Flap Irritation Phenomenon (FLIP): Etiology of Chronic Tenosynovitis After Finger Pulley Rupture

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After a pulley rupture, most climbers regain the full function of their previously uninjured fingers. However, in some cases of pulley rupture, a persistent inflammation of the tendon sheath is observed. In this study, 16 cadaver fingers were loaded until pulley rupture and then studied for the rupturing mechanism. In addition, two patients with this pathology were investigated using ultrasound and MRI, and received surgery. In 13 fingers, a rupture of one or several pulleys occurred and almost always at the medial or lateral insertion. In one finger, a capsizing of the pulley underneath the intact tendon sheath was observed, leading to an avulsion between tendon and tendon sheath. A similar pathology was observed in the ultrasound imaging, in MRI, and during surgery in two patients with prolonged recovery after minor pulley rupture. In cases of prolonged tenosynovitis after minor pulley rupture, a capsizing of the pulley stump is probably the cause for constant friction leading to inflammation. In those cases, a surgical removal of the remaining pulley stump and sometimes a pulley repair may be necessary.

Keywords: biomechanics, climbing, sports

Many studies have investigated the biomechanics of pulley ruptures and their implications for hand function (Lin et al., 1989; Marco et al., 1998; Moutet et al., 2004; I. Schöffl et al., 2009c; I. Schöffl et al., 2009a, 2009b; Vouilliaume et al., 2004). In general, the pulleys A2 and A4 are considered to be the most important (Bollen, 1990; Bowers et al., 1994; Marco et al., 1998; V. Schöffl & Schöffl, 2010; Tropet et al., 1990). With regard to the need for surgical repair after pulley rupture, the opinions vary. Some scientists suggest that full recovery of the former function can only be accomplished by repairing the injured pulley system using autologous grafts (Moutet, 2003; Moutet et al., 2004), whereas others suggest that surgical repair is only necessary when more than two pulleys or two major pulleys, namely, the A2 and A4 pulleys, are ruptured at the same time (Arora et al., 2007; Gabl et al., 2000; Kubiak et al., 2006; V. Schöffl et al., 2002, 2006; V. Schöffl & Roloff, 2005; V. Schöffl & Schöffl, 2006). A study investigating the conservative approach of single pulley lesions (V. Schöffl et al., 2006) was able to prove that the climbers had no strength deficit after pulley rupture and had regained their former climbing level, stressing that a surgical approach is most often needless. Therefore, surgical repair after pulley rupture can be limited to complex pathologies where finger function is impaired in a way that full flexion can no longer be achieved, as the so-called bowstringing of the tendon away from the bone becomes too pronounced.

However, it has also been observed that some patients develop chronic tenosynovitis after pulley rupture (V. Schöffl et al., 2003, 2006; V. Schöffl & Schöffl, 2007). So far, this has been regarded as a consequence of the higher friction between the remaining pulleys and the tendon because of the diminished angle between pulley edge and tendon (Roloff et al., 2006; I. Schöffl et al., 2007). Although this pathomechanism may explain the general inflammation observed after almost any pulley rupture, it cannot account for the small number of patients with chronic problems. We therefore wanted to investigate the chronic tenosynovitis after single pulley rupture and find the cause for this pathology.

Methods

We used 16 cadaver fingers from another previously published study (I. Schöffl et al., 2009b), in which fingers were loaded in an eccentric fashion until pulley rupture occurred. The 16 fingers were from eight different donors, and we only used fingers from one hand of each donor. The fingers were from fresh frozen cadavers and...
investigated immediately after thawing. All fingers were prepared previous to loading according to the following protocol: the palmar skin and subcutaneous tissues were removed to expose the entire pulley system from the A1 pulley to the flexion crease of the DIP joint. The tendon sheaths as well as the cruciate pulleys were removed except for the tendon sheath above the remaining pulleys, A2, A3, and A4. Therefore, the tendon sheath only remained over the annular pulleys. For this purpose, surgical magnifying glasses (magnification × 2.5) were used for a better visualization of the pulley system. The same researcher did all preparations of the fingers. Then the fingers were loaded in an eccentric fashion using an isokinetic loading device employed for investigating pulley ruptures in vivo and cadaver specimens (I. Schoffl et al., 2009; I. Schoffl et al., 2009b; Schweizer et al., 2003). After pulley rupture occurred, each finger was investigated using surgical magnifying glasses for determining the exact localization of the rupture.

In addition, we investigated two patients with chronic tenosynovitis after pulley rupture who had injured themselves during climbing. The initial event in the case of the C1 pulley rupture occurred while climbing a difficult route with the fingers in the crimp grip position and trying to reach the next hold but failing to maintain the strength on the little ledge he was holding onto. The second patient only contacted us after a few weeks had gone by and he could not recall the exact injury mechanism but recalled that the injury occurred toward the end of the climbing day on a difficult route with small handholds. Both patients were diagnosed using ultrasound. One was found to have a lesion of the C1 pulley and the other had an A1 pulley rupture. After diagnosis of a minor pulley rupture, the fingers were investigated using a 1.0-tesla whole-body scanner (Intera, Philips, Best, Netherlands) in combination with a surface coil (Sense Flex M, Philips, Best, Netherlands). A routine protocol including contrast-enhanced fat-suppressed T1-weighted imaging was performed in the transverse and sagittal planes. At first, these two patients underwent conservative treatment according to the recommendations (V. Schöffl et al., 2002) that consist in initial immobilization and early functional therapy under external pulley protection using the H-Tape (I. Schöffl et al., 2007). After lack of improvement with the first two treatment modalities, we injected corticosteroids into the tendon sheath. As there was no improvement after three injections with corticosteroids, the patients agreed to a surgical intervention. These operations were recorded using digital imaging and the tissue that was removed was later inspected using normal and transmission electron microscopy for analysis.

**Results**

Of the 17 fingers, eight showed an A2- and five an A4-pulley rupture as a first event. Four fingers did not suffer a pulley rupture because of the giving way of another structure, such as the fracture of a phalanx or the rupture of one of the flexor tendons.

When investigating the ruptures using magnifying glasses, we observed that the pulleys ruptured at their insertion sites in 12 events, and a rupture through the middle of the pulley only occurred twice (Figure 1). Table 1 indicates the sides on which the pulley ruptures occurred. Overall, there was no preference for the radial or ulnar insertion. However, when looking at each hand in turn, it can be observed that most often the same rupture occurred at the same insertion site on another finger of the same hand.

In one finger with an A4 pulley rupture, the tendon sheath above the pulley remained standing while the pulley underneath it ruptured at its ulnar insertion site and folded over, underneath the sheath (Figure 2).

In addition to the cadaver study, we investigated two patients who suffered from prolonged tenosynovitis after single pulley rupture. The examination using ultrasound revealed that in the case of one patient all major pulleys remained intact with no measurable bowstring. However, there was a lot of fluid around the tendons concordant with a tenosynovitis and floating material, which could not be further specified (Figure 3). This observation suggests the rupture of a cruciate pulley, as such a rupture will not lead to a detectable bowstring in the ultrasound measurements but the fluid and the floating material point toward such an injury. The other patient had an A1 pulley rupture, which could not well be documented using ultrasound, as it is in the palmar side of the hand, with a lot of tissues around the tendon and thus making an exact diagnosis most difficult. After conservative treatment with repetitive injections of corticosteroids did not lead to any improvement of the symptoms, MRI was employed as shown in Figures 4 and 5 for the patient with the C1 pulley rupture in a sagittal and a transversal plane. However, there was not much gain in information using this method, as the floating material could not be further specified. However, as the structure seen in ultrasound and MRI seemed to be the cause for the continuous problems of the patients, a surgical intervention was planned for the removal of this structure. Interestingly, the tendon sheath was intact in both cases and only the C1 pulley in

![Image](292_Schoeffl_Baier_Schoeffl)
Table 1  Distribution of the rupturing events with respect to the site of the rupture

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<thead>
<tr>
<th>Hand No.</th>
<th>A2 Radial Side</th>
<th>A2 Ulnar Side</th>
<th>A2 Center</th>
<th>A4 Radial Side</th>
<th>A4 Ulnar Side</th>
<th>A4 Center</th>
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one patient and the A1 pulley in the other patient were missing. Figure 6 depicts the intraoperative findings for the patient with the C1 pulley rupture. Furthermore, the tissue seen in the ultrasound was retrieved and resembled most likely ligament tissue altered by scarring and the prolonged inflammation inside the tendon sheath (Figure 7). This tissue was later analyzed using normal and transmission electron microscopy and was found to be collagenous connective tissue similar to the structure of a tendon, and it showed chondroid metaplasia. This is concordant with a pulley structure that has deteriorated due to scarring. Both patients recovered well, but rehabilitation consisting of immobilization for 1 week using a palmar splint, and then early functional therapy consisting of passive and later active physiotherapy, lymph drainage, and ergotherapy, was exceptionally long in one of the patients with remaining symptoms for almost 6 months.

Figure 2 — Picture of the FLIP in one of the cadaver fingers. The tendon sheath remained intact while the pulley underneath ruptured and folded over.

Figure 3 — Ultrasound of the finger with the C1 pulley rupture. The A2 pulley remained intact but there was a considerable amount of scar tissue between tendon and bone.
Discussion

The aim of this study was to investigate the causes for prolonged tenosynovitis after minor pulley rupture as observed in some climbers. Most authors agree that minor pulley ruptures have a good outcome with a conservative approach (Arora et al., 2007; Gabl et al., 2000; Kubiak et al., 2006; V. Schöffl et al., 2006; V. Schöffl & Schöffl, 2006); however, in a few cases this nonsurgical approach does not yield the desired effects, namely, the full strength of the fingers without pain. As the patients are most often climbers, they suffer from an inflammatory pain, which impedes them from climbing at their former ability level. When examining these patients using ultrasound, fluid can be observed around the flexor tendons of the fingers, which is in accordance with a tenosynovitis. Even repeated injections of corticosteroids only lead to an improvement of the symptoms for a limited time period and in the end surgery becomes necessary. It is therefore of prime importance to understand the underlying cause for these prolonged histories. In this study, cadaver fingers were investigated in which the pulleys were ruptured by pulling on the flexor tendons. In most cases, the pulleys
ruptured on their insertion sites, an observation which stands in concordance with a biomechanical model by Hume et al. (Hume et al., 1991), who stated that the forces acting on the pulleys need to be calculated at their insertion sites. A pulley rupture occurring on the insertion site of the pulley leads to a far larger remaining stump than if the rupture occurred through the middle. If such a stump happened to fold over, this would lead to a large impediment for the gliding of the tendon in the tendon sheath. Furthermore, although the rupture pattern did not show any preferences for the radial or ulnar insertion site, it could be observed that, when a second finger of the same hand was investigated, the pulley rupture (A2 or A4) was the same for four pairs and the side of the rupture (ulnar or radial) was also the same. This observation implies that the pattern of a pulley rupture depends on unique features of this pulley in the person experiencing this injury and this person will most likely experience the same sort of injury should the person rupture another pulley. Two fingers of the same hand did not suffer any pulley injury because another structure gave way first, implying that in this donor the pulleys may have been exceptionally strong. However, in two finger pairs, the observation regarding the rupture mechanism could not be made. The number of specimens in this experiment was probably too small to be sure of this result.

However, one of the fingers showed the flap irritation phenomenon (FLIP) speculated about. The tendon sheath above the ruptured pulley in this specimen remained intact and the long stump folded over, leading to an impediment inside the tendon sheath. Even though this event only occurred once, it is in line with the pathomechanism speculated about earlier. Furthermore, in the studied specimens, the tendon sheath had been removed from where the pulleys were underneath, as a consequence of the biomechanical study (I. Schoffl et al., 2009b) from which the specimens had been obtained. Had the complete tendon sheath been standing at the moment of rupture, it is possible that more such events could have been observed. Still, the number of patients with this prolonged injury is small and therefore it is not surprising we did not observe it more frequently.

In addition to the cadaver study, we were able to study two patients with this injury pattern and used MRI as well as digital imaging during the surgery to verify the observed FLIP in reality. In both cases, the pulley rupture was of minor importance—a C1 pulley rupture in one and an A1 pulley rupture in the other patient, as determined using ultrasound imaging. A rupture of these pulleys is reported in rare cases (V. Schoffl & Schoffl), which is either due to the fact that they are difficult to diagnose as they do not influence the tendon–bone distance in the ultrasound examination, or due to the fact that a rupture of one of these pulleys means no impairment for the climber unless the FLIP occurs. The MRI and the ultrasound backed up the diagnosis of a C1 and an A1 pulley rupture and showed a large lump inside the tendon sheath where the former pulley should have been, most likely resembling scar tissue. This lump was removed during surgery, and normal and electronic microscopy determined that it was made up of tissue that most likely resembled a pulley stump that had deteriorated due to scarring. After the surgery, both patients recovered well, although the rehabilitation was longer than it normally is after pulley surgery, in one patient as long as 6 months. Whether the effect of the surgery was due to a denervation effect or due to the removal of the remaining stump cannot be objectified; however, the aim of this study was the identification of the cause for prolonged recoveries after minor pulley ruptures. The prolonged rehabilitation is a consequence of a chronic tenosynovitis, which in turn is a consequence of the pulley stump irritating the tendon sheath, leading to inflammation and pain. The removal of both the stump as well as the inflamed tendon sheath is crucial for these patients.

As a conclusion, it can be stated that the FLIP is most likely the cause for prolonged tenosynovitis observed in some patients after minor pulley rupture. In such cases, especially ultrasound and MRI to a lesser extent can help determine the underlying cause and surgery is the only option for the full recovery of the former finger function.

References


