Applied tendon stiffness analysis

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Muscle-Tendon complex M. triceps surae
Main functions of muscles and tendons

M. triceps surae

- Force generation

Achilles tendon

- Force transmission to skeletal system
- Energy storage & return
- Create favorable conditions for force generation

Biomechanical properties of the Achilles tendon important for performance
Series elastic element - Tendon
Achilles tendon forces in different sport activities

- **Gait** (Finni et al. 1998) \(1.3 - 1.5\) kN
- **Jogging** (Komi 1990) \(3.7 - 3.9\) kN
- **Sprint** (Komi 1990) up to \(9.0\) kN
- **Cycling** (Gregor et al. 1987) \(0.48 - 0.66\) kN
- **SJ** (Fukashiro et al. 1995) \(1.9 - 2.0\) kN
- **CMJ** (Fukashiro et al. 1995) \(1.9 - 2.0\) kN
- **Hopping** (Fukashiro et al. 1995) \(3.7 - 4.0\) kN
- **DJ** (Brüggemann et al. 2000) \(3.5 - 5.0\) kN
Adaptation potential of tendons

• Tendon cells are sensitive to mechanical stimuli and adapt extracellular matrix depending on loading:
  – Magnitude
  – Frequency
  – Direction
  – Duration

(Banes et al. 1995; Lavagnino et al. 2003, Screen et al. 2005)

• Habitual load affects the biomechanical properties of tendons
  (Couppé et al. 2008; Kongsgaard et al. 2005; Magnusson & Kjaer 2003; Arampatzis et al. 2007)
Adaptation time in different tissues

Fast

- Nerves
- Muscles
- Bones
- Tendons/Ligaments
- Cartilage

Slow

Adaptation time

(Wick 2013)
Adaptation potential of tendons: Cross-sectional studies

• Sprinters compared to endurance runners:
  – Strain at the same Achilles tendon force
  – Stiffness  

(Arampatzis et al. 2007)
Adaptation potential of tendons: Cross-sectional studies

• Leading leg of fencers:
  Stiffness and CSA of the patellar tendon

Tendons are also able to adapt to mechanical loading

(Couppe et al. 2008)
Adaptation potential of tendons: Long-term reactions

Tendons need higher loads to adapt

(Arampatzis et al. 2007)
Adaptation potential of tendons: Long-term reactions

Isom. strength training more effective than plyometrics

(Bohm et al. 2014)
Adaptation potential of tendons: Detraining

- Max. muscle strength - **no changes after** 3 months detraining
- AT stiffness – decrease already **after 1 month**

(Kubo et al. 2012)
Adaptation potential of tendons: Short-term reactions

**Creep effect** of a tendon after cyclic loading

Tendons can fatigue due to mechanical loading

(Wren et al. 2003)
Adaptation potential of tendons: Short-term reactions

- After running a half marathon:
  - No changes in the tendon properties in young adults

(Ackermans et al. 2016)
Adaptation potential of tendons: Short-term reactions

- After running a half marathon:
  - **Older runners:** Tendon strain \( \uparrow \) Tendon stiffness \( \downarrow \)

(Ackermans et al. 2016)
Tendons from older runners have changed mechanical properties post half-marathon run, indicating lower tendon fatigue quality.

(Ackermans et al. 2016)
Adaptation potential of tendons: Short-term reactions

- Representative values of one young Runner:

- 4 of 20 young runners: Tendon strain \( \uparrow \) Tendon stiffness \( \downarrow \)

In the elite sport individual approach very important

(Ackermans et al. 2016)
Adaptation potential of tendons: Tendinopathy

- Tendinopathy-Patients: Tendon elongation ↑ Tendon stiffness ↓

(Arya and Kulig 2009)
**Short summary**

1. Not only muscles, but also tendons can adapt to mech. loading
2. Tendon however need high mechanical loads / tendon strains in order to change their properties
3. Detraining causes rapid decrease in tendon stiffness
4. **Important to note:** tendons can fatigue due to high loads

Too high load can lead to material failure
Short summary

Differences in adaptation time of muscles and tendons

Possible dysbalances in adaptation of muscle and tendon:
Risk of injuries

The risk of tendon injuries can be considerably reduced through an early identification of dysbalances between muscle and tendon.
Interaction Muscle & Tendon: Diagnostics & Training Planning

Since winter 2014

Muscle-tendon complex (M. triceps surae) diagnostics:
- 2-3 x year
- German A, B and C-Teams of High Jump and Pole Vault
Interaction Muscle & Tendon: Diagnostics & Training Planning

Muscle & Tendon Diagnostics:
- 25-30 min per measurement
- direct results after the measurement
- fast in comparison to earlier methods

(earlier methods: not mobile + up to 3 h + extra calculations for days)
Interaction Muscle & Tendon: Diagnostics & Training Planning

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Interaction Muscle & Tendon: Diagnostics & Training Planning

But what happens between?

Effect of different training periods?  Effect of training camps?
Since winter 2014
Regular muscle-tendon complex (M. triceps surae) diagnostics:
- every 2-3 weeks
- in TSV Bayer 04 Leverkusen
  (mainly with the athletes of Jumps/Sprints coach Hans-Jörg Thomaskamp)
Interaction Muscle & Tendon: Analysis over 6 weeks

(Karamanidis et al. 2016)
Interaction Muscle & Tendon: 2 year follow-up (Athlete 1)

(Karamanidis et al. 2016)
Interaction Muscle & Tendon: 2 year follow-up (Athlete 1)

High jumper (PB 2.30)

COMP – Competition period
PREP – Preparation period

(Karamanidis et al. 2016)
Interaction Muscle & Tendon: 2 year follow-up (Athlete 1)

High jumper (PB 2.30)

TC – Training camp

(Karamanidis et al. 2016)
Interaction Muscle & Tendon: 2 year follow-up (Athlete 2)

Long jumper (PB 8.29)

Max. torque [Nm]

Tendon stiffness [N/mm]

- Take-off leg
- Swing leg

(Karamanidis et al. 2016)
Interaction Muscle & Tendon: 2 year follow-up (Athlete 3)

(Karamanidhis et al. 2016)
Interaction Muscle & Tendon: 2 year follow-up (Athlete 4)

(Karamanidis et al. 2016)
Interaction Muscle & Tendon: 2 year follow-up (Athletes 1-4)

1. Athlete 1 (HJ) and Athlete 2 (LJ) take-off leg stronger and AT stiffer
2. Athlete 3 (HJ) exactly opposite + almost no drop in stiffness after an injury (metatar. fracture) despite unloading periods
3. Athlete 4 (Sprint) less differences between legs
4. Relatively homogenous adaptation between muscle and tendon in all athletes

Effects of high volume training camps?
Interaction Muscle & Tendon: 2 year follow-up (Athlete 1)

High jumper (PB 2.30)

TC1 - LAV 2015

TC2 - LAV 2016

(Karamanidisis et al. 2016)
Interaction Muscle & Tendon: TC in LAV 2015 (Athlete 1)

High jumper (PB 2.30)

Max. torque [Nm]

Tendon stiffness [N/mm]

TC in LAV Spring 2015 (3 weeks)

muscle strength

tendon stiffness

- Take-off leg
- Swing leg

Before TC

2 days after

5 days after

7 days after
Interaction Muscle & Tendon: TC in LAV 2016 (Athlete 1)

High jumper (PB 2.30)

Max. torque [Nm]

Tendon stiffness [N/mm]

TC in LAV Spring 2016 (2 weeks)

- Take-off leg
- Swing leg

muscle strength

tendon stiffness
Interaction Muscle & Tendon: Training camp

After the Spring Training camp 2015:
- Slight decrease not only in muscle strength but also in tendon stiffness
- Regeneration individual, but ca 6-8 days until the pre training camp levels

After the Spring training camp 2016:
- No changes in muscle strength and tendon stiffness
- After training camp in most athletes higher values in both parameters

Positive results with respect to prevention of muscle tendon injuries and for improvement of performance
Optimal tendon stiffness for performance?

Much more other factors play also role for the performance.
Interaction Muscle & Tendon: 10-15 months after tendon rupture

Despite permanent physio treatment & rehab training no changes in muscle and tendon properties 1.5 years after tendon rupture

(Karamanidis et al. 2016)
Summary

1. Take-off leg in various jumpers mostly stronger and with a higher tendon stiffness
2. Sprinters have less differences between the legs
3. Tendon is able to fatigue and needs to be accounted definitely in harder training phases to avoid dysbalances
4. If enough training stimuli and regeneration is applied, a relatively homogenous adaptation in muscle and tendon is possible
Service-Science Project

Application of a mobile Muscle-Tendon-Function laboratory for a structure analysis in elite sports

Principal investigator: Dr. Kiros Karamanidis
Service-Science Project: Mobile Muscle-Tendon-Lab

Since autumn 2016

Muscle-tendon complex (M. triceps surae) diagnostics:

- 1 x month German A, B and C-Teams of all jumping events (Long, Triple, High jump and Pole vault)
- 1 x week athletes in TSV Bayer 04 Leverkusen
Service-Science Project: Mobile Muscle-Tendon-Lab
New topics in the current project: tendon dimensions
New topics in the current project: Gender and tendons

Younger females have a higher risk for tendon / ligaments injuries


**Female sexual hormones:**

Fibroblast activity  
Collagen density  
Tendon stiffness  
Ultimate tensile strength

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Research group:

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Main cooperation partners:

Dr. Falk Schade  Hans-Jörg Thomaskamp
Thank you for your attention!