Loading rate and contraction type effects on the human Achilles tendon force-elongation relationship

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Introduction
While it is accepted that tendons are viscoelastic, the loading rate of contractions is often not strictly controlled when assessing human tendon mechanical properties in vivo. Given the potential benefits of sustained constant load isometric contractions for in vivo tendon property assessment, we aimed to determine if sustained submaximal isometric plantarflexion contractions result in a similar force-elongation relationship and stiffness of the Achilles tendon (AT) to other loading methods.

Methods
The AT mechanical properties (elongation and stiffness) of the dominant leg in ten male adults (26.5±5.5y) were assessed during isometric plantarflexion contractions by integrating dynamometry and ultrasonography (Aloka α7, Tokyo, Japan). Measurements were taken on two consecutive days and the results from all participants on day one and seven participants on day two (three excluded due to measurement problems) were pooled for the analysis. Maximum voluntary contractions (MVC; high loading rate), ramp maximum force contractions with three seconds loading (RAMP; lower loading rate), and sustained contractions (held for three seconds) at forces of 25%, 50% and 80% of the maximal tendon force with the lower loading rate (SUS) were conducted.

Results
A two way repeated measures ANOVA with method and tendon force level as factors revealed a significant method ($P<0.001$) effect on tendon elongation. Post hoc tests with Bonferroni corrections revealed significantly greater tendon elongation in SUS compared with MVC ($P=0.001$) and RAMP ($P=0.002$), but no differences in tendon elongation between MVC and RAMP ($P=0.077$). A one way ANOVA with method as a factor did not reveal a significant method effect ($P=0.079$; MVC: 653.6±220.9 N/mm; RAMP: 694.8±190.3 N/mm; SUS: 564.2±148.1 N/mm) on tendon stiffness.

Conclusion
Sustained plantarflexion contractions appear to lead to an increased AT elongation for a given force, presumably due to the reduced influence of the loading rate on the viscoelastic behaviour of the tendon during the sustained contractions. However, AT stiffness was not significantly different between methods, suggesting that the differences in the rate of elongation occurred prior to the linear region of the force elongation relationship. Sustained isometric contractions appear to be appropriate for assessing AT stiffness in vivo, although potential differences in tendon elongation should be considered when comparing results with other methods.

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