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REVIEW ARTICLE

The Flexor Tendon Pulley System and Rock Climbing

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Abstract Rock climbing has increased in popularity over the past two decades. Closed traumatic rupture of the finger flexor tendon pulleys is rare among the general population but is seen much more commonly in rock climbers. This article reviews the anatomy and biomechanics of the finger flexor tendon pulleys, how they may be injured in rock climbing and how these injuries are best diagnosed and managed.

Keywords Flexor tendon pulleys · Pulley injury · Rock climbing

Introduction

Rock climbing has increased in popularity significantly over the past 20 years. With increasing numbers taking part in both indoor and outdoor climbing there has been an unsurprising rise in the number of climbing related injuries. Forty percent of all climbing related injuries are to the fingers with half of these being injuries to the flexor tendon pulleys [1]. Closed rupture of the digital flexor tendon pulleys may lead to a significant reduction in sport specific ability.

Anatomy

The digital flexor sheath is a complex structure through which the flexor tendons of the fingers run. The sheath is essential for normal function of the flexor tendons, it holds the flexor tendons close to the bone allowing them to effectively 'turn a corner' and transfer the force developed in the muscle-tendon unit into movement at the phalanges [2].

The sheath is composed of two distinct tissue components; a synovial or membranous component and a retinacular or pulley component [3].

The membranous portion is composed of a closed synovium lined tube. The tube can be imagined with the floor (dorsal) running over the transverse metacarpal ligament, the palmar surfaces of the metacarpophalangeal, proximal interphalangeal and distal interphalangeal joints and the palmar surface of the proximal and middle phalanges [3, 4]. The membranous part of the sheath is most clearly seen between the flexor pulleys where it forms folds and out-pouches which allow it to stretch and compress with flexion and extension of the digits.

The retinacular portion of the sheath consists of fibrous tissue condensations which wrap around the flexor tendons. These condensations are the flexor tendon pulleys. There are five annular pulleys and three cruciform pulleys which are numbered as they run from proximal to distal. Of the pulleys the A3 and A5 pulleys are located over a joint, the proximal interphalangeal joint [3] and the distal interphalangeal joint respectively.

The annular pulleys can be divided further into those which insert into bone (true fibro-osseous pulleys) and those which insert into the volar plate. The A2 and A4 pulleys are true fibro-osseous pulleys and are the strongest pulleys withstanding the greatest forces during pinch and grasp. The other annular pulleys (A1, A3, A5) are more flexible and allow for compression during flexion without impinging on the tendons [5]. The anatomical position of the pulleys and their relative insertions can be seen in Fig. 1.

Together the two portions of the sheath act to prevent bow-stringing of the tendons and allow the transfer of the necessary forces for pinch and grasp [5].

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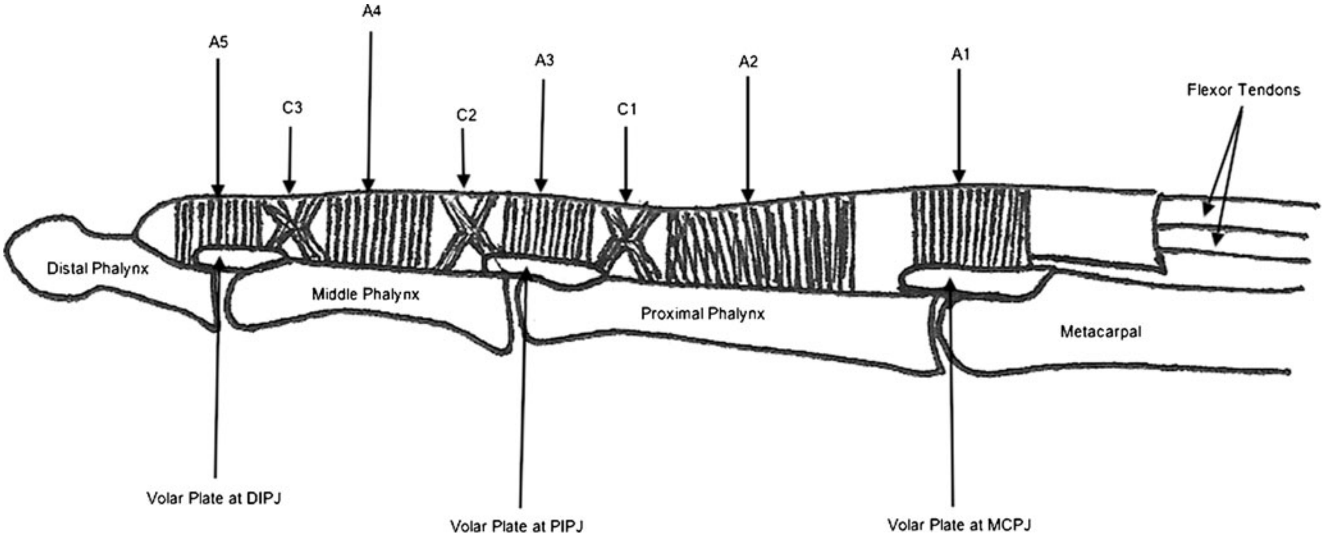

Fig. 1 The relative position and insertions of the finger flexor tendon pulleys

Biomechanics

Rock climbing is a biomechanically and anatomically unique activity. It defies the anatomical fact that as humans we are built to move and support the body's weight through our lower limbs. Often in climbing the majority of the body's weight is supported by only the distal phalanges at small ledges whose depth may be no more than a few millimetres [5, 6]. In addition to the very high loads that supporting body weight against gravity places on the flexor tendon pulleys, rock climbers use a unique grip configuration which increases the loads placed on the flexor tendon pulleys even further. This grip position is called the 'crimp' position [6].

Up to ninety percent of climbers use the crimp position when climbing and the frequency of its use rises with increasingly difficult climbs. The 'crimp' grip position involves flexion of the PIPJ's to 90–100° with the DIPJ's hyper-extended. The grip can be open, as in Fig. 2 or closed, as in Fig. 3 and this refers to the position of the thumb. In the closed grip the thumb pushes over the index finger allowing the thumb to be used as an extra holding force. This method of recruiting the thumb can only be done in the crimp position and this makes it a favourite grip for climbers faced with small holds.

In the 'crimp' position bowstringing of the flexor tendons applies very high forces to the flexor tendon pulleys. The greatest forces are exerted by the flexor digitorum profundus tendon at the A2 pulley. The forces at the A2 pulley are approximately 3–4 times greater than at the fingertip. It has been estimated that a recreational rock climber can load the A2 pulley with forces of around 380N [6]. Clearly repetitive loading of the pulleys with such forces can lead to injury and overuse symdomes.

While at first glance the 'crimp' position seems an abnormal grip posture analysis of the biomechanics show that it maximises the power available from the flexor digitorum profundus muscle. In the 'crimp' position the moment arm of the flexor digitorum profundus tendon is increased over the PIPJ and the forces are transferred maximally through the A2 and A4 pulleys [6]. The A2 and A4 pulleys are the true fibro-osseus pulleys and are best suited to coping with the high forces placed across them, showing that perhaps the crimp position is not as alien as it may first seem.

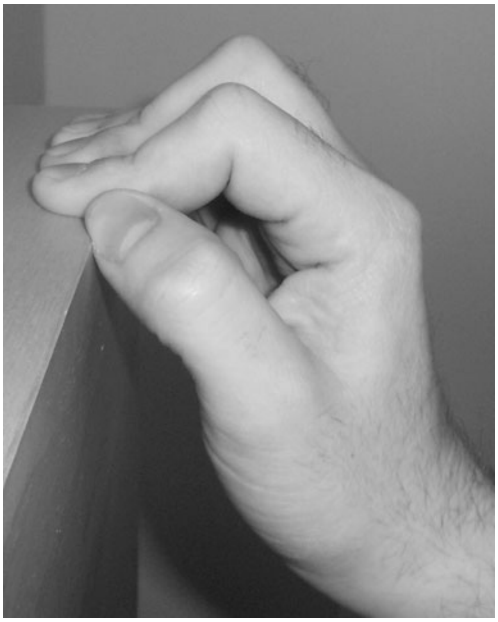

Fig. 2 The open 'crimp' grip position

Fig. 3 The closed ‘crimp’ grip position

Injury

Closed rupture of the finger flexor tendon pulleys in rock climbers was first recognised in the literature in the early 1990’s [7–11]. Analysis of the forces generated when a 70 kg individual falls and puts their body weight through one finger has shown that up to 450N can be generated [8]. This is in excess of the maximum load which the finger flexor tendon pulleys can withstand. The A2 pulley is the strongest and has been shown to withstand forces of around 400N [5].

Recent biomechanical analysis has shown that injury to the pulleys and in particular to the A2 pulley is most likely to occur when the pulleys are loaded eccentrically [12]. When loaded eccentrically the load at which the pulleys ruptured was found to be less than that when loaded concentrically [12–15]. It is thought that the high friction generated between the pulley and the flexor tendon in eccentric loading is one of the most significant risk factors for pulley rupture. It has also been shown however that this friction may be an advantage for rock climbers as it offers additional support for the holding power of the flexor tendon muscles [12, 13, 15].

The majority of climbers who have suffered either partial or complete rupture of a flexor tendon pulley describe acute onset while performing a difficult move in the ‘crimp’ position or when they have shock loaded their fingers as they lost their footing [1, 2, 16–18]. Occasionally a loud pop is heard but most commonly there is sudden onset of pain and swelling over the affected pulley or pulleys and there can be acute haematoma formation [1, 9].

Most commonly significant bowstringing will only occur if at least two sequential pulleys have been completely ruptured but there have been documented cases of it occurring in isolated A2 ruptures [8]. Bowstringing leads to incomplete shortening of the tendon on muscle contracture and the resultant loss of power and function. This occurs as the normal course of the tendon is shortened and there is an increase in the functional length of the tendon resulting in an active flexion deficit [2].

Injuries to the cruciate pulleys may also occur in rock climbing but are quite rare and normally occur as a result of a torsion force [19].

There have been documented cases of closed pulley rupture in non-rock climbers but the mechanism of injury would appear to be very similar. Most non-climbing injuries occurred while carrying heavy weights on the finger tips in a position similar to the ‘crimp’ grip but inverted [20]. Closed annuar pulley injuries have also been recently reported in high level baseball pitchers [21].

Diagnosis

Clinically it can be difficult to give an exact diagnosis. Differentiating between pulley strain, partial tear and complete rupture normally requires further investigation. Anteroposterior and lateral radiographs of the injured finger are worthwhile to exclude associated fracture or volar plate avulsion type injuries [22]. MRI has been shown to be particularly effective in detecting pulley injuries, the high cost associated with MRI means it is not in widespread use for finger injuries [23–25]. Ultrasound scan has been shown to be very effective as it allows dynamic studies to be performed at a lower cost and is now considered the gold standard relegating the role of MRI for cases with ongoing doubt post ultrasound [26, 27]. The accuracy of ultrasound is operator dependant and clinical experience is necessary to ensure its effectiveness.

Schöffl et al. proposed a grading system for flexor pulley injuries which has been adopted to help guide and correlate therapeutic options. They have divided pulley injuries into four grades. Grade I injuries are pulley strains where there is no dehiscence of the tendon from bone (<2 mm) on MRI or ultrasound examination. Grade II injuries comprise of complete rupture of the A4 pulley or partial rupture of the A2 or A3 pulleys. Grade III injuries are those with complete rupture of the A2 or A3 pulleys. Grade IV injuries are the most severe and include complex multiple pulley ruptures or single rupture of the A2 or A3 pulley with associated lumbrical muscle or collateral ligament injury [1].

Treatment

The mainstay of treatment is now non-surgical with the consensus being that Grade I–III injuries can all be managed conservatively [7, 10, 28–30]. Biomechanical analysis has shown that taping circumferentially around the injured pulley provides some protection of the pulley [7] although it is not supportive enough to prevent rupture of the pulley [29] and has no role in prophylactic use to avoid rupture [31].

The most described method of taping appears to be be where the tape is wrapped circumfrentially over the distal end of the proximal phalynx [7, 29, 31]. Here it reduces bowstringing by the greatest amount and has a secondary benefit of limiting flexion at the proximal interphalangeal joint thus reducing the load at the A2 pulley. Alternative methods of taping have been proposed including the H-tape method of Schöffl et al. [32] but appear less frequently in the literature.

Most climbers with Grade I and II injuries can achieve full recovery within 6 weeks although continued protective taping is recommend for up to 3 months following injury. Grade III injuries should be immobilised in a thermoplastic splint or soft-cast ring for 10 to 14 days with gentle mobilisation under tape protection commenced thereafter. Gentle climbing can normally begin in Grade III injuries 6–8 weeks after injury and full function achieved after 3 months with protective taping continuing for 6 months [1, 2, 4, 16, 22].

Grade IV injuries should be surgically repaired [1, 4, 33]. This is undertaken to prevent a functional deficit caused by reduced flexion at the distal interphalangeal joint. Clinically it is this loss of flexion that should guide the need for surgical repair.

The evidence for surgical repair comes from the biomechanical analysis of Lin et al. [5, 34, 35]. Simple suturing of the pulley remnants is not sufficient. Different surgical repair options exist and are based on the use of grafted material to replace the ruptured pulley or pulleys.

Palmaris longus tendon grafts wrapped around the tendon and phalanx are commonly used. There are several techniques involving wrapping the tendon around the phalanx between one and three times. The “loop and a half” technique of Widstrom et al. seems to provide the best biomechanical properties both in terms of strength and tendon glide through the graft [36–38].

Extensor retinaculum grafts are recommended for A2 and A3 pulley repair as its reduced bulk does not interfere with the extensor mechanism at the proximal interphalangeal joint and this reduces the risk of adhesions [4, 33, 39].

Extensor retinaculm grafts are however more technically difficult and offer less initial stability than palmaris tendon grafts. Gabl et al. claim however that this repair is the most likely to withstand a return to rock climing as the palmaris tendon graft is more likely to stretch over time [33].

Significantly Arora et al. have shown that there is little difference in the outcomes following reconstruction with either an extensor retinaculum graft or a wrap around palmaris tendon graft [40]. Both repairs allowed a return to pre-injury levels of rock climbing ability.

Conculsion

Rock climbers place significant loads through their hands, because of this they are at risk of flexor tendon and pulley rupture. The use of the ‘crimp’ grip position and the biomechanics involved further increase this risk. Despite these overwhelming forces the digital flexor pulleys are able to maintain the flexor tendons in a functionally beneficially position close to the bone and in the majority of climbers they rarely cause more of a problem than the occasional pulley strain. However there is no doubt that pulley tear and rupture is a significant and increasingly common injury. As the popularity of rock climbing increases specialist hand and sports medicine clinics will see an ever increasing number of people with these injuries. Ultrasound scan and MRI are the imaging modalities of choice. Conservative management the mainstay of treatment of Grade I–III injuires with surgical repair reserved for Grade IV injuires.

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