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Flexor Tendon Injuries: A Protocol Based on Factors that Enhance Intrinsic Tendon Healing and Improves the Postoperative Outcome

AMR I.F. ABDELFATTAH, M.D.; TAREK A. AMER, M.D. and MOHAMED S.M. HASSAN, M.D.

The Department of Surgery, Faculty of Medicine, Cairo University.

ABSTRACT

Purpose: To evaluate the functional outcome after flexor tendon repair with application of simple postoperative protocols that advise early controlled movement aiming to enhance intrinsic tendon healing, minimizing adhesion formation and thus improving the functional outcome.

Methods: This study was done between June 2005 and May 2008, as a prospective study that included 225 cases with flexor tendon injuries. All the injured tendons were repaired using the Modified Kessler's technique, then splinting of the wrist and metacarpophalangeal joints was done in 20 and 40 degree flexion respectively and dynamic splinting of fingers was done. Early movement was induced starting from the first postoperative day with pain control. Evaluation of the outcome was assessed by the hand grip strength and by measuring the amount of active flexion of proximal and distal interphalangeal joints.

Results: 11 patients didn't attend for follow-up and were excluded from the final analysis. 205 patients out of 214 (95.8%) achieved an excellent to good functional grade in the final outcome, while 9 patients (4.2%) achieved a fair to poor outcome. Only 3 patients experienced tendon rupture (1.4%). Average follow up period was 5.2 months.

Conclusion: The use of proper technique for repair of flexor tendons of the hand, followed by early controlled movements as a method of choice that on scientific background should enhance intrinsic tendon healing is; feasible, safe and has a good functional outcome.

INTRODUCTION

There are many different protocols and research approaches to tendon management. With so many choices, today's hand therapist must understand not only what those choices are, but also why and when to use them. The most important difference between the various approaches to repair postoperative digital flexor tendon, is rehabilitation and how the repaired tendon is treated during the first three to six weeks, in the earliest stages of healing. The specialist who does not understand how current techniques evolved is ill-equipped to design the appropriate treatment for a given patient **[1]**.

Tendon repair began to be accepted on 1752, when Albercht Von Haller, a Swiss investigator concluded that tendinous structure was insensitive to pain. In 1959, Verdan described the zones of flexor tendon repairs of the hand. In 1967. Potenza studied tendon healing based on extrinsic fibroblastic invasion and proliferation with adhesion formation. Lundborg explored intrinsic tendon healing based on synovial fluid nutrition. Strickland, Manske, Gelberman and others studied the delicate balance between healing and tendon motion, with regard to growth factors, fibronectin, the ratio of extrinsic to intrinsic tendon healing, tendon suture techniques, strength of repair and the effect of early active postoperative motion on outcome **[2]**.

The controversies in tendon repair may be as follows; in the initial stages of tendon healing, the formation of functionally weak tissue cannot resist the tensile forces that allow early active range of motion and so, there is a risk of rupture of the repair. In the same time, immobilization of the digit may promote healing, but inevitably results in the formation of adhesions between the tendon and tendon sheath, which leads to friction and reduced gliding. Also, loading during the healing phase is still critical to avoid these adhesions, but again, it involves an increased risk of rupture of the repaired tendon. It is clear that understanding the biology and organization of the native tendon and the process of morphogenesis of tendon tissue is necessary to improve current treatment modalities **[3]**.

In our work, we managed flexor tendon injuries; by one of the most popular tendon repair methods (modified Kessler technique), then allowing for early passive and controlled early active movement of the digits aiming for enhancing the intrinsic tendon healing and minimizing adhesions formation, thus giving the best chance for an excellent functional recovery for the repaired tendons.

Flexor tendon anatomy:

The flexor tendons of the wrist, flexor carpi radialis (FCR) and flexor carpi ulnaris (FCU) are strong and thick tendons, while the flexor pollicis longus (FPL) has a distal muscle belly. The flexor tendons of the fingers are arranged into three layers; flexor digitorum supericialis (FDS) tendons of the middle and ring fingers are most superficial; superficialis tendons of the index and little fingers are in the middle, while the deepest layer is composed of the FPL and the four tendons of the flexor digitorum profundi (FDP). There is often a tendon slip from the FDP of the index to the FPL, which may require excision to prevent post-surgical complications [4,5].

Clinical tendon zones of verdan:

These zones are used to describe flexor tendon injuries of the hand and wrist:

- Zone I: Extends from the finger tip to the midportion of the middle phalanx (the Green Zone).
- Zone II: Extends from the midportion of the middle phalanx to the distal palmar crease (No-Man's Land or the Red Zone).
- Zone III: Extends from the distal crease to the distal portion of the transverse carpal ligament.
- Zone IV: Overlies the transverse carpal ligament (carpal tunnel).
- Zone V: Extends from the wrist crease to the level of the musculotendinous junction of the flexor tendons. Zones III, IV and V constitute the Yellow Zone [6].

Pulleys' system:

Pulleys are thickening along flexor sheaths lined with synovium. They improve biomechanics of flexor tendons by preventing bowstringing of tendons during flexion. Fingers have 5 annular pulleys and 3 cruciate pulleys. Annular pulleys are A1 at metacarpophalangeal joint (MPJ), A2 over the proximal phalanx, A3 at the proximal interphalangeal joint (PIPJ), A4 over middle phalanx and A5 at the distal interphalangeal joint (DIPJ). A2 and A4 are the most important to prevent bowstringing. Cruciate pulleys are between the annular pulleys, they are thinner and less biomechanically important than annular pulleys. The thumb has 2 annular pulleys; A1 at MPJ, A2 at interphalangeal joint, and one oblique pulley, which is an extension of adductor pollicis attachment that lies between A1 and A2 and it is the most important thumb pulley to prevent bowstringing [7].

Nutrition of flexor tendons:

Tendons have two sources of nutrition, an internal source provided by vascular perfusion and external source provided by synovial fluid [6]. Tendons without synovial sheath receive blood supply from longitudinal anastomotic capillary system, that receive segmental blood supply from; Vessels in the perimysium and vessels at the bony insertions.

The source of nutrients for the flexor tendons with synovial sheath is either; vascular perfusion and synovial fluid diffusion. The segmental blood supply of the tendons is from vessels from muscular branches in the forearm, vessels in the surrounding connective tissue via the mesotenon conduit "vincula", vessels from the bone, at the insertion and vessels from periosteum near insertion [8].

In the last decades, many studies of synovial perfusion of the flexor tendons within the synovial sheath have been done [9]. Studies demonstrate that synovial fluid perfusion was more effective than vascular perfusion, indeed when the tendon was isolated from its vascular connections, diffusion could provide the total nutrition requirements to all segments. Synovial diffusion also contributes in tendon healing as the longitudinal tendon vasculature may be easily occluded by sutures, thus sheath repair or reconstruction is indicated.

Tendon healing:

Three phases of tendon healing are present; Inflammatory phase (first week), Proliferative phase (2^{nd}-$4r^{th}$ week) and Remodeling phase (2^{nd}-6^{th} month). Tendons exhibit two types of healing, with different ratios. Extrinsic healing: Fibroblasts migrate from the sheath into the injured site and also from adhesion. This type of healing is enhanced by postoperative immobilization [7]. This explains why immobilization protocols to restore tendon congruity result in scar formation at the repair site, rather than a linear fibrous array and peripheral adhesions that limit tendon movements [10]. Intrinsic healing: Tendon cells can migrate across closely approximated ends and heal with nutrients from synovial fluid. Peripheral adhesions do not participate in intrinsic tendon healing. Although some authors believed that adhesions formation is essential in tendon healing, several studies demonstrated the intrinsic ability of flexor tendons to heal via nutrients supplied by diffusion from the synovial fluid [11].

PATIENTS AND METHODS

This prospective study was performed in the Emergency Unit, Kasr Al-Aini Hospital (Faculty of Medicine, Cairo University) in the period between 6/2005 and 5/2008. Table (1) shows the demography of the included patients. The number of cases included was 225 cases suffering from flexor tendon injuries in zones I, II, III, IV and V, but eleven cases were excluded from the final analysis as they were not present during the follow-up period (Table 2). Included cases were cases with flexor tendon injuries presenting within less than 24 hours from the injury. Exclusion criteria were; children below 12 years for expected bad compliance, late presentation, infected, contused and crushed wounds and shocked poly-trauma patients.

Table (1): Demographic distribution of patients.

Number of patients	214
Sex (Male & Female respectively)	153 (75%) & 61 (25%)
Age in years	Between 12 & 63 years
Manual Workers	122 (60%)

Table (2): Distribution according to zone injuries.

Zone I injury	33 (15%)
Zone II injury	48 (22%)
Zone III injury	36 (17%)
Zone IV injury	38 (18%)
Zone V injury	59 (28%)
Total	214

First aid was done for every case, including ensuring of adequate general status of the patients (airway, breathing, circulation), followed by IV analgesia, IV antibiotics (single dose of 3rd generation cephalosporine), booster dose of antitetanic toxoid was administrated. Clinical assessment of the hand injury (vascularity, diagnosis of injured tendons and associated injures). The wound was washed by sterile saline, bovidone iodine, IV explored under either general anaesthesia or IV Bier's block and a pneumatic tourniquet was essential part in all cases (with monitoring of the tourniquet time). Minimal handling of the tendons was intentionally done. Tendons were repaired by core sutures by modified Kessler's technique using 4-0 polypropylene sutures and peripheral sutures. The wrist was splinted in 20 degree of flexion and metacarpophalangeal joint at 40 degree of flexion. Dynamic splint was applied to the fingers using elastics. Early passive and active movements were done with the control of pain. Movements started from the first postoperative day, hourly, for ten repetitions of active extension and flexion of fingers while the hand is in the splinted position, and passively the DIPJ is then fully flexed. Therapeutic ultrasound was applied for 19 cases to enhance intrinsic healing. Follow-up was done twice weekly for one month and then weekly for two months, then every month. Follow-up ranged between 6 months and 18 months.

RESULTS

From the 225 patients, 11 patients didn't attend the follow-up period and were excluded from the final analysis. All the included patients continued with the follow-up for at least 3 months, while only 193 completed a period of follow-up of 6 months. So, the final analysis was based on results recorded after 3 months of follow-up. Average follow-up period was 5.2 months.

Evaluation of the outcome was based upon hand function and this is the important issue in tendon repair and also it is impossible to assess the amount of intrinsic healing to the amount of intrinsic healing in a living human. So, the results of the repair were assessed by clinical evaluation of tendons' function.

This was done by assessing the hand grip strength and by testing for the amount of active flexion of the distal interphalangeal joints and proximal interphalangeal joints, then subtracting the amount of active extension deficit at these joints during active extension. The results were graded as A: Excellent (>132 degree total motion), B: Good (88- 131 degree), C: Fair (44- 87 degree), and D: Poor (<44 degree). In patients with multiple flexor tendon injuries, the average of the final functional outcome of all tendons was done. Final hand grip strength average was 80% in comparison to the un-injured hand, with 15% deficit, that is after taking in account the 10% rule.

In assessing the final outcome, 205 out of 214 (94.1%) achieved an excellent to good functional grade (A or B), while 9 patients (4.2%) achieved a fair to poor outcome (C or D). Functional outcome of grade C or D was related more to zone II injury (4 cases, representing 8.3% of zone II injuries). The other 5 cases of grade C or D functional outcome were as follows; two cases of zone I, two cases in zone V and a single case in zone IV. That's mean 6% of injuries in zone I, 3.4% of injuries in zone V and 2.6% of injuries in zone IV. All cases of zone III injury had either grade A or B functional outcome. Minor complications related to the skin wound and that did not affect the final outcome occurred in 12 patients (5.6%), that's including mild wound infection that was self-controlled, hematoma that may have required aspiration, hypertrophic scar in which silicon patch was applied and an adherent scar occurred in single patient. Total failure of the repair occurred only in 3 patients, who experienced tendon rupture (1.4%) and require re-suturing (two cases in zone II and one case in zone I and final outcome of such cases was added to the previous results).

Table (3): Final outcome according to the injured zone.

Injured zone	Total number	Excellent-Good outcome	Fair-poor outcome
Zone I (Green)	33 (14%)	31 (93.9%)	2 (6.1%)
Zone II (Red)	48 (23%)	44 (92.7%)	4 (8.3%)
Zone III (Yellow)	36 (17%)	36 (100%)	–
Zone IV (Yellow)	38 (18%)	37 (97.4%)	1 (2.6%)
Zone V (Yellow)	59 (28%)	57 (96.6%)	2 (3.4%)
Total	214 (100%)	205 (95.8%)	9 (4.2%)

DISCUSSION

Treatment of tendon injuries is an important part of hand surgery practice worldwide. Adhesion formation, rupture of the repairs, stiffness of finger joints, remain the principal problems of primary tendon repairs. Tendon injuries happen in all parts of the hand and forearm, but the tendon injuries in the digital flexor sheath area (zones 1 and 2) are the most difficult to treat and remain a focus of both clinical attention and basic investigations **[12]**. There is now ample evidence to substantiate several important facts. As an example, intrasynovial tendons receive their nutrition via both intrinsic vascular supply and perfusion of synovial fluid. This means that the tendons do not need to form adhesions to surrounding tendons to receive nutrition adequate for healing **[1]**.

In our study, we designed a plan for repairing injured flexor tendons that was totally based on the background known from the physiology of tendon healing. We included cases in which we could perform primary tendon repair, as there is no doubt that primary tendon repair gives better functional recovery than secondary tendon repair or graft **[13]**.

In regard the timing of repair, Swiontkowski **[6]** stated that acute tendon injuries require urgent care, ideally within 24 hours of injury. Zidel **[4]** considered that primary repair can be done within 24 hours and considered delayed primary repair with the 1^{st} day up to the 14^{th} day. In our study, we included cases that were presenting to the emergency unit within less than 24 hours.

Variety of methods may be used for tendon repair, but the modified Kessler repair is still widely used for the core tendon suture **[14]**. Also, modified Kessler repair is a good example of high-strength, low-friction repairs that minimize friction between the tendon and flexor sheath while maintaining sufficient strength to the repair **[15]**. We used the modified Kessler repair in all of our cases as the standard core suture in addition to peripheral sutures. Handling tendons was atraumatic to minimize mobilization as possible during preparation and sutures were preferentially placed nearer to the volar surface to least interfere with intratendinous circulation that enter dorsally.

Appropriate management of tendon sheath and pulleys is concern of hand surgeons in dealing with tendon injuries in digital sheath area. Suturing the sheath is controversial. Avoiding compression of the repaired tendon by the tightly closed sheath is considered of primary importance in treating the injured sheath **[16]**.

Closure of the synovial sheath is still controversial. Some authors mention that it is indicated, based on the fact that since intrinsic tendon vasculature is easily occluded by sutures and so, synovial nutrition may be required for healing **[8]**. In other's opinion, it is no longer considered essential **[17]**. Based on the fact of that the synovial nutrition has a role in tendon healing and that it may be enough for healing even without the need of intrinsic tendon vasculature, the sheath was sutured in all cases, aiming for enhancing intrinsic tendon healing and thus minimizing adhesions **[18]**.

Our management protocol for the pulleys was as prescribe by Tang, et al. **[19]**, which is the preservation of a sufficient number of pulleys is critical to tendon motion. Loss of an individual annular pulley (including a part of A2 pulley or the entire A4 pulley) when other pulleys are intact does not result in loss of function. Therefore, loss of a single pulley (A1, A3, or A4) or a part of the A2 pulley does not need repair. In case of tendon repairs within narrow A2 or A4 pulleys, some surgeons advocate venting a part of the A2 or entire A4 pulleys to release the compression of the repaired tendons **[20]**.

Postoperative tendon motion exercise is popularly employed after primary tendon repair, but exact protocols for rehabilitation vary greatly among countries or even among hand surgery centers in the same country. Protocols for passive flexion (active extension of the fingers with rubber band traction) are still in use in some hand units. However, over the last 5-10 years, there has been a trend towards combined active-passive finger flexion without rubber band traction, because rubber band traction limits full extension of the finger; while extension loss is a frequent complication [21]. In Duran and Houser, protocol, a dorsal splint or cast holds the wrist in 20 degrees of flexion and the finger in a relaxed unspecified position of protective flexion by means of a rubber band attached to a suture through the fingernail, to keep the tendon on slack. Two times a day, the patient performs six to eight repetitions of two exercises. Both exercises push flexor tendons proximally and then pull them distally: Passive flexion and extension of the DIP joint while the PIP and MP are held in flexion and passive flexion and extension of the PIP while the DIP and MP are held in flexion. Through intraoperative observations, it was observed that these exercises imparted 3 to 5mm of passive glide to the tendon, and they considered this to be sufficient to prevent formation of restrictive adhesions. Strickland and Glogovac introduced the modified Duran approach which is in use by many therapists today: A dorsal splint holds the wrist and MP joints flexed and the interphalangeal (IP) joints are strapped in extension between exercise sessions. The original Duran exercises are supplemented by composite passive flexion and active extension as far as allowed by the splint. Both logic and clinical studies tell us that including composite passive flexion will produce greater passive flexor tendon movement. Some of the best results with an early passive mobilization protocol are in patients who inadvertently or consciously flex their fingers actively. This makes great sense logically. Passive flexion attempts to push the tendon proximally, but the tendon is designed to pull, not to push. Edema is a normal part of healing after repair, even if the tendon is cut cleanly, with minimal injury to adjacent tissues and is repaired expeditiously and well. Any repair is bulkier than an uninjured tendon. Any associated injury will produce additional edema. All of these factors produce resistance to tendon movement. Some have noted "buckling" of the tendon rather than gliding with passive movement. Obviously, carefully controlled active flexion should produce greater tendon movement than does passive flexion. These active mobilization protocols are possible only because of the evolution of surgical techniques. It is well established that the strength of the core suture is related to the number of strands crossing the repair) and that a strong peripheral suture both improves gliding and increases suture strength [22].

In our study, further management was based on the fact of that early mobilization will enhance the intrinsic healing of the tendon, minimizes adhesions, stiffness and thus minimizes the limitations of movement. And in the same time, immobilization helps extrinsic tendon healing and adhesion formation. So, we splinted the wrist in 20 degree of flexion and MPJ at 40 degree [23], we planned for dynamic splinting of involved digits with early passive and active but controlled motions to avoid possible problems related to early movement such as rupture of the repaired tendon. Controlled active movement (CAM) after flexor tendon repair was advised by several authors since the last decades till now [24-28]. We found that the CAM protocol that was described by Elliott [23] was easy to be described to and to be applied even by the patient him/her self. The protocol starts the CAM from the first postoperative day, every hour for ten repetitions active extension and flexion of fingers while the hand is in the splinted position and passively the DIPJ is then fully flexed. In our application, we waited till postoperative pain subsided during which the patient may be hospitalized as describe also by Elliot, et al. [29]. The use of Postoperative therapeutic ultrasound from the 5th day, was done for a limited number of cases, aiming of reducing pain during finger movement, reducing edema and enhance maturation of the collagen fibers and intrinsic tendon healing. That was based on the study done by Gabriel and Dicky [30] who used therapeutic ultrasound on tendon Achilles.

In conclusion, immediate active mobilization following repairs of complete sections of the flexor tendons is, at present, a challenge in hand surgery which faces two major stumbling blocks. On one hand, surgeon has to obtain a sufficiently solid repair to permit active finger flexion and on the other hand, to determine a sector of mobilization which would allow maximal excursion of the repair site without additional risk of early rupture [18].

The tensile strength and gliding functions are greater in the postoperatively mobilized tendons, whereas adhesion formation is greater in immobilized tendons [11]. We found our protocol is a safe, simple, scientifically accepted protocol and gives an excellent functional results for a repaired tendon with no or at least minimal morbidity.

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