The role of tendon elasticity for sports performance

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Achilles tendon forces during human running

Komi et al. 1992, J Sports Sci

5 – 12 times body weight

Sports performance

No series-elastic compliance in all MTUs
- 26% maximum sprinting velocity
(Miller et al., 2012, J Biomech)

No series-elastic compliance in the Achilles Tendon
- 10% maximum walking velocity
(Sellers et al., 2010, Int J Primatol)

Material properties are important for tendon function

Jumps with a run up

Source of energy

COM ‘energy conservation’
Muscle ‘power amplification’
modified from Roberts & Azizi, 2011, J Exp Biol

Energy conservation

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

Muscle pre-activation

Muscle activation before ground contact regulates muscle stiffness and therefore energy storage in the tendon (Gollhofer & Kyrolainen, 1991; Komi & Gollhofer, 1997; Ishikawa & Komi, 2004).

Ultrasonography is used to study muscle and tendon behaviour of the GM during human locomotion (e.g., Agapitos et al., 2003; Fukunaga et al., 2001; Ishikawa et al., 2005; Kawakami et al., 2002; Lichtwarck et al., 2007; Sprengard et al., 2007).

Energy conservation


Force and Power generation

Force and Power generation - Muscle -

Over-challenging situation

Drop jumps

Optimum Drop Height

120% Optimum Drop Height

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

Jumps with a run up

Source of energy

COM

'energy conservation'

Muscle

'power amplification'

Power Amplifikation

- Squat Jump

'Catapult effect'

The catapult mechanism of frog jumping


Data adapted from Kurokawa et al., 2001, J Appl Physiol

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

Modified from Roberts & Azizi, 2011, J Exp Biol

Roberts & Azizi, 2011, J Exp Biol

http://www.iaaf.org/about-iaaf/documents/research

Source of energy

H. C. Astley & T. J. Robert, 2012

The catapult mechanism of frog jumping

M. C. Astley & T. J. Robert, 2012
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

Mechanical properties of the tendon
- Effects of resistance training -

Tendon mechanical properties
- Stiffness -

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

Tendon stiffness (%): The extent to which the tendon resists deformation in response to an applied force.

\[ k = \frac{\Delta F}{\Delta \text{Def}} \]

Tendon mechanical properties - Energy -

\[ W = \int F \, d\theta \]

Tendon mechanical properties - Energy storage -

equal force level, equal deformation

Mechanical & morphological Properties of the Tendon - Effects of resistance training -

Isometric resistance training, 14 weeks


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

Isometric training, 14 weeks

Mechanical & morphological Properties of the Tendon - 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

Jumping performance - Dependence of human squat jump performance on the Achilles tendon compliance

Data adapted from Bobbert 2001, J Biomech


14 week resistance training for the plantarflexors

- sign. Increase in tendon stiffness (~15%) and muscle strength (~7%)


Running economy

- sign. better running economy: ~4.0 %, p < 0.002

Conclusion

- Tendons material properties play an important role in athletic performance (Bobbert 2001, J Biomech, Miller et al., 2012)
- Tendons have the potential to adapt (CSA, material properties)
- Tendons' response to training is later than that of muscle (Kubo, 2008, J Theor Biol)
- Optimal tendon stiffness is task specific and depends on the mechanical and morphological properties of the MTU (Lichtwark & Wilson, 2008, J Theor Biol)

Thank you for your attention