

CLIMBER'S HAND INJURIES

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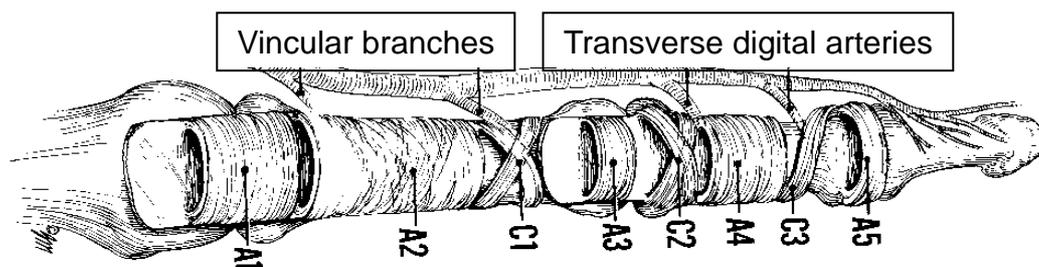
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Abstract: Rock climbing is a sport activity which solicited the fingers more than other any sport, leading to injuries typical for the rock climbers' hand. The biomechanical functioning of the finger is one of the most complicated problems of the human musculo-skeletal system. This paper describes the pathologies observed in rock climbing and the knowledge obtained thanks to biomechanical analysis for the evaluation and simulation for treatment and repair.

Key words: **SPORT ROCK CLIMBING, FINGER INJURIES, HAND BIOMECHANICAL MODELLING**

Climbing is a quadrupedal progression on boulders, buildings, and natural or training walls. It may cause micro traumatic injuries and overuse pathology due to intensive specific training. Over 60% of injuries occur during an indoor practice. Lesions may be acute or progressive.

Three main grip techniques are commonly used by rock climbers. The "hook" grip, the open or "slope" grip and the cling or "crimp" grip. According to Doyle and Blythe classification one observed five annular pulleys at the flexor digital sheath level. A1 to A5, made of strong circular fibres volar to phalangeal bones, and three cruciform pulleys, C1 to C3, which cross at the interphalangeal joints. The force applied by the flexor tendon apparatus to the surrounding digital sheath is approximately 34N at rest and up to 63N in grasp. The tensile strength required to rupture the various pulleys has been reported as 310N at the A1 pulley, 407N at the A2 pulley and 210 N at the A4 pulley.



Acute lesions:

The crimp grip is implicated in pulley ruptures (75% regarding A2 of the ring finger). Ruptures may associate A2, A3 and A4 pulleys. Rupture most often occurs during a strong, violent and sudden crimp position. The climber may experience a pain and may well have heard a loud "snap" noise which may be loud enough to be audible a few meters below by the belayed. The most reliable test is the "bow-stringing phenomenon". Actually, the ruptured pulley is unable to maintain the flexor tendons close to the finger skeleton. Then flexor tendons move in a volar direction and are readily palpable immediately under the skin. Most ruptures present with an acute pain and limited function however some may present more insidiously with lateral pain, weakness and swelling presenting several days later

If further evidence of rupture is required, the diagnosis can be made by imaging (in crimp position), using computed tomography (CT scan), magnetic resonance imaging (MRI) or ultrasound examination (US).

Partial ruptures (no evidence of bowstringing both clinically and on imaging) require a conservative treatment using a rigid ring-splint for 45 days. It implies a complete stop in climbing practice. Complete rupture leads to consider surgical exploration regarding the climber's ability level. It uses an extensor retinaculum graft to reconstruct the ruptured pulley and a 3 months rehabilitation program out of climbing. Results are: satisfactory outcome and usually return to patient previous climbing performance within six months. Education about injuries and measures of warm up, stretching and hydration has to be done.

Progressive lesions:

Tendinitis: Clinical symptoms involve a pain, a specific or diffuse swelling and a difficulty in the movement. Chronic infections must be treated (dental) actually they facilitate tendinitis

Articular swellings often occur and are due to repetitive micro sprains of the PIP joint, leading to a relative extension deficit. Some osseous changes are due to heavy traction on the pulley lateral attachments and may lead to cortical bone thickening or pulling diverticula.

A cutaneous thickening is frequent but does not lead to significant vascular or sensitive modifications.

In order to understand the pathomechanics of the finger injuries in rock climbing, it is crucial to determine:

- 1-The supporting forces level applied during climbing
- 2- The specific finger involvement during a sport-climbing grip
- 3-The internal force sharing patterns among the finger tissues during different rock climbing holds

1- Supporting forces in rock climbing:

A number of experimental studies (Quaine et al., 1997) have been performed to characterize the mechanical determinants of the postural stability during rock climbing through analysis of supporting force variations.

Tests were performed in laboratory environment for different climbing situations (e.g. tilt, hand or foot movement, initial posture, type of holds...) mimicking real rock climbing. Artificial climbing walls equipped with instrumented climbing holds (3D force sensors) were used. When one of the limbs was to be moved, the climber had to share body weight and tangential forces on the three remaining support to avoid loss of balance.

The upper limbs stabilize the posture, while the lower limbs counter balance the body weight. Releasing a hold is always associated with force transfers on the remaining supports, but different patterns of distribution were observed. The force level applied at one hand may amount to more than 330N, and be decomposed into a vertical component (75%) and a tangential component (25%) depending the rock climbing configuration. Dynamic movements may considerably increase this force and change this distribution.

2- Finger behavior in rock climbing

The neuromechanics control of the hand shows that the finger involvement is controlled thanks specific rules (Li et al., 1998). Applying these principles to rock climbing is helpful in order to understand the finger involvement, particularly the principle of minimization of the secondary moments (Quaine et al., 2003). This principle means that the four fingers force sharing was organized in order to minimize the efforts needed to stabilise the wrist joint.

Applied to both crimp and slope grips, this principle shows that the minimization of the secondary moment principle was stable. This means that the relative finger involvement does not change among the rock climbing grip technique. Moreover, the crimp and the slope posture do not affect the net force magnitude. The great force applied at the middle and the great relative involvement of the ring finger in the slope grip is presented as the main factor of injuries for these fingers.

Conversely, adding the thumb on the nail of the index finger allows to ideally place the fingers on the holds. This technique is frequently used in the crimp grip in skilled climbers. The thumb acts as an additional actuator by exerting supplementary force in the same direction as the other fingers. The supporting force was increased around 20%, the force at the index finger being doubled, while the force reduces at the little finger. Using the thumb as an additional support enables an increase in the performance of the grip force. Concomitantly, the forces exerted by the middle and ring fingers did not change, confirming that the pathology risks are not enhanced with the thumb technique.

3- The internal force sharing patterns

The main function of the finger flexor pulley system is to maintain the flexors tendons close to the bone, thus converting translation and force developed in the flexor muscle-tendon unit into rotation and torque at the finger joints. A biomechanical model which provides satisfactory mean was used to determine the pulley and tendon tensions, particularly when the DIP joint is hyperextended as in the crimp grip (Vigouroux et al., 2006). In this case, joint contact forces, ligament forces, and soft connective tissue loads produce a net passive torque for the DIP joint.

The model was three-dimensional, in static condition and associated to optimization procedures. Specifically in the crimp grip, a given procedure was proposed to estimate a passive moment around the DIP joint correlated with the FDP intramuscular electromyogram (EMG). This moment amounted to 25% of the joint external moment. It was concluded that this moment is essential for the moment balance equation.

The main problem for modeling humans' hand is that the number of muscles spanning a joint exceeds the number of degrees of freedom of the joint resulting in mathematical under-estimated problems. The proposed model used a numerical optimization procedure with the muscle stress squared criterion to determine a solution while the intramuscular EMG data of three extrinsic hand muscles serve to enforce additional inequality constraints.

This model shows that the flexor digitorum profundus muscle was the prime muscle flexor in the crimp grip, whereas the tensions were equally distributed between the flexor digitorum profundus and superficialis muscles in the slope grip. The forces acting on the pulley were 36 times lower for A2 in the slope grip than in the crimp grip, while the forces acting on A4 were four times lower.

When focusing on the middle and ring fingers, it appears that two main factors could explain the prevalence for injuries in the crimp grip. Firstly, the fingertip forces applied were higher than for the other fingers. Secondly, compared with cadaveric studies, the forces applied on the pulleys for these fingers were close to their rupture threshold, while it was not the case for the two other fingers.

Sensitive analysis of the model parameters, including the respective stiffness of the pulleys, showed that the most important parameter for the outcome of the model was the positioning of the pulley with respect to the center of rotation of the PIP joint. Simulations were performed to give the best possible placement for a pulley graft after pulley rupture (Roloff et al., 2006).

Finally, although the model guides the surgeon in the choice for pulley restoration with regard to biomechanical factors, it needs to be treated carefully since these factors may not be the only ones included in the choice of the optimal positioning. Other non-biomechanical factors may also be included.

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