

Acute A4 Pulley Reconstruction with a First Extensor Compartment Onlay Graft

Michael G. Jakubietz, MD*
 Rainer H. Meffert, MD*
 Karsten Schmidt, MD*
 Joerg G. Gruenert, MD†
 Rafael G. Jakubietz, MD*

Background: The integrity of the flexor tendon pulley apparatus is crucial for unimpaired function of the digits. Although secondary reconstruction is an established procedure in multi-pulley injuries, acute reconstruction of isolated, closed pulley ruptures is a rare occurrence. There are 3 factors influencing the functional outcome of a reconstruction: gapping distance between tendon and bone (E-space), bulkiness of the reconstruction, and stability. As direct repair is rarely done, grafts are used to reinforce the pulley. An advantage of the first extensor retinaculum graft is the synovial coating providing the possibility to be used both as a direct graft with synovial coating or as an onlay graft after removal of the synovia when the native synovial layer is present.

Methods: A graft from the first dorsal extensor compartment is used as an onlay graft to reinforce the sutured A4 pulley. This technique allows reconstruction of the original dimensions of the pulley system while stability is ensured by anchoring the onlay graft to the bony insertions of the pulley.

Results: Anatomical reconstruction can be achieved with this method. The measured E-space remained 0 mm throughout the recovery, while the graft incorporated as a slim reinforcement of the pulley, displaying no bulkiness.

Conclusions: The ideal reconstruction should provide synovial coating and sufficient strength with minimal bulk. Early reconstruction using an onlay graft offers these options. The native synovial lining is preserved and the graft is used to reinforce the pulley. (*Plast Reconstr Surg Glob Open* 2017;5:e1361; doi: 10.1097/GOX.0000000000001361; Published online 28 June 2017.)

INTRODUCTION

The functional relevance of the flexor tendon pulley system is well known, but indications for acute reconstruction are rare. While secondary reconstruction is an established procedure in multi-pulley injuries, acute reconstruction of isolated, closed pulley ruptures remains challenging. As these injuries mainly occur in advanced-level sport climbers, surgical reconstruction is done rarely. The indication for surgery also depends on the availability of a hand surgeon understanding the relevance of this injury.¹

MATERIALS AND METHODS

The pulley system is part of the fibro-osseous tendon sheath, which tethers the tendon to the palmar curvature of the bone. This enables the transfer of a translational force generated from the muscle-tendon unit into a rotational moment on the phalanx effectively flexing the digit. In a biomechanical evaluation by Peterson et al.,² the A2 pulley was found to be the single most important pulley for flexor tendon function. However, near-normal hand function could only be achieved when both A2 and A4 were present.^{2,3} Bowstringing results in an increased requirement of muscle activation to reach the same amount of finger flexion. This precludes full finger flexion and also alters kinematics of the adjacent joints. Ultimately, the equilibrium between flexor and extensor tendons will be influenced, resulting in loss of range of motion. According to an algorithm presented by Schöffl et al.,^{4,5} singular A4 pulley injuries rarely justify surgical intervention. On the other hand, Bouyer et al.⁶ have shown that isolated ruptures of the A4 pulley proved to be a poor prognostic factor for regaining preinjury performance levels.

From the *Department of Trauma-, Hand-, Plastic and Reconstructive Surgery, University of Wuerzburg, Wuerzburg, Germany; and †Department of Plastic and Hand Surgery, Kantonsspital St. Gallen, St. Gallen, Switzerland.

Received for publication December 14, 2016; accepted April 17, 2017.

Copyright © 2017 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of The American Society of Plastic Surgeons. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

DOI: 10.1097/GOX.0000000000001361

Disclosure: Supported by the German Research Foundation (DFG) and the University of Wuerzburg in the funding program Open Access Publishing. The Article Processing Charge was paid for by the authors.

Surgical reconstruction of the A4 pulley is only advocated in cases of multilevel pulley injuries and outcomes seem to be disappointing. As Chow et al.⁷ have shown in cadaveric testing, insufficiency of the proximal A4 pulley has considerable effects on the range of motion of the proximal interphalangeal joint (PIP) joint, whereas effects on metacarpophalangeal joint or distal interphalangeal joint (DIP) joints were not significant. The functional integrity of the pulley system can be shown by physiological E-space, ensuring system efficiency. There are 3 factors influencing the functional outcome of a reconstruction: gapping distance between tendon and bone (E-space), bulkiness of the reconstruction, and stability. If flexor bowstringing was corrected, patients were much more likely to regain preinjury sport performance.⁶ For patients with an E-space less than 2mm, the incomplete nature of correction compared with the healthy finger did not influence the functional result.⁶ Although loop techniques may yield superior mechanical strength of the repair, they are not anatomical and may interfere with function of the extensor tendon apparatus.⁸ Grafts from the extensor retinaculum have been advocated as the more anatomical choice.⁹⁻¹¹ Nevertheless, Bouyer described in the largest series extensor tendon bowstringing at the donor site in more than 25%.⁶ Therefore, other donor sites should be considered. The first extensor compartment is well known to hand surgeons from deQuervains disease. This extensor compartment displays a strong ligamentous portion of both sufficient width and length with regard to pulley reconstruction. The biomechanical properties of the ligament justify its use for scapholunate ligament reconstruction and should be considered sufficient for flexor tendon pulley reconstruction. Donor-site morbidity is low. Bowstringing after release is generally rare in the first extensor compartment. Iatrogenic injury to the superficial branch of the radial nerve is preventable. An advantage of the first extensor retinaculum is the synovial coating providing the possibility to be used both as a direct graft with synovial coating or as an onlay graft after removal of the synovia when the native synovial layer is present.

RESULTS

A functionally highly demanding surgeon presented with an isolated A4 pulley rupture acquired during sport climbing. Magnetic resonance imaging showed a completely torn A4 pulley of the left fourth finger, the tear was close to the radial insertion, whereas the pulley itself became entrapped under the deep flexor tendon (Fig. 1). This resulted in an enhanced E-Space (4mm), indicative of an inferior functional result in the future. Conservatively treated, this may lead to chronical synovitis, described as flap irritation phenomenon.¹² To avoid such late sequela and expedite return to work as a microsurgeon, reconstruction was scheduled. Because we regard the properties of the first dorsal compartment as advantageous, it was used as an onlay graft without synovial coating, anchored to the bony insertion of the pulley, reinforcing the pulley system (Fig. 2).

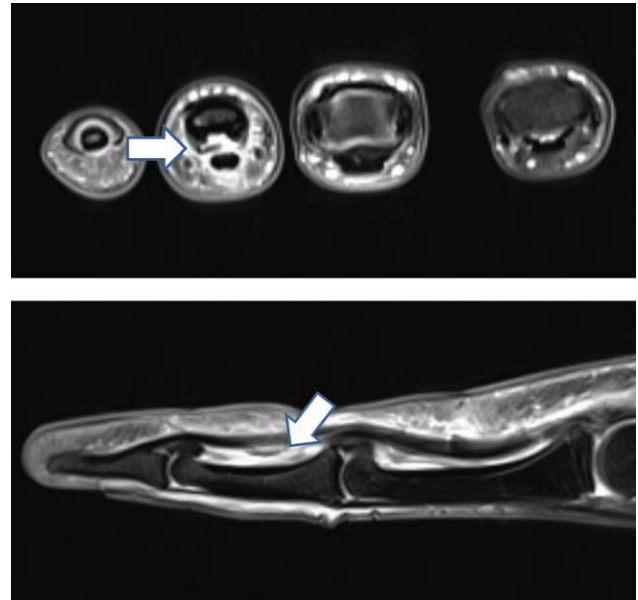


Fig. 1. Magnetic resonance imaging of the torn A4 pulley, displaying pulley entrapment under the deep flexor tendon resulting in increased E-Space.

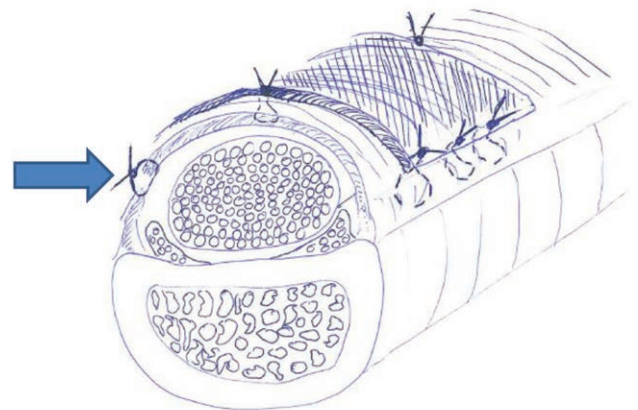


Fig. 2. Lateral sutures of the pulley (arrow), suturing of the onlay graft to the bony insertion of the pulley.

Through a diagonal incision over the ruptured A4 pulley, both neurovascular bundles were protected and the flexor tendon was located. The entrapped portion of the pulley was mobilized and the site of rupture at the bony insertion debrided. The deep flexor tendon was reduced into its original location. It was temporarily held in its bed by a needle. This is crucial as otherwise primary suture of the pulley is impossible. First sutures were placed at the bony insertion of the A4 pulley for the graft to be placed later on. Then the pulley was sutured with 4-0 polydioxanone suture in cross stitch fashion, placing the knots away from the gliding area. This allows tight reconstruction of the pulley. The ideal reconstruction still ensures unlimited gliding of the tendon but closely tethering the tendon sheath to the bone. This looks intraoperatively like a sharp bending of the tendon toward the bone, contrary to the previously straight course through the subcutaneous tis-

sue. Then the onlay graft was harvested and prepared. As a synovial layer was not required and might prevent stable integration of the graft, it was resected carefully to maintain maximum thickness of the graft. The size of the graft was chosen according to the size of the pulley, whereas great care was taken that the graft would not be wider than the pulley. The preplaced sutures at the bony insertion were used to tighten and attach the graft (Fig. 3). Three stitches on each side were employed. The proximal and distal borders of the pulley were additionally anchored to the graft to ensure better incorporation (Fig. 2). Throughout the procedure, care was taken not to place suture material in direct proximity to the gliding areas such as tendon or synovial layer. Then the needle was removed and gliding of the tendon tested before closure. A splint was administered for 7 days followed by a thermoplastic ring for 5

weeks. Active and passive range of motion exercises were initiated after 7 days. Return to climbing was allowed after 6 weeks; however, the crimp position (hyperextended DIP joint and fully flexed PIP joint) was avoided for 6 months. Return to surgery began 2 weeks postoperatively, mainly in microsurgery. Physically more demanding cases requiring full grip strength were begun 6 weeks postoperatively. The measured E-space remained 0mm throughout the recovery and ever since, whereas the graft did incorporate as a slim reinforcement of the pulley, displaying no bulkiness (Fig. 4), 2 years postoperative control. Full finger flexion at the DIP was impaired for 4 months. No impairment of range of motion regarding flexion and extension of the PIP and DIP remained. Only the inability to passively hyperextend the DIP joint persisted. Due to unrelated reasons, climbing level increased compared with the preoperative level. After residual swelling of the digit had resolved, the tightly fitted wedding band could be worn again.



Fig. 3. Intraoperative resemblance of the onlay graft. Exposure through a diagonal incision only (Limited Brunner) by request.

DISCUSSION

Although conservative treatment for isolated A4 pulley ruptures is generally recommended, reconstruction may be beneficial in individuals with high manual demands apart from sports-related activities. As these injuries usually occur in young athletes, most treatment regimens focus on the return to sports at preinjury level. Especially in hand injuries, it needs to be noted that athletes demands regarding hand function may not only vary significantly depending on the individual sport but may also be very different to functional demands of patients working in fields requiring high levels of digital skills. Therefore, the conclusion that once preinjury level is regained, treatment must have been sufficient and cannot be applied to all patients. Preinjury level in climbing is a reference point for treatment of pulley injuries. This by itself is highly vari-

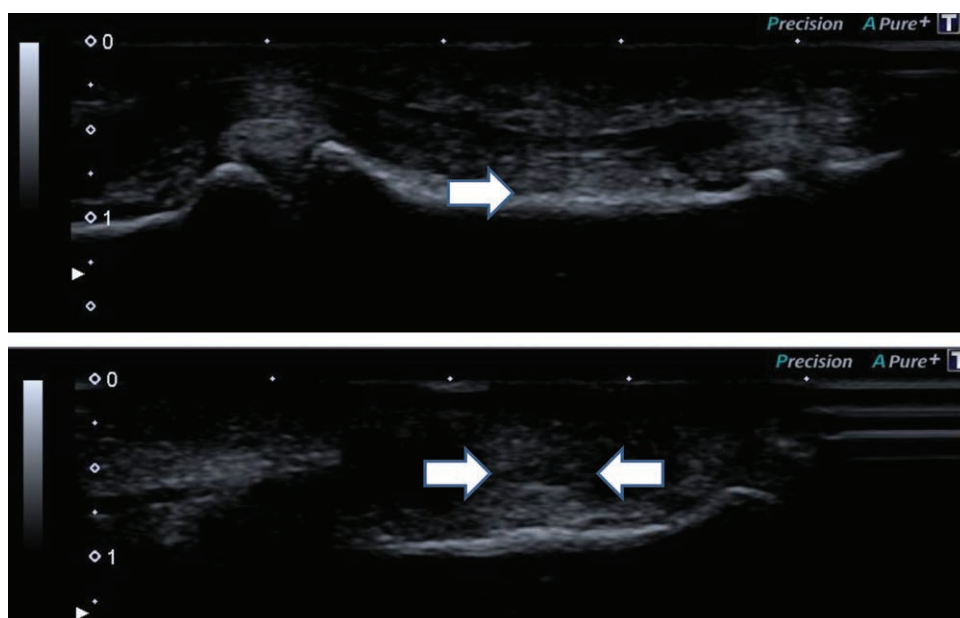


Fig. 4. Two years postoperative ultrasound, single arrow displaying E-Space of 0mm, double arrow showing width of the graft as well as slim appearance.

able. Due to the nature of grading rock climbs, routes of the same difficulty level may have completely different physical demands. As high level rock climbers are motivated, they will inevitably work around their weaknesses and might move toward other types of routes of the same difficulty level, requiring less finger strength but more core strength and endurance.

The functional result in pulley reconstruction needs to be emphasized more than difficulty level even if athletes only judge success of treatment by posttraumatic climbing level.^{4,5} A well-known sequela of pulley injury and resulting bowstringing is an extension deficit at the PIP joint. This may functionally be more relevant for a nonclimbing patient, whereas rock climbers may not be markedly impaired as finger flexion is unhindered. Emphasis has to be placed on regaining full range of motion based on minimal bowstringing, presenting as near normal E-space. Furthermore, it has to be noted that treatment recommendations may also be based on the availability of a hand surgeon with sufficient knowledge regarding such injuries. The ideal treatment will reconstruct the original

dimensions and biomechanical properties of the pulleys. Although a too wide/loose reconstruction will result in persistent bowstringing, seen in an enlarged E-space, too tight reconstruction will interfere with tendon gliding. Dy et al.¹³ reported the main reoperative procedure after pulley reconstruction being tenolysis. Increased tendon gliding resistance is a well-known factor for less favorable results in flexor tendon repair. Thus, authors also consider incising pulleys to reduce gliding resistance.¹⁴⁻¹⁶ These considerations cannot be applied to pulley ruptures where flexor tendons are intact. Persistent loss of motion and decreased strength is caused by anatomical alterations of the course of the flexor tendon apparatus. Thus, the functional absence of a pulley, while probably being tolerable in a slightly shortened flexor tendon after repair, will lead to more profound mechanical alteration in athletes with noninjured tendons.^{17,18} The ideal reconstruction will provide equilibrium of stability and function. Although grafts from the first extensor retinaculum have been used in our institution for several indications, the use for immediate singular A4 pulley reconstruction has not been reported

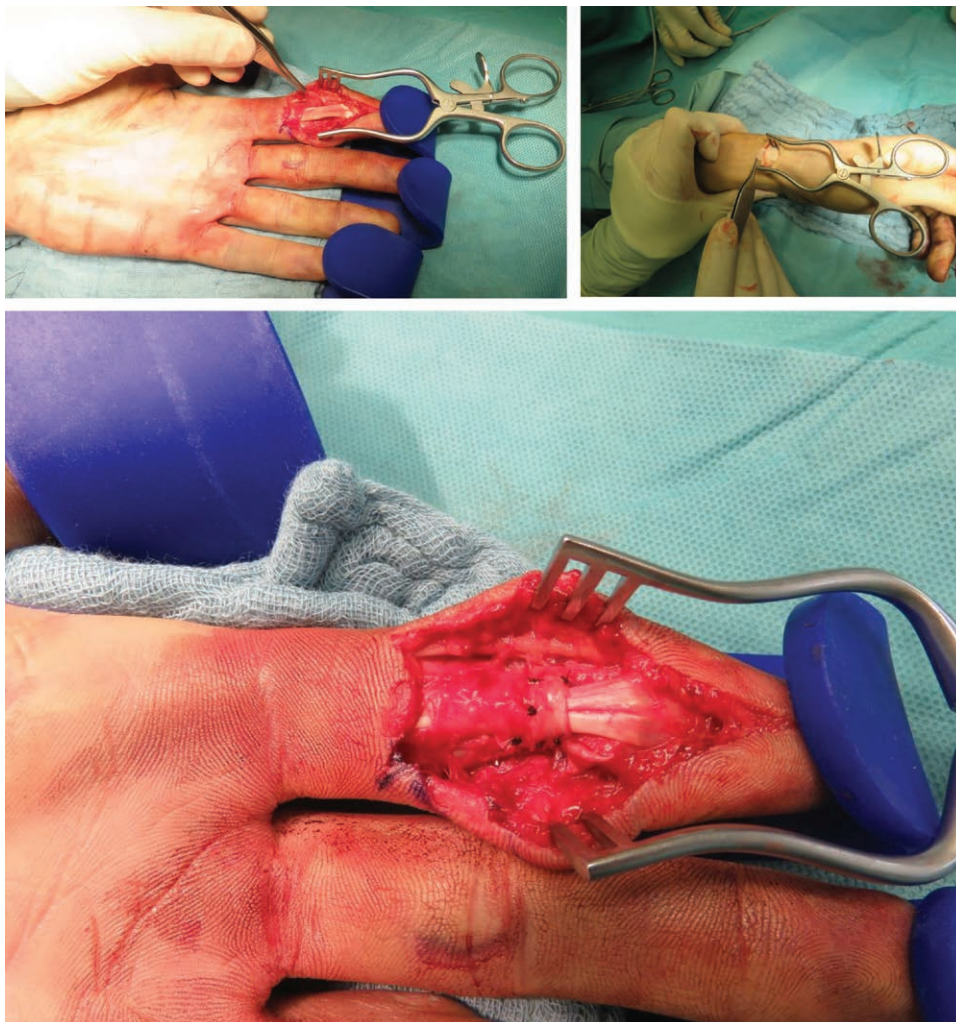


Fig. 5. Acute A4 pulley reconstruction with synovial coated first extensor compartment graft in an open injury with avulsion of the A4 pulley.

(Fig. 5). In most published series, reconstruction was delayed. Fresh injuries are rarely treated as most athletes present later. In acute injuries, retraction of the pulleys has not occurred yet, thus possibly allowing primary repair. Direct repair is mechanically debatable as the orientation of fibers does not allow good placement of sutures. An unretracted pulley, however, provides beneficial information about the dimension of the pulley system. When reducing the tendon and adapting the pulley, the anatomical dimension can be restored while preserving the native synovial surface. Augmentation of the pulley is recommended as primary repair is mechanically not very stable. An onlay graft from the first extensor compartment anchored to the bony origin of the pulley will provide a stable reconstruction without excessive soft-tissue impairment caused by looping techniques or weakening the bone through drill holes^{8–10} (Fig. 4). Looping techniques interfere with motion of the extensor tendons and use extra synovial grafts potentially causing tendon adhesions.^{9,13} The ideal reconstruction should provide synovial coating and sufficient strength with minimal bulk. Early reconstruction using an onlay graft offers these options. The native synovial lining is preserved and the graft is used to reinforce the pulley.^{19,20} As isolated, closed pulley ruptures are rare in hand surgery units, larger case series are not to be expected. Although this technique has only been employed in special cases, it has shown promising results. Especially in high-demand individuals this may be a good option, also allowing a fast return to occupational activities.

Michael G. Jakubietz, MD

Julius Maximilians Universität Würzburg
Oberduerrbacherstr. 6
97074 Würzburg
Germany
E-mail: Jakubietz_M@ukw.de

REFERENCES

- Schöffl V, Hochholzer T, Winkelmann HP, et al. Pulley injuries in rock climbers. *Wilderness Environ Med.* 2003;14:94–100.
- Peterson WW, Manske PR, Bollinger BA, et al. Effect of pulley excision on flexor tendon biomechanics. *J Orthop Res.* 1986;4:96–101.
- Zafonte B, Rendulic D, Szabo RM. Flexor pulley system: anatomy, injury, and management. *J Hand Surg Am.* 2014;39:2525–2532; quiz 2533.
- Schöffl VR, Schöffl I. Injuries to the finger flexor pulley system in rock climbers: current concepts. *J Hand Surg Am.* 2006;31:647–654.
- Schöffl VR, Einwag F, Strecker W, et al. Strength measurement and clinical outcome after pulley ruptures in climbers. *Med Sci Sports Exerc.* 2006;38:637–643.
- Bouyer M, Forli A, Semere A, et al. Recovery of rock climbing performance after surgical reconstruction of finger pulleys. *J Hand Surg Eur Vol.* 2016;41:406–412.
- Chow JC, Sensinger J, McNeal D, et al. Importance of proximal A2 and A4 pulleys to maintaining kinematics in the hand: a biomechanical study. *Hand (N Y).* 2014;9:105–111.
- Okutsu I, Ninomiya S, Hiraki S, et al. Three-loop technique for A2 pulley reconstruction. *J Hand Surg Am.* 1987;12:790–794.
- Arora R, Fritz D, Zimmermann R, et al. Reconstruction of the digital flexor pulley system: a retrospective comparison of two methods of treatment. *J Hand Surg Eur Vol.* 2007;32:60–66.
- Gabl M, Reinhardt C, Lutz M, et al. The use of a graft from the second extensor compartment to reconstruct the A2 flexor pulley in the long finger. *J Hand Surg Br.* 2000;25:98–101.
- Clark TA, Skeete K, Amadio PC. Flexor tendon pulley reconstruction. *J Hand Surg Am.* 2010;35:1685–1689.
- Schöffl I, Baier T, Schöffl V. Flap irritation phenomenon (FLIP): etiology of chronic tenosynovitis after finger pulley rupture. *J Appl Biomech.* 2011;27:291–296.
- Dy CJ, Lyman S, Schreiber JJ, et al. The epidemiology of reoperation after flexor pulley reconstruction. *J Hand Surg Am.* 2013;38:1705e1711.
- Cao Y, Tang JB. Strength of tendon repair decreases in the presence of an intact A2 pulley: biomechanical study in a chicken model. *J Hand Surg Am.* 2009;34:1763–1770.
- Tang JB, Cao Y, Wu YF, et al. Effect of A2 pulley release on repaired tendon gliding resistance and rupture in a chicken model. *J Hand Surg Am.* 2009;34:1080–1087.
- Mallo GC, Sless Y, Hurst LC, et al. A2 and A4 flexor pulley biomechanical analysis: comparison among gender and digit. *Hand (N Y).* 2008;3:13–16.
- Leefflang S, Coert JH. The role of proximal pulleys in preventing tendon bowstringing: pulley rupture and tendon bowstringing. *J Plast Reconstr Aesthet Surg.* 2014;67:822–827.
- Moutet F, Forli A, Voulliaume D. Pulley rupture and reconstruction in rock climbers. *Tech Hand Up Extrem Surg.* 2004;8:149–155.
- Roloff I, Schöffl VR, Vigouroux L, et al. Biomechanical model for the determination of the forces acting on the finger pulley system. *J Biomech.* 2006;39:915–923.
- Klinert HE, Bennett JB. Digital pulley reconstruction employing the always present rim of the previous pulley. *J Hand Surg Am.* 1978;3:297–298.