Biomechanical Properties of the Crimp Grip Position in Rock Climbers

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Introduction

Rock climbers are using in up to 90% the so called crimp grip position (Fig. 1) to hold small ledges, where only the pulp of the fingers are in contact with the rock. Thereby the PIP joints are flexed about 90° and the DIP joints are hyperextended maximally. During this unique position, in contrast to the slope grip position (Fig. 2), bowstringing of the flexor tendons is applying very high load to the flexor tendon pulleys and can cause injuries and overuse syndromes (Bollen, 1990) mainly to the distal edge of the A2 pulley. The objective of this study was to investigate different mechanical properties of bowstringing of the flexor tendon sheath during crimp grip position. The physiologically occurring bowstringing is well palpated over the course of the flexor tendon sheath as the finger is flexed. It can be determined by the distance from the bone to the flexor tendons and by the force which acts perpendicular to the flexor tendons and causes bowstringing. These parameters (distance and force of bowstringing) where measured. In addition, a method was developed to indirectly measure the friction between the flexor tendons and the flexor tendon pulleys during crimp grip position. The method based on the observation that the difference of eccentric to concentric maximum strength (strength deficit) was significantly larger during PIP flexion (crimp grip position) compared to wrist flexion and was larger than could be explained by muscular properties only. The results aimed to explain the mechanism of injury to the A2 pulley and to develop prophylactic means for rock climbers.

Methods

The *distance of bowstringing* between resisted isometric contraction and relaxed finger flexors was measured by a clamp like device (Fig. 3) at 6 different locations along the flexor tendon sheath (Fig. 9). Bowstringing during crimp grip position, slope grip position (IP joints flexed 20-40°; Fig. 2) and crimp grip position with isolated FDS activity was determined (Fig. 9). The amount of bowstringing over the distal edge of the A2 pulley during a warm up exercise done by rock climbers (cyclic load using the crimp grip) was determined. The *force of bowstringing* over the distal edge of the A2 pulley during resisted crimp grip was measured by a clamp like device with a transducer according to the force applied at the fingertip (Fig. 4). All measurements mentioned above were made in vivo on 16 fingers of 4 subjects.

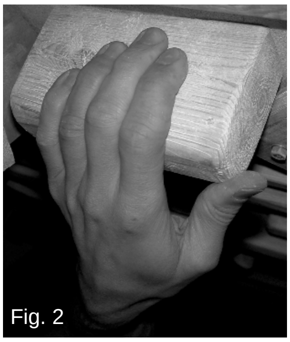
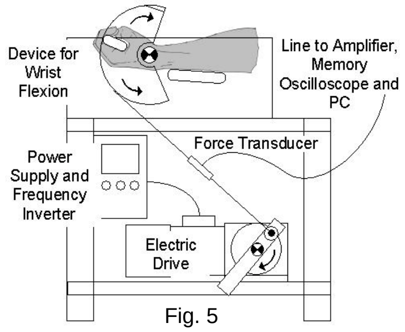


Fig. 1: Crimp grip position with flexed PIP and hyperextended DIP joints. Fig. 2: Slope grip position, PIP joints not flexed more than 60°, DIP joints almost extended. Fig. 3: Distance measuring device. Fig. 4: Force measuring device.

In order to evaluate *friction* between the flexor tendons and pulleys, 3 isokinetic movement devices were built where gliding of the flexor tendons along the sheath (pulleys) was involved differently: 1. Wrist flexion 30-0-30°, no involvement of the finger flexor tendon sheath (Fig. 5); 2. Rolling in movement using the DIP and PIP joint up to flexion of 60°, few bowstringing (Fig. 6); 3. Isolated flexion of the PIP joint (middle and ring finger parallel) between 60° and 100°, most distinct bowstringing (Fig. 7/8). Eccentric and concentric maximum strength of each of the 3 movements was measured. The method was evaluated (48 measurements in a single subject) to have a standard deviation of 7%. 51 hands in 26 male subjects were investigated. In order to exclude the factor of low motivation and eccentric to concentric strength deficit of untrained muscles all subjects were active rock climbers interested in the topic.



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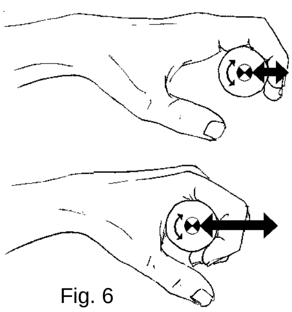
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Fig. 7

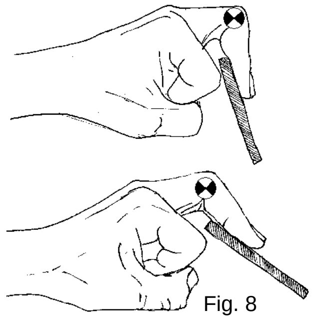


Fig. 8

Fig. 5: Construction of the isokinetic movement device with mounted wrist flexion module. Fig. 6: Finger rolling / IP joint flexion module. Fig. 7/8: PIP joint flexion module.

Results and Discussion

Distance of bowstringing (Fig 9.): The largest amount of bowstringing occurred over the PIP joint (4.3 mm, SD 0.7 mm) during resisted crimp grip position. Bowstringing was far less distinct during resisted crimp grip position with isolated FDS activity (over the PIP joint: 1.75 mm, SD 0.75 mm) and almost absent during the slope grip position (0.2 mm, SD 0.15 mm). The distal edge of the A2 pulley as well as the proximal edge of the A4 pulley and the A3 pulley therefore are loaded at most during the crimp grip position and may explain the mechanism of injury to the A2 pulley. The use of the slope grip position (least distinct bowstringing) may be favoured during rehabilitation of an injury to not undergo hypotrophy during complete inactivity (Noyes, 1977). During a warm-up 80 - 100 climbing moves using the crimp grip position were necessary until the distance of bowstringing over the distal edge of the A2 pulley increased by 0.6 mm (30 % from 1.15 to 1.75 mm). About three routes have to be climbed to achieve 100 climbing moves, to get warmed up and to be ready for maximum loads. Concerning the moment arm of the FDP at the PIP joint it implies a small but theoretically increase of 3 %. More important maybe is the fact that after a warming up the course of the tendon becomes more even and regular preventing peak forces at distinct points of the flexor tendon sheath.

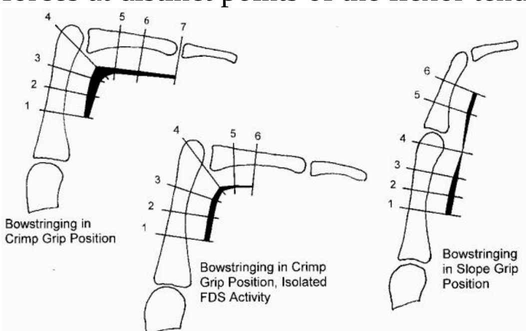
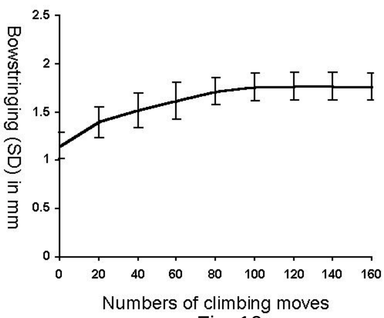


Fig. 9



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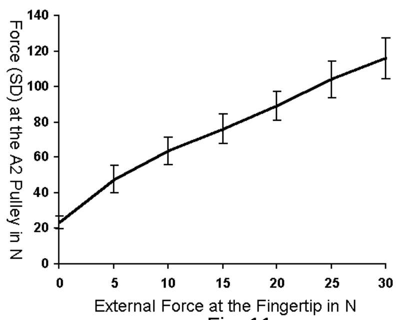

Fig. 11

Fig. 9: Distances of bowstringing along the flexor tendon sheath during crimp grip (left), isolated FDS (middle) and slope grip (right), location of measurements 1-6. Fig 10: Increase of bowstringing during a warm up using the crimp grip, measurements made after 20 climbing moves each. Fig. 11: Force of bowstringing during crimp grip according to resistance at the fingertip.

Force of bowstringing: The results of the force measuring showed that the distal edge of the A2 pulley was loaded about 3 times the force applied at the fingertip during crimp grip position (Fig. 11) which corresponds to the results of Hume et al. (1991). At 25 % of maximum strength in crimp grip position the load to the distal edge of the A2 pulley was about 120 N. On the assumption that the graph showed further linear increase, the force of bowstringing was calculated to be 373 N for an external resistance of 118 N at the fingertip. This is in the range of the maximum force of the finger flexors of a recreational climber. It corresponds to the calculated force of 450 N (Bollen, 1990) and is near the maximum strength of the A2 pulley of 407 N (Lin et al., 1990). The high load to the pulleys near maximum strength using the crimp grip means that pulleys in vivo may probably be much stronger than the pulleys of aged and cadaver fingers used in the above named other studies. The pulleys of professional rock climbers may be even much stronger because the loads to their fingers being far beyond the maximum strength named above. *Isokinetic movement:* Average maximum strength of wrist flexion was 22,59 Nm (SD 4.46) for eccentric and 19.09 Nm (SD 3,58) for concentric flexion. Analogous results of rolling in a bar with the IP joints was 581 N (SD 100) for eccentric and 430 N (SD 77) for concentric and for isolated PIP joint flexion 8.36 Nm (SD 2.33) for eccentric and 5.93 Nm (SD 1.69) for concentric flexion. The corresponding mean of eccentric to concentric difference in percentage was 14.52% (SD 5.91), 26.82% (SD 7.36) and 29.96% (SD 6.77) all being statistically significant to each other (Fig. 15). *Estimation of friction* between the flexor tendon and pulleys during PIP flexion can theoretically be determined from the eccentric to concentric difference of maximum force moment after subtraction of the muscular strength deficit. Strength deficit can be obtained during wrist flexion around neutral position where friction is known to be minimal (Goldstein et al. 1987) and similar muscles are used (except FCU, FCR). Assuming that friction is the same for eccentric and concentric movement, friction can be determined as follows: FR=[r1*[FE ecc*d-FE con]]/[r2*[d+1]]= 40.1 N (SD 11.4) for ring and middle finger, (FR: friction force, FE external force at the tip of the finger, d=F con wrist/F ecc wrist; r1= distance from PIP center of rotation to tip of the finger; r2 = perpendicular component from PIP center of rotation to distal edge of A2 pulley).

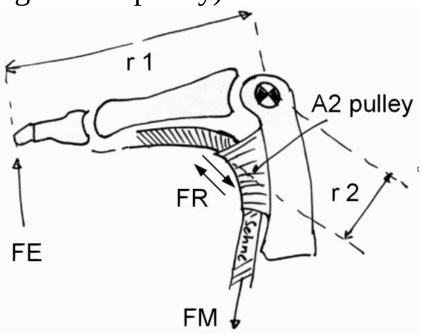

Fig. 12

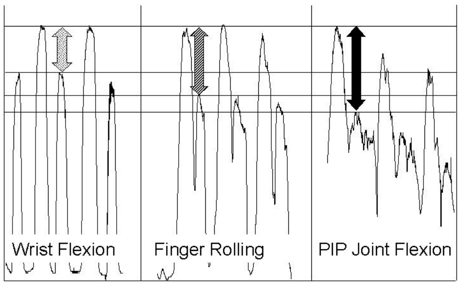

Fig. 13

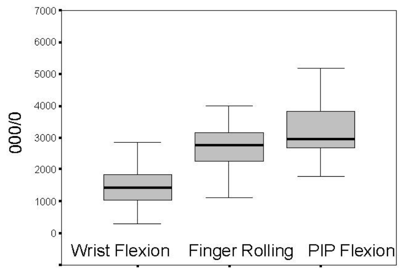

Fig. 14

Fig.12: Friction force moment (FR*r2) in concentric finger flexion results from the difference of flexor muscle force moment (FM*r2) and the external resistance force moment (FE*r1): FR*r2= FM*r2- FE*r1, and for eccentric movement: FR*r2= FM*r2+FE*r1. Fig. 13: graph of the 3 different movements, arrows indicate strength deficit. Fig. 14: Strength deficits (1000=10%) of the 3 different movements.

The present study support the hypothesis that friction during crimp grip position and high load is apparent. It supports the holding force of the flexor muscles in rock climbers for 9.1%. Coefficient of friction was μ=0.086 (+/-0.023) being greater than measured by Uchiyama (1995) in vitro (μ= 0.04,+/-0.014). Friction may increase the susceptibility to injury to the A2 pulley. When feet abruptly come off the rock the fingers experience a sudden increase of load. In this situation friction may contribute to injury. Injury mechanism therefore may not only be due to the bowstringing force but also due to high friction in near static high load.

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