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The role of proximal pulleys in preventing tendon bowstringing: Pulley rupture and tendon bowstringing☆

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A2 pulley;
Bowstringing;
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Summary *Purpose:* The aim of this study was to investigate factors that contribute to tendon bowstringing at the proximal phalanx. We hypothesised that: (1) a partial rupture of the A2 pulley leads to significant bowstringing, (2) the location of the A2 rupture, starting proximally or distally, influences bowstringing, (3) an additional A3 pulley rupture causes a significant increase in bowstringing following a complete A2 pulley rupture and (4) the skin and tendon sheath may prevent bowstringing in A2 and A3 pulley ruptures.
Methods: Index, middle and ring fingers of eight freshly frozen cadaver arms were used. A loading device pulled with 100 N force was attached to the flexor digitorum profundus (FDP). The flexor digitorum superficialis (FDS) was preloaded with 5 N. Bowstringing was measured and quantified by the size of the area between the FDP tendon and the proximal phalanx over a distance of 5 mm with ultrasonography (US).
Results: US images showed that already a 30% excision of the A2 pulley resulted in significant bowstringing. In addition, a partial distal incision of the A2 pulley showed significantly more bowstringing compared to a partial proximal incision. Additional A3 pulley incision and excision of the proximal tendon sheath did not increase bowstringing. Subsequently, removing the skin did increase the bowstringing significantly.
Conclusion: A partial A2 pulley rupture causes a significant bowstringing. A partial rupture of the A2 pulley at the distal rim of the A2 pulley resulted in more bowstringing than a partial rupture at the proximal rim.
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Sport climbers may have pulley strains or partial pulley ruptures without detectable bowstringing. This was the initial idea to conduct this study. Sport climbing has grown in popularity: new pathologies involving the hand, elbow and shoulder have been presented.[1–5] About 75% of sport climbers experience overuse syndromes or injuries of the upper extremity. The fingers and the wrist are the most commonly involved structures, with pulley ruptures being the most frequently seen injuries. Annular pulleys are important to keep the flexor tendons close to the phalanges to assure optimal mechanical efficiency.[6–8]

Forces on pulleys can become close to 400 N during climbing.[4,9,10]

Several papers focussed on effects of pulley ruptures on the finger excursion; some authors removed the skin or the flexor tendon sheath to do so.[3,7,8,11–13] Other studies tested the pulleys, while the finger was disarticulated from the hand.[7,14,15] However, the skin and the flexor tendon sheath themselves could function as a mechanical pulley for flexor tendons.

Several studies have shown that ultrasonography (US) allows good imaging of finger pulley injuries in sport climbers. Hauger et al. (2000) noted that the finger pulley system could be evaluated directly with US using cadaver fingers. Part of the study was done with fingers in the flexed position; the US images were made in the transverse plane. Their results showed that they could identify uninjured A2 pulleys in 100% and uninjured A4 pulleys in 67% of the cases.[16] Following partial and complete lesions of the pulleys, correct diagnosis was possible with US in 79–100% of the cases. Their study shows that US can be useful in diagnosing pulley injury: they could identify all pulleys and they could adequately detect if they were ruptured.

The aim of this report was to simulate the situation of climbing and study factors that could play a role in bowstringing at the proximal phalanx:

1) partial rupture of the A2 pulley
2) location (proximal/distal) of the rupture of the A2 pulley
3) subsequent A3 pulley rupture. In addition, the effect of the skin and the proximal tendon sheath in preventing bowstringing was studied in case of a rupture of the A2 and the A3 pulley.

Materials and methods

The specimens

Eight freshly frozen forearms were obtained from individuals who had a mean age of 76 years (range 73–82 years) at the time of death. The forearms were thawed 24 h before testing. For testing, only the second through fourth fingers were used, as those are the most common sites of injury and they are most comparable to each other.[4,5,16]

Arm preparation

The arms were immobilised in a custom-made jig (Figure 1). The proximal and distal sides of the forearm were fixed on the lateral sides. A Kirschner wire (K-wire) was placed through the distal radius. The K-wire was held in place with

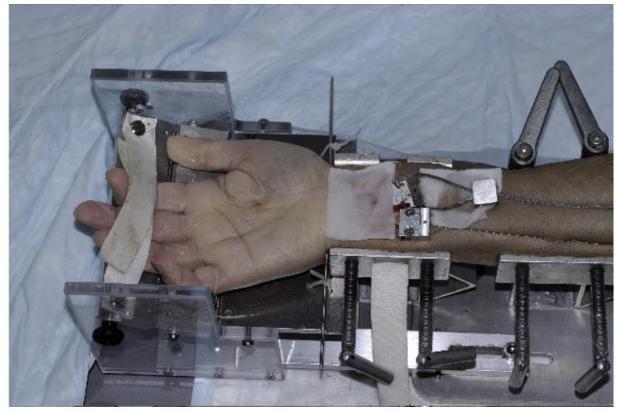

Figure 1 Custom-made jig for the arm to secure its position.

two tie wraps preventing the wrist from moving when the tendon was pulled. The hand was resting on a plate that reached to the proximal side of the metacarpophalangeal (MCP) joint. The fingers were positioned on two plates forming an angle of 15°. Proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints were held in an angle of 15° by using Velcro over the DIP joints.

The incision in the skin was made on the palmar side of the fingers. However, the incision of the pulley is made at the lateral side of the fingers.

The loading device

Tendons were pulled using a Testometric M250–2.5 kN (The Testometric Company Ltd. UK). Flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) tendons at the level of the distal forearm were connected to the machine (Figure 2). The Testometric machine was pulling from the proximal side in a straight line with the forearm by using a pulley. The FDP was loaded to 100 N. The FDS tendon was preloaded with 5 N each time to simulate a natural tension. The tendon was pulled with a speed of 50 mm min^{-1} tendon movement until a force of 100 N was reached. Then, this position was held for 5 min followed by reversing the movement to the starting position with the same speed. The tension was taken off the FDP tendon and the fingers were relaxed again for retesting. During the relaxation and

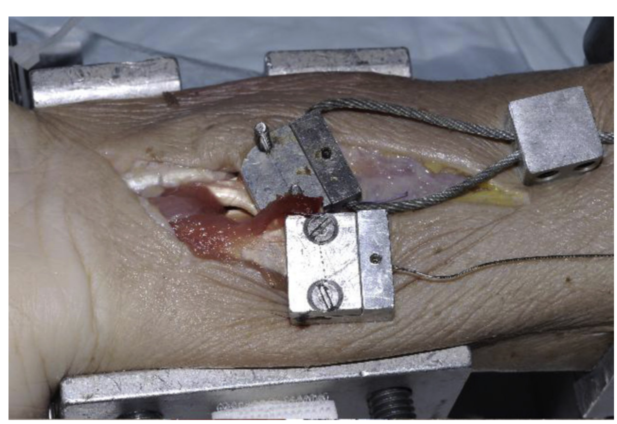

Figure 2 Attachment of the Testometric to the tendons.

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