Tendon hypertrophy
Is it possible? Do we want it? How can we target it?

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Effects of chronic knee loading pattern
Sports participation
Strength training

Achilles tendon CSA in runners and untrained subjects (males)

Methods
This study aimed to investigate the cross-sectional area (CSA) of the Achilles tendon in runners and untrained subjects. The study included 50 participants: 25 runners and 25 untrained subjects. The runners had a mean age of 25 years, a mean body mass of 65 kg, and a mean body mass index (BMI) of 20 kg/m². The untrained subjects had a mean age of 24 years, a mean body mass of 70 kg, and a mean BMI of 22 kg/m². The CSA of the Achilles tendon was measured using magnetic resonance imaging (MRI). The CSA was significantly greater in the runners compared to the untrained subjects. The results suggest that chronic knee loading patterns may contribute to the development of Achilles tendon hypertrophy in runners.
Stiffness = \frac{\Delta F}{\Delta L}

Table 1. Patellar tendon mechanical properties based on weight categories.

<table>
<thead>
<tr>
<th>Group</th>
<th>Young Adult</th>
<th>Normal (Kim)</th>
<th>Mean (Student)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Category</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Extremity</td>
<td>1.50 ± 1.35</td>
<td>3.45 ± 1.35</td>
<td>3.75 ± 1.36</td>
<td>0.05</td>
</tr>
<tr>
<td>Lead Extremity</td>
<td>2.38 ± 1.35</td>
<td>3.25 ± 1.36</td>
<td>3.60 ± 1.38</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*P < 0.05, statistically different from normal category.

Fig. 1. Patellar tendon force-displacement relationship in a common flexed position. Stiffness is calculated as the slope of the linear regression fit of the load-extension relationship.
Stiffness = \frac{\Delta F}{\Delta L}

Couppé et al, J Appl Physiol 2008

Young's Modulus (dimension normalized Stiffness) not different

Patellar Tendon CSA
Elite (National Team) badminton players

Patellar tendon stress (proximal site)
[at largest common force]

Couppé, Magnusson et al, unpublished results

Controls 26 yrs
Tendinopathy 22 yrs
Tendon hypertrophy
Is it possible? Do we want it? How can we target it?

Effects of resistance training?
Tendon CSA
Tendon stiffness
Tendon strain
Effects of 12 wks heavy-resistance strength training on patella tendon cross-sectional area (CSA)

**Tendon hypertrophy ⇒ reduced tendon stress (kN/cm²)**

for given level of force loading

⇒ may reduce the risk of tendon overuse injury

**Pre training**

**After training**

\[ \text{Tendon} \rightarrow \text{force } F \]

\[ \text{Tendon} \rightarrow \text{force } F \]

**CSA**

**↑**

**↓**

**Tendon mechanics calculated based on proximal tendon CSA.**

Values are means ± SE. Average common tendon force: 4725±374 N.

* Significantly higher than pre (p<0.05)

Increased tendon CSA → may reduce the risk of tendon overuse injury

- Increased tendon CSA
- Deformation △L (mm) Kongsgaard, Aagaard, Kjær Magnusson et al, Acta Physiol Scand 2007

Increased tendon CSA → reduce tendon strain (*) thereby reducing the risk of tendon overuse injury

↑ Stiffness (Slope = △F/△L)
Micro Biomechanics
single collagen fascicles

Haraldsson, Aagaard, Magnusson et al, 2005

Yield point
Failure point

Length change (mm)

Stress (MPa)

Haraldsson, Aagaard, Magnusson et al, 2007

Strain (∆L/Lo, percent)

0                 5                10               15

Effects of 14 wks strength training on Achilles tendon CSA


Low Force (55% MVC) - small strain
High Force (90% MVC) - large strain

Low Force resistance training
High Force resistance training

Similar total work less percent damage in both training groups

Changes in tendon stiffness with ECC training

7 wks (18 sessions) of ECC plantarflexor training:
6 sets x 6 reps at 120% CONC 1RM

Duclay et al, Muscle Nerve 2009
Changes in tendon stiffness with ECC training
7 wks (18 sessions) of ECC plantarflexor training:
6 sets x 6 reps at 120% CONC 1RM

Effects of resistance training on tendon properties [non-injured tendons]
Strength training results in increased tendon stiffness
Strength training may lead to increased tendon CSA
Kongsgaard 2007, Arampatzis 2007
...although not demonstrated in all studies
Reeves 2003 (old individuals: 74.3 ±3.5 yrs)
Strength training results in diminished tendon strain
Strength training may lead to increased Young’s Modulus,
indicating altered intrinsic tendon properties
Reeves 2003 (old individuals), Arampatzis 2007
...although not seen in all studies Kongsgaard et al 2007, 2009, 2010

Increased Tendon stiffness following heavy-resistance strength training
→ may protect against tendon overloading due to reduced magnitude of tendon strain
→ but may also lead to enhanced rapid force capacity (↑Rate of Force Development: RDF), hence causing enhanced athletic performance
Rationale: high tendon stiffness is known to be related to high RFD
Rapid Force Capacity

Rate of Force Development (RFD)
during maximal isometric muscle contraction

Aagaard et al., J Appl Physiol 2002

Influence of aponeurosis-tendon stiffness in vivo on RFD

Rapid force capacity (RFD) is positively influenced by muscle tendon stiffness

Bojsen-Møller, Aagaard et al., J Appl Physiol 2005

Influence of aponeurosis-tendon stiffness in vivo on RFD

Rapid force capacity (RFD) is positively influenced by muscle tendon stiffness

Bojsen-Møller, Aagaard et al., J Appl Physiol 2005
CONCLUSIONS

It is possible to achieve tendon hypertrophy? Yes!

Do we want it? Yes, indeed! It is likely to protect against tendon overuse due to a reduced tensile loading (↓F/CSA) and lowered tendon strain (↓ΔL/L).

Further, it results in a stiffer tendon → elevated contractile Rate of Force Development → allowing high acceleration and elevated muscle power production during rapid movements.

How can we target it? Certain types of exercise (RT) seem better than others (RUN).

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