Eccentric exercise: acute and chronic effects on healthy and diseased tendons

Michael Kjaer and Katja M. Heinemeier
Institute of Sports Medicine, Department of Orthopedic Surgery M, Bispebjerg Hospital, and Center for Healthy Aging, Faculty of Health and Medical Sciences, University of Copenhagen, Copenhagen, Denmark
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Kjaer M, Heinemeier KM. Eccentric exercise: acute and chronic effects on healthy and diseased tendons. J Appl Physiol 116: 1435–1438, 2014. First published January 16, 2014; doi:10.1152/japplphysiol.01044.2013.—Eccentric exercise can influence tendon mechanical properties and matrix protein synthesis. mRNA for collagen and regulatory factors thereof are upregulated in animal tendons, independent of muscular contraction type, supporting the view that tendon, compared with skeletal muscle, is less sensitive to differences in type and/or amount of mechanical stimulus with regard to expression of collagen, regulatory factors for collagen, and cross-link regulators. In overused (tendinopathic) human tendon, eccentric exercise training has a beneficial effect, but the mechanism by which this is elicited is unknown, and slow concentric loading appears to have similar beneficial effects. It may be that tendinopathic regions, as long as they are subjected to a certain magnitude of load at a slow speed, independent of whether this is eccentric or concentric in nature, can reestablish their normal tendon fibril alignment and cell morphology.

tendinosis; tendinitis; extracellular matrix

REVIEW

Disregarding whether muscular contractions are eccentric, concentric, or isometric in nature, the collagen-rich matrix of the myotendinous unit is crucial for force transmission and thus overall muscle function. The influence of eccentric exercise on skeletal muscle has been investigated thoroughly throughout the years and is dealt with in other papers in this issue, whereas investigation of the specific influence of eccentric loading on healthy and diseased tendon tissue has been carried out to a much lesser extent and only by a few research groups. However, the understanding of how eccentric exercise can influence both molecular regulation, structural adaptation, and mechanical properties of tendon is of the utmost importance for both normal movement, sports performance, and injury treatment (23).

Eccentric exercise and the influence on normal healthy tendon

In an animal experimental model, the effect of 4 days of eccentric, isometric, and concentric strength training on tendon and muscle tissue adaptation was studied (12, 13). Here the contraction induced upregulation of mRNA expression for important tendon structural proteins like collagen I and III, tendon regulatory factors such as insulin-like growth factor I, transforming growth factor-β, and connective tissue growth factor (CTGF), as well as cross-link forming enzymes (lysyl oxidase), was similar with all three contraction types. Thus the tendon response was independent of the contraction type (12, 13). With this experimental setup, the muscular work output (mean force × time integral) was almost doubled, with eccentric exercise compared with concentric exercise, and thus the similar gene-expression response to all loading types indicates that the animal tendon tissue response is also insensitive to differences in the total load experienced above a certain (unknown) threshold (12, 13). Interestingly, under the same three different contraction conditions, skeletal muscle expression of collagen, transforming growth factor-β, and CTGF was more pronounced with eccentric and isometric contractions compared with concentric work, which could of course also be a result of the differences in total load (12). This suggests that tendon, compared with skeletal muscle, is less sensitive to differences in type and/or amount of mechanical stimulus with regard to expression of collagen, regulatory factors for collagen, and cross-link regulators (12, 13). On the other hand, a recent study has found that 5 wk of regular treadmill running with eccentric vs. concentric loading (downhill vs. uphill running) tended to favor the eccentric loading with regard to improvement of mechanical properties and collagen accumulation (18). However, these results were not clear-cut (18), and the two animal studies are not easily compared, since the magnitude of load, the time courses, and the outcome measures were very different (12, 13, 18).

Whereas there was a clear gene-expression response to exercise loading of animal tendons (12, 13), it is questionable...
whether this can be extrapolated to human tendon. No studies have, to our knowledge, specifically studied the effect of eccentric exercise on human tendon expression of collagen (and related factors), but studies using concentric exercise indicate that human tendons are far less responsive than rodent tendons. Thus two studies on humans could not detect any stimulation of collagen expression in patellar tendon in response to acute concentric exercise (11, 38), whereas a more recent study did detect a stimulation of collagen and CTGF expression, although this was very moderate compared with responses seen in animals (7). Several explanations for these discrepancies between animal and human data exist. First of all, the loading/strain levels obtained in the animal studies are likely to be greater than those obtained in human studies. Second, recent data suggest that the human tendon has a very low turnover/activity after the end of height growth (14), and, therefore, rodent models, typically using animals that are still in a growth phase (although mature), may not be appropriate models for human tendon tissue, as the tendons of these animals presumably have far greater potential for growth and adaptation than adult human tendons.

When eccentric exercises [performed according to the “Alfredson” protocol (1)] were compared with concentric exercises in humans with healthy tendons, no clear differences in peak tendon force or tendon deformation were found during contractions (34). However, force fluctuations were more pronounced in eccentric vs. concentric exercise, and maybe these oscillations in tendon force could influence the tendon response to specific contraction types. In addition, studies on the acute response of tendon tissue to loading suggest that the Achilles tendon diameter is diminished more immediately after eccentric exercise than after concentric exercise in healthy tendon (10, 30). With longer term training, a human model demonstrated an increase in tendon stiffness and in tendon modulus with both concentric and eccentric exercises during the training period (24).

ECCENTRIC EXERCISE AND TENDON OVERUSE INJURY (TENDINOPATHY) CONDITIONS

Although the exact pathogenesis of tendinopathy remains to be fully understood, there have been a significant number of clinical trials using a variety of different treatment modalities to overcome this clinical condition (for detailed references, see Ref. 29). The fact that the majority of overuse injuries within sports have some sort of tendinopathy component makes it important to find a way to overcome these types of injuries, disregarding in what region of the body they are located (e.g., rotator cuff tendons, Achilles tendon, patella tendon). This is so, as they not only limit the individual athletes’ sports capability, but also represent a significant economic burden within the occupational area. One of the treatment modalities that has proven to have a significant clinical effect on tendinopathy is the use of frequent eccentric exercises that are carried out at a relatively slow contraction speed. The first to detect this clinical beneficial effect was Stanish et al. (37), who used the knowledge that eccentric exercise more intensely loads both muscle and tendon than concentric exercise, and the rationale for trying eccentric exercise was that the tendon thus should get used to high loads. They demonstrated an effect of eccentric training over 6 wk in patients with long-term Achilles tendinopathy, and, although the study was without a control group, they were the first to suggest an effect on tendinopathy symptoms with eccentric exercise training (37). This study was followed by more controlled studies, also on Achilles tendinopathy, that confirmed the initial results, but now using a somewhat longer (12 wk) and more intense program (1). At present, eccentric exercise is confirmed to be the treatment of choice for, at least midportion, Achilles tendinopathy (25, 39).

In addition to improved symptoms associated with training programs, including eccentric exercise, also normalization of the tendon thickness, in the ultrasonographic and magnetic resonance imaging, structural and vascular abnormalities have been found as a result of eccentric training on Achilles tendon (31). Somewhat in contrast to this, van der Plas et al. (40) found no significant relation between changes intratendinously and symptom improvement, and also others could not detect any clear relation between changes in tendon hypervascularization and symptom improvement (6, 8).

Also in other tendons around the body, the clinical effect of eccentric exercise was demonstrated, and in the patella tendon results similar to those obtained in the Achilles tendon were demonstrated (3). Whereas in that study no significant difference was found between eccentric and concentric exercises, later a difference between these contraction types, in favor of eccentric exercise, was demonstrated (16). Eccentric exercises were refined by performing them on a decline board to load the patella tendon to a greater degree, and it was shown that this exercise was superior to performing them on level surface (33, 41). Furthermore, a similar beneficial result was found when comparing eccentric exercises on a decline board with high-volume eccentric overload by trying to resist a very high external load (the “Bromsman”) (9). Both regimens demonstrated improvement in symptoms. In a later study that directly compared eccentric exercise with heavy slow concentric resistance training and with injections with glucocorticoids, the two different training regimens were shown to be equally beneficial, both on the short and on the long run (19). Thus, at present, it seems that both eccentric exercise and concentric slow-speed heavy, concentric strength training have beneficial effect, at least in patellar tendinopathy (22). It should, however, be considered that the etiology of disease may differ between tendons with different functions and loading patterns (e.g., patellar vs. rotator cuff), and correspondingly these tendons may not react in a similar manner to eccentric vs. concentric training.

In shoulder rotator cuff tendinopathies, eccentric exercises have been shown to be beneficial in treatment of painful impingement syndrome (17), and, furthermore, in a study where concentric exercises were compared with eccentric ones, it was indicated that the clinical effect seems somewhat better when eccentric exercises were used (15). In painful elbow conditions, eccentric exercise was superior in effect compared with therapeutic ultrasonography in relation to lateral elbow tendinopathy (36). Furthermore, specific isokinetic eccentric exercises had a better effect on symptoms, strength, and normalization of tendon enlargement compared with a rehabilitation program with passive modalities like ultrasound, stretching, and massage (5).

It is important to note that, despite significant treatment effects of eccentric exercise on tendinopathy, it is still unknown how this effect is mediated and whether it is connected
to the eccentric contraction mode per se. Thus it remains to be elucidated how the tissue morphology is normalized, the pain is reduced, and the hypervascularization of the tendon reduced. At present, it is known that tendinopathy displays specific tendon regions with altered morphology (rounded isolated cells, disaligned fibrils) (35), increased amounts of proteoglycans and water (35), an upregulation of expression and activity of proteolytic enzymes (matrix metalloproteinases) (4), angiogenesis, and limited upregulation of inflammation (probably only at the onset of the condition) (26, 28, 32). It is well supported that the tendinopathy differs markedly from responses observed with partial or full tendon rupture (4), and, when tendinopathy is present, there is good support for a “shielding-off” phenomenon, by which the surrounding tissue will “spare” the affected region from loading (2), and this may be part of the explanation for the effect of slow eccentric exercise. When a tendinopathic tendon region is subjected to explosive loading, the load development in the sick region is potentially markedly lower than in the surrounding healthy region, while the slow eccentric (or concentric) contractions may lead to a beneficial stimulation of the entire tendon. In other words, the equally beneficial effect of slow, heavy-resistance training, compared with eccentric loading regimens (in which the contractions are normally performed at low speed) (19), may give a clue toward the mechanisms responsible for the observed beneficial effects of eccentric loading in tendinopathy. Thus it may be speculated that it is not essential whether the contraction is eccentric or concentric or a combination of these. Rather, the speed of the movement and magnitude of loading (and thus strain) could be central.

No one has determined the dynamics of protein turnover or fibril formation within tendinopathic regions of human tendon. However, in the peritendon, it has been demonstrated that eccentric exercise of tendinopathic tendon upregulated the collagen synthesis (20), which fits with what happens in normal tendon in response to intense exercise (21, 27). This dynamic change does not, however, prove any structural changes within the tendon, and it has been shown in healthy tendon that major structural changes of human tendon do not occur after the 17th year of life (11). On the other hand, tissue turnover may be far higher in tendinopathic tendon, and it is hypothesized that slow eccentric (and for that case slow concentric) contractions are successful in mechanically loading the tendinopathic region and that this stimulation will encourage formation of new collagen fibrils and realigning of cells and fibrils. How often such stimulation is needed to optimally be beneficial for the tendinopathic tendon is unknown. It is known that, in healthy tendon, intense exercise can raise the collagen synthesis for 48–72 h after acute exercise (27), and, interestingly, Frohm et al. (9) demonstrated that only twice weekly heavy eccentric loading of the patellar tendon was sufficient to achieve a significant positive result in treatment of patellar tendinopathy.

In conclusion, eccentric loading has acute effects on tendon properties, but it is questionable how different this effect is to the one that concentric slow contraction will elicit. Furthermore, eccentric exercise training has a beneficial effect on tendinopathic tendon, but the mechanism by which this is elicited is unknown, and it may be that slow concentric contractions also can elicit a beneficial effect on tendinopathic tendon, so that tendinopathic regions can be subjected to mechanical strain that reestablishes normal fibril alignment and cell morphology.

DISCLOSURES
No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS
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