Feasibility of a new pulley repair: a cadaver study

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Abstract:
In this study, the feasibility of a new pulley reconstruction was evaluated using a isokinetic loading device on cadaver fingers.
9 fingers from 6 cadaver hands presenting intact pulley systems were compared to 9 fingers from 6 cadaver hands with missing A2 to A4 pulleys, but which featured a repair using the new surgical technique. Each finger was then fixed to an isokinetic loading device. The forces in the flexor tendons were recorded in each finger using a force transducer.
The forces recorded in the flexor tendons of the control group were significantly higher than in the operated fingers, but comparable to earlier studies with unoperated fingers. The most common event in the operated fingers was a graft failure. A fracture of the bone due to the used drill hole did not occur.
The new pulley reconstruction could represent an alternative to existing reconstructive techniques. The cause for the higher forces recorded in the control group could be attributed to sutures used in the operated fingers.
The new pulley reconstruction method may enable reduced extensor tendon irritation as it avoids contact with the extensor hood, and will hopefully prohibit cortical bone loss, a serious side effect in the standard technique.

Concept
Dans cette recherche, on a étudié la possibilité de reconstituer une nouvelle poulie en utilisant un dispositif de chargement isocinétique.
On a comparé 9 doigts intacts prélevés sur des cadavres avec 9 doigts également prélevés sur des cadavres mais où manquaient les poulies A2 à A4, sur lesquelles on a travaillé en utilisant une nouvelle technique chirurgicale. Chaque doigt a alors été fixé à un dispositif de chargement isocinétique . Les forces dans les tendons fléchisseurs étaient enregistrées dans chaque doigt qui utilisait un transducteur de force.
Les forces enregistrées dans les nouveaux tendons fléchisseurs du groupe de contrôle étaient bien plus grandes que dans les doigts opérés, mais ells étaient comparables à des études précédentes sur des doigts non-opérés. On a seulement remarqué une défaillance de la greffe sur les doigts opérés. Il ne s'est produit aucune fracture de l'os au niveau du trou de forage.
La nouvelle reconstruction de la poulie pourrait être une autre alternative aux techniques existant déjà. La cause des forces plus grandes enregistrées dans le groupe de contrôle pourrait être due à des sutures utilisées sur les doigts opérés.
Cette nouvelle technique pourrait réduire la possibilité d'une irritation du tendon fléchisseur en évitant un contact avec la capuche de l'extenseur. Elle pourrait aussi exclure une perte d'os cortical, qui représente encore un sérieux effet secondaire dans la technique standard.

Introduction

Pulley ruptures can be categorized according to a score introduced by Schöffl et al. (V. Schöffl, Hochholzer, & Winkelmann, 2002). This score differentiates between single and multiple pulley ruptures, and provides treatment guidelines according to the severity of the injury. At a pulley injury level of grade IV (multiple pulley ruptures), operative treatment is suggested. According to the literature(Kleinert & Bennett, 1978; Widstrom, Doyle, Johnson, Manske, & McGee, 1989; Widstrom, Johnson, Doyle, Manske, & Inhofe, 1989), the “loop and one half” repair technique yields the strongest pulleys [15], while the Weilby repair is reported to have highest post-operative functionality, defined as effectiveness in transforming of tendon excursion into finger flexion. In the “one and a half loop” technique, the palmaris longus tendon is looped around the proximal phalanx, passed underneath the extensor tendons, and then consecutively passed through itself in such a way that the positions of the flexor tendons are maintained close to the bone (Widstrom, Doyle, et al., 1989). The Weilby repair consists of a shoelace-like repair using a free tendon graft (e.g. palmaris longus), which is laced through the rims of the stumps of the ruptured pulley/tendon sheath (Widstrom, Johnson, et al., 1989). To achieve optimal function without compromising strength, the two repair techniques were combined as described previously by Schöffl et al. (V. Schoffl, Kupper, Hartmann, & Schoffl). In this integrated repair, the “one and a half loop” is continued by lacing the end of the autograft distally through the remaining pulley stumps to guarantee best possible functionality in in combination with high. However, there is strong evidence that the “one and a half loop” may lead to serious problems at the proximal interphalangeal joint, as irritation of the extensor tendons by the loop can lead to an extensor block (Widstrom, Doyle, et al., 1989) or even to intermittent inflammation of the bone and subsequent cortical bone loss of the proximal phalanx (Lutter & Schoeffl), likely due to compression of the dorsal cortex and interference with its osseous blood flow.

The concern with this strategy is whether drilling a hole through the middle of the proximal phalanx would weaken the bone structure to such an extent that the proximal phalanx would fracture during a typical climbing move in which the pulley and its supporting structure (the bone) is subjected to a high strain, namely pulling on a small hold with the finger in the “crimp grip” position. The focus of this study thus tested whether the aforementioned repair would lead to a fracture of the proximal phalanx as a consequence of the drill hole. As our main focus lay on the finger flexor tendon pulley system, we tested the system in a crimped grip position as previously described in several cadaver models (I. Schoffl, Oppelt, Jungert, Schweizer, Bayer, et al., 2009; I. Schoffl, Oppelt, Jungert, Schweizer, Neuhuber, et al., 2009).

Material and Methods

Eighteen fingers (index-, middle, and ring finger) from six fresh, non-embalmed, non-paired hands (six donors) were obtained from cadavers featuring a mean age of 80.7 years (range, sixty-nine to eighty-eight years old) at the time of death. Three of the specimens were from women, and three were from men. The hands were obtained within 2 days after death and were stored at -5 degrees Celsius. They were thawed 4 hours before testing. 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. For this study, only the second, third, and fourth fingers were used. Finger type was evenly distributed between the two study groups.

In the pulley reconstruction, the palmaris longus tendon or the deep flexor tendon of the fifth finger were used as the graft material. All surgical procedures were performed by a qualified hand surgeon.

Bone canals through the proximal phalanx were drilled. Then, the tendon graft was passed through the bone channel. The tendon graft was overlapped with itself for the initial “loop and a half” and sutured together for reinforcement. The remaining graft was continued distally as a "Weilby" repair as previously described (Kleinert & Bennett, 1978).

For the loading of the fingers, an isokinetic loading device developed by Schweizer et al. (Schweizer, Frank, Ochsner, & Jacob, 2003) was adapted to fit single fingers, similar to previous studies (I. Schöffl et al., in press; I. Schoffl, Oppelt, Jungert, Schweizer, Bayer, et al., 2009). Each finger was independently tested – loaded in the crimp grip position with the finger fixed to the Perspex plate. The flexor tendons were connected in series with the force transducers and an electric cage motor. This enabled increasing of the forces on the flexor tendons while the finger remained stationary, resulting in the application of a concentric load. The digit was placed with slight flexion (30°) at the Metacarpophalangeal (MCP) joint, flexion between 80° and 110° at the PIP joint, and hyperextension (5°) at the DIP joint. A FDP to FDS tendon-force ratio of 2:1 was set up using deflection pulleys, following recommendation by Vigouroux and Quaine (Vigouroux, Quaine, Labarre-Vila, & Moutet, 2005). Loading of the tendons continued until a failure event occurred, be it a pulley rupture, a rupture of the pulley reconstruction or any other failure mechanism (fracture of bone, tendon rupture, failure at the tendon-clamp interface).

Results

First, we investigated which structure failed at the maximum load. In the control group, represented by the intact pulley system, the most common first event was a failure of the pulleys A2 to A4 in seven out of nine cases (77.78%). In one finger, the Schanz-screws broke out of the bone, and in another specimen, the tendon tore (11.11 % respectively). In the test group with the pulley reconstruction, the most common first event was failure of the tendon graft in six out of nine cases (66.67%), which was followed by a tear of one of the flexor tendons. Most cases involved tearing of the profundus tendon, but in two specimens, both tendons tore simultaneouly. The one and a half loop always remained intact. In one case, there was a dislocation of the PIP joint (11.11%), and in two cases, the screws broke out of the bone (22.22%).

When comparing, the forces recorded at the moment of the first event for FDP, the forces in the control group were significantly higher (292.4 N, range 134 N - 334 N) than in the group with the operated fingers (212.4 N, range 231.5 N - 409 N). The forces recorded for FDS at the moment of failure were higher in the control group (216.3 N, range 149.5 N - 263 N vs. 158.2 N, range 66 N - 204 N).

Discussion

The main purpose of this study was to investigate the feasibility of a new operative technique for pulley reconstruction after complex pulley ruptures. Even though the one and a half loop repair yields the best post-operative results (Widstrom, Doyle, et al., 1989) as mentioned previously, the side-effects like irritation of the extensor tendons and cortical bone loss (Lutter & Schoeffl) have led us to develop a new operating technique, in which the tendon graft is pulled through a bone hole drilled in the proximal phalanx at the area of the former pulley. However, there was concern as to the strength of this bone channel.

In this study, we experienced no fracture of the bone at the site of the drill hole, when subjected to a "crimp grip", the grip form which is the main cause for pulley ruptures. The one and a half loop stayed intact in every finger. The forces recorded at the point of failure were higher in the control group. This can be attributed to the attachment of the distal end of the pulley reconstruction, which featured the end of the transplant sutured onto the remaining stumps of the former pulleys. The sutures and the rims of the ruptured pulley are both notably weak structures, making them the sites most vulnerable to failure in this system. It needs to taken into account that in a cadaver model there is no remodelling of tissue or development of scar tissue. Thus, simulation of the true strength of such a repair in an active patient cannot be achieved in a cadaver model.

Even though the forces recorded in this study were higher in the control group than in the operated fingers, the forces recorded in both groups were closely comparable to a previous study with an eccentric loading of the fingers that recorded 237 N at the moment of pulley rupture or other events (I. Schoffl, Oppelt, Jungert, Schweizer, Bayer, et al., 2009). Thus, in our study, even the fingers that had been operated upon tolerated loads as high as previously described in uninjured fingers.

This study was not designed to compare this new operation technique with other surgical techniques. Another limitation of the discussed surgical method is the fact the we don't know how much micro movements within the bone channel may lead to a windshield wiper effect and thus a secondary tunnel widening as known to happen in ACL repairs. In order to address this question cyclic testing is needed. In this study, we loaded each finger until failure which made cyclic testing impossible. Our main concern however was the failure of the graft due to a maximal load in the "crimp grip" position, which we investigated. After the cadaver study, 4 patients received the new transosseous pulley repair. All of them had an A2/3/4 pulley injury and received the repair in average 23 day after the injury. All of them were re-evaluated 12 months after the surgery. They were climbing again and no complications were reported.

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