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Stretching and Injury Prevention

An Obscure Relationship

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Abstract

It is generally accepted that increasing the flexibility of a muscle-tendon unit promotes better performances and decreases the number of injuries. Stretching exercises are regularly included in warm-up and cooling-down exercises; however, contradictory findings have been reported in the literature. Several authors have suggested that stretching has a beneficial effect on injury prevention. In contrast, clinical evidence suggesting that stretching before exercise does not prevent injuries has also been reported. Apparently, no scientifically based prescription for stretching exercises exists and no conclusive statements can be made about the relationship of stretching and athletic injuries. Stretching recommendations are clouded by misconceptions and conflicting research reports. We believe that part of these contradictions can be explained by considering the type of sports activity in which an individual is participating. Sports involving bouncing and jumping activities with a high intensity of stretch-shortening cycles (SSCs) [e.g. soccer and football] require a muscle-tendon unit that is compliant enough to store and release the high amount of elastic energy that benefits performance in such sports. If the participants of these sports have an insufficient compliant muscle-tendon unit, the demands in energy absorption and release may rapidly exceed the capacity of the muscle-tendon unit. This may lead to an increased risk for injury of this structure. Consequently, the rationale for injury prevention in these sports is to increase the compliance of the muscle-tendon unit.

Recent studies have shown that stretching programmes can significantly influence the viscosity of the tendon and make it significantly more compliant, and when a sport demands SSCs of high intensity, stretching may be important for injury prevention. This conjecture is in agreement with the available scientific clinical evidence from these types of sports activities. In contrast, when the type of sports activity contains low-intensity, or limited SSCs (e.g. jogging, cycling and swimming) there is no need for a very compliant muscle-tendon unit since most of its power generation is a consequence of active (contractile) muscle work that needs to be directly transferred (by the tendon) to the articular system to generate motion. Therefore, stretching (and thus making the tendon more compliant) may not be advantageous. This conjecture is supported by the literature, where strong evidence exists that stretching has no beneficial effect on injury prevention in these sports. If this point of view is used when examining research findings concerning stretching and injuries, the reasons for the contrasting findings in the literature are in many instances resolved.

Traditionally, it is generally accepted that stretching promotes better performances and decreases the number of injuries.[1-6] Consequently, stretching exercises are regularly included in warm--up and cooling-down exercises. However, today the scientific evidence concerning the preventive effect of stretching on injuries seems unclear. In the literature, prospective studies are lacking and contradictory findings have been reported concerning the relationship between stretching and injury prevention. The purpose of this article is to review the pertinent literature and to advance a new theory to explain the relationship between stretching and injury prevention.

Before looking at the available literature on stretching and athletic injuries, it seems essential to examine how the muscle-tendon unit works during movements and how stretching would be able to reduce the risk of athletic injuries. We believe that the contrasting results in the literature concerning the relationship between stretching and injuries can be explained by taking into account the type of sports activity in which the individual participates.

1. Working Mechanism of the Musculotendinous Unit during Movement

Muscle-tendon systems may generate forces in two distinctly different ways: (i) as an elastic-like spring in stretch-shortening motion[7] that occurs, for example, during jumping-type activities; and (ii) as converters of metabolic energy into mechanical work in predominantly concentric contractions,[8] such as in cycling, jogging and swimming. In the former role, an eccentric muscle action is immediately followed by a concentric action. It is well known that if an activated muscle is stretched before shortening, its performance is enhanced during the concentric phase. Consequently, jumping, hopping and leaping movements are improved by making a counter-movement. Many previous studies have indicated that this phenomenon is the result of strain energy stored in the tendon structures.[9-18] Muscle-tendon units can store mechanical work as elastic energy during eccentric contractions. The storage and subsequent release of elastic energy during stretch-shortening cycles (SSCs) have generally been considered as an ‘energy-saving’ mechanism. However, the effect of the re-utilisation of elastic energy on the efficiency of movement has been recently debated.[19]

When a muscle has a less compliant muscle-tendon unit, more work is directly converted into external work. Activities like cycling, flying, skating and swimming use predominantly positive work-loops and little opportunity exists for absorbing amounts of energy during the task or skill.[8,20,21] A more compliant muscle-tendon unit allows for the effective storage and release of series elastic energy, but seems to be less suited for a task with a predominantly positive work-loop. Wilson et al.[22] concluded that musculotendinous stiffness was significantly related to isometric and concentric performance but not to eccentric performance. In their study, they found that the stiffer subjects performed significantly better than the more compliant subjects on both the isometric tests and on the majority of the concentric tests, since the stiff muscles immediately transfer force to the muscle-bone junction. In contrast, compliant muscles generated less power due to the delayed transfer of energy through the musculotendinous unit. Wilson et al.[23] observed in another study that increasing the compliance of the musculotendinous unit through stretching, increased the contribution of elastic strain energy to movement, facilitating performance in an SSC movement.

Therefore, it seems that different types of sports need different levels of musculo-tendinous compliance. Many physical pursuits such as cycling, swimming, skating, wrestling and boxing involve the rapid development of force in an isometric or concentric muscular contraction, and it would appear that such performances could be enhanced through an increase in musculotendinous stiffness. The stiffer the muscle-tendon unit, the faster the force is transferred to the bones, and the resulting movement of the joint is quicker. Therefore, looking only at performance, it might be possible that in these sport activities there is no need for a highly elastic muscle-tendon that acts like a spring. The aim of sports with a high amount of positive work-loops is to convert metabolic energy as fast as possible into mechanical work.

Conversely, in sports with a high-intensity SSC, a more compliant muscle-tendon unit may be required for the storage and release of elastic energy. A muscle-tendon unit involved in such SSCs, needs a high storage capacity for potential energy and must, therefore, be sufficiently compliant. For enhanced performance, it seems that for these kinds of sports there is a great need for a more compliant muscle-tendon unit.

It should be considered that there may be an ideal level of compliance for a musculo-tendinous unit during a task. This level can be influenced by structural characteristics of the unit. For instance, Shadwick[24] has shown that compared with mature tendons, those of younger animals have a lower capacity to store and release strain energy as a result of higher compliance levels and greater amounts of hysteresis. The level of overall muscle compliance can also be influenced by contractile element activation and hence compliance can be modified to suit different tasks. As such, Bach et al.,[25] and more recently Wilson et al.,[26] have noted that when the mechanical properties of the unit are optimised then maximal performance (e.g. for rapid force production or economy) is obtained.

2. How Can Stretching Reduce the Risk of Injuries?

Before looking at the available literature where the relationship between stretching and injury prevention is examined, we need to understand how stretching would be able to reduce the risk of athletic injuries. Firstly, consideration of the compliance of the muscle-tendon unit is essential. To fully understand the effect of compliance, we need to appreciate differences between the active contractile (muscle) component and the passive (tendon tissue) component of the muscle-tendon unit. According to Safran et al.,[27] the ability of a muscle to absorb energy is dependent on both components. In a compliant system when the contractile elements are active to a high level, more energy can be absorbed by the tendon tissue, thereby reducing trauma to muscle fibres. However, in case of a low compliance of the tendon, forces will be transferred to the contractile apparatus with little energy absorption in the tendon. This provides a mechanism to explain the noted association between reduced flexibility and occurrence of muscle injury during SSC motion. Evidence for this conjecture is found in the *in vivo* work by McHugh et al.,[28] who found increased evidence of muscle damage following eccentric exercise in subjects with greater passive stiffness. In addition, this is consistent with other research,[29] which showed that in the outer ranges of movement, as tendon stiffness increases, greater passive forces are generated within the muscle. In people with stiff tendons, even greater passive muscle forces would be expected to develop during SSC, which would therefore increase the risk of muscle injury. In contrast, a more compliant tendon, with greater energy-absorbing capabilities, would therefore seem to reduce the risk of muscle injury during SSC motion.

On the basis of these findings, the rationale for stretching as part of an injury prevention programme is to increase the compliance of the tendon unit, and consequently more energy can be absorbed for a given SSC performance.[30] Can stretching influence the compliance of the tendon structure? Recently, Kubo et al.[31] investigated this question and looked for the acute and long-term effects of stretching on human tendons *in vivo*. They showed, using ultrasonography, that it was possible to quantify the viscoelastic properties of human tendon *in vivo*. Their results on seven healthy men showed that immediately after the execution of static stretching exercises the tendon stiffness was transiently decreased.[31] In a more recent study,[32] the same authors investigated whether resistance and stretching training programmes altered the viscoelastic properties of human tendon structures. In that study on eight healthy males they showed that an 8-week stretching programme (two stretching sessions daily, 7 days per week) made the tendon structures significantly more compliant.[32] Their findings are in agreement with previous animal studies that reported an increase in tendon compliance as a result of a stretching regime.[33-35] Kubo et al.[32] speculated that stretching may be an effective means to increase the elastic energy to be utilised during exercise involving a SSC, by reducing the viscosity of tendon structures.

Concerning the relationship between stretching and injury prevention, stretching and the subsequent decrease in tendon stiffness may lessen the imposed load across the muscle-tendon unit during SSC movements.[31] The mechanism by which the decrease in stiffness occurs immediately after stretching and on the long term cannot be determined from the available research. However, McNair et al.[36] states that immediately after stretching, the mechanism could involve the movement of the mobile components/elements within the tissues. That is, liquid and polysaccharides may be redistributed within the collagen matrixes.[36] After a periodic stretching programme, the changes are more likely to involve structural changes to collagen.

Nevertheless, transient or chronic increase in tendon compliance as an acute or chronic adaptation of stretching will theoretically lead to a higher ability of the tendon to absorb energy. In the case of a high-intensity SSC movement (when a large amount of energy needs to be absorbed), the greater energy absorbing capacity of the stretched tendon will theoretically lead to a lower injury risk in the tendon *and* the muscle structures: since (i) the tendon is able to absorb more energy, the high stresses on the tendon (typically coming from the high SSC movements) will less likely reach the maximal energy-absorbing capacity of the tendon, and thus will less likely lead to injury to the tendon; and (ii) since the stretched tendon is able to absorb more energy, less energy is transferred to the contractile apparatus, therefore reducing the risk of injury within this component of the muscle.

Does this theoretical background for stretching in injury prevention in sports with a high SSC component, as described in the paragraph above, stand-up when examined with the available literature in sports with high SSC movements?

3. Stretching and Injuries in Sports with High Stretch-Shortening Cycle (SSC) Movements

Ekstrand et al.[3] found that a group of elite soccer teams randomised to a routine of warm-up and stretching before exercise, leg guards, special shoes, ankle taping, controlled rehabilitation, education and close supervision had 75% fewer injuries than the control group, which received no intervention. They concluded that the proposed prophylactic programme, including close supervision and correction by doctors and physiotherapists, significantly reduces soccer injuries. The same authors[2] hypothesised that a redesign of the warm-up with more emphasis on stretching and the addition of cooling-down exercises reduces injuries. According to Bixler and Jones[1] high-school football injuries are very frequent each year in the US. In a randomised intervention study, they investigated whether completing a warm-up and stretching routine after halftime reduced the incidence of third-quarter injuries. The results of their study showed a reduction in injuries with the warm-up and stretching exercises.

Witvrouw et al.[5] determined the intrinsic risk factors for the development of patellar tendinopathy in an athletic population. Before the study, 138 male and female physical education students had been evaluated for anthropometric variables, leg alignment characteristics, muscle tightness and strength parameters. The study revealed that the only significant determining factor was muscular flexibility, with the patellar tendinosis group being less compliant in quadriceps and hamstring muscle-tendon unit. Lower flexibility of the quadriceps and hamstring muscles may contribute to the development of patellar tendinosis in an athletic population. Therefore, the authors concluded that a stiff quadriceps and hamstring muscle-tendon unit was a risk factor for the development of patellar tendinopathy. The same authors published a similar prospective study of 146 professional soccer players.[6] Players with a hamstring or quadriceps lesion were found to have a statistically lower compliance of these muscle-tendon units prior to their injury compared with non-injured soccer players. On the basis of these findings, they suggested that stretching might play an important role in the prevention of this condition.

4. Stretching and Injuries in Sports with No or Low SSC Movements

If one participates in a sport with a low or no frequency of SSC movements (e.g. cycling, swimming), or a sport with a high frequency of SSC movements but always at a low percentage of the maximum (e.g. jogging), these movements utilise little of the energy-absorbing capacity of the muscle-tendon unit. For optimal performance in such activity, the tendons do not need to function as good energy-absorbing structures. Since the maximal energy-absorbing capacity of these unstretched (stiff) tendons is less likely to be exceeded during these sporting activities, the risk of tendon or muscle damage will be relatively low. A stiff tendon will theoretically be sufficient to deal with the loads imposed on the musculo-tendinous structures during these sports, and hence one cannot expect to decrease the risk of injuries by instituting a stretching programme. Furthermore, stretching in these athletes will probably not lead to an *increase* of injuries. Subsequently, why shouldn't they stretch if it doesn't harm? The answer is related to performance. If these athletes stretch a lot and make their tendons more compliant, they may be less adapted for their sports activities and consequently be less efficient during movement. In some sporting activities, stiff tendons are advantageous for performing brisk, accurate movements because they allow rapid tension changes and hence faster joint motion responses, and perhaps provide more sensitive feedback to the central nervous system concerning muscle length and tension.[11,12,37] Looking at the literature concerning the effect of stretching on low SSC sports there seems to be some evidence for the above-stated concept.

In 1993, van Mechelen et al.[38] studied the effect of a health-education intervention on jogging injuries. The intervention consisted of information/education and the subsequent performance of standardised warm-up, cooling-down and stretching exercises. Male recreational joggers (n = 421) were randomly split into an intervention and a control group. During the 16-week study, both groups kept a daily diary of their jogging distance and time, and reported all injuries. The results of this study did not identify any evidence of a reduction in soft tissue injuries in the intervention group. The authors concluded that the intervention was not effective in reducing the number of jogging injuries. Recently, Yeung and Yeung[39] assessed in their review the available evidence for preventive strategies for lower limb soft tissue injuries caused by jogging. Their review identified five eligible trials (1944 participants in intervention groups, 3159 controls) that examined the effect of a stretching regimen on lower limb injuries caused by jogging.[4,38,40-42] Two studies evaluated the effect of stretching outside the training sessions.[4,40] The remaining three studies examined the effectiveness of stretching immediately before training.[38,41,42] Their exploratory analysis of these five studies showed that in only one study[4] a significant effect of stretching on the incidence of injuries could be found. The authors concluded on the basis of these findings that insufficient evidence exists to suggest that stretching is effective in preventing lower limb injuries in joggers.[39]

Looking in the literature concerning swimming and cycling, no prospective studies could be found examining the effect of stretching on the incidence of injuries. However, looking at the injury incidence in these sports,[43,44] the rather low incidence of musculo-tendinous injuries is interesting and supports our model. Looking at the regular training schedule of professional cyclists in Europe, it is surprising to see how little stretching is performed in most teams. In contrast, swimmers tend to devote considerable time to stretching. However, recent literature[45] advises to minimise stretching, particularly at the shoulders where hyper-mobility is often apparent.

5. Conclusions

In summary, stretching is perhaps the most common routine advocated by sports coaches and sports-medicine professionals. However, in the literature, conflicting data have been reported concerning the relationship between flexibility and athletic injury. Stretching recommendations are clouded by misconceptions and conflicting research reports. The literature reports opposing findings from different samples.

We believe that a part of this contradiction can be explained by considering the type of sports activity in which an individual participates. Sports involving ‘explosive’ type skills, with many and maximal SSC movements require a muscle-tendon unit which is compliant enough to store and release the high amount of elastic energy. Recently, it has been shown that stretching is able to increase the compliance of human tendons, and as a result increase the capacity of the tendon to absorb energy. Consequently, in these sports we suggest that stretching is important as a prophylactic measure for injury prevention. When an individual’s muscle-tendon unit is less flexible in these types of sports activities, there exists a predisposing factor for exercise-related injuries since the tendon is unable to absorb enough energy, which may lead to tendon and/or muscle damage. When the sports activity contains no, or only low SSC movements (cycling, jogging), all or most of the work is directly converted to external work. In these cases, there is no need for a compliant tendon since the amount of energy absorption remains low. Hence, additional stretching exercises to improve the compliance of the tendon may have no beneficial effect on injury prevention.

It must be acknowledged that the aetiology of injuries can be multifactorial. Taking out only one aspect (e.g. stretching) and examining its effect on the incidence of injuries is a rather narrow outlook on this problem. For example, fatigue is widely believed to be predisposing factor in muscle injury.[38] In addition, other problems remain. Even within the same sport, the demands on different players (position on the field) may be different. However, we believe that far greater attention should be given to an examination of the type of activity in which the athlete participates when one considers the merits of stretching to reduce injury.

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