TENDON ELASTICITY: LATEST FINDINGS AND STATE OF THE ART

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Achilles tendon forces during running

5 – 12 body weight

adapted from Ravi et al. 1980, J Sports Sci

Sprint performance - Tendon compliance-stiffness -

No series-elastic compliance in all MTUs

26% maximum sprinting velocity

(Miller et al., 2012, J Biomech)

Material properties are important to allow energy storage in the tendon.

Jumps with a run up

Source of energy

COM ‘energy conservation’

Muscle ‘power amplification’

modified from Roberts & Azizi, J Exp Biol

Energy conservation

high efficiency

adapted and modified from Roberts & Azizi, J Exp Biol, 2011

http://www.oeb.harvard.edu/affiliates/cfs/movies/cfs_wallaby.avi

adapted and modified from Biewener et al., J Exp Biol, 1998

Energy conservation

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adapted and modified from Biewener et al., J Exp Biol, 1998
Human muscle tendon behavior in vivo

Muscle tendon behaviour during human running

Muscle tendon function during human running

Muscle tendon function during hopping

Energy conservation

Energy storage and release

Phase 1: COM Deceleration
Phase 2: COM Acceleration

Tendons enable an independent behavior of the fascicle

Muscle tendon function during human running

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Eur J Appl Physiol, in press.
Muscle tendon function during drop jumps

Drop jumps

modified from Ishikawa & Komi, Exercise and Sport Science Reviews, 2008

Regulation of muscle stiffness

Muscle activation before ground contact (Pre-activation) regulates muscle stiffness and therefore energy storage in the tendon (Gohler & Rynasiewicz, 1981; Komi & Gollhofer, 1987; Ishikawa & Komi, 2004)

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The catapult mechanism of frog jumping


H. C. Ashby & T. J. Abbott, 2002


Power Amplifikation - Squat Jump

adapted and modified from Roberts & Azizi, 2011, J Exp Biol

Power Amplifikation - Squat Jump

adapted and modified from Kurokawa et al., 2001, J Appl Physiol

Power = Work / Time

"Catapult effect"
Tendon function

- Force transmission
- Energy Storage & Release
- Decoupling of the muscle from the entire muscle-tendon unit
  - enable the muscle to work at a higher force potential due to the force length and force velocity relationship
  - high power output due to a quick release of the stored energy
  - prevent the muscle from strain injuries

Tendon mechanical properties

- Stiffness
  - Tendon stiffness \( k \): The extent to which the tendon resists deformation in response to an applied force

Tendon mechanical properties in vivo

- Achilles tendon

Tendon mechanical properties

- Energy


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Tendon mechanical properties in vivo
- Patellar tendon -

Tendon mechanical properties
- Stiffness -

Tendon material properties
- Modulus of Elasticity or Young’s Modulus (YM) -

optimal muscle & tendon properties

sport performance

sport performance

adapted and modified from Biewener J Exp. Biol., 2016
Effects of *resistance* training

Similar results are published by A. Arampatzis et al., 2007, J. Biomech.

Stenroth et al., J. Appl. Physiol., 2013

Raspanti et al., 2002, Materialproperties


Habitual loading results in tendon hypertrophy and increased stiffness of the human patellar tendon

Plantarflexion resistance training 90% MVC

Plasticity of human Achilles tendon - Effects of strain magnitude-
Plasticity of human Achilles tendon
- Effects of strain magnitude -

Isometric resistance training 14 weeks

Low: 55% MVC / 2.85 ± 0.99 %
High: 90% MVC / 4.55 ± 1.38 %

Moments [Nm] vs. Stiffness [N/mm]


Plasticity of human Achilles tendon
- Effects of loading duration -

Arampatizs, Bierbaum, Peper, Albracht., 2010, J. Biomech

Plasticity of human Achilles tendon
- Effects of loading duration -

Arampatizs, Bierbaum, Peper, Albracht., 2010, J. Biomech

Human Achilles tendon plasticity
- Effects of strain rate and duration -

Bohm et al., 2014, J. Exp. Biol

Effect of eccentric training on the plantar flexor muscle-tendon properties

Bohm et al., 2014, J. Exp. Biol

Duclay et al., Muscle Nerve

Duclay et al., Muscle Nerve

Training protocol
- 18 sessions over 7 weeks
- Six sets of six eccentric contractions at 120% MVC
- 3-s eccentric actions
- ROM: 50° – 60°
- ~15° –20° /s
Modified muscle & tendon properties: impact on function?

14 weeks high intensive resistance training:
- sign. greater maximum isometric plantarflexion moment (~7%, p = 0.005)
- sign. greater normalized tendon stiffness (~15%, p < 0.0001)
- sign. better running economy: ~4.0%, p = 0.002


Mechanical & morphological properties of tendons
- Effects of resistance training

Tendon’s response to training is later than that of muscle

Kubo et al., Journal of Strength and Conditioning Research, 24 (2), 2010

Conclusion
- Tendons material properties play an important role in athletic performance!
- Optimal tendon stiffness is task specific and depends on the mechanical and morphological properties of the MTU
- Tendons have the potential to adapt (CSA, material properties)
- "Training a tendon" → high strain, moderate duration
- Tendons’ response to training is later than that of muscle

thanks for your attention

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