Biomechanics of the Finger

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Anatomy: Pulley System

- 4 anular fibroosseous pulleys (A1, A2, A4, A5)
- 1 anular pulley inserting on the palmar plate (A3)
- 3 cruciform pulleys (C1, C2, and C3)
Anatomy: Pulley System

- FDP runs through the pulleys A2, A3, and A4
- FDS only runs through the pulleys A2 and A3

=> The A4 pulley is not loaded by the FDS tendon.
Histology: Pulley System

- The pulley consists of three layers:
  1. Inner layer: connective tissue with collagen running perpendicular to the digital axis
  2. Middle layer: dense connective tissue with elastin fibrils also perpendicular to the digital axis
  3. Outermost layer: loose connective tissue with numerous vessels.

- The inner layer secretes hyaluronic acid.
Histology: Pulley System

- The inner layer has multiple folds and creases.
- Hyaluronic acid
Crimping and Hanging Fingerposition
One move too many

Biomechanics: Pulley System

\[ F_P = 2 \times TT \times \cos\left(\frac{\beta}{2}\right) \]

\( \beta \) is a function of:
- \( \alpha \) (PIP-angle)
- Position of the pulley

Roloff, Schöffl et al. J Biomech 2005
Concentric vs. Eccentric Motion

- Concentric Motion consists of Flexing of the finger.
- Eccentric Motion consists of Extending the previously flexed finger.
- Eccentric Movements are always stronger than concentric Movements as a consequence of the alignment of the muscle fibres.
The Importance of the Eccentric Motion

- Birds and Bats show a Tendon locking mechanism leading to a high strength deficit enabling them to hang effortlessly on their closed fingers.
Importance of the Eccentric Motion

- Same histology in humans?
- Possible pathomechanism for pulley ruptures: „opening of the hand“ when tired or when losing a foothold.
Material and Methods of Anatomic Study

FDS/FDP$^1$:
Hanging = 1:1
Crimp grip = 1:2

$^1$Vigouroux et al., Journal of Biomechanics 40, 2007
$^2$Schweizer et al., Journal of Biomechanics 36, 2003
Measuring of the Forces acting underneath the pulley System

Specifically designed force transducers:
• 1 finger with trasducer under A2 pulley
• 1 finger with transducer under A2 and A4 pulley
Results: Forces acting underneath the pulleys

Schöffl et al., J Sports Tech., 2009
Results: Hanging vs. Crimp Grip Position during Concentric Movement

Schöffl et al. 1, J. of Biomechanics, 2009
Results: Hanging vs. Crimp Grip Position during Concentric Movement

The forces acting on the pulleys at the moment of rupture are higher on the pulleys for crimp but comparable for FDP and fingertip.

The distance between pulleys at the moment of rupture is lower for cimp grip (pulleys approach each-other).

Schöffl et al. 1, J. of Biomechanics, 2009
Discussion: Hanging vs. Crimp Grip Position

- A pulley rupture was rare in the hanging finger position as a consequence of lower forces acting on the pulleys.
Discussion: Hanging vs. Crimp Grip Position

- A pulley rupture was rare in the hanging finger position as a consequence of lower forces acting on the pulleys.

- No A4 pulley rupture in the hanging finger position because of the lesser influence of FDS.

\[
\begin{align*}
FDP &= 1 \\
FDS &= 1/2 \\
\text{Total} &= 1 1/2
\end{align*}
\]
However, the forces at the first event were comparable. Thus the fact that the pulleys approach each other in the crimp grip is a protective factor for other injuries.
Discussion: Hanging vs. Crimp Grip Position

Slopers are better than Crimps
Results: Concentric vs. Eccentric Motion

First Event

Primary Failure in %

- Eccentric
- Concentric

Loading condition

Schöffl et al. 1, J. of Biomechanics, 2009
Results: Concentric vs. Eccentric Motion

At the moment of pulley rupture comparable forces on the pulleys but lower in FDP and fingertip = Less force needed for pulley rupture in eccentric movement.

Schöffl et al. 1, J. of Biomechanics, 2009
Ruptures occurred at far lower forces for the Eccentric Motion => Friction underneath the pulleys also relevant in humans
Discussion: Concentric vs. Eccentric Motion

- Ruptures occurred at far lower forces for the Eccentric Motion => Friction underneath the pulleys also relevant in humans
- A2 rupture was more common in the Eccentric Motion. This reflects the injuries we observe.
Discussion: Concentric vs. Eccentric Motion

- Ruptures occurred at far lower forces for the Eccentric Motion => Friction underneath the pulleys also relevant in humans
- A2 rupture was more common in the Eccentric Motion. This reflects the injuries we observe.
- Beware with difficult moves when being tired!
Thank you for your attention