Eccentric exercises; why do they work, what are the problems and how can we improve them?

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ABSTRACT

Eccentric exercises (EE) have proved successful in the management of chronic tendinopathy, particularly of the Achilles and patellar tendons, where they have been shown to be effective in controlled trials. However, numerous questions regarding EE remain. The standard protocols are time-consuming and require very motivated patients. EE are effective in some tendinopathies but not others. Furthermore, the location of the lesion can have a profound effect on efficacy; for example, standard EE in insertional lesions of the Achilles are ineffective.

Until recently little was known of the effect of EE on tendinopathic tendons, although a greater understanding of this process is emerging. Additionally, recent in vivo evidence directly comparing eccentric and concentric exercises provides a possible explanation for the therapeutic benefit of EE. The challenge now is to make EE more effective. Suggestions on areas of future research are made.

Tendinopathies are a major component of sports medicine. The prevalence of Achilles tendinopathy in runners has been estimated at 11%,[1] 20% of knee injuries presenting at a sports clinic have been diagnosed as patellar tendinopathy[2] and 1–2% of the general population experience tendinopathy of the forearm extensor tendons.[3] Other common tendinopathies include the rotator cuff, hamstring and adductor tendons.[4] Tendinopathy can be regarded as common, often difficult to treat and potentially career-threatening.

Although the pathology of tendinopathy is poorly understood, it is generally accepted that in the chronically injured tendon the repair capacity of the tendon is exceeded. Chronic tendinopathy is a degenerative condition, or at least one with a failed healing response, which is essentially devoid of an inflammatory infiltrate. Consequently it has become increasingly recognised that anti-inflammatory strategies are largely ineffective in the management of chronic tendon conditions.[4] This has led to increased interest in other therapeutic modalities.

ECCENTRIC EXERCISES

Eccentric exercises (EE) involve the lengthening of a muscle–tendon unit as a load is applied to it. This is in distinction to concentric exercises (CE) where the muscle–tendon unit shortens and isometric exercises where the muscle–tendon unit length remains constant. Eccentric exercises have emerged as a popular treatment modality for tendinopathy, particularly for the Achilles and patellar tendons. Although the quality of some of the trials relating to EE have been criticised,[5] there is a body of evidence to suggest that in these conditions EE are an effective management option.

Eccentric exercises and Achilles tendinopathy

Eccentric exercises were initially suggested by Stanish and Curwin. In 1986 they reported that a 6-week EE programme in 200 patients with Achilles tendinopathy led to complete relief in 44% and a marked improvement in a further 43% of patients.[6] Unfortunately their study was weak methodologically as there were no control subjects. The Stanish protocol involves once-daily exercises, stretching, and a progressive increase in the speed of the movements.

Influenced by the ideas of Stanish and Curwin, Alfredson produced the first controlled (but non-randomised) study on eccentric loading in patients with mid-body tendinosis using surgical management as the control group.[7] The Alfredson eccentric loading protocol involved six sets of eccentric loading exercises (three sets of 15 repetitions with an extended knee and three sets with a flexed knee) repeated twice daily, every day for 12 weeks and progressed by adding weight. Alfredson suggested, based on the work of Kellis,[8] that the effects of eccentric exercise were not velocity-specific and his patients therefore performed the exercises slowly. This paper demonstrated very high success rates of EE in rehabilitation of mid-Achilles tendon lesions.

Several subsequent studies on Achilles tendinopathy have been published, generally with athletic (or at least physically active) subjects.[9–12] Whilst many of the studies have limitations of trial design, the body of evidence does suggest EE are effective for treatment of mid-portion tendinopathy of the Achilles tendon. When the studies have been extended to a more general and less athletic population, although still positive, the results of EE have been less impressive.[13]

It does appear that it is the eccentric component of the exercise that is the key to a successful outcome. In a direct comparison of EE and CE in mid-Achilles tendinopathy, Alfredson found that the eccentric group improved to a much greater extent than the concentric group.[9] Hence the eccentric component of the exercise appears to be instrumental in the therapeutic response. However, many unanswered questions remain. Stanish used an eccentric loading protocol with increasing speed; Alfredson adopted a protocol with a constant slow speed and allowed patients to exercise into their pain. It is not known which is the most effective treatment, as direct comparisons between the two protocols have not been made. Although the study by Young[14] did use both

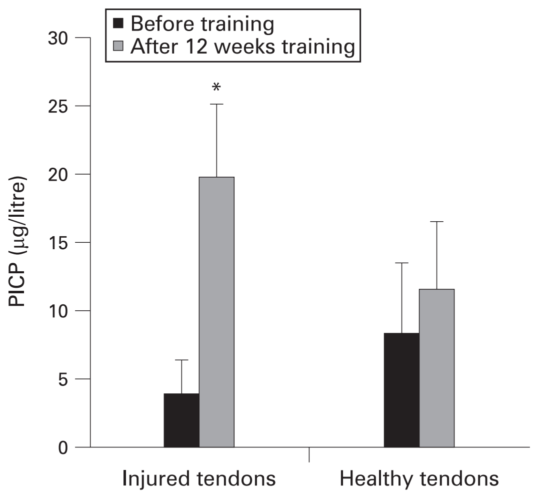


Figure 1 Eccentric training and collagen type I synthesis. Carboxyterminal propeptide of type I collagen (PICP) was determined in the tissue around the Achilles tendon before and after 12 weeks of eccentric training. Interstitial tissue concentrations were calculated from microdialysis determinations. In the previously injured tendons (n = 6), eccentric training was found to increase collagen synthesis, whereas the synthesis was unchanged in the healthy tendons (n = 6) (mean (SEM)) (*p<0.05 vs rest). Figures 1 and 2 are reproduced from Langberg H, Ellingsgaard H, Madsen T, Jansson J *et al*. Eccentric rehabilitation exercise increases peritendinous type I collagen synthesis in humans with Achilles tendinosis. *Scand J Med Sci Sports* 2007;**17**:61–6, with the permission of Blackwell Publishing.

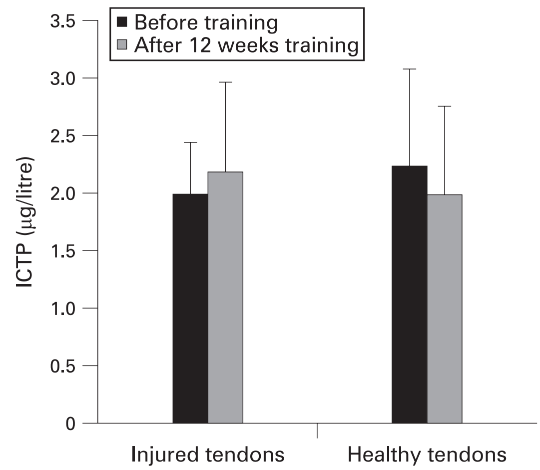


Figure 2 Eccentric training and collagen type I breakdown. Carboxyterminal telopeptide region of type I collagen (ICTP) was determined in the tissue around the Achilles tendon in response to 12 weeks of eccentric training. Interstitial tissue concentrations were calculated from microdialysis determinations. No effect could be determined in either the previously injured tendons (n = 6) or in the healthy ones (n = 6) (mean (SEM)) (*p<0.05 vs rest).

protocols in the management of patellar tendinopathy, because of the methodology adopted in this study (several parameters were varied simultaneously) the study does not provide a clear answer to this important question.

Insertional Achilles tendinopathy

Although the pathophysiology of tendinopathy is poorly understood, it has become apparent that different areas of the tendon behave in different ways. The role, structure and pathology of the enthesis[15 16] are very different to those of the main tendon body. Whilst the tendon body acts as both an energy store and to transfer energy from the muscle to the limb, it is the enthesis that acts to anchor the tendon to the bone. The area of the enthesis is complex and has been described as an "enthesis organ".[15 16] Several different pathologies are possible at the enthesis; for example, at the Achilles these include retrocalcaneal bursitis, degenerative tendinopathy and calcification.

Most of the studies on EE have concentrated on injury to the main body of the tendon. When patients with insertional Achilles tendinopathy have been studied, the results have been disappointing. In the Fahlström study of EE,[17] 89% of patients with tendon body lesions reported a satisfactory response. For those with insertional lesions only 32% had a satisfactory response (although this figure is likely to be an overestimate as it may include both a placebo response and patients in whom their condition might have improved spontaneously). Clearly EE are unsatisfactory in insertional Achilles tendinopathy. A small pilot study examined a modified protocol where EE were performed without dorsiflexion and reported greater satisfaction levels (67%), but unfortunately this study did not include a control group.[18] Further work in this area would be extremely welcome.

Patellar tendon

In a recent review of EE for patellar tendinopathy,[19] seven trials were identified.[14 20–25] As with EE in Achilles tendinopathy, most involve only small numbers of patients and generally have a short follow-up time. All studies combined involve only a total of 162 patients. Nevertheless, eccentric training for patellar tendinopathy has become a popular clinical therapy.

There is great variation in EE protocols for patellar tendinopathy. The study by Cannell *et al*,[20] using a similar protocol to Stanish and Curwin (patients were instructed to exercise daily with a warm-up, stretching and progressively faster EE), failed to show a benefit of EE over CE. The study was limited by small numbers (10 patients in the EE group, nine patients in the CE group). However, the subsequent study by Alfredson, using a similar protocol to that used in his Achilles studies (exercises performed slowly, twice daily with no stretching or warm-up but can be performed into pain), showed a very marked positive effect of EE compared with CE. Again the study was limited by small numbers (15 patients only).[21] This study, and most that have followed, have used a decline board rather than a flat step.[21 23–25]

Subsequent studies have shown a mixed picture. The study by Young[14] and a further study by Alfredson[24] both suggested benefit from eccentric loading. The study by Visnes of volleyball players who continued to train and compete during the treatment period found no benefit from EE compared with a non-EE control group.[23] The study by Bahr demonstrated equivalence of surgery (open tenotomy) and EE.[25]

Regarding the relationship between the location of pathology within the patellar tendon and effectiveness of EE, it is impossible to draw a conclusion since each study adopts different inclusion criteria. Two studies looked at patients with lesions at the proximal patellar tendon,[21 24] three studies looked at patients with insertional patellar tendinopathy,[20 22 23] one study looked at both proximal and distal patellar tendinopathy,[25] and one study did not distinguish between different anatomical sites of pathology.[14] Given the small number of patients in each subgroup of patellar tendinopathy (tendon

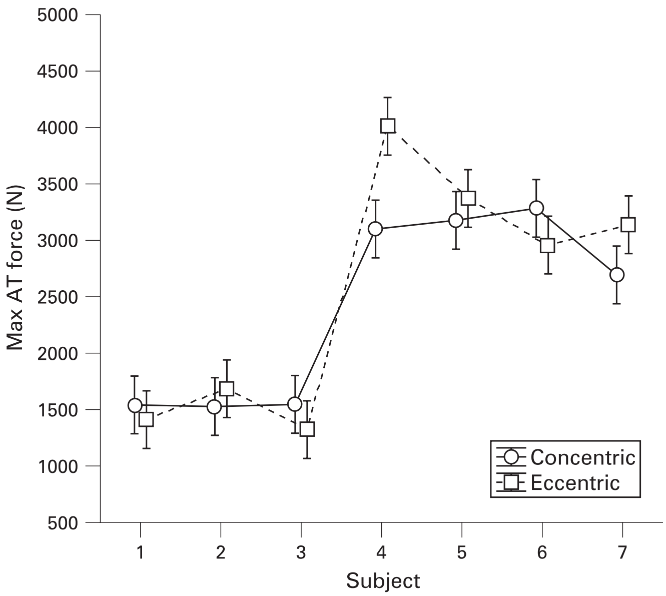


Figure 3 Mean number of inflexions per cycle for each subject/activity. No error bars due to low number of potential values. Inflexions of the AT force pattern occurred much more frequently during eccentric loading of the AT than during concentric loading for all subjects ($p<0.001$). Figures 3 and 4 are reproduced from Rees JD, Lichtwark GA, Wolman RL and Wilson AM. The mechanism for efficacy of eccentric loading in Achilles tendon injury; an *in vivo* study in humans. *Rheumatology* 2008;**47**:1493–97, with the permission of Oxford University Press.

origin, mid tendon body and tendon insertion) it is difficult to draw a conclusion on how effective EE are in each subgroup.

Tendinopathy at other locations

A small number of studies have examined the use of eccentric exercises in the management of tendinopathy of the lateral extensors of the forearms.[26–28] There is some evidence suggestive of an increase in function using EE compared with ultrasound in the treatment of lateral extensor tendons,[29] and a recent study adopted an isokinetic eccentric protocol in the management of lateral elbow tendinosis and reported promising results.[30] No randomised study on the effectiveness of EE on the rotator cuff has been published, although a small uncontrolled pilot study of nine patients did suggest a significant benefit of EE (patients with arthritis of the acromioclavicular joint or significant calcification were, however, excluded).[31] Further trials on both tendinopathy of the rotator cuff and lateral extensor forearm tendons are required in order to evaluate EE more fully.

WHAT MAKES ECCENTRIC EXERCISES EFFECTIVE?

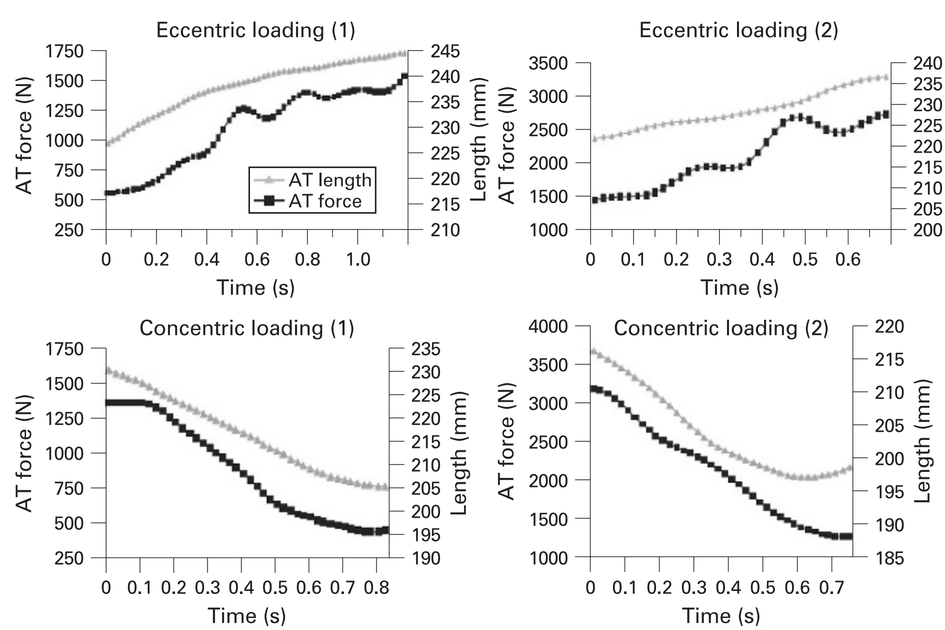
Initially there was only speculation to explain why EE was effective. Stanish and Curwin suggested that in EE the tendon is subjected to greater forces than in CE and hence to a greater remodelling stimulus.[6 32] They further suggested that EE may lengthen the muscle–tendon unit, resulting in less strain being placed on the tendon during motion. Certainly the incidence of tendinopathy increases with increasing age, and this parallels data showing that tendinous tissue becomes more compliant with ageing.[33] However, no evidence was presented to suggest that their EE increased tendon stiffness. There is evidence that EE can develop greater forces in muscle during dynamic movements,[34] but this evidence does not extend to the specific exercises in the Stanish (or Alfredson) EE protocols.

Effects of eccentric training on the tendon and muscle–tendon unit

The pathophysiology of tendon injury and healing is incompletely understood. It does appear, however, that in established tendinosis the tendon often does not progress into an active (or at least successful) healing cycle. EE may work by providing a mechanical stimulus to the quiescent tendon cells.

Alfredson initially speculated that EE may be associated with changes in the metabolism of undefined substances in the tendon causing alterations in the tendon pain perception. He later observed that during each eccentric exercise cycle there was a temporary halting of blood flow within the tendon neovessels. He suggested this blood flow interruption may damage both the neovessels and accompanying nerves, leading to both a normalisation of tendon vasculature and reduction in

Figure 4 Force characteristics for eccentric and concentric loading of the AT. In eccentric loading the AT is subject to repeated unloading and loading in a sinusoidal-type pattern. In concentric loading, this additional loading and unloading are largely absent. Typical examples are shown for one woman (subject 1) and one man (subject 2). Eccentric loading is shown in the top two graphs and concentric loading in the bottom two graphs.



pain levels.[35] However, no evidence is presented to support this theory and, furthermore, the effect of CE (or running) on tendon neovessels was not studied.

Some authors have studied the physical effects of EE on pathological tendons. Generally these studies have not contrasted EE with CE, and therefore the observations will not necessarily be specific to EE. Nevertheless, these studies do shed light on changes over time to the eccentrically loaded tendon.

There is some evidence to support the view that tendon stiffness may increase following EE. Pousson *et al*[36] have reported an increase in passive stiffness after eccentrically training the elbow flexors. EE have also been reported to induce sarcomereogenesis and it has been speculated that EE could also cause an increase in fascicle length.[37]

However, in a prospective study Mahieu[38] evaluated the mechanical properties of the plantar flexor muscle–tendon unit during a six week EE training period. It was found that tendon stiffness did not alter, but that the degree of ankle dorsiflexion did increase, suggesting structural change within the plantar flexor muscles. The study is limited by the short duration (6 weeks only) and it is possible that changes in tendon stiffness may still occur over a longer period. Nevertheless, the study is an important reminder that it is the whole muscle–tendon unit that is likely to be involved in mechanical adaptations during exercise training and not just the tendon.

Physical training in general has been shown to increase both the synthesis and degradation of collagen,[39] and in the longer term this may lead to a net increase in collagen. Recently it has been recently elegantly demonstrated by Langberg and coworkers, by use of the microdialysis technique, that a chronically injured Achilles tendon responds to a 12 week EE programme by increasing the rate of collagen synthesis.[40] In this study 12 patients (six with Achilles tendinosis and six normal controls) performed EE over a 12 week period. The EE group had increased collagen synthesis (peritendinous type I collagen) without a corresponding increase in collagen degradation. There was also a corresponding drop in pain levels (in line with other studies). The results of this study are shown in figs 1 and 2.

The effect of EE on Achilles tendon microcirculation has also been studied.[41] Achilles tendon oxygenation was not impaired by an EE programme but was accompanied by a decrease in postcapillary venous filling pressures, the authors suggesting that this reflects improved blood flow. Again this study looked only at eccentric exercise so it is not possible to determine whether this is a specific effect of EE.

Studies comparing eccentric and concentric exercises

Only a very small number of studies have compared concentric and eccentric loading directly. One study has compared Achilles tendon volume and intratendinous signal before and immediately after EE and CE.[42] The method was complex in that, whilst all the eccentrically loaded tendons were symptomatic, the concentrically loaded tendons included both symptomatic and asymptomatic tendons. Both exercise programmes resulted in increased total tendon volume and intratendinous signal. The authors suggest this increase may be explained by higher water content and/or by increased blood flow in the Achilles tendon during and/or immediately after training, but found no difference in these parameters between the CE and EE groups.

Most recently we have investigated the in vivo mechanical properties of the Achilles tendon during EE and CE. We utilised a method that combines real-time ultrasonography (US) and motion analysis with concurrent force and EMG recording and directly compared the physiological stimulus to the Achilles tendon during the two exercises.[43] We demonstrated that peak tendon forces in EE are of the same magnitude as those seen in CE (fig 3). This means that tendon force magnitude, as originally suggested by Stanish,[6] cannot alone be responsible for the therapeutic benefit seen in EE. Our result is in keeping with the conclusion from previous work, highlighted by Newham, that, although there is in vitro evidence to suggest eccentrically generated peak forces should be higher than peak concentrically generated forces, this does not extend to the in vivo situation.[44]

If the efficacy of EE cannot be explained by the magnitude of force, then what is responsible? Intriguingly, we observed a pattern of sinusoidal loading and unloading in EE which was not demonstrated in CE (fig 4). The fluctuations in force probably reflect the difficulty in controlling a dynamic movement with a lengthening muscle; similar to the experience that it is easier to lift a heavy weight under precise control than to lower the same weight. We propose that these fluctuations in force may provide an important stimulus for the remodelling of tendon. Certainly in the remodelling of bone it is known that bone responds to high-frequency loading and appropriate mechanical signals can lead to a dramatic increase in bone density.[45]

THE FUTURE

Although the quality of trials concerning eccentric exercise has deficiencies and has been criticised, EE have proved to be a popular conservative treatment, particularly for tendinopathy of the body of the Achilles tendon and the patellar tendon. However, many questions remain. Trials from a more general population[13] suggest that in real life EE are less effective than some of the earlier trials have suggested.[7] Adherence to the EE protocols requires highly motivated patients; this may not always be possible in non-trial clinical situations and in sedentary populations. However, if the protocols could made more effective (and quicker to perform or required to be

What is known on this topic

- Tendinopathy is common although pathology of this condition is poorly understood.
- Eccentric exercises have become a popular treatment for degenerative tendinopathy.
- Various suggestions have been made for the efficacy of eccentric exercises but they have not been evaluated systematically.

What this study adds

- The importance of site of the pathology within the tendon is highlighted. It is demonstrated that in patellar tendinopathy, in particular, eccentric exercises have not been evaluated systematically for treatment of lesions in the different anatomical areas of the tendon.
- This study systematically examines the effects of eccentric training on tendons over time and reviews studies directly comparing eccentric and concentric exercises.
- Suggestions for future research are made.

performed less frequently) this might improve both patient adherence and also therapeutic efficacy in "real life" situations.

Little is known of the optimal protocol for EE. Indeed, fundamental questions remain unanswered, such as how fast the exercises should be performed and progressed. This is certainly an area worthy of future research. The specific location of the pathology within a tendon has increasingly been shown to have an effect on the efficacy of EE, and further study in this area is also suggested. Other potential areas of research include studying the effect of periodisation of training, a technique currently perhaps more familiar to athletes and their coaches than to sports medicine physicians.

Evidence is emerging on the effects of EE on tendons over time, including effects on collagen synthesis, biomechanics, structure and capillary blood flow, although most of these studies have not compared EE with CE. Recently, however, in vivo evidence has emerged suggesting that the mechanical stimulus during eccentric loading of a tendon is fundamentally different to concentric loading, not in terms of force magnitude, but in terms of the frequency of force fluctuations. It may be that these force fluctuations may have an important role in stimulating successful tendon remodelling. Further studies in this area are also suggested.

Competing interests: None.

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