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Flexor Tendon Injuries

JIN BO TANG

Introduction

Flexor tendon injuries are among commonly seen hand trauma, and outcomes of the treatment in the fingers and thumbs are traditionally unsatisfactory. In the hand and the forearm, flexor tendons are divided into five anatomical zones. Zone 2 is the most complex area, which has attracted most attention from surgeons and investigators alike. Over the past decades, zone 2 flexor tendon repairs have evolved greatly, and outcomes have changed dramatically.[1–5] Several conceptual changes, as well as key surgical methods and postoperative hand therapy protocols, have led to the changes.[6–16] The new principles and clinical practices include: (1) using strong core sutures, typically 4- or 6-strand repairs; (2) judicious venting of the critical annular pulley; (3) ensuring that a slight tension is created by the repair to prevent gapping at the repair site; (4) performing on-table digital extension–flexion tests to confirm the quality of the surgical repair; and (5) early partial-range active motion to ensure tendon gliding, without overloading the repair.

In addition, having the patient wide awake under local anesthesia with epinephrine without use of a tourniquet during surgery is an important advance. In such settings, the patient can actively move the tendon to ascertain that after end-to-end repair the repair site has no gapping or does not impinge against the pulleys.[9,10] Wide-awake surgery also enables better intraoperative judgment of tenolysis or proper tensioning of the tendon graft during secondary surgery.

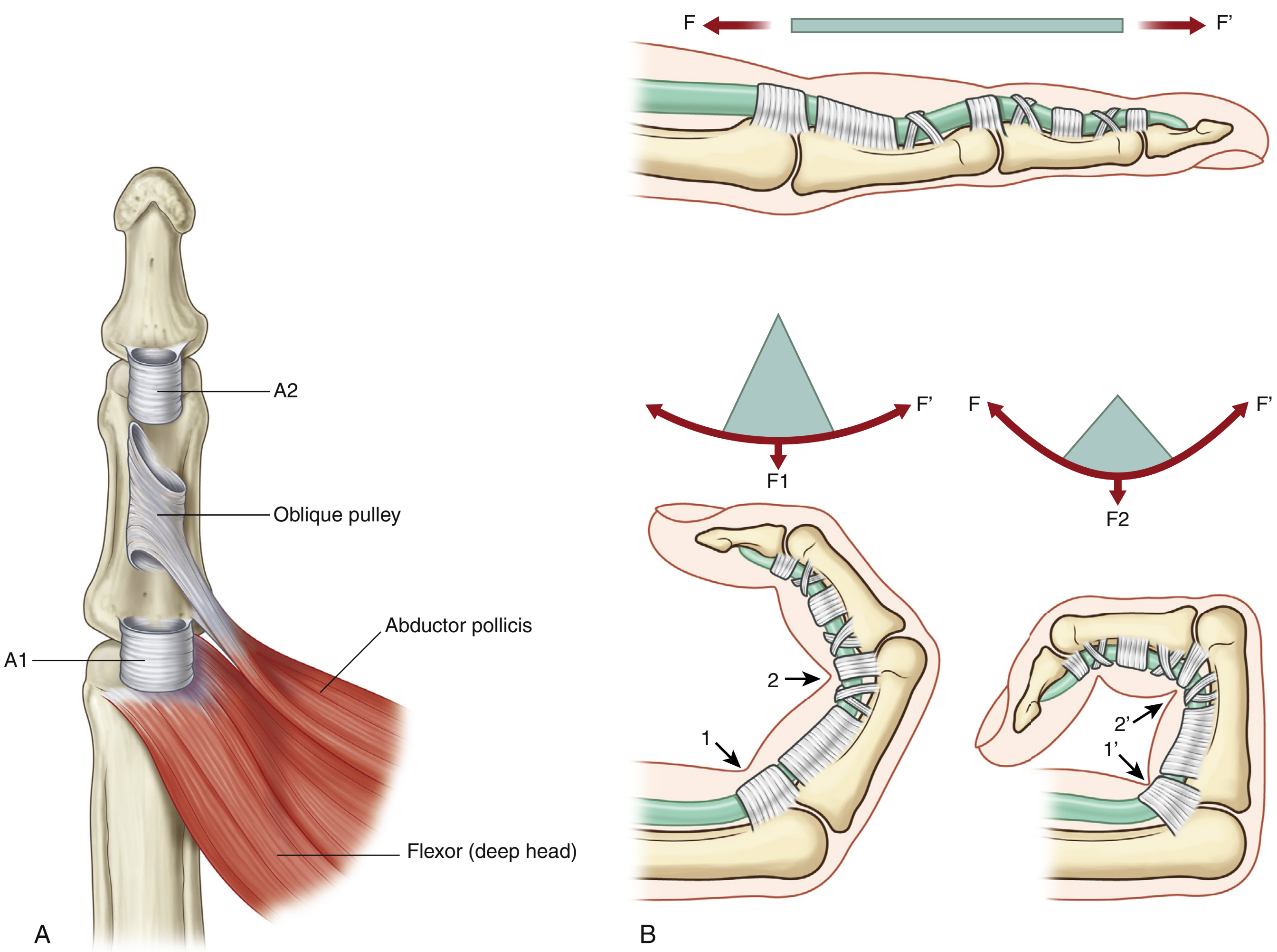
Anatomical Features

There are 12 flexor tendons in the hand and forearm regions. These tendons include finger and thumb flexors and wrist flexors. Finger flexor tendons are the flexor digitorum superficialis (FDS) and the flexor digitorum profundus (FDP). In the thumb there is only one flexor tendon, i.e., the flexor pollicis longus (FPL). The tendons of the FDP come from a common muscle belly in the mid forearm. The tendons of the FDS originate from the separate muscle bellies, which allow more independent finger flexion. Within the carpal tunnel, nine tendons (four FDS, four FDP, and one FPL) exist.

In the fingers and thumb, the digital flexor tendons glide within a closed fibro-osseous sheath with segmental, semi-rigid, constrictive bands present. Proximally, the synovial sheath ends proximal to the neck of the metacarpals, forming the proximal reflection of the digital flexor sheath. The FDS tendons lie superficial to the FDP tendons proximal to the bifurcation of the FDS tendon at the level of the metacarpophalangeal joint. Distal to the bifurcation, the FDS tendon becomes two slips coursing laterally and then deeper to the FDP tendons. This FDS bifurcation is in the middle part of the A2 pulley area. In this area, the FDS tendon also serves to constrain the FDP tendon, acting as the second sheath constricting the FDP tendon. Deep to the FDP tendon, the FDS slips rejoin to form Camper's chiasm, and insert on the middle phalanx as two separate slips. The FDP tendon inserts into the distal phalanx. Inside the flexor sheath of the thumb, the FPL tendon is the only tendon and inserts at the distal phalanx.

The digital flexor sheath consists of *synovial sheath* and segmental, condensed fibrous bands called *pulleys*. Synovial sheath, a thin layer of continuous paratenon covering the inner surface of the fibrous sheath, provides a smooth surface for tendon gliding and nutrition to the tendons. The pulley system of the fingers consists of *annular pulleys* (condensed, rigid, and heavier annular bands) and *cruciate pulleys* (filmy cruciform bands) (Fig. 47.1). In the thumb, there are two annular pulleys (A1 and A2) palmar to the two thumb joints and one oblique pulley; there are no cruciate pulleys. In the fingers, there are five annular pulleys (A1, A2, A3, A4, and A5), three cruciate pulleys (C1, C2, and C3), and one palmar aponeurosis (PA) pulley (see Fig. 47.3A). The A1, A3, and A5 pulleys attach to the palmar plates of the metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints, and the A2 pulley attaches to the proximal two-thirds of the proximal phalange and A4 pulleys attach to the middle portion of the middle phalange.

The presence of annular pulleys is a unique anatomical feature. The A2 pulley is the largest and strongest, and the A4 pulley the second largest. The annular pulleys serve to prevent tendon bowstringing during digital flexion. The A3 and A1 pulleys also perform this function, but their role is less critical than the A2 and A4. Loss of integrity of any one



• **Fig. 47.1** The location of pulleys in the (A) thumb and (B) fingers. (A) In the thumb, there are only three pulleys: A1, oblique, and A2. (B) The cruciate and annular pulleys. When the finger flexes, the cruciate pulleys shorten ("concertina effect") but annular pulleys are more rigid and do not change their shapes. (From Tang JB. Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery*: Vol 6: *Hand and Upper Extremity.* 4th edn. Elsevier; 2018: (A) Fig. 9.2; (B) Fig. 9.8C.)

of the pulleys alone has no marked functional consequence, though anatomically, minor tendon bowstringing occurs at the site of the loss.

The middle and distal part of the A2 pulley (1.5–1.7 cm long in adult middle finger) and the A4 pulley (about 0.5 cm long) are the narrowest and constricting. These sites become very compressive to the repaired tendons because of postoperative tendon swelling. These narrow pulley sites can be incised to allow the repaired tendons to glide more freely.

Zones and Subzones of Flexor Tendons

In the 1960s, the flexor tendons were divided into five zones by Verdan. In the 1990s, subdivisions of zone 1 by Moiemen and Elliot[17] and zone 2 by Tang[18] were added into the zoning system, in order to describe the location of injuries and repairs more specifically. These zoning and subzoning systems provide surgeons with the nomenclature to document the injuries and outcomes, and describe treatment methods.

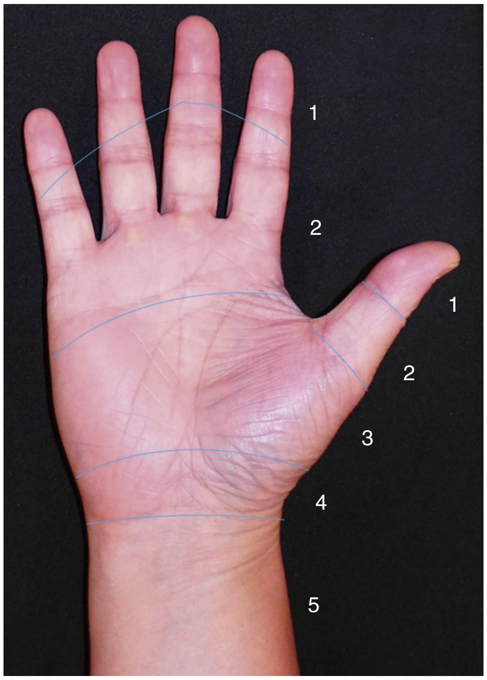
The zoning of flexor tendons is described below and seen in Figs. 47.2 and 47.3:

Zone 1: From the insertion of the FDS tendon to the terminal insertion of the FDP tendon
Zone 2: From the proximal reflection of the digital synovial sheath to the FDS insertion
Zone 3: From the distal margin of the transverse carpal ligament to the digital synovial sheath
Zone 4: Area covered by the transverse carpal ligament
Zone 5: Proximal to the transverse carpal ligament.

In the thumb, zone 1 is distal to the interphalangeal joint, zone 2 is from the interphalangeal joint to the A1 pulley, and zone 3 is the area of the thenar eminence.

The subdivisions of zone 1 by Moiemen and Elliot are:

1A: The very distal FDP tendon (usually <1 cm), not possible to insert a core suture



• **Fig. 47.2** Location of the five zones of the flexor tendons in the hand and forearm.

1B: From zone 1A to the distal margin of the A4 pulley
1C: The FDP tendon within the A4 pulley

The subdivisions of zone 2 by Tang are:

2A: The area of the FDS tendon insertion
2B: From the proximal margin of the FDS insertion to the distal margin of the A2 pulley
2C: The area covered by the A2 pulley
2D: From the proximal margin of the A2 pulley to the proximal reflection of the digital sheath.

Biomechanical Considerations

Two major considerations are factors affecting the strength of repaired tendons as well as contributing to the resistance to active digital flexion.

Factors Affecting the Strength of Repaired Tendons

The following factors affect the strength of repaired tendons: (1) the number of core suture strands across the repair sites – strength is roughly proportional to the number of core sutures; (2) the tension of repairs – most relevant to gap formation and stiffness of repairs; (3) the core suture purchase; (4) the types of tendon–suture junction – locking or grasping; (5) the diameter of suture locks in the tendons – a small diameter of locks diminishes anchor power; (6) the suture calibers (diameter); (7) the material properties of suture materials; (8) the curvature of tendon gliding paths – the repair strength decreases as tendon curvature increases; and (9) above all, the holding capacity of a tendon, affected by varying degrees of trauma and posttraumatic tissue softening, plays a vital role in repair strength.

It must be realized that tendon curvature during finger flexion greatly effects the repair strength. A tendon under curvilinear tension is subjected to both linear pulling and bending forces. Therefore, a repair in a tendon under a curvilinear load is weaker than that under a linear load. The repair strength decreases progressively as the curvature increases.[19,20] Therefore, the repair fails more easily in the flexed finger and when the finger moves to approach full flexion, a bent tendon is particularly prone to fail. This is the mechanical basis of current partial active finger flexion protocols and one reason why a full fist should be avoided in the initial few weeks post surgery (Table 47.1).

Factors Affecting the Resistance to Tendon Gliding after Surgery

Fig. 47.4 summarizes the breakdown of contributors to postoperative resistance to tendon gliding,[21] which should be considered in planning and adjusting the active motion protocols. The safety margin of early active digital flexion can be enhanced by a strong surgical tendon repair or appropriately decompressing the tendon during surgery through releasing restricting pulleys, limiting the lengths of skin incisions, and minimizing the trauma to the tendon and sheath. After surgery, delicate adjustments in early active flexion to fit individual patients by therapist or surgeon is also important.

Clinical Diagnosis

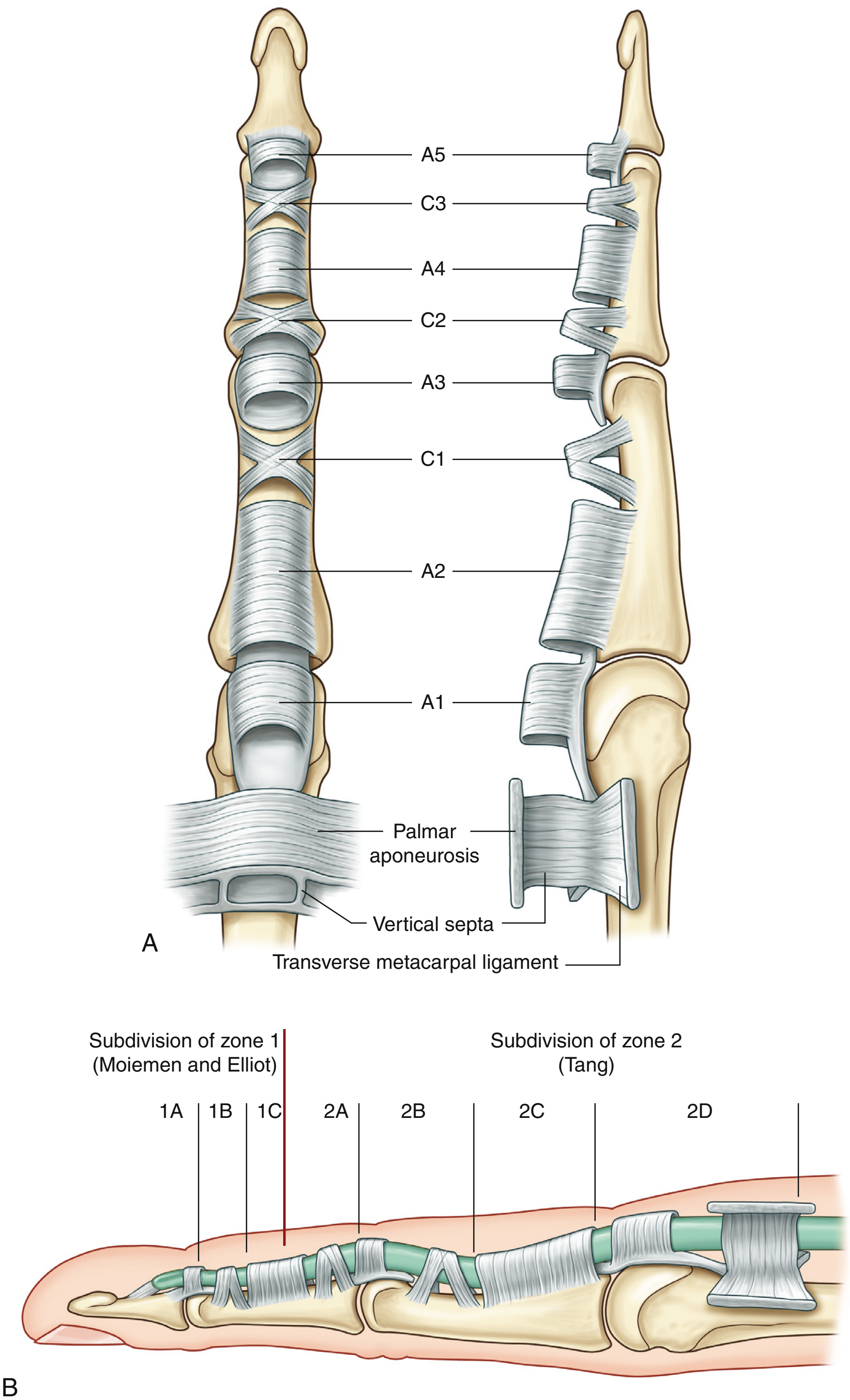
Open injuries are the most common cause of flexor tendon injuries in the hand and upper extremity. Less commonly the rupture of the tendons is found with a closed injury, such as forceful finger flexion. After injury, the natural resting posture of the wounded digits are usually changed, with the affected fingers seen in a relatively extended position and loss of active finger flexion at PIP and DIP joints. During clinical examination, if the patient can actively flex the DIP joint while the motion of the PIP joint is blocked, the FDP tendon has no injuries or has only a partial disruption (Fig. 47.5). To assess the continuity of the FDS tendon, the adjacent fingers must be held in full extension by the examiner. The FDS tendon is severed completely if the patient cannot actively flex the PIP joint (Fig. 47.6).

The FDS in 30%–35% of little fingers has connection with the FDS in the ring or middle fingers, and the FDS tendon is missing in 10%–20% of the little fingers. These patients have limited or no PIP flexion of the little finger during testing.

Weakness and pain during resisted finger flexion indicates a possible partial tendon cut. Loss of active flexion at the interphalangeal (IP) joint indicates complete severance of the FPL tendon.

Primary and Delayed Primary Repair

Nowadays the majority of lacerated flexor tendons in the hand and forearm are repaired at the same day of injury or



• **Fig. 47.3** (A) Locations of the annular and cruciate pulleys of the fingers. (B) The subdivisions of zone 1 and 2. (From Tang JB: Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery*. Vol 6: *Hand and Upper Extremity*. 4th edn. Elsevier; 2018: (A) Fig. 9.1; (B) Fig. 9.5.)

a few days later. Primary repair indicates end-to-end repair performed within 24 hours after tendon injury. When an experienced surgeon is not available at the day of injury, the repair can be deliberately delayed and delayed primary repair is performed in a selective surgical setting. The delay usually has no adverse effects on outcomes, but in this period of delay antibiotic use reduces the risk of infection of the wound. Delayed primary repair is a repair performed within 3 or even 4 weeks after injury. The end-to-end repair is often still possible 5 weeks after injury. Because zone 2 is the most complex and demanding, the repair methods for zone 2 injuries are given in detail below.

Repair in Zone 2

Exposure and Finding Tendon Ends in Zone 2

The surgical incision to access the tendons is usually a Bruner's skin incision of 1.5–2 cm (Fig. 47.7). We keep the skin incision as limited as possible to decrease edema of the digit and resistance to tendon gliding after surgery. Retraction of the proximal tendon stump is very common, especially in delayed primary repair. If the FDP tendon end has not retracted far proximally, flexion of the MCP or PIP joints can deliver the proximal end into the incision site.

If the proximal FDP tendon end retracts into the palm, it is preferable not to extend the incision to the palm, but instead to make an additional incision in the distal palm. In the author's experience, the retracted tendon end can always be found in the distal palm. From this small incision, the proximal tendon end is pushed distally within the synovial sheath bit by bit using two forceps, like pushing a rope until the distal end is seen out of the distal opening in the sheath.

TABLE 47.1 Resistance to Tendon Gliding during Active Finger Flexion in Initial Weeks of Tendon Healing

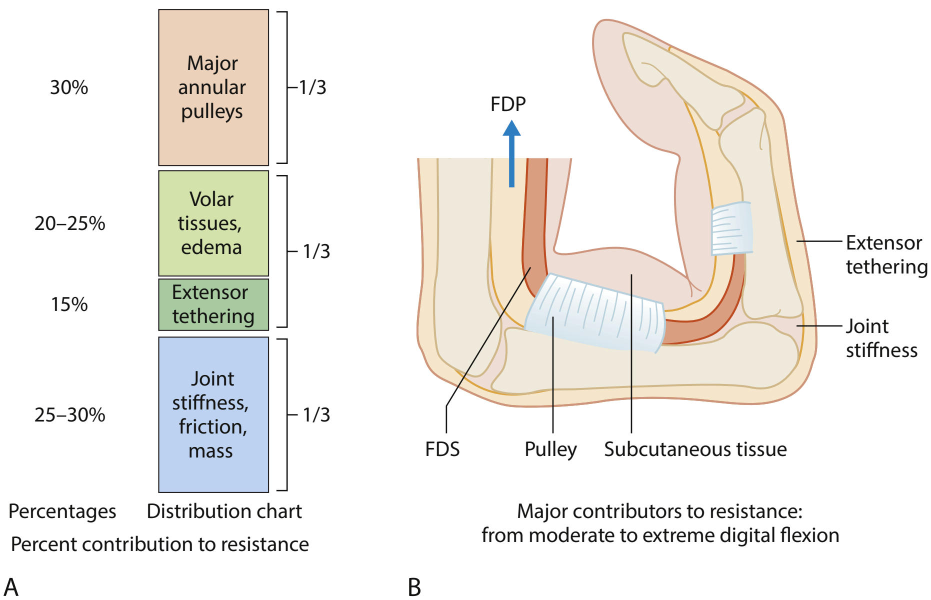
Active Flexion	Resistance to Tendon Gliding	Healing Tendons during Active Motion
None to mild	Low	Not easily disrupted
Mild to moderate	Low or moderately high	Not easily disrupted
Moderate to full	Very high	Easy to disrupt. Should avoid such motion

The forceps instrument is used to pull the exposed proximal stump distally out of the preserved sheath for about 1 cm. Then the finger is held in slight flexion, a 25G needle is inserted at the base of the finger through the proximal tendon stump to hold it during repair (Fig. 47.8).

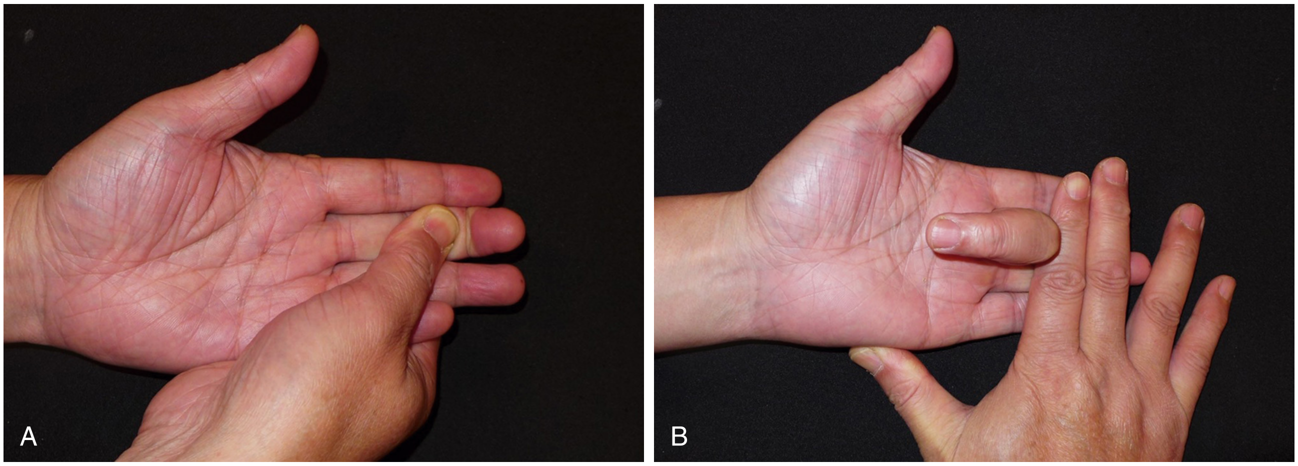
Surgical Repair Techniques

At the cut ends the tendon tissue is often ragged, which should be conservatively shaved with a scalpel or sharp scissors. Basic requirements of direct end-to-end repair are: (1) sufficient strength of the repair methods; (2) smooth tendon gliding surface, with fewer suture exposures; (3) prevent gapping of the repair site under tension; and (4) easy to perform. Different configurations of the suture strands in the tendon may produce good outcomes given all the requirements are met. Surgeons in different centers use different multistrand repairs (Fig. 47.9).[22] In the author's patients, a 6-strand M-Tang method is used as the core suture (Figs. 47.10 and 47.11).[12] Then a simple running epitendon suture or 3 or 4 stitches of separated peripheral stitches are added sparsely over the palmar repair site with 6-0 nylon, to smoothen the junction of the two tendon ends (Fig. 47.12).

Surgical essentials for making a strong tendon repair are, firstly, we must ensure core suture purchase of at least 0.7–1.0 cm to generate maximal holding power and a sufficiently large size (2 mm in diameter) of locks if a locking suture is used. Surgical repair strength decreases as the length of the purchase decreases. Tendon cut surfaces tend to soften after trauma. The repair is at great risk of rupture if the suture purchase is short. The second key to successful repair is that a certain amount of tension across the repair site should be maintained. To prevent gapping, it is very important to ensure the repair has tension or bulkiness that results in 10%–20% shortening of the tendon parts

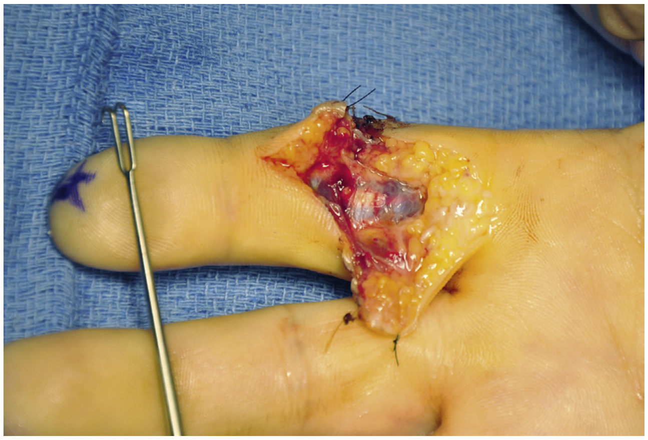


• **Fig. 47.4** The breakdown of contributors to postoperative resistance to active gliding of the flexor tendons.



• **Fig. 47.5** Examination of function of the flexor tendons in fingers. (A) No injuries or only partial injuries to the FDP tendon can be diagnosed if the patient can actively flex the DIP joint while the motion of the PIP joint is blocked. (B) To assess the continuity of the FDS tendon, the adjacent fingers are held in full extension. The FDS tendon is severed completely if the patient cannot actively flex the PIP joint.

• **Fig. 47.6** The index finger has complete laceration of both flexor tendons, and resting position of the finger is different from that of the other fingers.



• **Fig. 47.7** A Bruner skin incision of 1.5–2 cm for exposure of the laceration site. A limited skin incision is preferred to decrease postoperative swelling of the finger.

encompassed by core sutures, or a 20%–30% increase in the diameter of the junction site of the two tendon ends (Fig. 47.13).[23] A small amount of baseline tension would counteract the tension of the flexor muscles during resting or active motion. The repair site becomes more flattened once it is under the load of active digital flexion. Such degrees of bulkiness do not hamper tendon gliding with proper pulley venting. Thirdly, at least a 4-strand core suture is required; a 6-strand core suture is ideal. The caliber of suture used in adults is either 4-0 or 3-0. Key clinical technical points for achieving repair are summarized in Box 47.1.

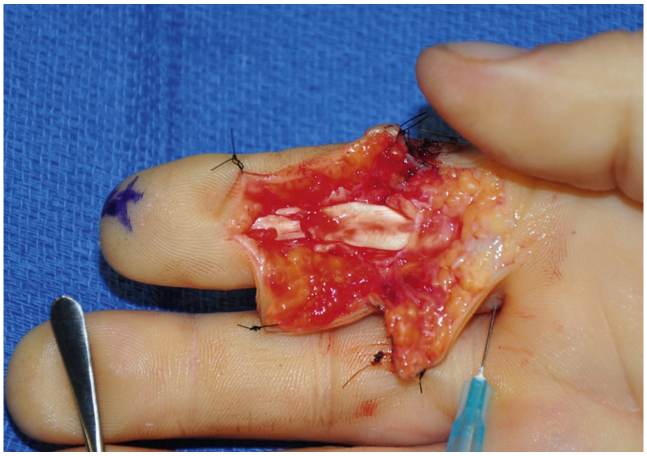
Locking suture-junction in the tendon is not a must, though locking anchors are slightly more secure. If the locks are incorporated, the locking circles of the suture in the tendon should be of a sufficient size (approximately 2 mm in diameter).

Epitendon sutures mainly serve to tidy up the repaired tendon stumps. Most surgeons now choose to insert only simple or sparse peripheral stitches. Some surgeons even do not supplement epitendinous sutures when multistrand core sutures have been used.[24,25] In the presence of a strong core repair that has been tensioned over the repair sites, peripheral sutures are less important (Box 47.2).

The author does not usually repair the FDS tendon unless the FDS injury is partial or the wound is very clean. The author's practice is not to repair the FDS tendon during delayed primary repair or if the injury is in the area of the A2 pulley (zone 2C).

Venting of the Critical Pulleys

It was previously believed that the A2 and A4 pulleys should not be divided. One of the important improvements in tendon repair in recent decades is the understanding that clinically significant bowstringing does not occur when the A2 pulley is released up to two-thirds of its length and that the A4 pulley can be entirely released, given the integrity of the other critical pulleys.[12] A part of the synovial sheath including cruciate pulleys is often released together with the annular pulleys (Fig. 47.14). The release is a longitudinal cut



• **Fig. 47.8** After pulling the retracted FDP tendon to approximate the distal tendon stump, a needle is inserted at the base of the finger to transfix the FDP tendon to reduce tension during repair.

through the midline with scissors. Clinically, the A4 pulley needs complete venting, but the A2 pulley should be vented partially only (Fig. 47.15).

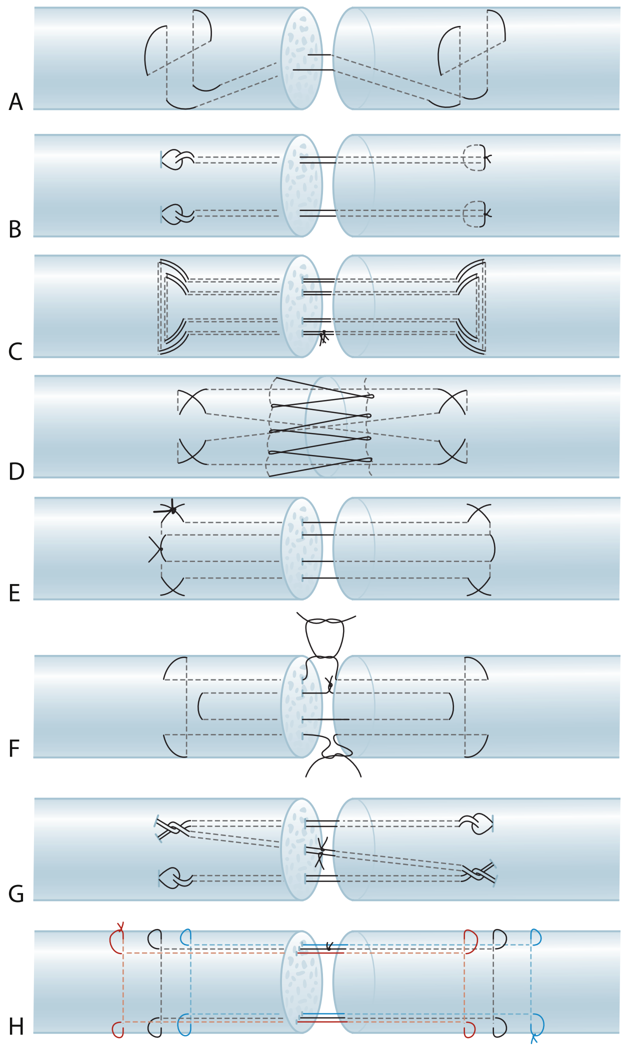
Usually no more than 1.5–2 cm length of the pulleys with the synovial sheath should be released.[12] In fact, such a release does not need to be over 2 cm, because in the proximal part of a finger of an average adult, the flexor tendons glide only 1.5–2 cm. This judicious pulley venting permits unimpeded gliding of a strong, yet slightly bunched or edematous tendon repair site during active tendon motion postoperatively.

Venting the A4 pulley entirely does not lead to clinically significant bowstringing, though anatomically there is minor tendon bowstringing, this is of no clinical consequence. In some patients, where the tendons are cut just distal to the A3 pulley, the A3 pulley has to be vented together with the A4 to allow surgical repair or gliding of the tendon.[23,24] Venting of the two pulleys has been found to have minor tendon bowstringing at the PIP joint, but it did not impair finger function.[24]

Performing Digital Extension–Flexion Test

After repairing the tendon and venting of pulleys, it is always necessary to verify the quality of the repair and adequate venting through an on-table *digital extension–flexion test.*[1,13,23] The test has three steps: (1) The repaired finger is held at full extension to confirm that no gaps are seen between the two cut ends. (2) The finger is moderately flexed to make sure the repaired tendon moves smoothly. (3) Finally, the finger is further pushed to marked flexion to confirm that the repair site does not bunch against the pulleys and that venting of the pulley is adequate (Fig. 47.16).

With sedation, brachial plexus blocks, or general anesthesia, the above test is performed with the surgeon's hand holding the repaired finger to obtain passive finger motion. Under local anesthesia without a tourniquet and no sedation, the patient can actively move the tendon to ascertain repair quality,[26] which is an even more powerful way to validate quality of the repair (Box 47.2).

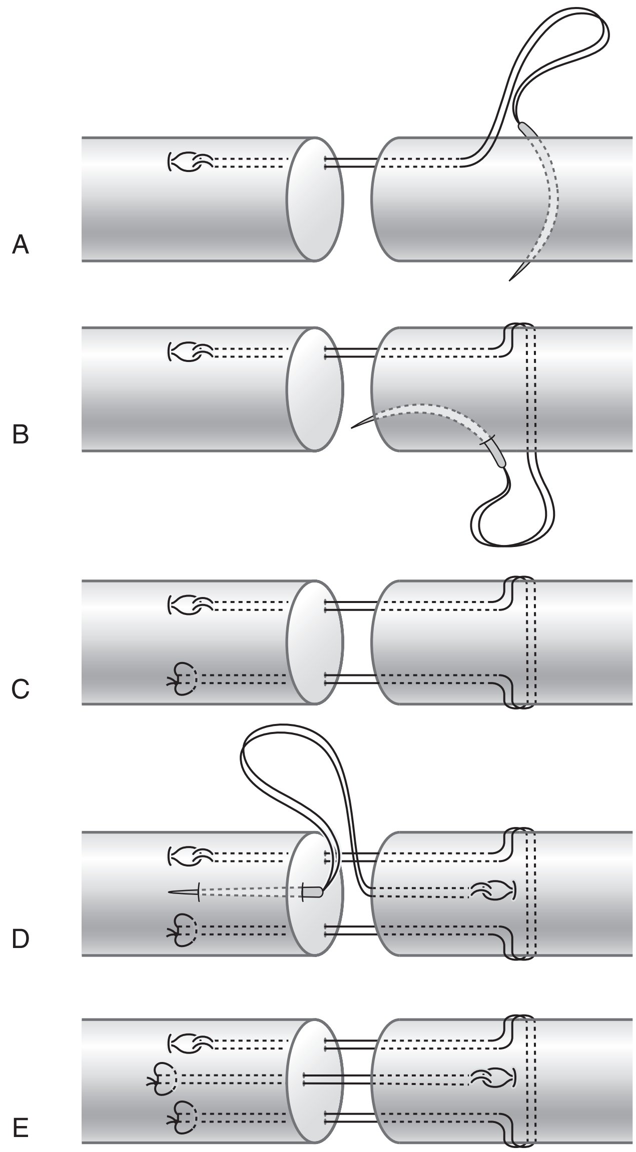


• **Fig. 47.9** Different multistrand repairs used in different centers. (A,B) Mayo Clinic. (C) 8-strand repair used in Washington University in St. Louis. (D) Cruciate repair plus cross-stitch repair used in The Hospital for Special Surgery in New York. (E) 4-strand repair used in Stanford University, USA. (F) 4-strand repair used in Indiana Hand Center. (G) 4-strand repair used in Bern University, Switzerland. Looped sutures (one needle carrying two suture strands) are used for repair methods shown in (B), (C), and (G). (H) A 6-strand repair made from three groups (each in a different color) of the Kessler repair in asymmetric placement in two tendon stumps, which is sometimes used by the author.

During the testing, if gapping is found between tendon ends, the repair is too loose and should be revised with additional core or peripheral sutures. If the pulley is found to block smooth tendon gliding, it should be further released. However, such additional release should be progressive, 1–2 mm at a time, with repeated digital extension–flexion tests, to ensure the release is just enough to let the repair site glide smoothly, rather than making one unnecessary lengthy cut.

Postoperative Active Motion Protocols

A short dorsal splint is usually sufficient for postoperative protection. The splint extends from the distal forearm to the fingertips. Some other surgeons use an even shorter splint, which ends at the wrist proximally.[27] The exact wrist



• **Fig. 47.10** (A–E) The method of making a 6-strand M-Tang repair, which the author uses for the FDP and PFL repair in almost all zone 2 and proximal zone 1 repairs. (From Tang JB. Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery*. Vol 6: *Hand and Upper Extremity*. 4th edn. Elsevier; 2018: Fig. 9.19.)

position is unimportant. The wrist can be in neutral, mild flexion, or mild extension as long as the patient is comfortable. The splint should be slightly flexed at the MCP joint, usually for 30–40 degrees, and be straight beyond this joint. The wrist position for splinting should avoid marked flexion (which is uncomfortable) or marked extension (which adds a lot of tension to the repaired tendon).

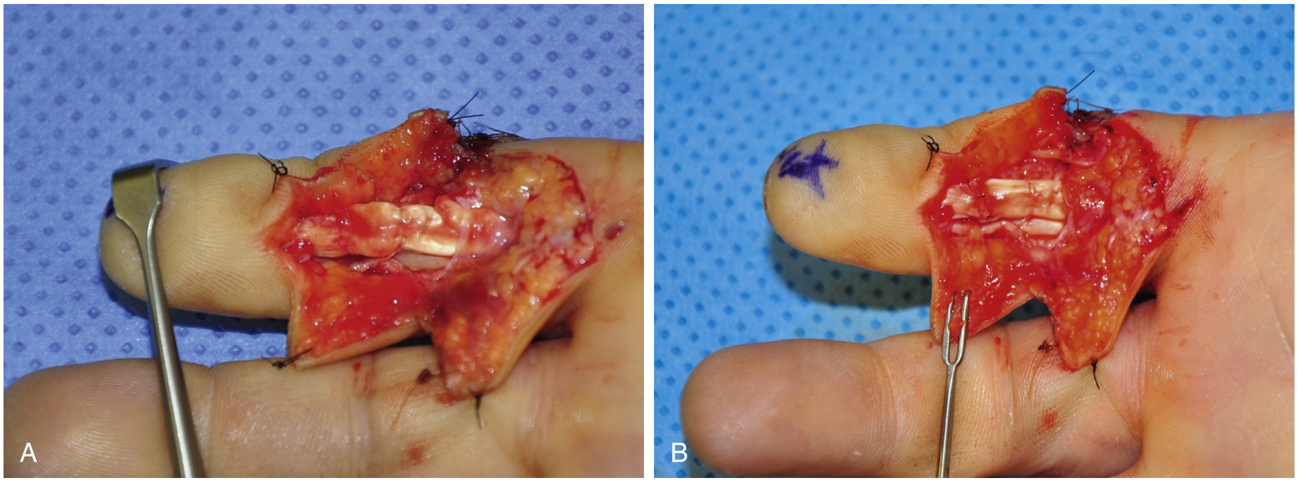
There is no need to start motion or therapy in the first 3 or 4 days after surgery, which also avoids pain and discomfort.[1,12] From day 4 or 5, the patient performs at least a few sessions of digital motion exercises. In each session, to lessen resistance of joint stiffness, full passive finger motion – usually 20 to 40 repetitions – should be performed before active digital flexion (Fig. 47.17). Then active digital flexion should proceed gradually[1,12]. In the first 3–4 weeks, only one-third to two-thirds active motion range should be the goal. Extreme digital flexion should be avoided, because marked finger flexion would overload the repaired tendons, risking repair disruption (Fig. 47.18). Most patients have marked swelling at this time; a full range of active motion of the operated finger is difficult to achieve. Aiming at full active flexion of the finger is both unnecessary and unrealistic. However, full passive finger flexion and extension should always be performed to make the hand and finger as supple as possible.

From the end of week 3 or 4, a full range of active flexion is the goal. Some patients who have difficulty with full active flexion at week 4 or 5 may gradually achieve full flexion in later weeks. However, exercise to reduce joint stiffness and prevent extension lag should always be performed for eventual recovery of active finger flexion. The splint protection can be removed at the end of week 5 or 6, but therapy usually should persist for a few weeks to get rid of often-seen remaining stiffness of the DIP joint, with or with nighttime splint protection. After week 6, the author sometimes urges patients to wear a splint only when they go outside, which prevents unintentional use or injury.

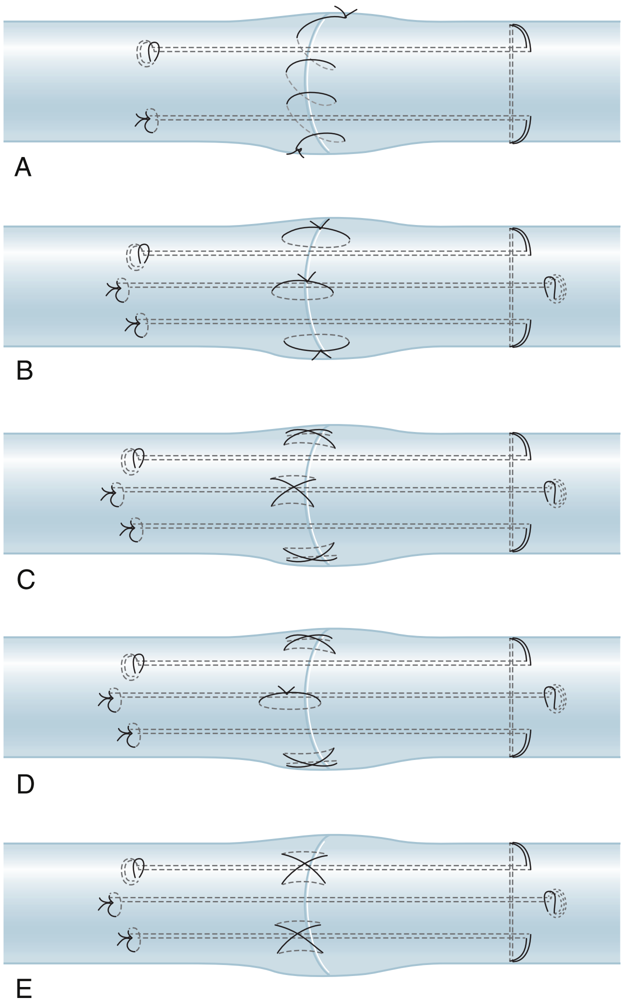
More Recent Evolution of Methods

The major conceptual changes in the past three decades in repairing flexor tendons are summarized in Table 47.2. Some of the recent trends and evolution are further highlighted here.

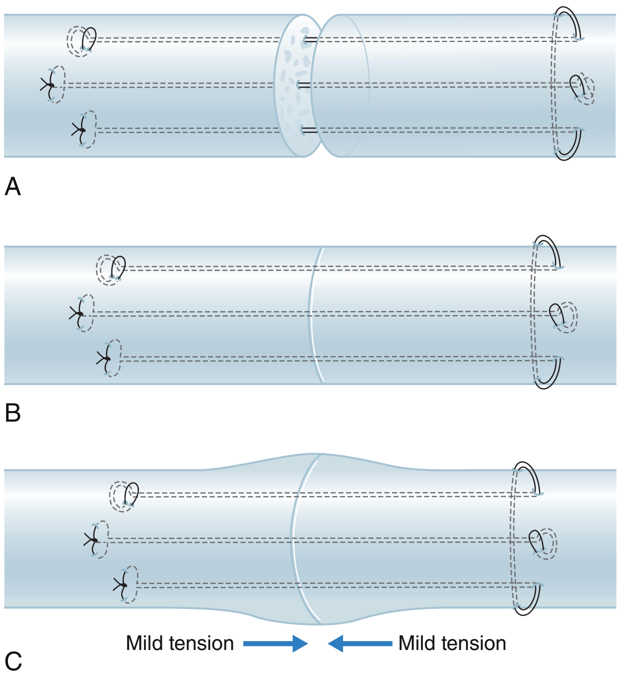
1. *Placing the knots between the two tendon ends may not favor the repair.* Most current multistrand repairs have knots over the tendon surface, and no adverse clinical consequences have been noted. It is now believed that placement of the knots between tendon ends is not important.[28]
2. *Asymmetric suture configurations may be preferable to symmetric designs.* Recent investigations have revealed that asymmetry in the configuration of sutures attaching two tendon stumps are better than symmetric suture placement.[29,30] Asymmetric placement likely favors gap resistance, and this design can be found in some popular suture methods.
3. *A tensioned slightly bunched repair is better than a flat tension-free repair.* A flat, tension-free repair should be avoided. A tensioned slightly bunched repair favors gap resistance and does not hamper tendon gliding as the narrow pulleys are released.[28]
4. *Slightly extended pulley venting to benefit finger flexion outweighs the drawbacks of minor tendon bowstringing.* In case of need to allow gliding of the repaired tendons, slightly extended release favors gliding of the repaired tendon, and the bowstringing caused by slightly extended release is noticeable but still mild. This practice appears especially beneficial at the PIP joint area, where we may extend the venting of the sheath and pulleys from the A4 to A3.[24]
5. *Epitendinous suture is unnecessary when a strong core suture (a 6-strand repair) is used.* This is a recent observation.



• **Fig. 47.11** (A) The tendon of the patient shown in Fig. 47.8 was repaired with a 6-strand M-Tang repair. Note the core suture was made with some tension to resist tendon gapping, but the tendon should not be too bulky after core suture. The allowed bulkiness at the repair site is a 20%–30% increase in tendon diameter at the repair site. (B) Separate peripheral stitches were sparsely added at three sites – two at the lateral aspect, one at the volar center – where the approximation of tendon ends may be further smoothened by these sparse stitches.



• **Fig. 47.12** (A–E) The simpler, sparse peripheral stitches that can be used after completion of a strong and tensioned core suture that has already approximated the tendon ends closely and tightly.



• **Fig. 47.13** (A–C) Appropriately tensioning the repair site is key to preventing gap formation during active finger flexion. The recommended degree of bunching up is 20%–30% increases in diameter of the tendons at the junction of the two tendon ends.

A few surgeons have reported not adding epitendinous sutures when a strong 6-strand repair is made with tension; no repair ruptures were reported.[25,26,31]

6. *Wrist positioning is unimportant and a short splint is safe.* It is now understood that if the tendon repair is strong, the wrist does not have to be placed in a specific position; this allows considerable freedom in wrist positioning.
7. *Out-of-splint exercise is safe.* In the author's practice, out-of-splint motion has been safe for compliant patients; it

• BOX 47.1 Clinical Technical Keys for Achieving Ideal Repair Outcomes

Zone 2 flexor tendon repair has evolved greatly over the past three decades. Some key clinical techniques for ideal outcomes are:

1. Using strong core sutures, typically 4- or 6-strand repairs
2. Judicious venting of the critical annular pulley
3. Ensuring that a slight tension is created by the repair to prevent gapping
4. Performing digital extension–flexion tests to confirm the quality of the surgical repair
5. Early partial-range active motion to ensure tendon gliding without overloading the repair

• BOX 47.2 Repair Techniques that Have Become Popular

1. Direct strong repair of the terminal FDP tendon to any tissues available distally to repair tendon cut close to the distal insertion. Similar methods can be used in making the distal junction of the grafted tendon.
2. Using strong core-suture-only repair or a strong core suture plus separate simple peripheral stitches.
3. Venting the A3 together with A4 pulleys if greater range of motion of the finger is needed.
4. Using a wide-awake setting for tendon repair, including grafting.

is actually more efficient. Splinting compliant patients mainly serves to protect them from getting hurt or unintentional hand use. For this reason, the splint should be worn only between exercise sessions and at night.

Repair in Other Zones and the Thumb

Zone 1

The methods of proximal zone 1 (zone 1B and 1C) repairs are similar to those of zone 2. The postoperative therapy methods are the same as those of zone 2 as well. When the FDP tendon is cut in distal zone 1 (zone 1A), pull-out sutures through the finger nail have been a common treatment (Fig. 47.19). The pull-out suture is reliable, but it passes through the nail. More recently, the author's preference is a direct repair using several strong core suture, i.e., up to 10- or 12-strand core suture repair, which connects the proximal stump to the remnant of the distal stump and tissues such as periosteum adjacent to the tendon insertion on the distal phalanx (Fig. 47.20). This direct repair from proximal tendon stump to any distal tendon tissue and those around it can be applied to the cut close to tendon insertion (zone 1A). There are a variety of bone anchors, including small-sized anchors, which some surgeons use for tendon–bone junction. Large anchors may not fit the fingertip area. The author has no experience with them.

A strong tendon-to-bone junction can be achieved without conventional pull-out suture. The fact is that the terminal tendon just proximal to its insertion to the distal phalanx is distal to the DIP joint, which does not require motion. Adhesions are allowed to develop to help strengthen the repair. Therefore, as much as possible, suture strands can be used to achieve a strong and somewhat bulky repair, which favors both healing and strength. After such a repair, the finger is protected with a dorsal splint for 2 weeks without early mobilization. From week 3, passive finger motion is started. From week 5, active motion of the finger is started and the splint can be discarded at the end of week 6.

Zone 3, 4, and 5

The FDP tendons in zone 3 are repaired using the same technique as in zone 2. The repairs are easier because of lack of sheath covering the tendon. The injuries in the carpal tunnel area (zone 4) are rare and are accompanied by lacerations in the median nerve and arteries. The transverse carpal ligament has to be opened to facilitate repairs. Zone 5 injuries often involve multiple tendons with neurovascular injury. Repair of the FDS and FDP tendons is preferred, and early postoperative motion is advised.

Thumb Flexor Tendon

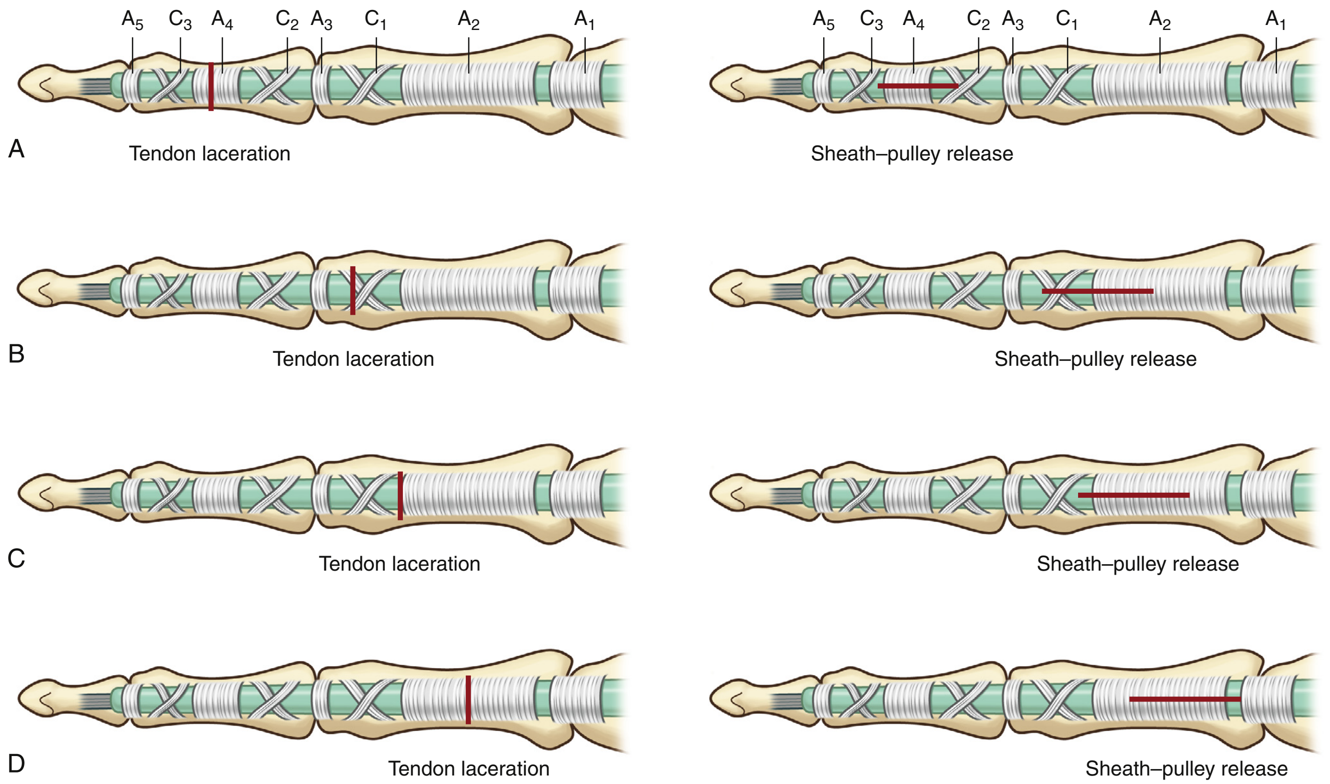
The FPL tendon repairs follow the same methods of repair as the FDP tendon in fingers. The surgical incision should usually be less than 2 cm. The oblique pulley has to be vented to allow performing the repair. The author uses the 6-strand M-Tang repair for all FPL tendons (Fig. 47.21). The proximal tendon frequently retracts into the thenar muscles, which can be retrieved through an incision in thenar muscles or the carpal tunnel.

Repair of Partial Tendon Laceration

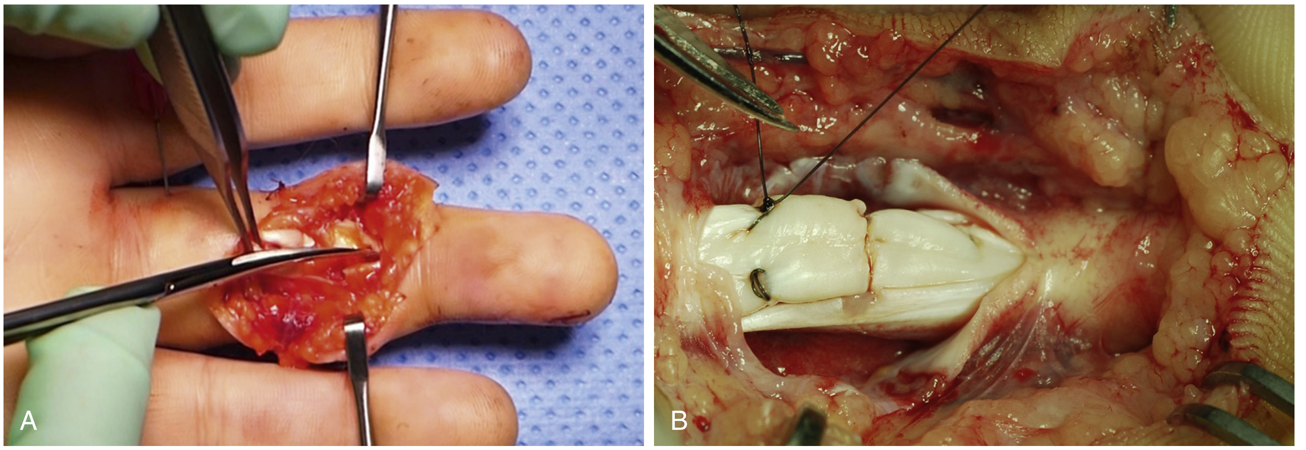
Treatment of the partially-lacerated tendon depends on the extent of the injury. Any laceration through less than 60% of the diameter of the tendon does not necessitate a repair by core sutures. The lacerated ends can be trimmed to reduce the chance of entrapment by pulley edges and friction against the sheath. Alternatively, the cut portion of the tendon may be repaired with epitendinous stitches to smooth the tendon surface and to strengthen the tendon. If the laceration is over 60% of the tendon diameter, risk of triggering, entrapment, or ruptures is increased. A core suture is necessary to prevent tendon entrapment and disruption. Lacerations of 60%–80% require an epitendinous repair and are better repaired using a 2-strand core suture through the cut portion. Lacerations of 80%–90% are treated as complete lacerations with strong core suture supplemented with a epitendinous sutures as described earlier.

Flexor Tendon Repairs in Children

The repair techniques of flexor tendons used for children are the same as in adults. In children, it is more difficult to recognize the pulleys. Therefore, care must be taken not to vent the pulleys unnecessarily or incorrectly. Tendon healing

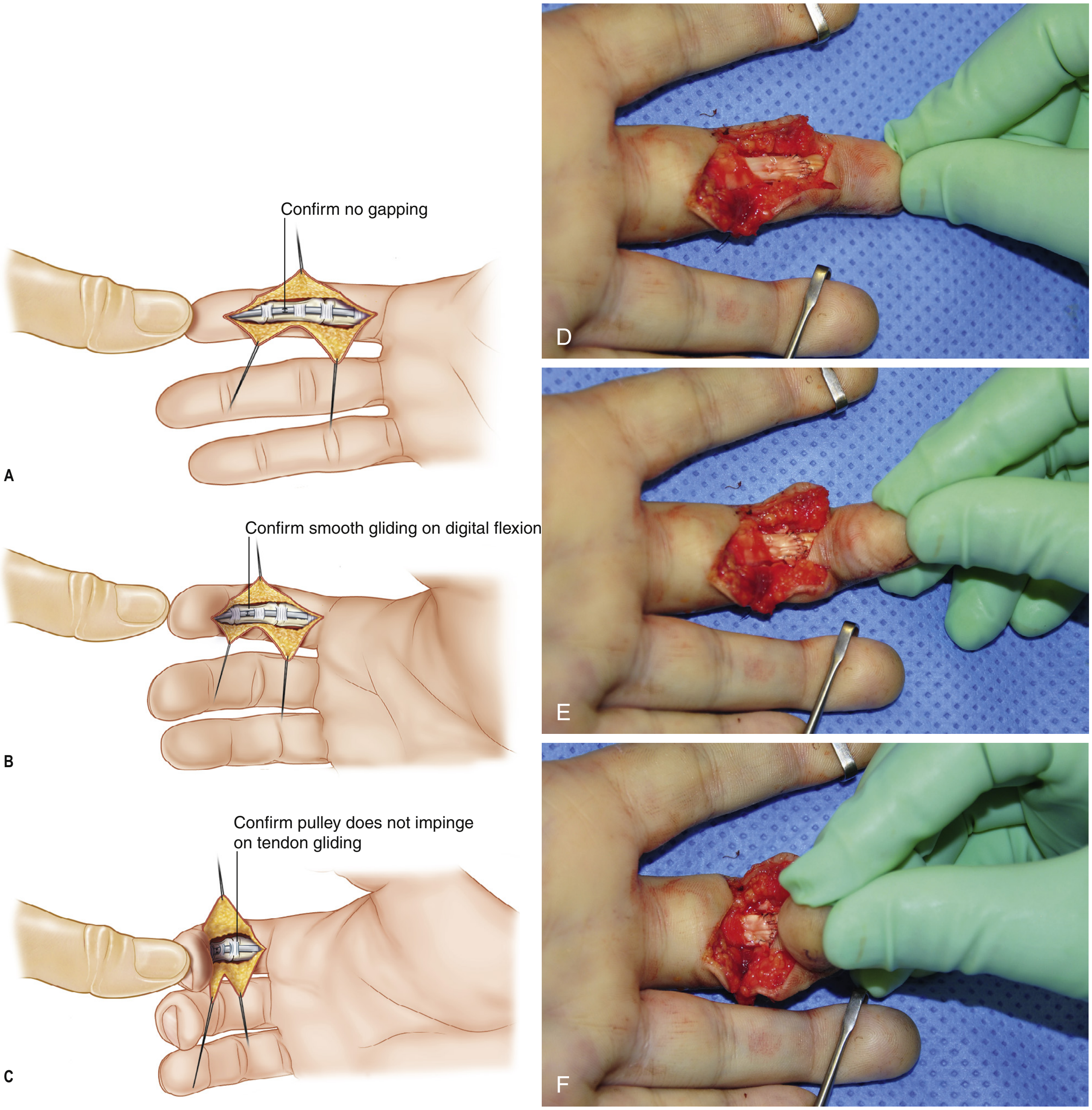


• **Fig. 47.14** Drawings depicting the length and areas of release of the sheath–pulley complex to decompress the repaired tendons, without bowstringing and loss of tendon function. (A) Release of the entire A4 pulley when the FDP tendon has been cut around the A4 pulley and the tendon cannot pass easily beneath this pulley. (B) Release of a part of the sheath distal to the A2 pulley and the distal half of the A2 pulley, when the tendons are cut a little distal to the A2 pulley. (C) Release of a short part of sheath distal to the A2 pulley and the distal two-thirds of the A2 pulley when repairing tendons cut at the edge of, or in the distal part, of the A2 pulley. (D) Release of the proximal two-thirds of the A2 pulley when repairing a cut in the middle, or proximal part of, the A2 pulley. The allowed length of venting is indicated with red lines. (From Tang JB. Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery*. Volume 6: *Hand and Upper Extremity*. 4th edn. Elsevier; 2018: Fig. 9.38.)



• **Fig. 47.15** Operative pictures showing the complete venting of the A4 pulley and partial venting of the A2 pulley. (A) The entire A4 pulley is vented through a midline cut with scissors to facilitate surgical repair. (B) The distal 60% of the A2 pulley is vented through a midline cut. The tendon is repaired with a 6-strand M-Tang repair.

in children is quicker with less adhesions. It is important to avoid lengthy pulley venting. In children younger than 10 years old, the tendons can be repaired with a 2-strand or, at most, a 4-strand core suture, plus some epitendinous sutures. The fingers or the thumb are protected with a dorsal short-arm splint with the wrist in moderate flexion for 5–6 weeks. Early mobilization of the tendons is not necessary in children.

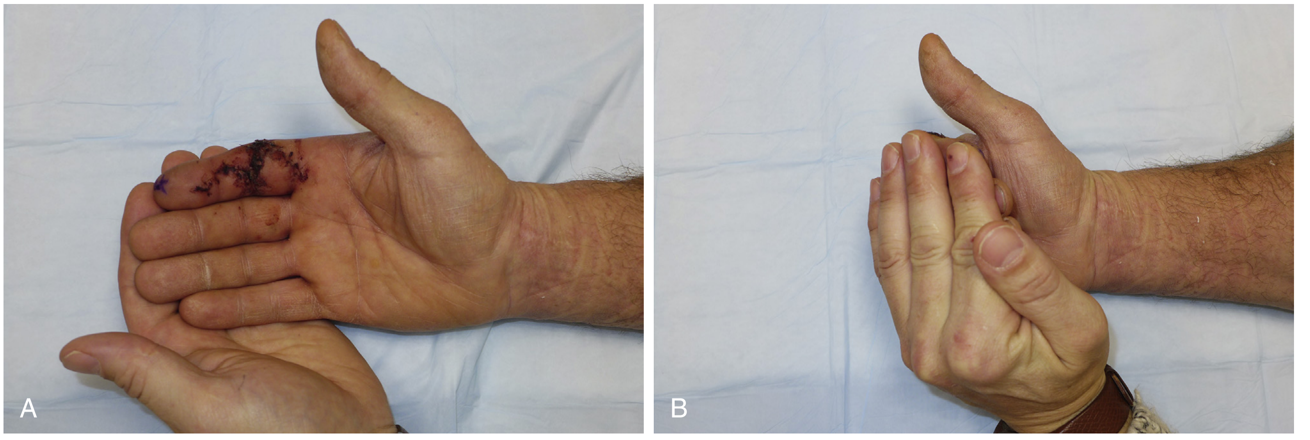


• **Fig. 47.16** (A–C) The extension–flexion test has three steps, performed immediately after completion of the tendon repair to check quality of the repair. (A) *Part I*: passive full extension of the digit to ensure the tendon repair site shows no gapping (above). (B) *Part II*: passive flexion of the digit to confirm that gliding is smooth (middle). (C) *Part III*: pushing the digit to almost full flexion to check whether the tendon repair site impinges against the edge of the sheath or a pulley. (D–F) Operative photos showing the three steps of the test after a repair in the border area of zone 1 and 2. (A–C, From Tang JB. Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery*. Vol 6: *Hand and Upper Extremity*. 4th edn. Philadelphia: Elsevier; 2018: Fig. 9.39; D–F, courtesy Celeste Ryfa.)

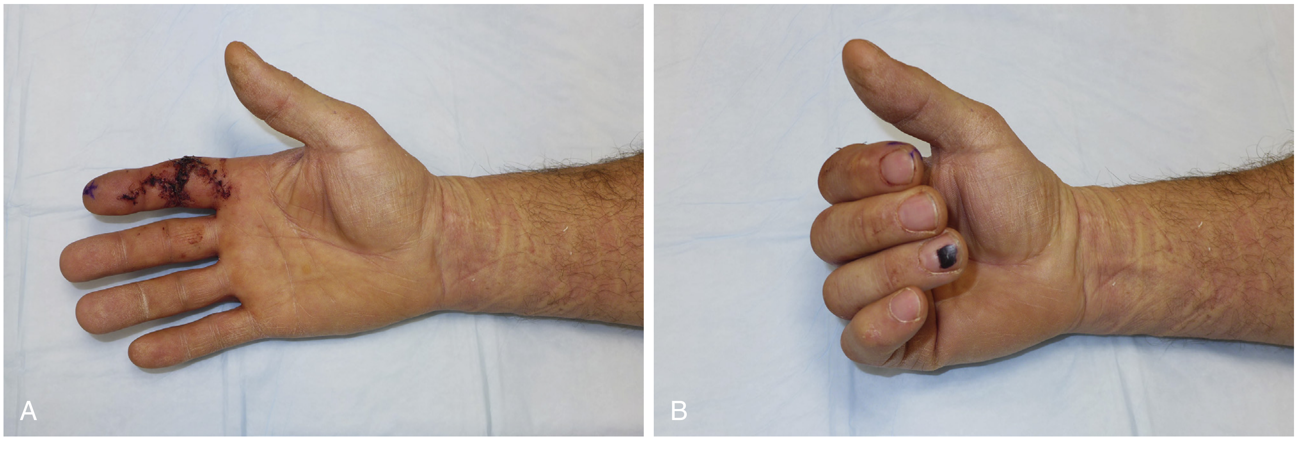
Closed Rupture of the Flexor Tendons

The FDP tendon can be avulsed from the insertion to the distal phalanx during forceful extension of the DIP joint, which is called *jersey finger*. During examination, the patient has pain and tenderness over the volar distal finger. The finger lies in slight extension relative to other fingers in resting position, with no active flexion of DIP joint. It may be possible to palpate the flexor tendon retracted proximally along flexor sheath. Radiographs may reveal avulsion fracture in the distal phalanx in the patient with bony avulsion. Three types of closed avulsion are seen:

I. *Tendon avulsion only*: the tendon is avulsed from its insertion site and retracts to the palm or within the finger.
II. *Bony avulsion only*: the tendon insertion site is intact, but the bone attaching to the FDP tendon end is avulsed with limited retraction.
III. *Double avulsion*: both the FDP tendon and the bone attaching to it are avulsed.



• **Fig. 47.17** (A,B) Full passive motion of the repaired finger should be performed to lessen the stiffness of the joint before active flexion exercise. Patient is shown at postoperative day 7.



• **Fig. 47.18** (A,B) Partial-range active motion in the initial 2–3 weeks after surgery. Only partial active finger flexion is allowed. Full fist or marked active finger flexion should be avoided to prevent repair rupture.

The three types are easier to use than the Leddy and Packer classification, without loss of detail. Once diagnosed, the tendon needs to be repaired through the volar approach and the avulsed tendon is repaired with sutures, or a pullout suture, or a bone anchor followed by protected finger joint motion after surgery.

The FDP or FDS tendons can be disrupted by a fractured hamate. The closed rupture can be associated with other fractures or surgical plating. The disrupted tendon should be repaired directly or with a graft once surgical exploration has confirmed the diagnosis.

Outcomes

When they followed an updated protocol, young or junior hand surgeons were able to obtain good outcomes in the majority of patients with very few or no repair ruptures.[23] Surgeons have also reported zero ruptures in a case series of more than 50 tendons.[25,26] Repair rupture appears to no longer be a major concern if all modern guidelines are carefully followed. Rupture occurs only in patients who actively use the fingers in the first few weeks after surgery and there are rare instances (estimated to be less than 1%) of unexplained ruptures of ordinarily reliable repairs.[23] With early active motion after surgery, cases of tenolysis have dropped. However, severe tissue damage always poses the risk of developing dense adhesions, which remain a concern.

Strickland criteria have been popular in evaluation of outcomes. In recent years, the criteria have been modified to include stringent criteria for "excellent" and a category of "failure" (Table 47.3).[13,32]

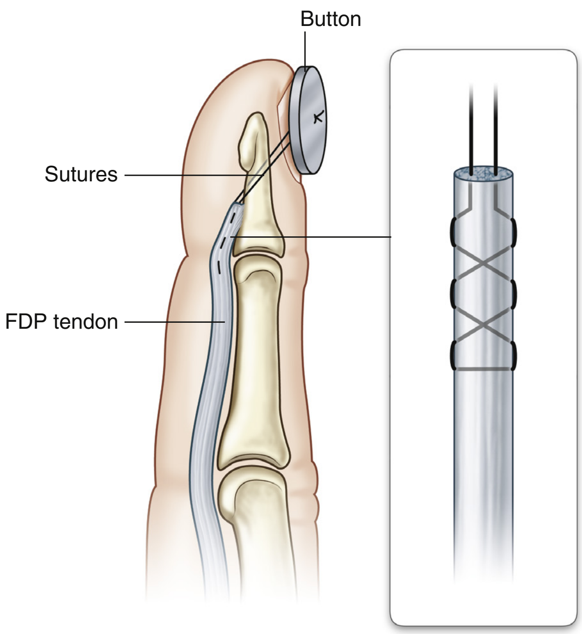
Tenolysis

Tenolysis is indicated when the passive range of digital motion greatly exceeds that of active flexion, several months after direct end-to-end tendon repair or tendon grafting. Tendon trauma with severe damage to peritendinous tissues or compound injuries (such as digital or palm replantation) have greater chances of adhesion formation, thus are more likely to require tenolysis as a later surgery. Children may also be candidates for this surgery.

The prerequisites for this operation are: (1) all fractures are healed; (2) wounds have reached equilibrium

TABLE 47.2 The Major Conceptual Changes in Repairing Flexor Tendons over the Past Three Decades

	1980s and 1990s	2010s
Surgical Techniques		
Tendon repair	Zone 2 2-strand suture	Multistrand suture (4 or 6 strands)
A2 pulley	Should not be violated	Can be partially vented if needed
A4 pulley	Should not be violated	Can be entirely vented if needed
Synovial sheath	Closure recommended	Do not need to repair the sheath
Suture purchase of repair	Not been stressed	Should be more than 0.7–1 cm
Tension across repair site	Not been discussed	An essential key of surgical repair
Extension–flexor test	None	A common quality check point
Wide-awake surgery	Not incorporated	A better approach for tendon repair
After Surgery		
Wrist position in protection	Wrist flexion stressed	Flexible, from mild flexion to extension
Starting motion within 4 days	Common	Unnecessary; no motion is better
Active flexion: first 2–3 weeks	Not popular	Popular
Avoid extreme flexion	None	A key to ensure safety of active flexion
Place-and-hold motion	Popular	Not a useful or efficient exercise
Out-of-splint motion	None	Advocated for reliable patients



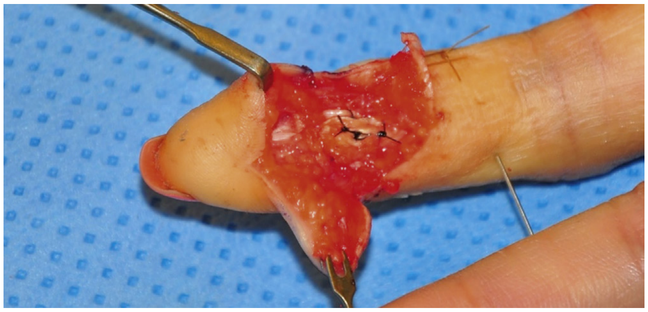
• **Fig. 47.19** A conventional method to anchor the FDP tendon to the bone by pull-out sutures through the nail and tied over a button. (From Tang JB. Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery.* Vol 6: *Hand and Upper Extremity.* 4th edn. Elsevier; 2018: Fig. 9.14A.)

with soft, pliable skin and subcutaneous tissues, and minimal reactions around the incision scars; and (3) joint contractures must have been corrected and a normal or near-normal passive range of digital motion achieved. The exact optimal timing of tenolysis remains controversial. It is reasonable to consider tenolysis if the desired range of motion is not achieved after 3 months of therapy or if there is no improvement of active range of motion for 3 months of therapy. However, surgery should only be considered at the very least 3–6 months following primary repair or graft, to allow necessary healing and revascularization of tendons; this helps to avoid endangering tendon strength.

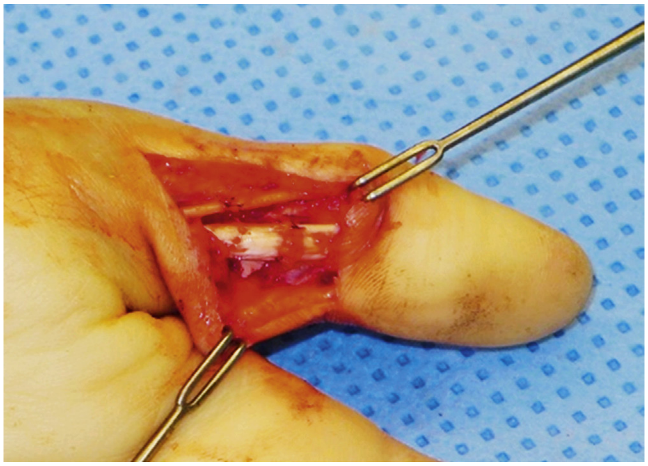
There is no absolute criterion for how poor the range of motion ranges must be to indicate tenolysis. Surgeons should consider the patient's age, occupational requirements, and functionality of the hand in decision of the operation. Preoperatively, the patients should be informed that intraoperative findings may be incompatible with intended tenolysis; thus the surgeon may need to proceed to the first step of staged reconstruction on finding serious destruction of pulleys or a lengthy lysed tendon segment. It is estimated that about 10%–20% of patients need tenolysis after primary or delayed primary repair.

Anesthesia

Tenolysis is best performed in the wide-awake setting without tourniquet. The patient should move actively during the procedure to demonstrate ample active tendon motion. In addition, the patient is asked to forcefully flex the finger and wrist to break any remaining adhesions after surgical release of adhesions. Axillary block, sedation, or general anesthesia



• **Fig. 47.20** An operative picture showing the robust direct repair of the lacerated FDP tendon at the insertion site, with 12 core strands across the cut sites to connect the proximal stump with the very short distal stump, periosteum, and other soft tissue which could be found adjacent to the insertion site. (Courtesy Celeste Ryfa.)



• **Fig. 47.21** Harvesting a tendon graft through a small skin incision and using a tendon tripper.

are used if the surgeon expects an extensive operation, such as tenolysis in multiple digits, a staged reconstruction procedure, or if the patient is unlikely to tolerate surgery with local anesthesia.

Operative Techniques

Through either a Bruner's or midlateral incision, dissection proceeds from the unaffected area to the affected area. Tenolysis requires wider surgical exposure. All limiting adhesions are meticulously divided. Care is taken to define the borders of the flexor tendons. During dissection, the major pulleys should be maintained, and the synovial sheath embedded within the scar is removed. However, if other sheath and major pulleys are intact, it is acceptable to excise a part of the A2 pulley or the A4 pulley. It is vital to avoid any sheath defect over 2 cm. If possible, the A3 pulley and its adjacent sheath are also preserved. Whenever possible, the FDS and FDP tendons are separated from one another. Dissection is continued until normal tissues are revealed and no scar around the tendon is visible. Adequacy of the release is then checked by active digital flexion of the

TABLE 47.3 The Strickland Criteria and Tang Criteria Based on Active Range of Motion (ROM) of the Repaired Finger

Grade	Strickland (1980)[a]	Tang (2013)[b]
Excellent	85–100%	90–100%
Good	70–84%	70–89%
Fair	50–69%	50–69%
Poor	0–49%	30–49%
Failure[c]	–	0–30 %

[a]This criterion is mostly used in zone 2 repair. The normal active ROM of the PIP and DIP joints is considered 175 degrees. The ROM of the repaired finger is divided by 175 degrees to compute percentage return of ROM.
[b]Percentage total active motion of the contralateral side is used in this criterion after repair in any zone. For zone 2 injury, only the PIP and DIP joints are measured; 175 degrees is the sum of the motion of the normal PIP and DIP joints. For zone 2 injury, either 175 degrees or measured actual ROM of the contralateral hand is used to compute percentage return of ROM.
[c]No failure grade in Strickland criteria.

patient or by a gentle proximal traction in the palm through a separate proximal incision.

After surgery, the patient is protected with a dorsal splint and should proceed to early active tendon motion starting from day 3 or 4 after tenolysis.

Intraoperative Judgment of Tendon and Pulley Quality

During the surgery, it is important to check the quality of the tendon and integrity of the pulleys. If direct evaluation shows that tendon continuity is maintained only by scar, or greater than one-third of the tendon width is lost, the tendon is unlikely to function properly. Silicone tendon rod is inserted, as the first stage operation of staged reconstruction. Similarly, if the critical pulleys are destroyed, it is appropriate to proceed to pulley reconstruction.

Tendon Grafting, Pulley Reconstruction, and Staged Reconstruction

One-Stage Tendon Grafting

Traumatic lacerations of the digital flexor tendons are usually treated with end-to-end repair. Only those patients who are not treated primarily or have tendon defects that prevent direct end-to-end repair require secondary repairs. In the presence of severe contamination, infection, lengthy loss of tendon substance, extensive destruction of the pulleys, or accompanying injuries, primary tendon repairs are not indicated.[33,34] These patients should be treated secondarily with a tendon graft.

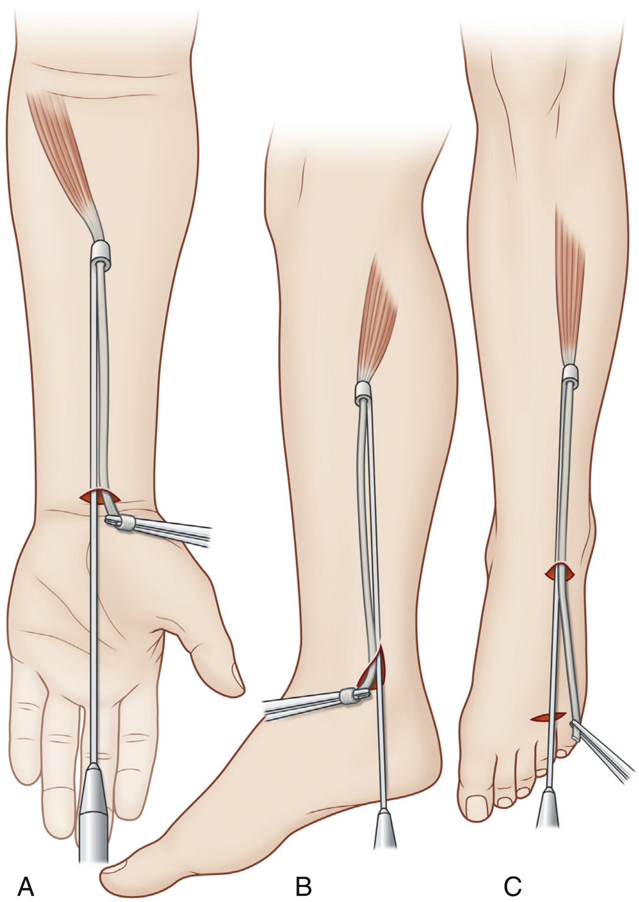
Secondary tendon repairs are achieved mainly by one-stage free tendon grafting, or in some instances by staged tendon reconstruction. Patients who have failed primary surgery or previous efforts at one-stage tendon grafting, or serious scarring are appropriate for a staged tendon reconstruction, rather than one-stage tendon grafting. The surgeon may make this decision intraoperatively based on findings, such as severity of scarring and pulley loss, as described earlier.

Before one-stage tendon grafting or staged tendon reconstruction is attempted, the soft tissue wound should be well healed, with supple passive motion of the hand. Physical therapy is prescribed to improve the range of motion of the digits if passive joint motion is limited substantially. Lack of passive range of joint motion is a contraindication for one-stage tendon grafting, but may be suitable for staged tendon reconstruction. The timing of tendon grafting is usually at least 3 months after injury.

The donors are palmaris longus, plantaris, long toe extensors, or in rare instances the FDS tendon from a normal finger. The palmaris longus tendon (about 15 cm) from the ipsilateral limb is frequently used as donor and is appropriate for a palm-to-fingertip graft. It can be easily harvested through a short transverse incision over the tendon just proximal to the flexion crease of the wrist. The tendon is divided and grasped with a hemostat, while a tendon stripper is advanced slowly into the proximal forearm. Care must be taken to protect the median nerve trunk and its cutaneous lying beneath the tendon. This tendon is absent in about 15% of all hands, examination to confirm its presence is essential prior to surgery. The plantaris tendon is another option for a graft; it is obtained by an incision medial to the Achilles tendon and with a tendon stripper (Fig. 47.22). The length of this tendon (25 cm) is well suited for a long distal forearm–fingertip graft. However, this tendon is absent in 7%–20% of limbs, and its presence cannot be predicted preoperatively except with imaging. Extensor digitorum longus tendons to the second, third, and fourth toes, the extensor indicis proprius, the extensor digit quinto proprius, and the FDS tendon to the fifth finger can be used as well. The author uses the palmaris longus tendon most frequently.

The flexor tendon is exposed through a palmar Bruner's incision or the midlateral approach. Integrity of the major annular pulleys is important to the function of the tendon graft. At least the A2 and A4 pulleys should be preserved. If possible, other annular pulleys such as A1 or A3 and a part of the synovial sheath are preserved to foster better gliding of the grafted tendon.

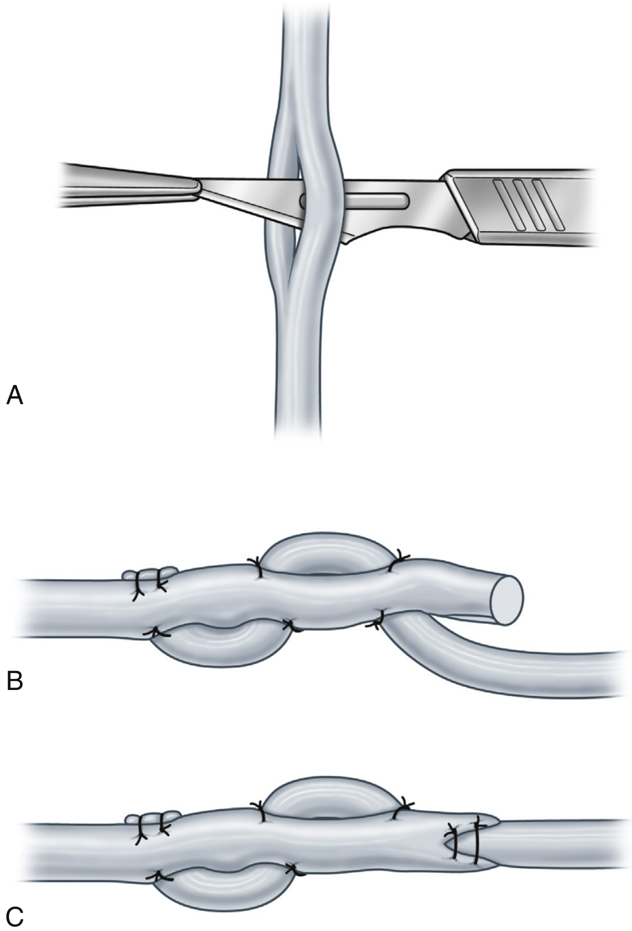
The distal junction of the graft is placed at the fingertip. The most common method is to suture the graft directly to the residual FDP stump or bury it under an osteoperiosteal flap in the volar phalanx. In the latter case, the straight needles are passed through the distal phalangeal drill hole and exit over the proximal portion of the nail. After emerging from the nail surface, the needles are passed through a gauze pad or a sponge, and



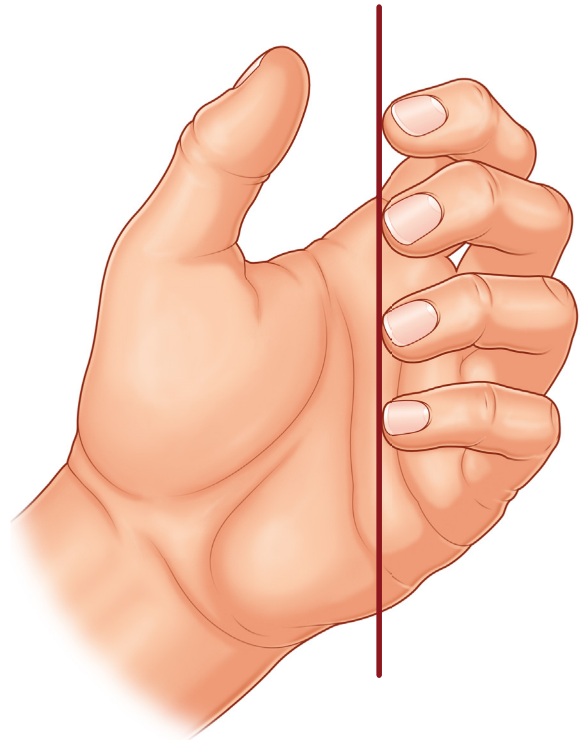
• **Fig. 47.22** Three common donors of tendon grafts. (A) Palmaris longus tendon. (B) Plantaris. (C) Toe extensors. (From Tang JB. Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery*. Vol 6: *Hand and Upper Extremity*. 4th edn. Elsevier; 2018: Fig. 9.47A–C.)

through the holes of an overlaying button. The sutures are tied over the button to anchor the graft. Additional sutures are used to secure the FDP tendon stump to the graft. In children, drill-holes at the distal phalanx may damage the open epiphyses; the graft is sutured directly to the stump of the profundus instead. The author now uses direct suture of the graft to the remnants of the FDP tendon repair using strong repair methods as described earlier for zone 1 tendon repair. The author no longer uses a pull-out suture and has not used bone anchors.

The proximal junction of the graft can be made either at the palm or in the forearm. Placement of the junction at the palm requires only a shorter graft and preserves the function of lumbrical muscles. Care is taken to avoid suturing the tendon to the lumbrical muscle, because this tends to increase the tension in the muscle. Placement of the junction proximal to the wrist allows easy adjustment of the tension of the graft, and scar may be less severe. In the author's experience, a Pulvertaft weave suture is



• **Fig. 47.23** A Pulvertaft weave junction of the grafted tendon. (A) A blade is used to split the tendon through the midline. (B) The graft is passed through the opening in the middle of the recipient tendon and sutured together. (C) The graft and the recipient tendon are weaved together through 2–3 weaves. The sutures are added to secure the connection of two tendons as shown in the drawings. (From Tang JB. Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery*. Vol 6: *Hand and Upper Extremity.* 4th edn. Elsevier; 2018: Fig. 9.48B.)



• **Fig. 47.24** Tension status of the fingers at the time of suturing the proximal tendon junction of a graft. With the wrist in neutral position, the fingers are slightly more flexed than at the resting position, with each finger falling into slightly more flexion than its radial neighboring fingers. (From Tang JB. Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery*: Vol 6: *Hand and Upper Extremity*. 4th edn. Elsevier; 2018: Fig. 9.50.)

appropriate for the proximal junction in both areas (Fig. 47.23), and the finger is held in slightly greater flexion than in the resting position when the proximal stump is sutured (Fig. 47.24).

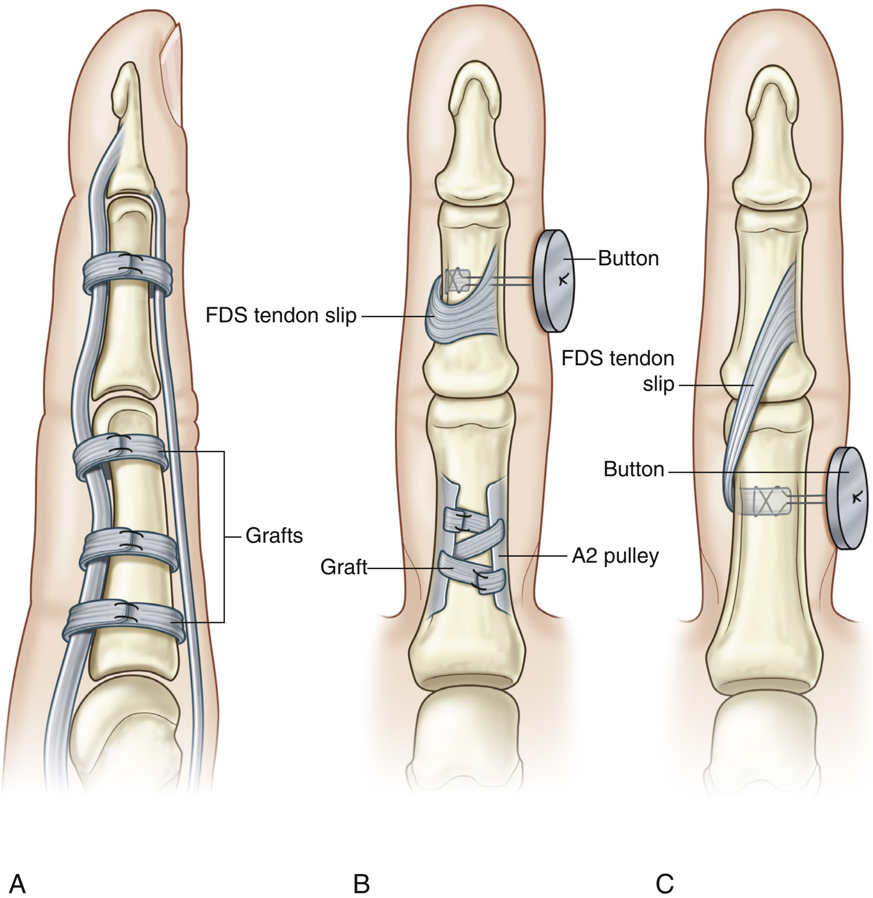
Pulley Reconstructions

If a series of annular pulleys are found to be destroyed, reconstruction of the A2 and A4 pulleys is required. Some surgeons do not think that the A4 pulley should be reconstructed; they feel the A2 needs reconstruction, but the A4 does not. Various materials can be used. A portion of an excised flexor tendon or the palmaris longus tendon may be used. This is wrapped around the phalanx twice to obtain sufficient width, and has to be placed deep to the extensor mechanism. Another method is to make use of one rim of a residual pulley, and a tendon graft, a portion of an excised flexor tendon, or a part of the extensor retinaculum is woven back and forth to form a volar part of the residual pulley, or the grafted tendon is sutured to the rim of residual pulleys without weaving (Fig. 47.25). Most cases requiring pulley reconstruction need to be preceded by staged tendon reconstruction.

When the FDS tendon is fully functional, but the FDP tendon is cut and has not been repaired directly within 3–4 weeks after trauma, the need of tendon graft or reconstruction is controversial. There is a risk of losing function if a profundus graft fails. However, such operations are worth the risk in selected cases, such as in young people with a reasonable need for active DIP joint flexion. The procedures are similar to those described above. A thinner donor tendon is preferable. Alternatively, one slip of the FDS tendon can be removed to favor passage of the graft. Overall, caution must be exercised with patient selection. Patients with intact superficialis tendon may adapt nicely and require no treatment. The surgeon should fully inform patients about the expected gain of function as well as the risks of this operation.

Staged Tendon Reconstruction

The staged reconstruction is indicated in cases with severely scarred digits, because of injury or multiple failed attempts



• **Fig. 47.25** Several methods of flexor pulley reconstruction. (A) Reconstruction of the A4 and A2 pulleys using flexor tendon grafts passed circumferentially around proximal and middle phalanges. The tendon graft passes deeper to the extensor apparatus at the proximal phalangeal level and superficial to the extensors at the middle phalangeal level. (B) A tendon graft is weaved through remnant of the A2 pulley to reconstruct the A2 pulley. (C) Use of a slip of FDS tendon for middle digital pulley reconstruction. (From Tang JB. Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery*: Vol 6: *Hand and Upper Extremity*. 4th edn. Elsevier; 2018: Fig. 9.52AB.)

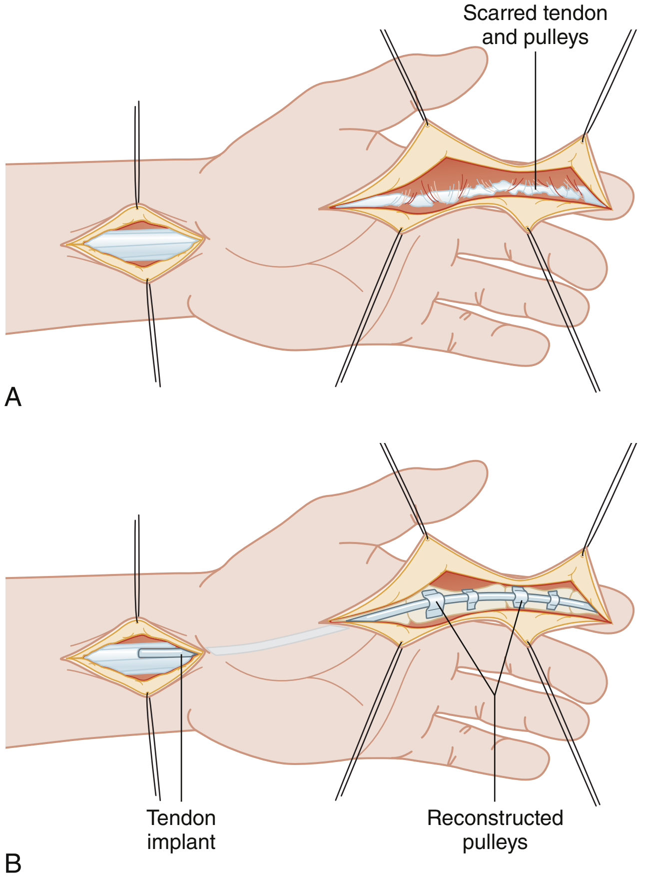
to restore tendon continuity and tendon gliding. This operation is divided into two stages. The first stage consists of excising the tendon and scar from the tendon bed, preserving or reconstructing pulleys. A silicone gliding implant (Hunter rod) is inserted into the scarred tendon bed to maintain the tunnel and to stimulate the formation of a pseudosheath. Following maturation of the pseudosheath a tendon is grafted to replace the implant in the second stage.[35]

The Surgery at the First Stage

The approach to the tendons is similar to that for tendon grafting. The tendons are excised with a 1-cm stump of the profundus tendon retained at its distal insertion. Unscarred portions of the flexor pulleys are carefully preserved. In the presence of flexion contracture of the finger joint, checkrein extensions of the palmar plate and the accessory collateral ligaments are divided to release the contracture. The profundus tendon is transected at the midpalm. The size of the Hunter rod is determined by the tightness of the digital pulleys. In adults, smaller (4 mm) Hunter rods are often preferable, which are closer in size to the tendon graft. After insertion of the implant underneath the pulleys, the implant should be able to glide freely. The distal end of the Hunter rod is sutured to the FDP tendon stump using 2–3 stitches of nonabsorbable sutures. The author places the proximal end of the rod to the palm, not extending it to the distal forearm. However, the rod can be passed from the proximal palm into the distal forearm using a tendon passer. After the Hunter rod is seated, traction is placed on the proximal end of the Hunter rod to make sure that it glides smoothly beneath the pulleys (Fig. 47.26).

The Surgery at the Second Stage

The second stage surgery should follow in 3 months. A small incision is made adjacent to the DIP joint, exposing the implant–tendon junction. After disconnecting the implant from the tendon, the implant is tagged. Proximal incision of about 2 cm is made in the palm to find the proximal end of the implant. A free tendon graft is harvested and inserted



• **Fig. 47.26** (A) In stage 1 of the staged reconstruction, the Hunter rod is placed into the scarred tendon bed. The annular pulleys are preserved. (B) Proximal end of the tendon implant is left free without suturing to any tendons. (From Tang JB. Flexor tendon injuries and reconstruction. In: Chang J, Neligan P, eds. *Plastic Surgery*. Vol 6: *Hand and Upper Extremity*. 4th edn. Elsevier; 2018: Fig. 9.53A–C.)

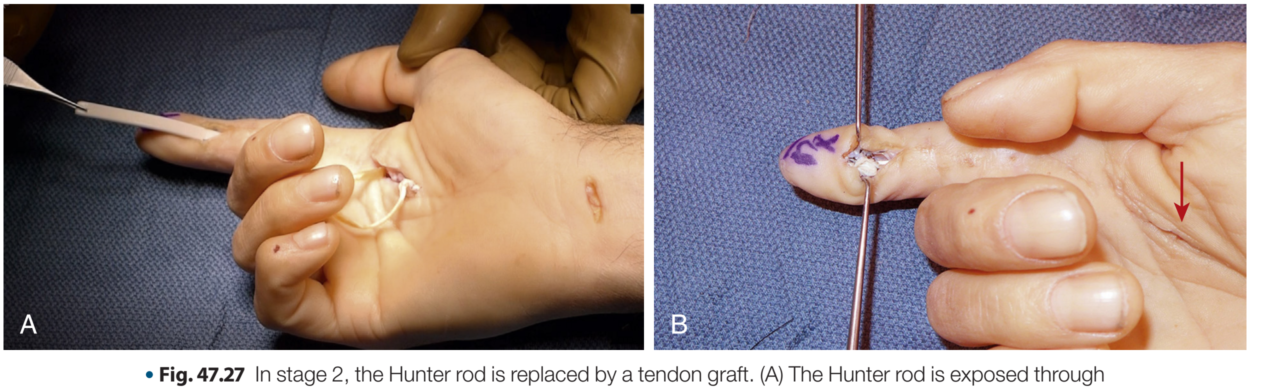
into the pseudosheath tunnel from the incision in the palm (Fig. 47.27A). The Hunter rod is then pulled from the distal incision until the entire grafted tendon sits inside the digit. The distal tendon junction is made as previously described for free tendon grafting (Fig. 47.27B).

Care is taken not to open the pseudosheath proximal to the DIP joint. In the palm a suitable profundus tendon stump is chosen for a Pulvertaft suture with the finger held in moderate flexion. The author prefers to put the proximal repair in the palm. It can be placed in the distal forearm, however the tendon graft is usually not long enough. Correct tension on the graft is essential for good function.

Postoperative Care

After one-stage tendon grafting or after stage 2 of the staged reconstruction, the wrist is held in slight flexion (30 degrees) and the MCP joint in marked flexion with a short arm splint. Some surgeons immobilize the hand for 3–4 weeks; others favor an early protected motion program initiated days after surgery. The author prefers a less aggressive early active finger flexion program with passive finger motion. Therapy proceeds carefully through passive and light active motion until at least 6 weeks, when the tensile strength of the tendon and its junctures are sufficiently strong to tolerate more vigorous motion. By 8 weeks, full activity is permitted, except powerful grip until 12 weeks.

After stage 1 of the staged reconstruction, passive finger motion should start a few days postoperatively. The hand should not be immobilized for a period of weeks. In cases with pulley reconstruction over the Hunter rod, the fingers must be protected by circumferential taping or Orthoplast rings and passive finger motion should be instructed. In cases with pulley reconstruction over an intact tendon, only very gentle active flexion of the digit is allowed in the first few weeks.



• **Fig. 47.27** In stage 2, the Hunter rod is replaced by a tendon graft. (A) The Hunter rod is exposed through a small incision at the distal part of the finger. After the rod is disconnected from the FDP tendon stump, it is sutured to the tendon graft. The distal end of the Hunter rod is pulled from the distal incision to lead the grafted tendon into the newly formed sheath. The incision in the distal forearm is for harvesting a palmaris longus tendon. (B) The graft has been tunneled in the finger, with the proximal junction site indicated with a red arrow. The proximal tendon junction is completed with a Pulvertaft weave suture. Distally, the graft is repaired to the residual FDP tendon stump through a robust direct repair as used for repair of the terminal zone 1 FDP tendon.

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