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Therapeutic Strategies in Flexor Tendon Lesions: A One-Year Retrospective Study to Guide Rehabilitation Protocol Standardization

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Abstract

Flexor tendon injuries of the hand are a common yet complex clinical challenge in reconstructive surgery, predominantly affecting young, working-age individuals and often resulting in significant functional impairment. Successful management requires a precise surgical approach combined with a structured, zone-specific rehabilitation protocol to restore optimal hand function.

A one-year retrospective study was conducted in the Clinic of Plastic Surgery and Reconstructive Microsurgery at the Clinical Emergency Hospital Bucharest, reviewing the medical records of all patients admitted with traumatic flexor tendon injuries of the upper limb. A total of 58 patients with surgically confirmed flexor tendon injuries were included. Collected data encompassed demographic information, injury mechanism and anatomical location, zone classification, associated neurovascular injuries, timing and type of surgical intervention, and the rehabilitation protocols applied.

All patients underwent operative treatment, followed by individualized rehabilitation programs tailored to the anatomical zone and severity of the injury. The data were analysed to identify patterns in injury aetiology, characteristics, and treatment strategies. These findings were compared with current literature and formed the basis for the development of a comprehensive, standardized rehabilitation protocol for flexor tendon injuries of the upper limb.

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BACKGROUND

Anatomical considerations

The extrinsic flexor tendon system of the hand comprises of the flexor digitorum superficialis (FDS) tendons, the flexor digitorum profundus (FDP) tendons, and the flexor pollicis longus (FPL) tendon for the thumb.[1]

Each finger has two flexor tendons: the flexor digitorum superficialis (FDS) and the flexor digitorum profundus (FDP). In the palm, the FDS tendons are located superficial to the FDP tendons, but after passing the level of the metacarpophalangeal (MCP) joint, the FDS divides into two bands (Campbell's chiasm) above the proximal phalanx, allowing the FDP to pass between them and then become superficial to them. Ultimately, the FDS inserts on the lateral sides of the middle phalanx, and the FDS inserts on the base of the distal phalanx.[1,2]

The FDP serves as the primary flexor during composite finger flexion, providing fine motor control across the MCP, proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints, while the FDS plays a crucial role in power grip and is essential for finger flexion at the level of the MCP and PIP joints when the wrist is flexed. The loss of FDP function in the small finger poses a significant functional challenge, as the FDS alone is generally insufficient to provide the necessary power and functionality for the digit.[3,4]

The thumb has only one extrinsic flexor tendon, the flexor pollicis longus (FPL), which passes between the two sesamoid bones on the volar side of the thumb MCP and it then attaches to the base of the distal phalanx. It mediates flexion at the interphalangeal (IP) and MCP joints and, since it is the sole flexor tendon of the thumb, it is critical for precision tasks.[3]

A fibrous digital flexor sheath encases the flexor tendons, extending from the neck of the metacarpal to the base of the distal phalanx. This sheath is reinforced in certain anatomical locations by specialized thickenings known as pulleys, which serve to maintain the tendons in close apposition to the osseous structures during flexion. The pulley system is categorized into annular and cruciate components based on their morphology. The annular pulleys are designated A1 through A5, while the cruciate pulleys are labelled C1 through C3, as we can see in Figure 1.[5,6]

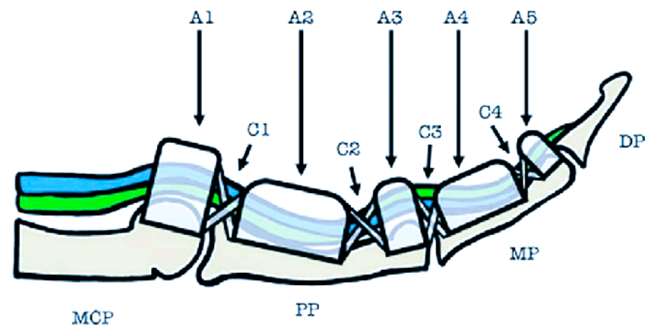

Figure 1: Sagittal view of the finger flexors pulley system (Modified after Berrigan W et al.[6], under the terms of the http://creativecommons.org/licenses/by-nc-nd/4.0/ License)

The pulleys A1, A3, and A5 overlie the MCP, PIP, and DIP joints, respectively, and originate from the volar plates. A1 is commonly implicated in trigger finger due to stenosing tenosynovitis. A2 and A4 resist bowstringing, making them the most important pulleys from a biomechanical point of view. C1-C3 allow sheath flexibility, preventing collapse and maintaining cohesion of annular pulleys during flexion.[7]

In the thumb, the pulley system differs both functionally and anatomically. It traditionally consists of three main pulleys: A1 (over the MCP joint), A2 (over the IP joint) and the oblique pulley (which courses obliquely across the proximal phalanx). The oblique pulley, considered an extension of the adductor pollicis aponeurosis, is the most biomechanically significant component for the function of the FPL, as it prevents bowstringing and permits full tendon excursion during thumb flexion. An annular variable pulley (Av) has been described between A1 and the oblique pulley, with an additional contribution to bowstringing prevention.[3]

The flexor tendons of the hand receive their nutrition through a dual system: passive diffusion from synovial fluid and an intrinsic vascular network. These tendons are enclosed within a synovial sheath that secretes synovial fluid, which plays a critical role in nourishing the avascular regions of the tendons. Through diffusion, synovial fluid delivers oxygen and essential nutrients to support cellular metabolism, maintain tendon gliding, and promote tissue health, particularly in areas not directly supplied by blood vessels.[8]

Complementing this system is a direct vascular supply that reaches the tendons through specialized connective tissue structures known as the vincula. The vincula serve both as mechanical stabilizers and as conduits for blood vessels. There are four distinct vincula associated with the flexor tendons of each digit. Vinculum longus profundus (VLP) is a long, slender band that connects the FDP tendon to the palmar plate of the PIP joint or the anterior aspect of the proximal phalanx. Vinculum brevis profundus is a short, thick band that attaches the FDP tendon to the base of the distal phalanx. Vinculum longus superficialis is another long band connecting the FDS tendon to the anterior aspect of the FDP tendon or proximal phalanx. Lastly, vinculum brevis superficialis is a short band that connects the split portions of the FDS tendon to the base of the middle phalanx.[8,9]

The vincular system in the thumb is less complex than the one in the fingers. Typically, the thumb has only the vinculum longus pollicis, connecting the FPL tendon to the anterior surface of the proximal phalanx or the palmar plate at the level of the MCP joint. Occasionally, a vinculum brevis may also be present, attaching the FPL tendon closer to its insertion on the distal phalanx, but its presence is variable and often absent or rudimentary.[10,11]

These vincula transmit branches of the digital arteries, primarily derived from the common and proper palmar digital arteries, allowing the vascular supply to penetrate the tendons at strategic points. The short (brevis) vincula are typically stronger and closer to the tendon insertions, while the long (longus) vincula are more delicate and positioned more proximally. Together, they ensure a continuous blood supply across various sections of the tendons, even during movement, where the tendons are under tension within the digital sheath.[8]

This integrated system of nutrition, via both synovial diffusion and vascular perfusion through the vincula, is essential for tendon homeostasis, healing after injury, and overall hand function. Damage to the synovial sheath or to the vincula during trauma or surgery can significantly compromise tendon repair and regenerative capacity, making their preservation a critical objective in hand surgery.[8]

Tendon healing

Tendon healing is a complex biological process aimed at restoring the tendon's structure, strength, and, critically, its ability to glide smoothly within the synovial sheath. This gliding function is fundamental to tendon biomechanics, enabling efficient motion and reducing the risk of adhesion formation, which can severely limit mobility and functional outcomes.[7]

Intrinsic healing is driven by tenocytes, which are specialized fibroblast-like cells residing within the tendon itself. These cells migrate into the injury site and synthesize collagen and other extracellular matrix (ECM) components necessary for tendon regeneration. Through longitudinal alignment of collagen fibres, intrinsic healing contributes to improved biomechanical properties and restoration of gliding function within the tendon sheath. This mode of healing is favoured for its ability to regenerate tendon tissue with less scarring. Extrinsic healing**,** in contrast, involves the recruitment of fibroblasts and inflammatory cells from the surrounding connective tissue, including the synovium, paratenon, and tendon sheath. While extrinsic processes contribute to structural repair, they often result in disorganized collagen deposition and adhesion formation, which can impair tendon gliding and function.[7,12]

Although traditionally viewed in isolation, intrinsic and extrinsic healing mechanisms occur simultaneously and interact dynamically during tendon repair. Extrinsic processes tend to predominate in the early stages following injury and surgery, while intrinsic repair becomes more prominent during the remodelling phase. The distinction, while conceptually useful, especially in areas with a synovial sheath such as flexor zones 1 and 2, is somewhat oversimplified, as modern understanding highlights a complex interplay of local cells, signalling pathways, and gene expression.[7]

Tendon healing progresses through three overlapping but distinct phases. The inflammatory phase (days 0-5) is characterized by hematoma formation, inflammatory cell infiltration, and the release of cytokines. The repair is biomechanically fragile and entirely dependent on the suture, as little to no collagen has yet been synthesized. During the fibroblastic or proliferative phase (day 5 - week 4), fibroblasts and tenocytes become highly active, leading to the deposition of type III collagen and proteoglycans. The tendon begins to gain tensile strength, although collagen fibres remain disorganized. Early in this phase (days 7–10), the tendon is at its weakest, and repair is most vulnerable to rupture. By the late proliferative stage (after 21 days), collagen remodelling begins, and tendon strength gradually increases. Lastly, the remodelling phase (after 4 weeks, up to 12 months) is a long-term phase marked by continued collagen synthesis, maturation, and reorganization. Type III collagen is gradually replaced by type I collagen, and fibres align along the tensile axis. Despite this remodelling, the repaired tendon never fully regains the mechanical strength of the uninjured tendon. Histologically, collagen fibrils remain thinner, and tensile strength reaches only about 40–70% of the original tendon's capacity.[5,7]

Flexor Tendon Injuries: classification and particularities

Flexor tendon injuries have been classified by Verdan and Kleinert according to the anatomical zone in which the injury occurs, as follows[13-15]:

- Zone 1: Located between the insertion of the FDS and the insertion of the FDP.
- Zone 2: Spans from the proximal edge of the A1 pulley to the insertion of the FDS. This area is also referred to as “no man's land” due to the complexity of tendon repair and the historically poor outcomes associated with it.
- Zone 3: Extends from the transverse carpal ligament proximally to the A1 pulley distally. This zone corresponds to the origin of the lumbrical muscles from the FDP tendons.
- Zone 4: Represents the passage of the flexor tendons through the carpal tunnel.
- Zone 5: Begins at the musculotendinous junction and continues to the entrance of the tendons into the carpal tunnel.

Flexor tendon injuries in the thumb are also classified into distinct zones: Zone TI (from the FPL tendon insertion to the A2 pulley), Zone TII (from the A2 pulley to the distal edge of the A1 pulley), and Zone TIII (from the distal edge of the A1 pulley to the carpal tunnel).[1,16]

These anatomical zones are depicted in Figure 2[13-16].

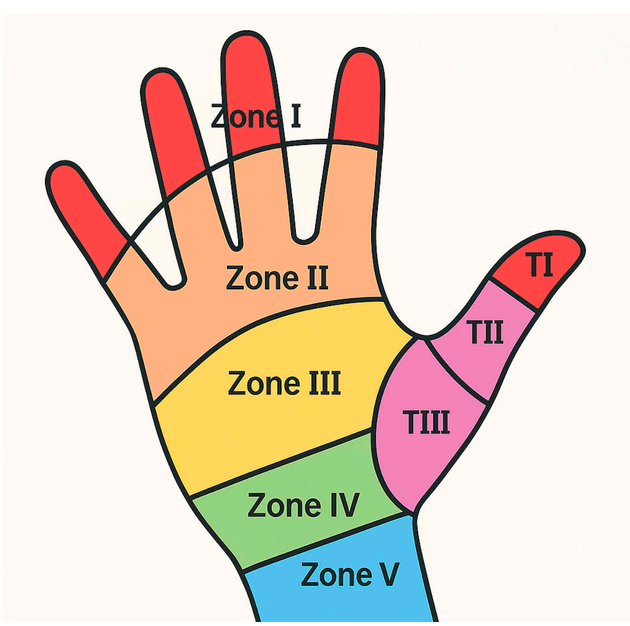

Figure 2. Flexor tendon injuries zonal classification

This zonal classification is critical for guiding both surgical approach and prognosis, as each zone presents unique anatomical and functional challenges. Surgical principles vary depending on the anatomical zone of the injury.

A Zone 1 injury involves either a laceration of the flexor digitorum profundus tendon distal to the insertion of the FDS or an avulsion of the FDP from its insertion on the base of the distal phalanx.[13]

This type of injury, known also as ”jersey finger” is a traumatic flexor tendon injury caused by an avulsion injury of the FDP from the insertion at the base of the distal phalanx. It commonly occurs due to a sudden, forceful hyperextension of the DIP joint, typically when a player's finger is caught in an opponent's jersey and pulled backward. This mechanism results in the FDP tendon being avulsed from its insertion on the distal phalanx, often accompanied by a small osseous fragment.[17]

Two surgical strategies are considered based on distal stump length: if the distal tendon stump measures at least 1 cm, primary tendon repair (tenorrhaphy) is indicated; if the stump is shorter than 1 cm, tendon advancement with reinsertion into the bone is required. It is important to avoid shortening the FDP tendon by more than 1 cm, as this increases the risk of developing the Quadriga effect, which can compromise flexion strength in adjacent fingers due to reduced excursion of the repaired tendon.[13]

Avulsions of the FDP tendon were originally classified by Leddy and Packer into three types, with a fourth type later added[13,18,19]:

- Type I: Avulsion of the FDP tendon with complete retraction into the palm, due to rupture of both vincula and absence of bony attachment.
- Type II: The vinculum longum profundus remains intact, limiting the retraction of the tendon to the level of the PIP joint.
- Type III: The avulsion occurs with a bony fragment attached to the tendon, which becomes trapped at the level of the A4 pulley, preventing further retraction.
- Type IV: A combined fracture-avulsion injury, where a bony fragment detaches from the distal phalanx, and the FDP tendon avulses from the fragment itself. In this case, the proximal tendon stump may be located either within the flexor sheath or retracted into the palm.

Flexor tendon injuries occurring in Zone 2 of the hand have historically been referred to as occurring in “no man's land.” This designation, first introduced by Bunnell, underscores the significant challenges associated with surgical management in this region. The anatomical complexity of Zone 2 is considerable, given the close relationship between the FDP and FDS tendons, their synovial sheaths, and the surrounding pulley system, making precise tendon repair technically demanding and increasing the risk of iatrogenic damage to adjacent structures.[5,20,21]

A major complicating factor in Zone 2 injuries is the high propensity for adhesion formation during the healing process. Scar tissue within the flexor sheath can severely restrict tendon gliding, often leading to compromised digital function even after technically successful repairs. Consequently, achieving a balance between securing tendon integrity and preserving tendon gliding is critical but difficult to attain. The anatomical reports of structures in this area render surgical exposure and tendon mobilization particularly complex, necessitating a meticulous and highly skilled surgical approach to optimize functional outcomes.[5,12,13,22]

The surgical repair of flexor tendons at the level of the wrist and hand must aim for optimal alignment and coaptation of the two tendon ends in order to achieve the following objectives: minimization of local adhesion formation, restoration of a surface that allows proper tendon gliding, promoting the implementation of a postoperative rehabilitation protocol that ensures early tendon mobilization and gliding and achievement of a range of motion in the fingers as close to normal as possible. This approach ensures the functional recovery of the hand by maintaining tendon integrity and mobility while reducing complications associated with scarring and stiffness. The method of tendon repair depends on the area of tendon injury and whether it is a primary or secondary lesion.[7,13,23]

The objective of this study was to conduct a retrospective analysis of the cases involving flexor tendon injuries admitted to our clinic, to evaluate the etiopathogenesis of these injuries, the treatment strategies employed, and the optimal approaches to functional recovery. The data obtained were correlated with findings from the existing literature, and based on this analysis, we developed a therapeutic rehabilitation protocol that can be broadly applied in the management of these debilitating injuries.

MATERIALS AND METHODS

A retrospective study was conducted in the Clinic of Plastic Surgery and Reconstructive Microsurgery at the Clinical Emergency Hospital Bucharest. We reviewed the medical records of all patients admitted with traumatic flexor tendon injuries of the fingers of the upper limb between January 1st and December 31st, 2024.

A total of 58 patients were included in the study, selected based on the presence of surgically confirmed flexor tendon injuries. Data collected included patient demographics, mechanism and anatomical location of injury, zone classification (using the Verdan system for fingers and the specific thumb zones), presence of associated neurovascular damage, timing of surgical intervention, the surgical procedures performed, and rehabilitation protocol applied.

All injuries were managed operatively and each case was followed by a structured rehabilitation program tailored to the zone and severity of injury conducted in the Department of Physical and Rehabilitation Medicine of the Clinical Emergency Hospital Bucharest.

Collected data were analysed to identify trends in etiopathogenesis, treatment methods and functional recovery. These findings were compared with existing literature, forming the basis for the development of a comprehensive and standardized rehabilitation protocol for flexor tendon injuries of the upper limb.

RESULTS

The study included a total of 58 patients with traumatic injuries involving the flexor tendons of the fingers of the upper limb, admitted between January 1st and December 31st, 2024, to the Department of Plastic Surgery and Reconstructive Microsurgery at the Clinical Emergency Hospital Bucharest.

The age of the patients ranged from 20 to 89 years, with a mean age of 44.72 years and a median age of 45 years (Figure 3). The study group consisted of 47 males (81.03%) and 11 females (18.97%). No statistically significant differences were observed between sexes in terms of either mean age or age variance. The F-test indicated comparable variability between the two groups (p = 0.068), while the two-sample t-test assuming equal variances showed no significant difference in mean age (p = 0.847).

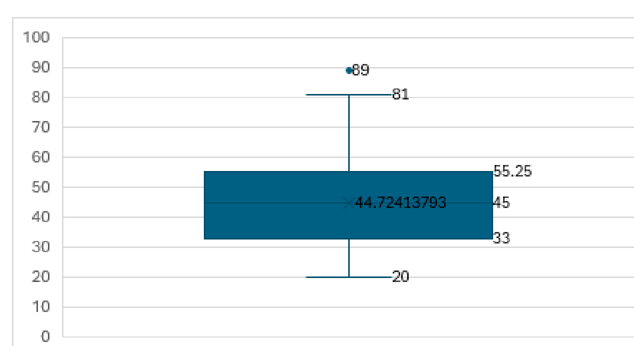

Figure 3. Age distribution in the study group

A total of 63.79% of patients originated from urban areas, while 36.21% were from rural settings. Most injuries (91.38%) occurred in domestic environments, with only 8.62% being work-related.

Regarding the mechanism of injury (Figure 4), the most frequent was laceration (58.62%), followed by crush-avulsion injuries (37.93%). Spontaneous tendon ruptures were observed in 3.45% of cases. In our clinic, the most common aetiologic agent for flexor tendon injuries of the upper limb was the angle grinder (30.36%), followed by glass (26.79%), knife-induced wounds (21.43%), and various other blunt objects, which accounted for an additional 21.43% of cases.

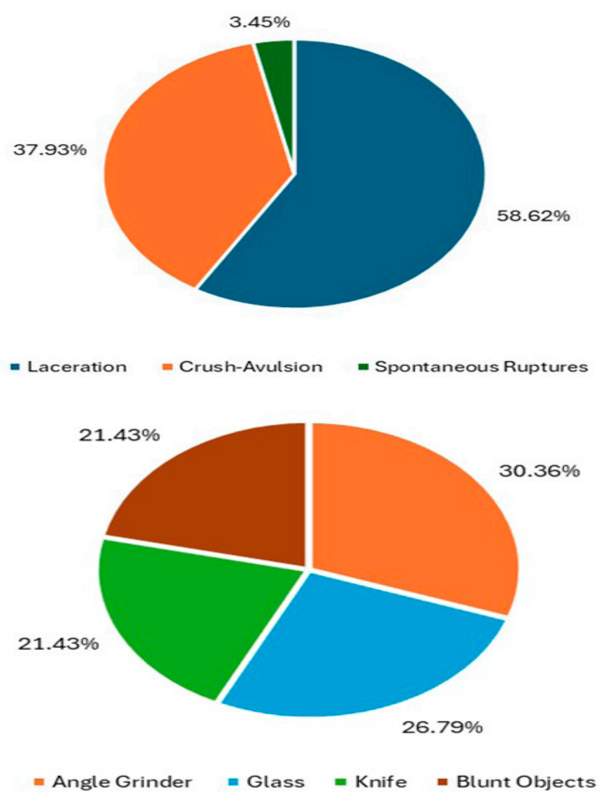

Figure 4. Mechanism of injury and causative object

In the majority of cases, patients were brought to the Emergency Department within the first hours following trauma and received urgent treatment. Thus, 68.97% of cases underwent primary repair, 13.79% underwent delayed primary repair, and 17.24% were managed with secondary repair (Figure 5).

In the studied group, the majority of patients sustained injuries involving two or more flexor tendons, representing 51.72% of cases. Complete transection of a single tendon was diagnosed in 48.28% of patients, followed by injuries involving two tendons in 18.97%

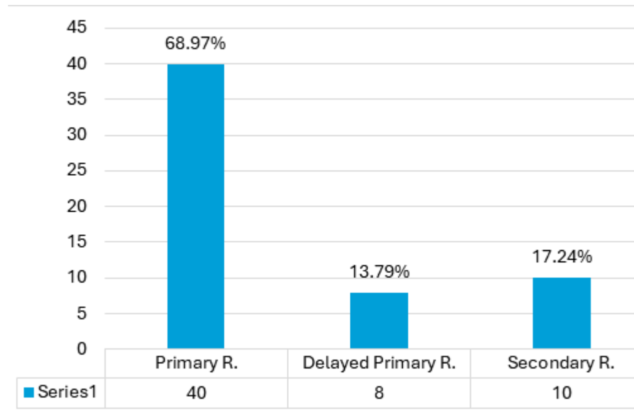

Figure 5. Time of flexor tendons repair

of cases. Complex trauma involving complete transection of all nine flexor tendons was identified in 8.62% of patients. Partial tendon lacerations were present in 4 patients (6.9%), whereas 93.10% had complete transection of at least one flexor tendon. This distribution is depicted in Figure 6.

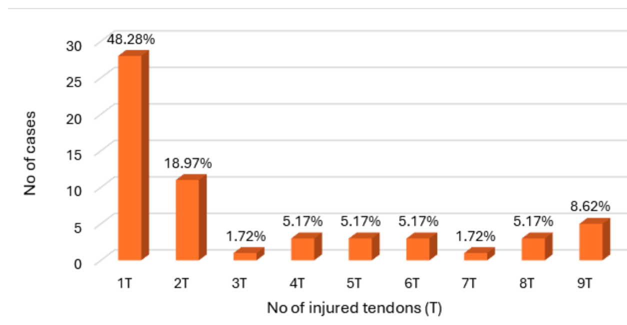

Figure 6. Number of tendons involved per case

Although the FDP tendons were the most commonly affected overall (77.59%), the most frequently injured individual tendon was the FDS of the third digit, involved in 43.10% of cases (Figure 7).

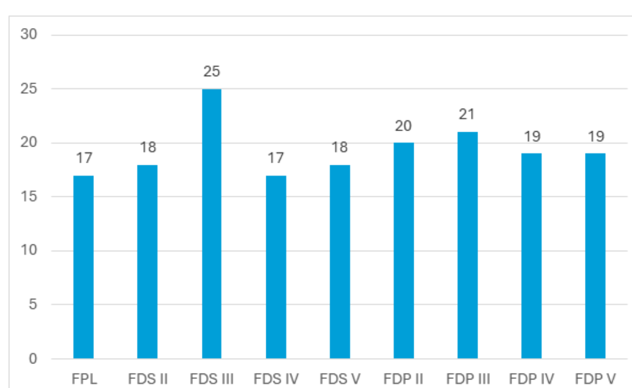

Figure 7. Distribution of injured tendons by digit

Regarding injury distribution by flexor tendon zones, Zone II was the most commonly affected, with 48.28% of patients exhibiting at least one tendon injury within this anatomical zone. Figure 8 shows the distribution of tendon injuries according to flexor tendon injury zones.

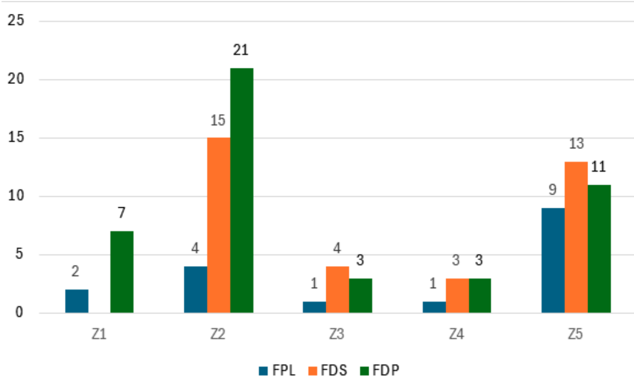

Figure 8. Distribution of tendon injuries according to flexor tendon injury zones

The FPL tendon was involved in 29.31% of cases, most frequently in Zone V (52.94%), followed by Zone II (23.53%) and Zone I (11.76%). Zones III and IV were the least affected, each accounting for 5.88% of FPL tendon injuries.

FDS tendons were involved in 60.34% of patients. Among these, the most frequently injured was the FDS tendon of the third digit (32.05% of all FDS tendon injuries), followed by the FDS tendons of the second and fifth digits (each accounting for 23.08%). The least affected was the FDS tendon of the fourth digit (21.79%).

Regarding the anatomical distribution of FDS tendon injuries, the majority occurred in Zone II (42.86%), followed by Zone V (37.14%), Zone III (11.43%), and least frequently in Zone IV (8.57%).

FDP tendons were involved in 77.59% of the study subjects, with a relatively even distribution across the digits. The third digit was the most frequently affected (26.58% of all FDP tendon injuries), followed by the second digit (25.32%), and the fourth and fifth digits (each accounting for 24.05%).

Similarly to FDS injuries, Zone II was the most commonly affected area for FDP tendons, with 46.67% of FDP transections occurring in this zone. This was followed by Zone V (24.44%), Zone I (15.56%), and Zones III and IV, which were the least affected (each with 6.67%). Figure 9 presents the distribution of FDS and FDP injuries in each affected digit.

In 56.90% of the subjects, flexor tendon lacerations were accompanied by injuries to other important

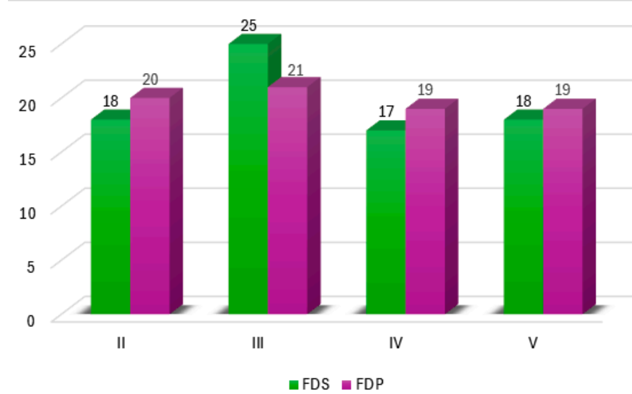

Figure 9. Distribution of FDS and FDP injuries by digit

anatomical structures. Of the associated lesions, 38.46% involved nerves, 30.77% vascular structures and 15.38% muscle and fractures. Among all patients, 51.72% sustained nerve damage, 41.38% vascular involvement, and 20.69% muscle lesions and/or fractures (Figure 10).

Considering the surgical approach applied in each case, tenorrhaphy alone, consisting of core sutures

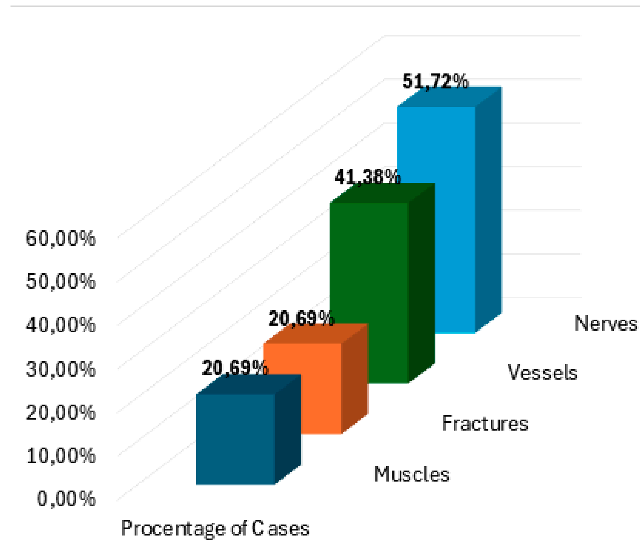

Figure 10. Percentage of subjects with associated injuries

combined with an epitendinous suture, was performed in 42 cases (72.41%). In contrast, 16 patients (27.59%) required complex, combined procedures. Among these, tendon graft reconstructions and FDP reinsertion were the most frequently performed (8.62% of all surgeries), followed by pulley reconstruction procedures (6.90%) and tenolysis (3.45%). Figure 11 illustrates the surgical procedures performed in our study group.

Figure 11. Surgical approach

The postoperative rehabilitation program following surgical repair in this cohort was structured according to evidence-based practices, with modifications based on the complexity of each case. The protocols were carefully adapted to ensure both tendon protection and functional restoration. Post-surgery, all patients were immobilized using a custom dorsal blocking splint, essential to protect the repair and maintain safe tendon alignment.

Most patients (68.97%) underwent primary repair shortly after injury, reflecting prompt presentation and urgent surgical intervention. Rehabilitation in these cases followed standard early mobilization protocols, such as the modified Duran or Kleinert approaches, aimed at protecting the repair while promoting tendon gliding and preventing adhesions. Early passive motion was initiated soon after surgery, with gradual introduction of active flexion at approximately 4 weeks and strengthening commencing between 6 and 8 weeks postoperatively. Active flexion exercises were introduced gradually at 4 weeks postoperatively, once tendon integrity was sufficient to tolerate increased loading. Strengthening activities began between weeks 6 and 8, focusing on light resistance and functional hand use, progressing to task-specific activities as tolerated. For patients who underwent more complex surgical procedures, such as tendon grafting, FDP reinsertion (8.62%), pulley reconstruction (6.90%), or tenolysis (3.45%), rehabilitation timelines were modified accordingly to allow for adequate healing of reconstructed structures. Patients were also encouraged to perform hourly home exercises, reinforcing active motion and promoting tendon excursion.

For the subset of patients (13.79%) who underwent delayed primary repair, typically performed within days after injury but beyond the immediate acute phase, rehabilitation protocols were adapted to account for a slightly increased risk of stiffness and adhesion formation. These patients often required a more cautious progression, with closer monitoring and potentially extended immobilization periods before initiating active motion, to ensure tendon healing without compromising repair integrity.

The remaining 17.24% of cases were managed with secondary repair, generally following complications such as tendon rupture, failed primary repair, or delayed presentation. Rehabilitation following secondary repair necessitated a prolonged protective phase due to the increased surgical complexity, such as tendon grafting or tenolysis. Early motion was typically delayed, and therapy places greater emphasis on scar management, prevention of joint contractures, and gradual restoration of function over a longer timeframe.

DISCUSSION

Upper limb injuries can result in a wide range of unexpected soft tissue defects, from simple to complex, depending on the underlying mechanism, such as clean cuts, stabs, crushing, torsion, avulsion, or mixed trauma. These varied injury patterns often affect young, active individuals and present significant challenges for the reconstructive surgeon.[24]

Flexor tendon injuries remain a significant clinical challenge in hand surgery, both in terms of surgical management and achieving optimal functional outcomes. These injuries are relatively common due to the superficial location of the flexor tendons, making them susceptible to trauma. They typically result from sharp lacerations caused by objects such as knives or glass, crush injuries, or avulsion at the tendon-bone junction during high-impact activities, particularly in contact sports like football, rugby, or combat sports.[25,26]

In our study, we found that the most affected patients were young adults, with a mean age of 45 years, and most cases involved male patients. According to existing data from the literature, flexor tendon injuries cause significant morbidity in the working-age population. It predominantly affects working-aged young males (a ratio of 1:5 between female and male patients was reported), with injuries incidence declining progressively with increasing age.[27,28] This highlights that such injuries predominantly impact a socio-professionally active segment of the population and have a substantial effect on quality of life. Consequently, these injuries must be managed with the highest level of attention and seriousness.

Regarding the mechanism of injury, it was observed in our study that over one-third of these traumas occurred through a crush-avulsion mechanism, which indicates a high degree of severity. This type of lesion is typically associated with high-energy trauma and usually results in a much more extensive zone of injury than initially apparent upon first evaluation. Over half of the patients sustained injuries involving two or more flexor tendons, with the FDP being most frequently affected. These tendon injuries were often associated with significant damage to additional anatomical structures, most commonly involving nerves and blood vessels. In a smaller proportion of cases, muscle injuries and fractures were also observed.

Manninen et al. also highlighted that flexor tendon lacerations are frequently associated with injuries to other hand structures, most commonly involving nerve damage, requiring adequate microsurgical techniques by the operating surgeon.[28]

There are three primary reasons why flexor tendon injuries are particularly difficult to manage. First, these tendons cannot heal spontaneously without surgical intervention; precise approximation of the tendon ends is essential for biological healing. Second, postoperative rehabilitation presents a delicate balance: early mobilization is crucial to prevent adhesions and promote tendon gliding, yet it also increases the risk of repair rupture. Third, the intricate anatomy of the flexor tendon system, especially its course through narrow fibro-osseous sheaths, demands meticulous surgical technique to avoid excessive bulk or scarring, which can severely compromise tendon gliding and functional recovery.[13,26,29]

The strategy for flexor tendon repair is influenced by the anatomical zone involved and the timing of the injury, distinguishing between primary (acute) and secondary (delayed or chronic) lesions. These factors critically impact the choice of surgical technique, the prognosis and rehabilitation protocol. Restoring optimal digital function after an untreated or unsuccessfully repaired flexor tendon injury continues to represent a significant clinical and surgical challenge in the field of hand surgery.[1,16,30]

Flexor tendon repair can be categorized as primary, delayed primary, or secondary, based on the timing of intervention and the nature of the injury. This classification reflects the extent of tissue damage, the presence of contamination or infection, and the interval between injury and surgical management.[30-32]

In general, for flexor tendon injuries of the wrist and hand, the preferred approach is either primary repair or delayed primary repair. No universally established timeframe defines the optimal moment for performing the repair. Primary repair refers to tendon reconstruction performed within the first 24 hours following the trauma. Delayed primary repair refers to tenorrhaphy performed within the first 4 weeks after the injury.[31,33] Decision making regarding primary repair of flexor tendons is summarized in table 1.

Table 1. Indications and contraindications of primary repair in flexor tendon injuries.

Primary Repair	Criteria
Indications	- Clean-cut tendon injuries - No significant damage to adjacent soft tissues
Borderline Indications	- Concomitant phalangeal fractures - Soft tissue defects overlying the tendon (coverage may be achieved with a flap transfer)
Contraindications	- Multilevel phalangeal fractures or unstable fractures not amenable to internal fixation - Severe and multiple joint injuries - Extensive adjacent soft tissue loss - Heavily contaminated wounds - High-energy crush injuries - Severe tendon damage over a long segment or destruction of the pulley system

The repair technique is determined by the tendon injury zones described by Verdan15.

Repair in Zone 1 of the FDP tendon at the level of the distal phalanx (tendon-to-bone repair) can be performed using either internal or external suture techniques.[13,29]

Leddy and Packer type I and II FDP avulsion injuries, which occur without associated fracture fragments, can be managed using a variety of reattachment techniques.[34,35]

Modern internal fixation methods involve the use of specialized anchors or other fixation devices to secure the proximal end of the tendon to the bone surface of the distal phalanx.[35,36] However, these techniques require additional materials and implants, which may not be available in all surgical centres.

As a result, traditional external fixation techniques, first described by Bunnell remain commonly used. These involve placing a core suture through the proximal tendon stump, with the suture ends passed through or around the base of the distal phalanx, then exteriorized through the sterile matrix and nail plate, where they are tied and secured. The fixation is typically maintained for approximately 6 weeks.[13,21]

In Type III avulsion injuries, surgical fixation of the bone fragment is necessary, using small screws or Kirschner wires. In Type IV injuries, the recommended approach is initial fixation of the fracture, followed by tendon advancement and tendon-to-bone repair. If the avulsed bone fragment is very small, it can be excised, and the tendon can be reinserted directly into the distal phalanx, using the same methods as in Type I or II injuries.[13,17]

Tendon injuries in Zone 2 require special attention due to their historically poor prognosis. Surgical repair in this area must ensure precise, atraumatic coaptation of the tendon ends while preserving the ability of the tendon to glide smoothly through the flexor sheath. Additionally, the tenorrhaphy must be strong enough to allow for early postoperative mobilization, which is essential for achieving favourable functional outcomes.[13,20]

The tenorrhaphy typically consists of core sutures combined with an epitendinous suture. Several techniques are available for the core suture. Traditional methods, such as Kessler or Tajima, use two-strand suture techniques. More recent approaches involve multistrand sutures, which provide enhanced strength and reliability. Common examples include the Becker, Cruciate, Savage, and Strickland techniques. Multistrand sutures are now preferred, as they offer superior tensile strength both in the immediate postoperative period and up to 6 weeks after surgery. The primary purpose of the epitendinous suture is to smooth the surface of the repaired tendon, promoting better gliding through the flexor sheath. However, studies have shown that it also contributes additional mechanical strength to the core repair.[13,16,20,37,38] Table 2 illustrates various repair techniques for Zone 2 flexor tendon lesions.

Table 2. Summary of Zone 2 flexor tendon repair techniques[16,38-43]

Technique	Key Features	Outcomes	Drawbacks
Two-Strand Repair	Simple technique	High rupture rate; limited use	Limited strength; outdated in most settings
Four-Strand Repair	Most commonly used; multiple suture patterns A simple running epitendinous repair is also used	High success with proper rehabilitation; low rupture rate	Technique variability; requires strict rehabilitation program adherence
Six-Strand Repair	Stronger constructs (Yoshizu 1(Y1) technique, Lim-Tsai); support early mobilization	Excellent outcomes with rehabilitation; between78-96% good-excellent reported results in tendon repair	Increased technical complexity and tissue handling
Eight- & Ten-Strand Repairs	Maximal strength; technically demanding and bulky	Rarely used; potential for high strength but impractical	Bulky and time-consuming; not routine
Teno Fix Device	Knotless, device-assisted repair; standardized application	No tendon rupture in trials; functional outcomes similar to standard techniques	Costly and needs training; no functional superiority

For tendon injuries in Zones 3, 4, and 5, the surgical principles are similar: the use of a strong core suture and an epitendinous suture is recommended. However, the prognosis is generally more favourable in these zones, as the risk of adhesion formation, particularly those that interfere with tendon gliding, is significantly lower compared to injuries distal to the A1 pulley.[13,16]

In our study, all primary flexor tendon repairs were performed either under local anaesthesia using WALANT technique, regional or general anaesthesia with tourniquet control, using loupe magnification (2.5–4.0×). Anaesthesia and the surgical field setup are determined based on the anatomical location of the injury, the severity of the lesion, and the presence of associated injuries. A Bruner incision is made to expose the zone of injury. After identification and retrieval of the tendon ends, a 4-strand core suture repair is usually performed (modified Kessler sutures or modified Kessler and a mattress core suture) using 3-0 or 4-0 nonabsorbable monofilament (polypropylene) or absorbable monofilament (PDO) sutures. This core suture is reinforced with a 6-0 running epitendinous suture to improve glide and reduce gapping. Care was taken to preserve the A2 and A4 pulleys. Venting was limited to situations where repair bulk prevented tendon excursion. Associated injuries (nerve, vessel, or fracture) were addressed as indicated in each particular case. Wounds were irrigated and closed in layers.

A dorsal blocking splint was applied immediately postoperatively with the wrist positioned in approximately 20–30° of flexion or in a neutral position, depending on the affected tendon zone. The MCP joints are maintained in approximately 70° of flexion, while the PIP and DIP joints are positioned in slight flexion (approximately 10–20°), although in some cases they may be held in passive extension, depending on the injured zone and associated lesions.

WALANT (the Wide-Awake Local Anaesthesia No Tourniquet) technique provides several advantages compared to brachial plexus block, offering comparable surgical field visibility and effective intraoperative and postoperative pain control. It eliminates the discomfort associated with tourniquet use and allows for intraoperative testing of the tendon repair. As such, WALANT represents a safe and effective alternative to brachial plexus block for flexor tendon repair in Zone 2.[44]

In cases where primary tenorrhaphy cannot be performed within the first four weeks post-injury, or when there is a significant loss of tendon substance, a staged tendon reconstruction or tendon grafting is the preferred approach. These procedures are typically indicated after a minimum of three months from the time of injury. Between the delayed primary repair period (the first four weeks) and up to 90 days post-trauma, there is generally no surgical indication. Beyond the required time interval, other essential preconditions for surgical intervention include adequate soft tissue coverage in good condition and preserved passive joint mobility in the affected area.[13,31-33]

Cases suitable for such secondary repair include those in which primary repair was contraindicated, tendon injuries that remained untreated during the delayed repair window, secondary tendon ruptures following initial surgical repair, and cases with significant scar tissue formation involving the affected digits. There are, however, several contraindications to secondary tendon repair: soft tissue defects with inadequate tendon coverage, malunited fractures, and unsatisfactory passive joint mobility.[13,31]

The required length of the tendon graft is estimated by measuring the fully extended digit from the distal to the proximal juncture and adding approximately 4 to 6 cm, based on the anticipated method of tendon graft insertion and fixation. The technique for securing the distal end of the graft is determined by the available length of the distal FDP stump. If the stump is of adequate length, direct suturing or a weaving technique may be employed. In cases where the stump is insufficient, the graft may be anchored by trans-osseous passage through the distal phalanx and nail plate.[13,32]

The tendon grafts are most frequently harvested from the palmaris longus for palm-to-finger reconstructions and from the plantaris tendon for forearm-to-fingertip reconstructions. Alternative donor tendons include the long extensors of the second to fourth toes, toe flexors, extensor indicis proprius, and one slip of the extensor digiti minimi. Graft selection is guided by the specific anatomical and functional requirements of each case. In selected situations, and when it does not compromise overall hand function, the FDS tendon may also serve as a viable graft source.[13,32]

Hunter rod reconstruction involves the use of a silicone implant to create a pseudo-sheath that facilitates later tendon grafting. Experimental studies, primarily in animals, have shown that silicone implants can induce the formation of a well-organized, flexible sheath capable of supporting tendon nutrition and revascularization through synovial fluid and vascular adhesions. This sheath mimics a natural tendon sheath, promoting favourable conditions for graft integration. In humans, similar sheaths are typically soft and translucent, though outcomes vary, and complications during the first stage of implantation can include rod buckling, migration, synovitis, and infection.[13,31-33]

Paneva-Holevich described a two-stage reconstruction technique designed for cases with extensive tendon damage and limited graft options. In the first stage, the injured FDS and FDP tendons are transected and sutured proximally in the palm, and the flexor sheath is prepared. Approximately six weeks later, in the second stage, the FDS tendon is detached at the muscle-tendon junction in the forearm and passed through the sheath to be attached distally to the distal phalanx or remaining FDP stump. This approach results in a single functional tendon.[45]

A silicone rod can be placed during the first stage to facilitate sheath formation and accommodate the larger diameter of the FDS tendon.[46]

The A2 and A4 annular pulleys are critical elements of the flexor pulley system and must remain intact to preserve its functional integrity. Absence or damage to these pulleys results in volar displacement and "bowstringing" of the tendon, often leading to reduced grip strength as reported by patients. Injury to the A2 or A4 pulleys is a recognized indication for two-stage flexor tendon reconstruction, with pulley reconstruction performed during the first stage of the procedure.[33]

Whether dealing with primary or secondary flexor tendon injuries, functional outcomes are entirely dependent on adherence to a rehabilitation program initiated in the immediate postoperative period. A continuous collaboration between the surgical team and the rehabilitation specialists is essential for the multidisciplinary management of these patients.

Given the anatomical distribution of FDS tendon injuries observed in our study group, Zone II (42.86%), Zone V (37.14%), Zone III (11.43%), and Zone IV (8.57%), the rehabilitation strategies were tailored to the specific challenges and healing potential associated with each zone.

Zone II injuries were the most prevalent and the most complex due to the confined space and the presence of both FDS and FDP tendons within the fibrous sheath. Rehabilitation prioritized early passive mobilization, to prevent adhesions, controlled active motion after 3–4 weeks and close monitoring to balance tendon gliding with the risk of rupture, under therapist supervision.

For Zone III injuries, rehabilitation involved early active motion exercises, functional splinting to maintain tendon position and facilitate tendon gliding, progressive strengthening and dexterity training initiated in the intermediate phase (4–6 weeks post-op).

Though less common, Zone IV injuries required special attention due to confined space and potential for median nerve involvement. Rehabilitation strategies included initial immobilization with wrist in slight flexion to offload tension, gradual introduction of tendon gliding and differential motion exercises, and close observation for signs of nerve irritation or carpal tunnel syndrome during recovery.

In case of injuries in the zone V, proximal to the carpal tunnel, rehabilitation focused on protection of repaired structures with a dorsal blocking splint for up to 4–6 weeks, early active motion protocols, depending on associated injuries, and emphasis on regaining full wrist and finger range of motion, along with strength training in later phases.

The rehabilitation protocol was individualized based also on the complexity of the surgical intervention performed.

For patients who underwent primary tenorrhaphy with core and epitendinous sutures, rehabilitation followed the early passive mobilization approach.

In cases involving tendon grafting or FDP reinsertion, rehabilitation was more conservative. The initial immobilization period was prolonged to allow for graft incorporation and healing. Passive mobilization protocols were modified to minimize tension on grafted tissues, often limiting tendon excursion. Active motion was delayed and introduced cautiously, with close monitoring for signs of graft compromise. Strengthening and functional activities were initiated later in the rehabilitation timeline, typically after 8 weeks.

Following pulley reconstruction, rehabilitation focused on restoring tendon gliding while protecting the reconstructed pulley system. Splinting maintained optimal finger positioning to avoid bowstringing. Early passive motion was carefully controlled, and active exercises were gradually incorporated to improve flexion without placing excessive stress on the repair. Close attention was paid to preventing joint stiffness and pulley rupture.

Patients who underwent tenolysis required a tailored program aimed at regaining lost tendon excursion. Rehabilitation began with early active and passive mobilization to maximize the range of motion while avoiding rupture. Scar management techniques and edema control were emphasized to enhance gliding. Strengthening and fine motor re-education were progressed cautiously based on patient tolerance and surgical guidance.

Given the high prevalence of associated injuries in our patient population, the rehabilitation protocols were carefully adapted to address not only the flexor tendon repair but also the specific challenges posed by concurrent nerve, vascular, muscle and fractures.

Patients with associated nerve damage required an integrated rehabilitation approach that combined tendon repair protection with sensory and motor re-education. Early therapy emphasized gentle mobilization to prevent stiffness while avoiding stress on nerve repairs. Sensory retraining and desensitization techniques were incorporated as nerve regeneration progresses, alongside motor exercises to maintain muscle tone and prevent atrophy. Coordination exercises were used to address neuropathic pain and motor deficits.

The presence of vascular involvement mandated careful monitoring of tissue perfusion and wound healing throughout rehabilitation. Edema control through elevation and compression (Coban wrapping) became a priority to reduce swelling and facilitate circulation. Early passive mobilization was introduced cautiously, balancing tendon gliding with protection of vascular integrity.

In patients with associated fractures, immobilization periods were prolonged to allow fracture consolidation, with gradual introduction of controlled motion to prevent joint stiffness. Strengthening programs were adapted to avoid overloading injured muscles while promoting gradual functional recovery.

Functional outcomes were assessed using standardized measures, collected at regular intervals during follow-up. These tools provided objective data on range of motion and patient-perceived disability, guiding the progression of therapy and helping to identify patients who required additional interventions such as scar management, splint adjustments, or surgical revision. Assessments were conducted at three key time points: prior to the initiation of rehabilitation (baseline), at 4 weeks into the rehabilitation process (interim), and at 12 weeks following the start of rehabilitation (final).

Based on these findings and corroborated with literature data, a comprehensive protocol was developed to address flexor tendon injuries.

REHABILITATION PROTOCOL IN FLEXOR TENDON INJURIES

Recovery follows the stages of healing, following international protocols and in consultation with the physician. The protocol is adapted based on the level of the injury, the quality of the suturing, the patient's understanding and compliance, and any associated injuries. The interdisciplinary team plays a crucial role in this process.

Goals of the rehabilitation protocol

The rehabilitation protocol for flexor tendon lesions is designed with multiple objectives to ensure optimal functional recovery. These goals include effective pain relief and the reduction of oedema to enhance patient comfort and healing. A primary focus is the protection of the repaired tendon and surrounding structures, particularly critical in cases involving concurrent injuries to prevent tendon rupture.

Facilitating tendon excursion is essential to minimize the formation of adhesions, both at the repair site and between the FDP and FDS tendons. The protocol also aims to minimize joint stiffness and prevent the development of fixed flexion deformities.

Additionally, the rehabilitation process supports the re-education of both gross and fine motor skills, contributing to the restoration of hand function. Finally, a progressive approach is taken to increase the strength of the injured hand muscles, promoting a return to pre-injury activity levels.

It is recommended for some patients that rehabilitation treatment include bilateral training, as it contributes to enhancing neuroplasticity after immobilization, improved coordination, as well as the restoration of digital pinch functionality, the physiological range of wrist flexion, and global hand proprioception.[47,48]

Specific protocols for flexor tendons rehabilitation

Flexor rehabilitation protocols vary between patients and can also differ from one rehabilitation centre to another.

Immobilization protocol.

This approach is recommended for children younger than age 12 and patients who struggle to comply with the treatment plan (those that have cognitive limitations – Alzheimer disease or non-compliant patients). In cases of a concurrent fracture or substantial skin loss that requires a skin graft, a period of immobilization may be needed to ensure proper healing of the bone or skin before starting any movement.[48,49]

Phase I (0-4 weeks)

Goals: to reduce mechanical stress on the repaired tendon, prevent infection, manage pain and swelling (Coban wrapping, limb elevation, cryotherapy); to restore full active range of motion (AROM) in the shoulder and elbow; to educate the patient about the importance of immobilization; to prevent joint stiffness and flexion contractures.

Means: customized plaster casts or splints, pain and swelling management, active range of motion (AROM) exercises for the shoulder and elbow, passive flexion of the MP and IF joints and IP extension up to the splint's limit (exclusively during therapy and with physician clearance).

Phase II (4 to 6 weeks)

Goals: to reduce the swelling, to minimise the risk of tendon rupture, to reduce the tendon adhesions, to reduce the scar tissue formation, to achieve complete passive flexion of the finger joints, full active extension of the IP joints, partial active flexion, and to educate the patient on how to perform their home exercise program independently.

Means: modification of the splint to maintain the wrist in a neutral position, scar tissue mobilization and fibrosis massage, passive flexion of the finger joints, active extension of the IP joints, wrist tenodesis, soft tendon gliding exercises, fist exercises, and gentle compression bandaging to control swelling.

Phase III (6 to 12 weeks)

Goals: to control edema, to minimize scar density and rigidity, to restore movement with minimal or no pain, to maintain the integrity of the tendon repair, to achieve full passive range of motion (PROM), to support restoration of full active fingers movement, to enhance muscular strength to support light functional activities, to promote adherence to an independent home exercise program.

Means: remove splint as part of progression, warming techniques to decrease pain and enhance mobility, scar massage combined with the use of silicone scar pads during nighttime to enhance scar remodelling; mild compressive bandaging; passive finger flexion exercises; encourage staged advancement of tendon gliding techniques; stretching into passive IP extension when contractures are present; simultaneous active extension of the MCP, PIP, and DIP joints; composite fist closure and controlled blocking movements; low-resistance strengthening activities; begin gentle functional activities.

Early Passive Motion Approach

Early passive mobilization plays a critical role in the post-operative rehabilitation of flexor tendon injuries by promoting tendon healing while minimizing adhesion formation. Two commonly used protocols exemplify this approach. The Duran Protocol involves low force and restricted tendon excursion, relying on patient-assisted passive finger flexion combined with active finger extension, all performed within the protection of a static splint. In contrast, the Kleinert Protocol also applies low force and restricted excursion but incorporates dynamic splinting to assist passive finger flexion, while allowing the patient to actively extend the fingers. Both protocols aim to balance tendon protection with controlled mobilization during the early healing phase.[50-53]

Phase I (0 to 4 weeks)

Goals: to protect tendon repair, to prevent infection, to control pain and tissue swelling, to regain complete active range of motion in the shoulder and elbow, to maintain full passive flexion range for each finger joint, to achieve complete extension of the IP joints, to provide patient education and guidance on a home exercise program as well as strategies to protect the repaired tendon.

Means: custom splint fabrication after surgical repair, management of pain and edema using Coban compression and limb elevation, active range of motion (AROM) exercises for the shoulder and elbow, passive flexion of all finger joints, prescribed home exercises to be performed every hour

Phase II (4 to 8 weeks)

Goals: to protect against tendon rupture, to decrease edema, to facilitate scar management, to reduce adhesion formation; to facilitate finger flexion with the wrist held in extension and regain active extension of the finger joints with the wrist in flexion; to implement a structured home exercise plan.

Means: discontinue splinting until 7 weeks; swelling control using elevation combined with Coban bandaging; heat therapy for pain and stiffness; scar management; passive digit flexion, active IP extension exercises, wrist tenodesis movements, tendon gliding exercises; patient instruction on safety measures and prescribed home exercises.

Phase III (8 to 12 weeks)

Goals: to control edema, to manage scars, to protect the repaired tendon from rupture; to regain comfortable, unrestricted motion; to achieve full passive and active mobility of the fingers, to improve grip and hand strength for light daily activities, to facilitate restoration of hand function, to participate consistently in home-based rehabilitation exercises.

Means: heat therapy for pain and stiffness, edema management, scar massage, manual passive finger joint mobilization, active extension exercises, strengthening exercises, patient education.

Early Active Motion Approach

This approach is the latest advancement in rehabilitation following flexor tendon repair. It is implemented in patients who have received robust enough surgical repair to handle the extra stress exerted on the tendon by active flexion. It includes:

- Controlled Active Mobilization protocol: For patients with associated ulnar nerve lesions. The active gliding of flexor tendons prevents or reduces adhesion.[54]
- Belfast Early Mobilization Protocol[55]
- "Place and hold" exercises are performed with the fingers[48]
- Manchester Short Splint regime- The short splint is designed to allow full wrist flexion and up to 45° of wrist extension, with a block limiting metacarpophalangeal joint extension to 30°. The rehabilitation protocol includes early combined passive flexion exercises alongside active motion.[49]

CONCLUSION

Hand injuries, including those involving flexor tendons, represent a significant health concern, predominantly affecting young, active individuals. These injuries can have profound and long-lasting repercussions on hand function, leading to substantial impairments in daily activities and overall quality of life. Flexor tendon injuries, especially those involving Zone II, continue to pose substantial challenges in hand surgery due to the intricate anatomy, high risk of adhesion formation, and need for precise surgical intervention. Our study emphasizes that successful outcomes depend not only on the timing and quality of tendon repair but also on the integration of individualized rehabilitation protocols tailored to the injury zone and complexity. Functional recovery is most effective when early mobilization is balanced with adequate protection of the repair, supported by adequate surgical strong multistrand suture techniques and guided rehabilitation. Ultimately, optimal tendon healing and hand function restoration are best achieved through a multidisciplinary approach, combining surgical expertise with patient-specific rehabilitation strategies.

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REFERENCES

1. Venkatramani H, Varadharajan V, Bhardwaj P, Vallurupalli A, Sabapathy SR. Flexor tendon injuries. J Clin Orthop Trauma. 2019 Sep-Oct;10(5):853-861. doi: 10.1016/j.jcot.2019.08.005. Epub 2019 Aug 19. PMID: 31528057; PMCID: PMC6739511.
2. Bennett DJ, Bango J, Rothkopf DM. Hand Therapy after Flexor and Extensor Tendon Repair: Assessing Predictors of Loss to Follow-up. Plast Reconstr Surg Glob Open. 2023 Apr 26;11(4):e4941. doi: 10.1097/GOX.0000000000004941. PMID: 37124389; PMCID: PMC10132707.
3. Benson DC, Miao KH, Varacallo MA. Anatomy, Shoulder and Upper Limb, Hand Flexor Pollicis Longus Muscle. [Updated 2023 Jul 24]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK538490/, accessed 04.05.2025
4. Bateman, H. An Introduction to Hand Therapy. Derby BAHT Course, 2018.
5. Tang JB. Flexor Tendon Injuries. Clin Plast Surg. 2019 Jul;46(3):295-306. doi: 10.1016/j.cps.2019.02.003. PMID: 31103074
6. Berrigan W, White W, Cipriano K, Wickstrom J, Smith J, Hager N. Diagnostic Imaging of A2 Pulley Injuries: A Review of the Literature. J Ultrasound Med. 2022 May;41(5):1047-1059. doi: 10.1002/jum.15796. Epub 2021 Aug 2. PMID: 34342037; PMCID: PMC9292555
7. Sasor SE, Chung KC. Surgical Considerations for Flexor Tendon Repair: Timing and Choice of Repair Technique and Rehabilitation. Hand Clin. 2023 May;39(2):151-163. doi: 10.1016/j.hcl.2022.08.016. PMID: 37080647.
8. Chartier C, El Hawary H, Baradaran A, Vorstenbosch J, Xu L, Efanov JI. Tendon: Principles of Healing and Repair. Semin Plast Surg. 2021 Aug;35(3):211-215. doi: 10.1055/s-0041-1731632. Epub 2021 Jul 15. PMID: 34526870; PMCID: PMC8432990.
9. Stewart DA, Smitham PJ, Gianoutsos MP, Walsh WR. Biomechanical influence of the vincula tendinum on digital motion after isolated flexor tendon injury: a cadaveric study. J Hand Surg Am. 2007 Oct;32(8):1190-4. doi: 10.1016/j.jhsa.2007.05.017. PMID: 17923302.
10. Kikuchi Y, Sato K, Doita M. An anatomical study of flexor pollicis longus blood supply with specific reference to volar locking plate surgery. J Orthop. 2020 Jan 21;20:119-121. doi: 10.1016/j.jor.2020.01.022. PMID: 32042238; PMCID: PMC7000556.
11. Armenta E, Fisher J. Anatomy of flexor pollicis longus vinculum system. J Hand Surg Am. 1984 Mar;9(2):210-2. doi: 10.1016/s0363-5023(84)80143-4. PMID: 6715826.
12. Titan AL, Foster DS, Chang J, Longaker MT. Flexor Tendon: Development, Healing, Adhesion Formation, and Contributing Growth Factors. Plast Reconstr Surg. 2019 Oct;144(4):639e-647e. doi: 10.1097/PRS.0000000000006048. PMID: 31568303; PMCID: PMC7092377.
13. Gray Seiler III J.Flexor Tendon Injury, chapter in Wolfe SW, Pederson WC, Kozin SH, Cohen MS. Green's Operative Hand Surgery. 7th ed. Philadelphia: Elsevier; 2016.pages 183-230
14. Kleinert H, Kutz J, Ashbell T, et al. Primary repair of lacerated flexor tendons in "no man's land,". J Bone Joint Surg Am. 1967;49:577.
15. Verdan CE. Half a century of flexor-tendon surgery: current status and changing philosophies. J Bone Joint Surg Am. 1972;54:472-491.
16. Ishak A, Rajangam A, Khajuria A. The evidence-base for the management of flexor tendon injuries of the hand: Review. Ann Med Surg (Lond). 2019 Oct 15;48:1-6. doi: 10.1016/j.amsu.2019.10.006. PMID: 31660149; PMCID: PMC6806617.
17. Falcon M, Vilke GM. Jersey fracture: Avulsion-fracture injury of the flexor digitorum profundus. JEM Rep. 2024 Jun;3(2):100089. doi:10.1016/j.jemrpt.2024.100089.
18. Leddy JP, Packer JW. Avulsion of the profundus tendon insertion in athletes. J Hand Surg Am. 1977 Jan;2(1):66-9. doi: 10.1016/s0363-5023(77)80012-9. PMID: 839056.
19. Tuttle HG, Olvey SP, Stern PJ. Tendon avulsion injuries of the distal phalanx. Clin Orthop Relat Res. 2006 Apr;445:157-68. doi: 10.1097/01.blo.0000205903.51727.62. PMID: 16601414.
20. Kotwal PP, Ansari MT. Zone 2 flexor tendon injuries: Venturing into the no man's land. Indian J Orthop. 2012 Nov;46(6):608-15. doi: 10.4103/0019-5413.104183. PMID: 23325961; PMCID: PMC3543876.
21. Bunnell S. Surgery of the Hand. 5th ed. Philadelphia, PA: J. B. Lippincott Company; 1944 (pp. xvii-734).
22. Jia Q, Chen D, Guo J, Luo X, Alimujiang A, Zhang J, Hu N, Liu Y, Xie Z, Ma C. Risk factors associated with tendon adhesions after hand tendon repair. Front Surg. 2023 Apr 18;10:1121892. doi: 10.3389/fsurg.2023.1121892. PMID: 37143766; PMCID: PMC10151704.
23. Wong JKF, Peck F. Improving results of flexor tendon repair and rehabilitation. Plast Reconstr Surg. 2014 Dec;134(6):913e-925e. doi: 10.1097/PRS.0000000000000749. PMID: 25415114.
24. Stoian A, Hodea FV, Tomek-Enescu RM, Grosu Bularda A, Andrei MC, Lita FF, Popescu M, Lascar I, Teodoreanu R. Versatility of vein grafts in hand neurovascular reconstruction – clinical cases and literature review. Modern Medicine. 2021;28(4):453. doi:10.31689/rmm.2021.28.4.453.
25. Yousef J, Anthony S. Flexor Tendon Injuries [Internet]. Essentials of Hand Surgery. InTech; 2018. Available from: http://dx.doi.org/10.5772/intechopen.73392, accessed 11.05.2025
26. Griffin M, Hindocha S, Jordan D, Saleh M, Khan W. An overview of the management of flexor tendon injuries. Open Orthop J. 2012;6:28-35. doi: 10.2174/1874325001206010028. Epub 2012 Feb 23. PMID: 22431948; PMCID: PMC3293389.
27. de Jong JP, Nguyen JT, Sonnema AJ, Nguyen EC, Amadio PC, Moran SL. The incidence of acute traumatic tendon injuries in the

hand and wrist: a 10-year population-based study. Clin Orthop Surg. 2014 Jun;6(2):196-202. doi: 10.4055/cios.2014.6.2.196. Epub 2014 May 16. PMID: 24900902; PMCID: PMC4040381.
28. Manninen M, Karjalainen T, Määttä J, Flinkkilä T. Epidemiology of Flexor Tendon Injuries of the Hand in a Northern Finnish Population. Scand J Surg. 2017 Sep;106(3):278-282. doi: 10.1177/1457496916665544. Epub 2016 Aug 22. PMID: 27550244.
29. Lee SK, Fajardo M, Kardashian G, Klein J, Tsai P, Christoforou D. Repair of flexor digitorum profundus to distal phalanx: a biomechanical evaluation of four techniques. J Hand Surg Am. 2011 Oct;36(10):1604-9. doi: 10.1016/j.jhsa.2011.07.017. Epub 2011 Aug 27. PMID: 21873002.
30. Stevens KA, Caruso JC, Fallahi AKM, et al. Flexor Tendon Lacerations. [Updated 2023 Jun 20]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK493223/, accessed 11.05.2025
31. Tang JB. Flexor tendon injuries and reconstruction. Chapter in Chang J, Neligan PC.(Editors). Plastic Surgery 4th Edition-Volume Six: Hand and Upper Extremity, Elsevier Health Sciences 2017. Pag. 188-225.
32. Kamble R, Shah R, Kiely AL, Nolan GS, Wong J. Secondary Flexor Tendon Reconstruction: Protocol for a Systematic Review and Meta-Analysis. Int J Surg Protoc. 2022 Jul 4;26(1):49-56. doi: 10.29337/ijsp.176. PMID: 35859728; PMCID: PMC9266938.
33. Chattopadhyay A, McGoldrick R, Umansky E, Chang J. Principles of tendon reconstruction following complex trauma of the upper limb. Semin Plast Surg. 2015 Feb;29(1):30-9. doi: 10.1055/s-0035-1544168. PMID: 25685101; PMCID: PMC4317277.
34. Ruchelsman DE, Christoforou D, Wasserman B, Lee SK, Rettig ME. Avulsion injuries of the flexor digitorum profundus tendon. J Am Acad Orthop Surg. 2011 Mar;19(3):152-62. doi: 10.5435/00124635-201103000-00004. PMID: 21368096.
35. Imbergamo CM, Sequeira SB, Miles MR, Means KR Jr. A Meta-Analysis of Biomechanical Studies for Suture Button Pullout Versus Suture Anchor Repair of Flexor Digitorum Profundus Avulsions. Hand (N Y). 2024 Jun;19(4):671-678. doi: 10.1177/15589447221126760. Epub 2022 Oct 5. PMID: 36196928; PMCID: PMC11141426.
36. Bond S, Rust P, Boland M. The Accommodation of Bone Anchors Within the Distal Phalanx for Repair of Flexor Digitorum Profundus Avulsions. J Hand Surg Am. 2019 Nov;44(11):986.e1-986.e6. doi: 10.1016/j.jhsa.2018.12.012. Epub 2019 Feb 15. PMID: 30777399.
37. Rawson S, Cartmell S, Wong J. Suture techniques for tendon repair; a comparative review. Muscles Ligaments Tendons J. 2013 Aug 11;3(3):220-8. PMID: 24367784; PMCID: PMC3838333.
38. Moriya T, Zhao C, An KN, Amadio PC. The effect of epitendinous suture technique on gliding resistance during cyclic motion after flexor tendon repair: a cadaveric study. J Hand Surg Am. 2010 Apr;35(4):552-8. doi: 10.1016/j.jhsa.2009.12.025. Epub 2010 Feb 26. PMID: 20189323; PMCID: PMC3591492.
39. Osada D, Fujita S, Tamai K, Yamaguchi T, Iwamoto A, Saotome K. Flexor tendon repair in zone II with 6-strand techniques and early active mobilization. J Hand Surg Am. 2006 Jul-Aug;31(6):987-92. doi: 10.1016/j.jhsa.2006.03.012. PMID: 16843161.
40. Chauhan A, Palmer BA, Merrell GA. Flexor tendon repairs: techniques, eponyms, and evidence. J Hand Surg Am. 2014 Sep;39(9):1846-53. doi: 10.1016/j.jhsa.2014.06.025. PMID: 25154573.
41. Savvidou C, Tsai TM. Clinical Results of Flexor Tendon Repair in Zone II Using a six Strand Double Loop Technique. J Hand Microsurg. 2015 Jun;7(1):25-9. doi: 10.1007/s12593-014-0156-0. Epub 2014 Aug 28. PMID: 26078499; PMCID: PMC4461623.
42. Hoffmann GL, Büchler U, Vögelin E. Clinical results of flexor tendon repair in zone II using a six-strand double-loop technique compared with a two-strand technique. J Hand Surg Eur Vol. 2008 Aug;33(4):418-23. doi: 10.1177/1753193408091570. PMID: 18687827.
43. Su BW, Solomons M, Barrow A, Senoge ME, Gilberti M, Lubbers L, Diao E, Quitkin HM, Rosenwasser MP. Device for zone-II flexor tendon repair. A multicenter, randomized, blinded, clinical trial. J Bone Joint Surg Am. 2005 May;87(5):923-35. doi: 10.2106/JBJS.C.01483. PMID: 15866953.
44. Radhakrishnapillai SS, Parameswaran SC, Titus HM, Malathi L. WALANT vs. brachial plexus block with tourniquet in zone 2 flexor tendon repair: an evidence-based comparison. J Hand Microsurg. 2025:100280. doi:10.1016/j.jham.2025.100280.
45. Paneva-Holevich E. Two-stage tenoplasty in injury of the flexor tendons of the hand. J Bone Joint Surg Am. 1969 Jan;51(1):21-32. PMID: 5764348.
46. Beris AE, Darlis NA, Korompilias AV, Vekris MD, Mitsionis GI, Soucacos PN. Two-stage flexor tendon reconstruction in zone II using a silicone rod and a pedicled intrasynovial graft. J Hand Surg Am. 2003 Jul;28(4):652-60. doi: 10.1016/s0363-5023(03)00146-1. PMID: 12877856.
47. Sporea C, Ferechide D. Influence of the Upper Limb Motor Deficit on Functional Independence in Patients with Cerebral Palsy. Modern Medicine. 2021;28(1):77–82. doi:10.31689/rmm.2021.28.1.77.
48. Peters SE, Jha B, Ross M. Rehabilitation following surgery for flexor tendon injuries of the hand. Cochrane Database Syst Rev. 2021 Jan 13;1(1):CD012479. doi: 10.1002/14651858.CD012479.pub2. PMID: 33434949; PMCID: PMC8094509.
49. Peck F, Roe A, Ng C, Duff C, McGrouther D, Lees V. The Manchester short splint: A change to splinting practice in the rehabilitation of zone II flexor tendon repairs. Hand Therapy. 2014;19(2):47-53. doi:10.1177/1758998314533306
50. Cetin A, Dinçer F, Keçik A, Cetin M. Rehabilitation of flexor tendon injuries by use of a combined regimen of modified Kleinert and modified Duran techniques. Am J Phys Med Rehabil. 2001 Oct;80(10):721-8. doi: 10.1097/00002060-200110000-00003. PMID: 11562553.
51. Chesney A, Chauhan A, Kattan A, Farrokhyar F, Thoma A. Systematic review of flexor tendon rehabilitation protocols in zone II of the hand. Plast Reconstr Surg. 2011 Apr;127(4):1583-1592. doi: 10.1097/PRS.0b013e318208d28e. PMID: 21187807.
52. Starr HM, Snoddy M, Hammond KE, Seiler JG 3rd. Flexor tendon repair rehabilitation protocols: a systematic review. J Hand Surg Am. 2013 Sep;38(9):1712-7.e1-14. doi: 10.1016/j.jhsa.2013.06.025. PMID: 23981421.
53. Klein LJ, Crimmins CA. Surgery and rehabilitation for primary flexor tendon repair in the digit. In: Prigent M, editor. Rehabilitation for the Postsurgical Orthopedic Patient. 3rd ed. Elsevier; 2013. p. 193–215.
54. Frueh FS, Kunz VS, Gravestock IJ, Held L, Haefeli M, Giovanoli P, Calcagni M. Primary flexor tendon repair in zones 1 and 2: early passive mobilization versus controlled active motion. J Hand Surg Am. 2014 Jul;39(7):1344-50. doi: 10.1016/j.jhsa.2014.03.025. Epub 2014 May 5. PMID: 24799144.
55. Woythal L, Hølmer P, Brorson S. Splints, with or without wrist immobilization, following surgical repair of flexor tendon lesions of the hand: A systematic review. Hand Surg Rehabil. 2019 Sep;38(4):217-222. doi: 10.1016/j.hansur.2019.05.004. Epub 2019 May 24. PMID: 31132525.