamstrings, no injuries were reported during this exercise. In addition, it has been shown that the eccentric isokinetic assessment of the hamstrings with professional football players was the most discriminating and would require a suitable eccentric building program, and this in prevention of muscle injury in case of deficit.[12] In fact, the risk of muscle damage may be multiplied by 4.7 in the case of pre-existing deficiency.[17] Recently, it was shown that a 8-week training of hip-adduction (with elastic bands) increases eccentric strength of adductor muscles among soccer players, and may be a promising approach towards prevention of groin pain.[18] It also demonstrated the benefit of an eccentric work at the upper limbs. In fact, about twenty eccentric exercises of the shoulder external rotators with tennis women helps prevent the muscle imbalances of the rotator cuff and the risk of shoulder disorders such as cuff tendinopathies.[19]

The Nordic Hamstring Exercise protocol was compared to concentric exercises for the same period of training.[20] The authors observed that, over a period of 10 months, there exist a greater incidence of injuries per 1,000 hours of match in the concentric training group, but also a lower injury severity in the eccentric training group after the intervention.

Finally, in recent years a great attention has been paid to the pain appearing after all intense and unusual effort, especially after an eccentric exercise. In fact, it may cause delayed onset muscle soreness with variable intensity ("high and low responders") also known as DOMS (Delayed Onset Muscle Soreness).[21,22] These DOMS are accompanied by stiffness, swelling and reduced strength making the muscle structure particularly sensitive to palpation and movement. Muscle biopsy and electron microscopy techniques have shown the presence of microlesions of muscle tissues and muscle-tendon junctions following an eccentric exercise. The exact mechanism of occurrence of these microlesions is at present yet unclear, but there is certainly a primary mechanical component, along with a worsening process, particularly of inflammatory origin. Although they disappear spontaneously after a few days of recovery, DOMS often delay the start-up of rehabilitation programs.[21] The risk of residual inhibition cannot be overlooked and some authors[23] reported a period in excess of two weeks before recovering the initial level of maximal isometric strength. Moreover, the connective tissue remodeling involves transient periods of mechanical weakness, resulting in an intrinsic muscle lesion temporarily increased in case of new intense stresses.[7] Therefore, in order to optimize the rehabilitative programs of various diseases of the musculoskeletal system, several methods have been proposed to reduce the intensity of the DOMS. However, on investigation of the literature, we cannot fail to notice the lack of therapeutic solutions likely to reduce the intensity of the DOMS and their associated functional consequences.[24] However, it is now well accepted that the only truly effective method to avoid these muscle soreness remains sub maximal eccentric exercise gradually intensified. In this way, several studies have brought out the fact that the implementation of eccentric exercises at submaximal intensity helped give a significant protective effect vis-ŭ-vis DOMS while avoiding adverse effects related to an initial maximum eccentric exercise.[25,26] The protective adaptation granted by the eccentric training program would be optimal after two weeks[27], would persist for several weeks or even months[24,25], but would be totally ended after one year.[28] In addition, it has been revealed that the presence of a protective effect to a lesser extent, in the muscles of the contralateral limb after an initial session of maximal eccentric exercise.[29-32] Adaptive mechanisms implemented in this specific training remain however hypothetical and probably multifactorial.[33] Neurological theory justifies the appearance of muscular lesions in the aftermath of an initial eccentric exercise through the preferential recruitment of a small number of fast muscle fibers subject to high stresses.[34] During later eccentric sessions, an increased activation of motor units and/or complement activation of

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slow fibers result in a more harmonious distribution of mechanical stresses between the active fibers.[33,35] The cell theory offers the appearance of irreversible sarcomeric damage. The length of sarcomeres upon eccentric contractions would be variable, with some retaining their original length while others are stretched beyond the filaments cover membrane.36 This mechanism would become a lesion during mechanical rupture associated with an intermediate filament.[37] Else, the electron microscopy reveals some disruptions when it comes to the Z discs and their alignment within the parallel myofibrils.[23] The «cell» adaptations induced by the training concern the muscle fiber, the myofibril or the sarcomere itself: fortification of the cell membrane[38]; replacement of a pool of fibers or sarcomeres more sensitive to stress39, increase in the number of sarcomeres arranged in series, reducing, in subsequent exercises, their individual appeal and the inherent risk of a lesion.[40] Another possible adaptation would be based on the reorganization of intermediate filaments and/or filaments fortification of the intramuscular adjacent tissue by enhanced collagen synthesis.[31-43]

The extreme eccentric work can be very grueling on the musculoskeletal system, but also for the whole body. Although it's generally never been offered in clinic, either in evaluation or rehabilitation, it has been shown in experimental conditions that a maximum quadriceps work (3 x 30 maximal contractions) on isokinetic dynamometer had no more significant effect on the heart function among young sedentary patients in eccentric than in concentric mode.[44,45] This is interesting and reassuring for the examiner who is having patients performing this type of maximum physical stress.

Secondary prevention

After muscle injury, the eccentric exercise boosts each phase of the healing process, both at the muscle-tendon junction and muscular level, particularly in activating the protein synthesis, stimulating and strengthening the connective framework, increasing the number of serial sarcomeres, promoting the alignment of muscle fibers and ultimately increasing the resistance to stretch of the injured site.[7,9,14,46] This justifies the application of the low-intensity eccentric exercise (according to the no-pain rule) in the early stages during muscle anatomical lesions, primarily for therapeutic purpose, but also having regard to the improvement of the muscle healing to prevent injury recurrences.[46,47] Indeed, the eccentric exercise can be applied in the first week post-lesional but in appropriate: benignity, low intensities with about 10 to 20% maximum and slow movements. Gradually intensified over the weeks, the eccentric contractions can then participate in the neuro-muscular fortification, especially "suppressive" oriented muscles.[4,46] After a tear of the hamstrings, the decrease in time of maximum eccentric strength is frequently accompanied by a shift from the joint angle of maximum efficiency to the medium track. A goal is to reacquaint the patient with the high eccentric tension development at the end of the movement (outer track).[4] Of course, normalizing muscle performance after a tear by an isokinetic testing also helps to reduce this risk significantly,[12,13] but also helps reduce potential residual pain when back on the field.[47]

TENDON ASPECTS

Primary prevention

Mechanical forces are essential for successful tissue engineering of the tendon formation, repair or regeneration.[48] *In vitro,* it has been proved that a mechanical stimulation applied on stem cells was leading to an increase in the gene expression of collagen type I and III.[49] We have shown in an animal model involving rats that the tendon structure could change when the tendon is subjected to physical stress.[50] In fact, the tendons subject to a concentric or eccentric stress were having better resistance associated with an increased collagen synthesis leading to an increase in

cross-section. These modifications were particularly important given that the tendon was put under eccentric stress compared to concentric stress.[51] The mechanism responsible for this adaptation of the tendon to external stresses is mechanotransduction.[48,51] Mechanical loads are converted to intra-cellular response leading to an increased collagen synthesis, an improved alignment of collagen fibers, the prevention of adhesions, the stimulation of the neovascularization, a lengthening of the musculotendinous unit.[48,51-54] The cytoskeleton was playing a key role in mechanotransduction. It transmits and modulates tension between the extracellular matrix, the adhesion sites and integrins, stimulating membrane receptors and inducing a complex biochemical cascade: activation of transcriptional factors, protein synthesis, cellular differentiation ...[48]

Clinically, it has been shown that the muscle strength, of the triceps sural muscle, of patients with Achilles tendinopathy was significantly less strong in concentric and eccentric mode. This lead to a pathological aspect relative compared to the healthy characteristic.[55] This indicates that the eccentric and especially concentric work (furthermore increasing flexibility) of the triceps sural might be important for the prevention of Achilles tendonopathy.[56,57] Furthermore, it is well shown that the immobilization of a tendon would lead to a decrease in its total weight, its stiffness, its resistance to stretching but also significant changes in the number of cells. It also affects of the collagen fiber alignment and a decrease in Young's modulus (or modulus of longitudinal elasticity).[49,58] This is making it more fragile and prone to disease. However, when subjected to cyclic mechanical stress, it will maintain its normal histological pattern.[49] The footrace is a major cause of Achilles tendinopathy. In order to prevent this disease, a progressive eccentric work on the triceps sural has been proposed.56 However, a study of nearly 200 players of the Danish Super League has shown that intratendinous changes (Achilles and patellar tendon), detected sonographically, enables us to identify players at risk before they are symptomatic.[59] They have received an eccentric training program associated with stretching exercises which helped to reduce the risk of developing ultrasonographic abnormalities but did not decrease the risk of injury; on the contrary the risk would be increased.[59] This may be the result of a certain work overload at the tendon due to the regular sports practice combined with an eccentric work burdensome for the tendon as well. For a greater eccentric training preventive action to be made on tendinopathies, it should perhaps be practiced during a period of lower sportive or competitive activity.

Secondary prevention

The pathophysiology of tendinopathies is a multifactorial process involving both intrinsic and extrinsic factors, evolving independently or in combination.[3] In particular, it seems that repetitive mechanical loads and/or the application of a load exceeding the resistance of the tendon could gradually lead to micro and macroscopic lesions. The collagen fibers start becoming denatured, gradually causing tendinitis that can lead to a partial or even total rupture of the Achilles tendon.[3] In addition, these overuse lesions will result in the appearance of neovascularization associated with a neoinnervation that can cause chronic pain. Eventually, the older tendon is characterized by a slowed metabolism, with a gradual decrease in its elasticity and tensile strength.[3]

The eccentric exercise may suitably be integrated in the treatment of Achilles, patellar and even epicondylian tendon injuries.[46,60-62] This application could help foster the structural adaptation of the tendon with the aim to protect it from microlesions resulting from external stresses.[63] The exercise incorporates stretch-resisting parameters of the musculotendinous unit, the speed of movement and intensity of the contraction. The number of repetitions required to be raised, as well as a minimum of 20 to 30 treatment sessions, 3 times a week, seem necessary for maximum effictiveness.[4] However, there is clear evidence that concentric physiotherapy did not allow the same effectiveness on pain in patients with jumper's knee, only in eccentric.[64] It is also shown ultrasonographically that the eccentric rehabilitation in an Achilles tendinopathy will help

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"normalize" the tendon structure.[55] By enabling this tendon remodeling which will find its properties and adapt to external stresses, the eccentric work and will help prevent recurrences. Eccentric exercises would bring the following adaptive mechanisms: they favor the disappearance of "neovascularization" associated with tendinopathy, they stimulate the synthesis of collagen type I, they reorganize the extracellular matrix and allow the tendon to regain its homeostasis through mechanotransduction properties of the tendon, they alter the mechanical properties of the musculoskeletal unit by protecting the tendon from mechanical overload.[3,65] The precise modes of action of these adaptive mechanisms currently remain largely speculative.[65] In addition, it would seem necessary to rest at least relatively from sport in any patient wishing to receive an eccentric treatment for therapeutic use. Indeed, a randomized and controlled study among volleyball players with patellar tendinopathy having received a 12-week eccentric program, but while continuing to train and to attend competitions, did not show any improvement in symptoms.[66]

Finally, chronic pain or tendinopathy recurrence are the result of a lack of consensus regarding their treatment and the lack of effectiveness of conventional treatment which are generally analgesics or anti-inflammatory.[3] Only active treatments such as eccentric exercises or shock waves have a real effect on the tendon structure and the adaptation to external stresses by the mechanotransduction.[3] Indeed, a study conducted among Swedish professional football players has shown a significant reduction in tendinopathy relapse rate of the lower limb following a regular eccentric program enabling the tendon to gradually adapt to external stresses.[67] Another recurrent cause of tendinopathies is the lack of return to the field of play criterion. Indeed, a very early return may deprive the tendon to adapt its structure to external stresses caused by the prolonged eccentric exercises (minimum 20-30 meeting). Moreover, it is shown that the recovery of an painless Achilles tendon does not mean a recovery of the muscle-tendon function whence comes the importance of continuing in the long term the rehabilitation protocols even in the absence any symptoms in order to obtain an effective healing tissue.[68]

DISCUSSION

The muscle and tendon pathologies remain very common in sport as well as in manual workers.[1,3] Different studies have demonstrated that a primary and secondary prevention programs could decrease the occurrence of these pathologies and prevent recurrence. The eccentric contractions, which lead to a greater stress than the concentric mode, give certain preventive and rehabilitative characteristics. Indeed, it has now been clearly shown that the eccentric work applied to the muscle-tendon complex, leads to progressive structural changes. These changes are linked to the mechanotransduction process which convert mechanical stress to cellular process. These adaptations allow the muscles and tendons to better suit external stresses under which they are subjected and thereby reduce the lesion risk but also to prevent recurrence. In practice, for the hamstrings, it was demonstrated that a progressive Nordic Hamstring Exercise protocol of 1 or 2 sessions per week (3-6 sets with 6 repetitions) during 10 weeks is efficient to prevent injuries.[16,19] It was also suggested that the these eccentric exercises could be implemented and incorporated into regular soccer practice as a warmup program before starting technical and tactical drills.[69] The use of an isokinetic dynamometer could be useful, after testing the muscle strength, to a better eccentric protocol standardization.[17] These eccentric exercises are even recommended, in their sub maximal mode, in the few days after a specific treatment with platelet-rich plasma injection for tendinopathies to guide the tendon healing process.[70] Finally, it is also accepted that only the sub maximal eccentric exercise gradually increased helped protect (up to 1 year) of DOMS in case of severe and unusual eccentric work.

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