Chapter 24

Tendon and Nerve Injuries

Louis Carter with Jennifer Durham

Important Notice: The author of this chapter has extensive experience throughout Africa and will present a different approach to the treatment of flexor tendon injuries in order to obtain acceptable range of motion (ROM) for patients who must use their hands to make a living. Invariably fingers end up stiff and immobile after tendon repairs, especially flexor tendon repairs. This chapter will suggest a repair and therapy protocol which will give your patients the best opportunity to have a functional hand but you will need to keep patient in hospital 7-10 days postop.

Outline of Chapter

General Considerations
Principles of tendon repair
Tendon repairs
  Upper Extremity
    Biceps
    Extensor tendons
    Flexor tendons

Therapy

Additional tendon subjects:
  Staged Tendon Reconstruction
  Tendon ruptures
  Partial Tendon Injuries
  Flexor Tendon Avulsion—Jersey finger

Nerve and vascular injuries

General considerations

Tendon injuries should be repaired as soon as possible. Wounds are irrigated and débrided and the tendon ends are identified. If the wound is clean the tendons may be repaired immediately as described below. If the surgeon does not feel comfortable in performing the repair, the wound can be closed loosely and the repair can be carried out at a later date in a clean wound. See under Clean Closed Wound Concept in the Chronic Wound chapter. Tendons and nerves can be repaired the following day or up to two weeks later if the wound is irrigated, débrided and loosely closed as this gives a Clean Closed Wound. An acute clean wound should never be left open for a later repair. This will allow the wound to become contaminated.

If the wound is heavily contaminated and the wound cannot be closed initially, tendon repair can be delayed. The wound will require further irrigation and débridement on Days 2, 4, etc., with closure by Day 7 if at all possible. As soon as the wound can be closed the tendons should be repaired. Therefore, if the wound is clean at day 3 or 4, the tendons should be repaired and the wound closed at that time.

If the wound has been initially closed, tendon repair may be carried out up to 2 weeks after injury. If later than 2 weeks, repair will be difficult because of muscle contraction and tendon softening. Secondary repair later than 2 weeks post injury is not recommended.
Delayed Tendon Repair after 2-3 weeks with tendon grafts is possible but also not recommended in most situations. If there is a gap between the tendon ends, tendon transfer is best.

**Important surgical principles:**

1. Know function of each tendon  
2. Know how to exam for tendon injuries  
3. Knowledge of muscle/tendon relationships in upper and lower extremities  
4. Know how to dissect and identify tendons at surgery  
5. Technical repair of extensor and flexor tendons at different levels  
7. Length of immobilization in splint or cast after repair  
8. When should therapy and range of motion exercises begin?  
9. Once one has examined the patient in casualty, it is good to give the patient a local wrist block anesthetic to relieve pain before surgery, since surgery may be delayed several hours. See chapter on “Regional Anesthesia.” This is for hand injuries alone.

Before tendons can be repaired, they must be identified and this requires knowledge of anatomy and muscle/tendon relationships in the upper and lower extremities. Textbooks of anatomy should be in every theatre or operating room for reference. This chapter will cover the repair of commonly injured tendons in the upper extremity. **Surgeons should not be embarrassed to have an anatomy textbook in the theatre!**

**Anesthesia and Tourniquet**

- Extensor tendon injuries to the dorsum of hand can be repaired under local/wrist or digital block anesthesia. In these cases it still best to use a tourniquet. Method:  
  1. Infiltrate local anesthesia  
  2. Place tourniquet over forearm  
  3. Exsanguinate or elevate hand for few minutes  
  4. Inflate tourniquet for desired time

This will give at least 20 minutes of anesthesia time. With sedation there will be approximately 40 minutes operating time. Ischemic pain does not develop as quickly when the tourniquet is placed over forearm tendons in contrast to over arm muscles.

- Extensor tendon injuries at the wrist and in the forearm and all flexor tendon injuries require regional or general anesthesia and a tourniquet should always be used.

**Tendon Repair Technique:**

- Tendon repair must be strong. It is important for **flexor tendons** that one has 4 suture strands across the tendon repair—one core suture equals 2 strands, so any flexor tendon repair should have two core sutures. (Some new sutures have two strands attached to the needle so that one core suture equals 4 strands.) The primary core suture should be a weave suture, preferably a Bunnell as described below or a modified Kessler. Ideally it should be a braided suture which holds better. The second suture across the repair should also be a Kessler though some
us a horizontal mattress. It is very important to use a running locked epiten- 
dinous suture. Many find it easier to put in the posterior or distal wall of this suture first.

♦ Extensor tendon repairs from Zone III into the forearm (see below), should have one 
core suture—2 strands across the repair site. Many will use a horizontal mattress 
suture for extensor tendon repairs and the author has used this technique; however, 
where there are few physical or occupational therapists to monitor rehabilitation, the 
weave technique is stronger. In Extensor Tendon zones I and II horizontal mattress 
or running sutures may be used

♦ Additional suture: As stated above, a running locked epitendinous suture of 5-0 
nylon or Prolene should be used for both flexor and extensor tendons. This adds 
strength and provides a smooth surface to help with better gliding 
of the tendon. This is especially true in all flexor zones. Most important it prevents gapping at the 
repair site.

♦ Suture material: In the West, newer sutures as Supramid and Fiberwire are now 
used for important repairs. What is most important is that a braided suture is used. 
It ties and holds better. Therefore, an Ethibond, Mersilene or silk suture should be 
used if available. If none of these are available, Prolene may be used. Prolene 
requires multiple knots to hold and it often slips loose. It is definitely contraindicated 
in Flexor Zone II or No Man’s Land where the fibro-osseous canal is small and tight.

**Specific Tendon Repairs:**

**Biceps Avulsion:**

♦ Mechanism:

This occurs most often in middle age males with forced extension on a 
maximally flexed elbow.

♦ Findings:

Common findings are ecchymosis in antecubital fossa, weakness of elbow 
flexion and supination, and abnormal contour and bulging of proximal biceps. Biceps 
rupture may be incomplete or complete and treatment may be either 
conservative or operative. Since brachialis, brachioradialis and supinator are still 
intact there will be weak flexion (70%) and weak supination (60%) with conservative, 
non-operative, treatment for complete ruptures.

♦ Treatment:

Partial injuries can be easily repaired if found early. Complete avulsions can 
be repaired early with interference screws or suture anchors, if these are available, to 
radiual tuberosity. If these are unavailable, drill holes may be made in the tuberosity. 
In each method a strong core weave suture or two Krachow whip stitches using # 1 or 
#2 nonabsorbable suture should be placed in the proximal tendon. If drill holes are 
used, the suture ends can be passed through the tuberosity and tied down posteriorly through a separate posterior incision. The forearm should be pronated to 
identify the tuberosity through a posterior lateral incision. Posterior exposure 
requires splitting the common extensor and supinator muscles.
Postoperative care:
The elbow should be placed in flexion in a cast for 4 weeks. After 4 weeks flexion without resistance may be allowed. Gradual resistance can be added after 6 weeks. (The surgeon should review a detailed description of this procedure and the anatomy before surgery.)

Hand and Forearm

Anatomy, exposure, and relationships:

With injuries in the hand and forearm, it is important to know the relationship of the muscles and tendons to each other and to nerves and vessels. After an injury in the hand and forearm the proximal tendon ends retract proximally and lie within the muscles and hematoma. This makes identification difficult in the forearm. It is not uncommon for an inexperienced surgeon to give up trying to identify the proximal tendon ends thinking that there is only muscle there and no tendons. The tendon ends are present and identification of the proximal tendon ends requires proximal extension of the wound, usually in a zigzag fashion, irrigation and removal of the hematoma and dissection of the tendon ends within the muscles. **Wide, extensive exposure is mandatory**, both proximally and distally. The apex of each zigzag can be sutured back to the skin for retraction and exposure. Finding each tendon not only requires knowledge of anatomy and muscle relationships but also patience as this dissection may take time. The location of the tendons both proximally and distally will depend on the position of the fingers and wrist during injury and also the angle of the injury. Identification of distal tendon ends is easier as the wrist and fingers can be flexed to find flexor tendon ends or extended to find the extensor tendon ends.
Fig 4 Relationships of muscles, nerves and vessels in forearm (From Atlas of Human Anatomy, Netter, Courtesy Elsevier)
It is difficult to remember these relationships. An anatomy textbook should be available in every operating room for reference.

**Extensor Tendons and Abbreviation**

<table>
<thead>
<tr>
<th>Tendon</th>
<th>Abbreviation</th>
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<tr>
<td>Abductor Pollicis Longus</td>
<td>APL</td>
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<tr>
<td>Extensor Pollicis Brevis</td>
<td>APB</td>
</tr>
<tr>
<td>Extensor Carpi Radialis Longus</td>
<td>ECRL</td>
</tr>
<tr>
<td>Extensor Carpi Radialis Brevis</td>
<td>ECRB</td>
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<tr>
<td>Extensor Pollicis Longus</td>
<td>EPL</td>
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<tr>
<td>Extensor Digitorum Longus</td>
<td>EDL</td>
</tr>
<tr>
<td>Extensor Indicus</td>
<td>EIP</td>
</tr>
<tr>
<td>Extensor Digiti Minimi</td>
<td>EDM</td>
</tr>
<tr>
<td>Extensor Carpi Ulnaris</td>
<td>ECU</td>
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Repair of an extensor tendons

This is not difficult but it must be done carefully with good exposure. Usually a 3-0 or 4-0 core, weave, braided, non-absorbable suture is needed for an extensor in the forearm or wrist (see details under flexor tendons). Many only have Prolene for these sutures but a braided suture as silk, Ethibond, or Mersilene is recommended. Multiple knots must be used to prevent unraveling if Prolene or a similar monofilament suture is available. One weave suture (see under flexor tendons) or two 4-0 or 5-0 horizontal mattress sutures can be used in tendons over the dorsum of the hand and in the fingers. Even though extensor tendons in the hand do not retract as extensor tendons in the forearm or flexor tendons, one should extend the wound proximately and distally in order to carefully identify the ends and perform an adequate repair. There are zones for tendon injuries, both for extensors as well as flexors. The nine zones for extensor tendon injuries help in determining the proper repair. Below is listed the Zone, suggested repair, splint method, and rehab methods. The odd number extensor zone is over a joint.

![Fig 5 Extensor Tendon Zones](image-url)
Zone 1—Terminal tendon injury over Distal Interphalangeal joint and mallet Injury:

Tendons are thin at this level. If after a laceration the ends are clearly seen, primary repair is done with a running 5-0 or 6-0 monofilament suture, but if difficult to identify, continuous splinting or pinning of the DIPJ at 0 degrees of extension or slight hyperextension for 6 weeks will work well. An excellent repair at this level combines the skin and tendon in a horizontal mattress or running suture tied over the skin. Closed Mallet injuries involving only the terminal tendon require continuous splinting for 6 weeks with gradual tapering after 6 weeks, allowing progressive exercise periods during the day.

![Fig 6](Splinting for Mallet injury)
(From Rehabilitation of the Hand and Upper Extremity, 6th edition: Used by permission from Elsevier)

Splinting at night is then continued for 4 more weeks. If there is a bony Mallet, usually a closed fracture at the insertion of the extensor tendon, splinting alone is sufficient for 6 weeks. For either open or closed injuries the author would use a K-wire to hold the DIPJ in extension for 6 weeks as this will eliminate the need for compliance in keeping a small splint on continuously. The K-wire can be bent and pushed under the skin at the tip of the finger so that it is not exposed. (The end of the wire must be bent to prevent proximal migration.) If there is volar subluxation of the volar fragment of the distal phalanx, there are several methods of reducing and holding the reduction with K-wires for 6 weeks. See in Chapter on Hand Fractures.

Zone II—Between Distal Interphalangeal Joint (DIPJ) and Proximal Interphalangeal Joint (PIPJ)

The terminal tendon and lateral bands may both be divided: tendon is very thin and repair is performed with fine monofilament running or horizontal mattress sutures. Skin can also be combined with the tendon in the repair at this site.

Splint and rehab as Zone I.

Zone III—over the Proximal Interphalangeal joint and Central Slip insertion:

There should be a high degree of suspicion with any injury over the PIPJ since the slightest and most insignificant laceration can partially divide the central slip. The patient may initially extend the PIPJ with the lateral bands, but if the injury is missed and untreated, the lateral bands will in time slip to the volar side and become flexors rather
than extensors. A boutonniere deformity will result with a PIPJ flexion deformity with an extensor lag at the PIPJ. The DIPJ will be extended. If the laceration is through the tendon, a core suture as a Bunnell or modified Kessler technique with 4-0 braided suture as discussed under flexor tendon injuries can be used. A monofilament as Prolene can be used if that is what is available. If the injury is at the insertion into the middle phalanx the repair into the middle phalanx can be done with bone anchors if available or by passing a suture through a transverse drill hole in the middle phalanx and then through the tendon with a core suture.

**Technique for anchoring suture to bone without anchors:** With open exposure, use a .035 or .045 inch K-wire to drill transversely through bone where you wish to anchor the tendon, pass a 20 gauge needle through drill hole, then pass a 4-0 suture (monofilament if available may be easier) through the needle, remove needle, pass suture ends next to base of middle phalanx and weave suture through tendon and anchor the tendon down to bone.

Splint/cast or pin PIPJ in extension for 6 weeks, allowing DIPJ and MPJ freedom to flex. In delayed injuries to central slip with extensor lag (incomplete extension of middle phalanx), if the PIPJ can be passively extended, then splinting/casting of PIPJ for 6-12 weeks is usually satisfactory. **To eliminate the need for compliance required in wearing a splint for either acute or delayed injuries, a K-wire across the joint for 6 weeks may be used in place of a splint.**

The rare closed rupture of the central slip may be treated closed with extension and preferably a K-wire across the joint.

![Fig 7](https://example.com/fig7.png)

Splinting for Central slip injury at PIPJ—important to allow flexion at DIPJ
(From Rehabilitation of the Hand and Upper Extremity, 6th edition. Used by permission from Elsevier)

♦ **Zone IV**—over proximal phalanx

Repair with multiple horizontal mattress sutures or a modified Kessler type core suture. Postop: Splint the PIPJ in absolute 0 degrees of extension for 6 weeks and include the DIPJ if the lateral bands were repaired. Add a continuous locking small monofilament suture on the tendon surface.

♦ **Zone V**—over Metacarpal Phalangeal joint
This injury may involve the joint. Modified Kessler core sutures are adequate with a continuous locking epitenon or surface suture. Index and Small fingers have two tendons with the EDC always the radial tendon. Repair both tendons. Beware of lacerations over MPJ as these may be from a clenched fist or human bite injury. These may or may not lacerate the tendon but be aware of possible metacarpal phalangeal joint (MPJ) bacterial inoculation. Unless recognized, this injury may lead to a septic joint and/or severe cellulitis. X-rays are necessary to rule out a foreign body, as a tooth, within the joint. Copious irrigation and antibiotics are required with delayed closure.

Postop: After tendon repair, the MPJ should be held in extension at \(0^\circ\) with the wrist extended \(20^\circ\) for 2-3 weeks. The IP joints are free during the day for exercise but may be placed in extension with a removable piece if necessary to prevent finger tightness. After 6 weeks the splint can be removed, allowing full range of motion. Avoid forceful gripping until 6-8 weeks post op.
Fig 10
Dorsal tendon apparatus and intrinsic extensor tendon Zones I-V
Note annular pulleys 1, 3 and 5 on volar side are over joints

♦ Zone VI—over dorsum of hand
Because of juncturae (fascial connections between the extensor tendons) there may
be weak extension of the finger even if a proximal extensor to finger is lacerated. In this
Zone tendons retract and proximal extension of wound maybe necessary to find the
proximal end for repair. Care must also be taken when evaluating EPL injuries as intrinsic
tendons to thumb (APB and AddP) will give weak extension when the EPL is divided. Repair
with a core 4-0 suture, braided if available or monofilament, and an epitenon running
suture.
Splint the hand and fingers as for Zone V.

If only one or two tendons are lacerated in the zones above, then repair may be carried out
under local anesthesia. If there are multiple injuries, then regional or general anesthesia
will be necessary. A forearm tourniquet should always be used to give a bloodless field.

♦ Zone VII—over wrist joint and extensor retinaculum. Knowledge of extensor
compartments is important. There are six compartments with Compartment 1
radial.
Compartment 1—APL and EPB are usually in the same compartment but maybe in two separate compartments. (This is something one must be aware of when treating tenosynovitis of the First Dorsal Compartment or de Quervain’s Syndrome as one must release both compartments if present.) Leave retinaculum open after repair.

Compartment 2—long extensor tendons to wrist, ECRL and ECRB. These large tendons will retract when divided. Repair with a 2-0 or 3-0 core suture (a braided suture should be used). Care must be taken to hold wrist joint in extension after repair to take tension off repair while other injuries and skin are repaired.

Compartment 3—long extensor to thumb, EPL. It courses around Lister’s tubercle with the tubercle as a fulcrum. This tight compartment must always be released for repair and EPL should be left subluxed radially and lying over the second compartment after repair.

Compartment 4—EDC tendons are superficial with the EI (EIP) deep--5 tendons. The Extensor Indicis can usually be identified deep to the other tendons and it has a more distal muscle belly. The retinaculum may be opened in a zigzag fashion for later repair as to prevent bowstringing. Often this is not possible. A core suture with an epitelenon suture is used for repair of these tendons.

Compartment 5—EDM: open retinaculum, repair tendon, and leave retinaculum open, repair with horizontal mattress (usually a small tendon)

Compartment 6—ECU: over ulna, requires strong core suture for repair and repair of overlying sheath if possible to prevent subluxation

Postoperative Care Zone VII repairs: tendon repairs of the wrist extensors in Zone VII require splinting of the wrist in 20-30° extension for 6 weeks continuously. For finger extensor tendon injuries at the wrist, the wrist is held in 45° extension and the MPJs are splinted (blocked) at 0 for 4 weeks with a volar splint. The fingers are allowed to begin gentle Active Range of Motion (AROM) after 3 weeks but the splint is worn until 6 weeks post op when not exercising. The IPJs (PIPJ and DIPJ) are not included in the splint and the patient is encouraged to exercise these joints.

♦ Zone VIII—distal forearm
Anatomical relationships are important to know in order to identify the injured tendons. Repair may be at the musculotendinous junction. Four extensor tendons originate on the ulna and course from ulna to radial side and deep to the long extensors. Beginning proximally, these are APL, EPB, EPL and EI. Repair the tendons under a tourniquet and with IV regional, axillary Block or general anesthesia. Postop: splint with the wrist extended 45° and MPJs as under Zone VII.

♦ Zone IX---proximal forearm: Dissect tendons out of muscle for repair. In the proximal forearm the muscle will need to be approximated.

♦ Extensor Tendons Zones for Thumb:
Zone I and II are similar to Zone 1 and IV in the fingers. For Zone I, splint the IPJ at 0 or slight hyperextension. Non-operative: splint continuously for 8 weeks. Operative: splint 5-6
weeks continuously. For **Zone II**, splint the MP and IP at 0 degrees, thumb in radial abduction. Begin active flexion at each joint at 4 weeks; progress in 25-30 degree increments each week. Begin weaning from the splint at week 6.

**Zone III** is similar to Zone 5 for the fingers.

The EPB inserts to the proximal phalanx base on radial side. There is no sagittal band. EPL is ulnar and inserts at base of distal phalanx (no middle phalanx in thumb). Keep MPJ extended for 6 weeks and then begin gradual flexion as above.

**Zone IV** is similar to Zone VI: Repair both EPB and EPL

**Zone V** is through extensor retinaculum described above. The retinaculum over the EPL is released and the repaired EPL allowed to sublux radially. The retinaculum over the first compartment is released, the EPB repaired and the retinaculum left open.

When the thumb tendons are injured, a thumb spica splint is used to hold the thumb and wrist in extension.

Reason for epitenon suture in addition to core suture:
1. Gives additional strength
2. Provides a smooth surface for gliding
3. Helps to prevent gaping between tendon ends

♦ **Flexor Tendons**

♦ **Important facts about flexor tendon injuries**:
  - Ulnar Artery and Nerve are radial to FCU with artery volar and nerve dorsal.  
  - Any injury to FCU and flexor tendons will likely injure these structures.  
  - There are 10 structures in the Carpal Tunnel: All FDS and FDP tendons (8), FPL and Medial Nerve  
  - Approximately 20% of individuals do not have an independent FDS slip to the small finger  
  - Approximately 20% of individuals do not have a PL  
  - All long flexors to fingers are ulnar and dorsal (deep) to Palmaris Longus. Any injury at wrist **ulnar** to Palmaris Longus may injure all 8 flexor tendons to the fingers.  
  - Flexion of MPJ is through intrinsic tendons and not the long flexors. On exam after injury, be aware of patient who flexes proximal phalanges only. Distal flexors may be divided.  
  - The palmar cutaneous branch of median nerve lies superficially between the PL and FCR tendons at wrist. Repair if injured to prevent neuroma.  
  - Injuries to the PL will likely damage the median nerve
Fig 14
Flexor Muscles, Superficial layer (From Atlas of Human Anatomy, Netter: Courtesy Elsevier)
Fig 15
Flexor muscles, deep layer
Important to know anatomy and relationships of tendons, nerves and vessels
(From Atlas of Human Anatomy, Netter: Courtesy Elsevier)
Flexor tendons at the wrist from ulnar to radial:

<table>
<thead>
<tr>
<th>Flexor Tendons</th>
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<tbody>
<tr>
<td>Flexor Carpi Ulnaris</td>
<td>FCU</td>
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<tr>
<td>Flexor Digitorum Superficialis</td>
<td>FDS</td>
</tr>
<tr>
<td>Flexor Digitorum Profundus</td>
<td>FDP</td>
</tr>
<tr>
<td>Palmaris Longus</td>
<td>PL</td>
</tr>
<tr>
<td>Flexor Pollicis Longus</td>
<td>FPL</td>
</tr>
<tr>
<td>Flexor Carpi Radialis</td>
<td>FCR</td>
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<tr>
<td>Brachioradialis</td>
<td>BR</td>
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Fig 16

Structures in carpal tunnel and ulnar artery

Note 10 structures pass through carpal tunnel—8 flexor tendons to fingers (4 FDS and 4 FDP tendons), long thumb flexor (FPL) and medial nerve. See Fig 17, 18 and 19.

(From Atlas of Human Anatomy, Netter: Courtesy Elsevier)
Fig 17
Cross section of wrist at level of carpal canal (From Atlas of Human Anatomy, Netter: Courtesy Elsevier)

Fig 18
Arrangement of FDS tendons within carpal canal with long and ring FDS tendons superficial

Fig 19
Cross section through carpal canal demonstrating the ten structures within canal: All FDS and FDP tendons, FPL and median nerve (From Atlas of Human Anatomy, Netter: Courtesy Elsevier)
**Pulley System:**

Before discussing flexor tendon repairs, it is important to discuss the pulley system. There are 5 annular pulleys in each finger.

![Fig 20 Pulley System](image)

- A-2 and A-4 are over phalanges and must be preserved for complete finger flexion
  - A-1—located over MPJ (divided in trigger fingers)
  - A-2—located over Proximal Phalanx and must be preserved for full flexion
  - A-3—located over PIPJ, usually divided in tendon repairs
  - A-4—located over Middle Phalanx and must be preserved for full flexion
  - A-5—located over DIPJ—can be divided for Zone I repairs

- **Remember:** important pulleys are over phalanges not joints

- Cruciate pulleys between annular pulleys allow finger flexion

- Thumb has three pulleys:
  - A-1—located over MPJ (divided in trigger thumb)
  - A-2 or oblique—located over Proximal Phalanx and must be preserved
  - A-3—located over IPJ

- **Pulley injuries:**
  - Pulleys are difficult to repair primarily. It is rare to have a complete injury to A-2 and a half of A-2 is sufficient to prevent bowstringing. If either A-2, A-4 or the thumb oblique pulley is completely divided, they should be repaired with a tendon graft (portion of unrepaired FDS or slip of EDM or PL. Look up repair in major hand text). With A-4 injuries, a slip of distally based FDS can be used to recreate an A-4 pulley.

For a complete pulley reconstruction:

- **A-2 reconstruction,** the graft should be wrapped around the entire proximal phalanx but beneath the extensor tendons.
- **A-4 reconstruction,** the graft should be wrapped around the middle phalanx over or superficial/dorsal to the extensor tendons

- Since adhesions may form after primary reconstruction, some prefer to perform delayed pulley reconstruction. The author prefers to do this acutely in clean wounds
recognizing that secondary tenolysis may be necessary. In addition, the protocol below for tendon motion would still be used.

♦ **Flexor Zones in the fingers and repair of tendons in each Zone:**

![Fig 21 Flexion tendon zones](image)

**Important information regarding flexor tendon repairs:**

This information is based on suture availability, expected patient non-compliance and limited therapists: Recommend a braided suture, either a 3-0 to 4-0 silk/Ethibond/Mersilene sutures for core sutures—need 4 strands across repair site. One may use 2 weave sutures or a weave suture plus a modified Kessler suture to give the 4 strands across the repair. Most hospitals have one of these and they are easy to tie with minimal knots and they do not slip as Prolene suture. Silk core sutures with a 5-0 nylon/Prolene epitenon running locked suture should allow early range of motion as described below.

♦ **Zone I**—from A-4 pulley to insertion FDP—repair FDP with core suture. One may need to attach tendon end to base of distal phalanx with an anchor or through drill holes or with sutures passed around the phalanx and through the nail bed on either side. May also use wire suture.

♦ **Zone II**—from A-1 pulley to FDS insertion under A-4 pulley. This is the Fibrous Osseous Canal or “No Man’s Land”— repair profundus tendon only if both are lacerated as there is not enough room for excursion if both tendons repaired. The FDS is excised if injured. (If the FDS is intact and for some reason the FDP cannot be repaired acutely and secondary reconstruction will also not be performed, then the distal FDP should be sutured to either A-2 or A-4 pulley to decrease the incidence of DIP hyperextension.)

- With Zone II injuries, one should explore injury through a window made in the tendon sheath between A-2 and A-4. A-3 and cruciate pulleys can be sacrificed to provide a “window” for repair. If absolutely necessary, the distal half of A-2 and the proximal half of A-4 can be divided in order to retrieve the tendons and perform the repair, but this must be done carefully as A-4 is very short.
• Many injuries in this Zone occur with the fingers flexed and the proximal end of FDP may retract into the palm and the distal end may retract under A-4 pulley. Exploration in the palm will likely be necessary. One may flex the wrist and MPJ and look for the proximal end of the FDP. Blind grasping for the tendon end is discouraged! If the proximal end cannot be readily seen, it is better to identify the tendon in a distal palm incision. A core suture can be placed in the proximal FDP and the suture with the proximal tendon passed under A-2 pulley and the repair carried out between A-2 and A-4 pulleys. If the FDS is intact then the proximal end of the FDP should be passed back through the split in the FDS if possible. If the FDS has been lacerated, it is excised. If one slip of the FDS is intact, it may be left and the lacerated slip excised. The distal FDP end may be retrieved distal to A-4. A core suture may be placed distal to A-4 and the end passed proximally under A-4 for repair in the “window” described above, between A-2 and A-4. The pulleys may be dilated gently with a hemostat or small urethral dilator so tendons may pass through easily. If both tendons are lacerated in Zone II, repair only one.

• Zone III—from distal end of Transverse Carpal Ligament to A-1 pulley, area of lumbrical muscles, one may repair both tendons if both injured though many will only repair the FDP. The author recommends that only the FDP is repaired.

The proximal tendon may or may not retract according to whether or not the lumbricals are divided. Usually the lumbricals are divided and the laceration will need to be extended proximately through the Transverse Carpal Ligament and into the forearm. The proximal end may retract into the forearm and into a hematoma adjacent to muscle belly where careful dissection is required to identify it in the hematoma. (Note: divide Transverse Carpal Ligament on the ulnar side in line with the 4th ray so that the motor branch of the Median Nerve is not injured.)

• Zone IV—beneath Transverse Carpal Ligament—divide ligament and repair only the profundus tendon if both FDS and FDP divided. If the surgeon anticipates good compliance with good therapy after surgery, then both may be repaired but this is unlikely in most situations. Again, the author recommends FDP repair only.

• Zone V—proximal to Transverse Carpal Ligament in forearm—may repair both if sharp, clean lacerations but repair of the FDP alone is adequate. It is important to know muscle relationships and remove hematomas so that proximal tendon ends can be found. Sometimes it is not easy to identify the tendons when there is a hematoma, but one must dissect these out in order to get a good repair.

♦ Incisions in the hand and fingers:
  Incisions for tendon exploration in the fingers can either be a Bruner zigzag incision (small finger below) or a mid-lateral incision or a combination of both. The Bruner incision extends from the end of one crease to the opposite end of the next adjacent crease. In the palm these zigzag incisions can be continued. The author feels a Bruner incision gives the best and easiest exposure for a non-hand surgeon.
- **Flexor tendon repair technique:**
  Repair flexor tendons with core or weave suture using 2-0 to 4-0 braided non-absorbable suture—we recommend silk, Mersilene or Ethibond if available. A braided suture holds best and does not slip. A Kessler or Modified Kessler suture core techniques are the easiest to use. See **IMPORTANT SUGGESTION** below. It is best to tie the suture inside the repair as in the modified Kessler repair so that the knot does not interfere with excursion. An additional horizontal mattress suture or modified Kessler suture increases the strength of the repair and gives 4 strands across the repair site as in the Indianapolis repair below. The epitenon should be repaired with a running suture of 4-0 to 6-0 monofilament suture. This also increases the strength of the repair and reduces gapping and bulk. Different techniques have been used but a running suture is easy and works well. (See below) It may also be locked.
During repair, **the tendon surface/epitenon should not be grasped as this leads to adhesions.** The tendons are held by grasping inside the end of the tendon with small toothed forceps. Once the tendons are pulled into position and approximated in preparation for repair, **one may pass hypodermic needles through the tendons and into surrounding soft tissue** so that the ends are touching and ready for repair. This prevents the tendon ends from retracting and allows tendon repair without the need to grasp and pull on the tendon.

♦ **Important suggestion:**

Though a 4 strand repair using the Modified Kessler suture and additional horizontal mattress suture as described above may be sufficient for extensor tendons, the author strongly suggests a stronger repair for the early range of motion protocol described below for flexor tendons. One may use the Savage/Sandow weave technique shown below or the old Bunnell weave for a core suture followed by another core suture and then an epitendinous repair. The Savage/Sandow weave technique is technically demanding, requiring practice and additional operating time. (Some sutures are now made with two strands attached to one needle for tendon reconstruction. If these are used for a core suture, immediately one has 4 strands across the repair site and an additional horizontal mattress suture adds two more strands.) Most will have silk or Ethibond and the author suggests you use the older Bunnell weave for the main core suture with an additional Bunnell weave or modified Kessler suture→this gives 4 strands across the repair. If the silk or Ethibond core sutures are buried, then there will less chance for adhesions. An epitendinous suture is always added for the reasons given above. Below we will describe early motion which will not only reduce adhesions but improve tensile strength at the repair site. Here is the Sandow modification of the Savage weave repair:
This is a great suture technique but may not be practical for the average general surgeon in the district hospital. The Bunnell suture shown above is recommended (with an additional core suture—either an additional Bunnell, Modified Kessler or horizontal mattress to give 4 strands). The Bunnell is an old repair and has not been widely used in recent years because of the tendency to bunch up the tendon. If only one tendon is repaired and an epitendinous suture is used to smooth out the repair site, the author feels this is the best repair to allow the early motion protocol. It is so important to allow early gentle range of motion exercises which demands only minimal patient compliance. See discussion under splinting and exercises below.

♦ **Recommended Flexor Tendon repair:**
  1. Bunnell Suture--Would begin suture from inside as shown in the modified Kessler suture above so that knot is on inside.
  2. Additional Bunnell or modified Kessler suture—this gives 4 strands across the repair. A horizontal mattress suture may be used as second core suture but this is not as strong.
  3. Locked epitendinous repair as seen above.

♦ **Tendons healing:**
Tendons heal through direct vascular supply at musculotendinous junctions, their vinculae and through synovial diffusion. They can also receive blood supply through adhesions but these are not desirable.
Splinting and exercises: A different approach for your District Hospital

The authors strongly recommend that patients with flexion tendon injuries are kept in the hospital for one week in order to gain full range of active motion for the PIP and DIP joints before leaving the hospital. MPJ range of motion will come after the splint is removed at 4 weeks.

- In the OR, the patient is placed in a dorsal slab cast, positioning the wrist in 20-30 degrees extension and the MCP’s at 80-90° flexion. The IP’s are positioned at 0 degrees. While still under regional anesthesia, the surgeon performs passive range of motion (PROM) to the finger(s) in the post op splint:
See Chapter 32 on Hand Therapy

**IF THE PATIENT IS UNDER GENERAL ANAESTHESIA, AS SOON AS THE PATIENT WAKES UP, BEGIN THE NEXT STEP, WHICH IS:**

- 10 x’s composite passive finger flexion
- 10 active finger extensions to the limit of the splint/cast—if possible
- 5 place/hold flexion of the fingers—fingers are passively flexed with fingers in palm and then the patient attempts to keep the fingers in the palm actively, with their own muscle power.
- As above, the fingers are actively extended to the limit of the splint (80-90° of MCP flexion)—if possible.

- **Passive range of motion** is done hourly by the patient during waking hours while in the splint. If the patient is hospitalized for the first week, the therapist/surgeon should see the patient 2x/day and do the above passive flexion, then place and hold, and active extension exercises with the patient. (Place and hold=fingers are “placed” passively into the palm and then the patient attempts to “hold” them there.) The patient should have full active digital flexion by day 7 post operatively within the splint. Number of repetitions of the exercises can be increased as needed to get the full passive flexion. Emphasis must be placed on just gentle squeezing for the “hold” procedure and not trying to grip tightly in Step 2 above. There should be no resistance to this active motion. In other words, the patient should not try and lift anything for these weeks. Have the patient practice place and hold using the uninvolved hand so that they better understand how hard to make a fist. The plaster cast is changed at 5 days if necessary for dressing changes.
• If the surgeon and therapist are satisfied with the patient’s progress and if the patient lives far away, the patient can be seen back at 4 weeks post op. Otherwise, if there are any concerns about the patient’s understanding of the required therapy or concerns about the wound, the patient should be seen at least weekly on an outpatient basis. At 4 weeks the patient can come out of the dorsal block splint/cast under the guidance of the therapist and begin **coordinated wrist/hand movements. Specifically, begin with the wrist in 20-30 degrees of extension and fingers flexed into the palm as much as possible. Begin flexing the wrist while actively extending the fingers.**

• Continue to wear the splint/cast between exercise sessions.

• At 6 weeks post op begin light activities of daily living (ADL’s), while continuing the exercises above. At 8 weeks light resistive exercises are included picking up 1-2 pound objects and activities of daily living are increased.

• Splinting and therapy may be individualized according to age, intelligence, compliance, location and realistic opportunity for follow-up. Often the patient is not seen for weeks and a realistic approach is necessary.

• Children should be splinted or casted for 4 weeks without active or passive range of motion. Children will usually recover full range of motion.

• With flexor tendon injuries in the hand and fingers, care must be taken to clearly identify nerves and vessels and repair each one. Whether or not an individual artery
is repaired is determined by an Allen test and the presence of a contralateral patent artery.

Please see Chapter 32 for the complete therapy protocol for flexor tendon injuries.

**Staged Tendon Reconstruction:**

This two to three stage technique is a secondary procedure and is used when the tendons are damaged beyond repair or when after a previous repair there are severe adhesions. This technique requires the use of a silastic rod, Hunter Rod, for the first stage. The reader is referred to hand surgery textbooks for further information. This technique requires close follow-up, an excellent therapist and is not recommended in most situations. If a functional FDS is available, staged reconstruction is contraindicated.

**Tendon Ruptures:**

Occasionally a tendon repair will rupture accidentally a few days after repair or when dealing with a non-compliant patient. If this was an accidental rupture, these ruptures can be repaired immediately with fairly good results. After a few days repair will be difficult.

**Partial Tendon Lacerations:**

Occasionally, a patient may present with a partial tendon laceration. This should be suspected if flexion is weak, painful or incomplete. If the tendon laceration is greater than 50% of the diameter, routine repair with core sutures should be done. If less than 50%, nothing is required other than trimming or tacking down the cut edges with 5-0 or 6-0 epitendinous suture to prevent catching or triggering on a pulley edge. Exercises are generally begun sooner in these injuries, depending on the injury. (Recent studies show only a small percentage of the flexor tendon is necessary for good function.)

**Flexor Tendon Avulsion:**

This is a closed injury with avulsion of the Flexor Digitorum Profundus at its insertion at base of distal phalanx. This should be suspected with any enlarged and tender finger after a **rugby match or rock climbing.** This is often called a “jersey injury” from catching a finger, often ring finger, on a jersey with forced extension of the distal phalanx while there is maximum FDP flexion. Suspicion with a swollen finger after closed trauma is most important for early recognition. There are four types:
I—FDP retracts into palm: early recognition is important, repair within 1 week

II—FDP retracts to PIPJ or distal edge of A2 pulley with or without small bone fragment (may have vincula still intact), may still be able to repair at 4-6 weeks

III—FDP with larger fragment of distal phalanx retracts to A4 pulley, may be able to repair at 6-8 weeks

IV—FDP and small fragment of distal phalanx retract but separately and both need repair urgently as FDP may retract into palm—unusual injury

Achilles tendon injuries:

Acute open injuries can be repaired with several core weave sutures as in flexor tendon injuries or a Krachow whip stitch with a large braided non-absorbable suture—probably the largest available in the hospital (usually silk or Ethibond). It is best to expose the tendon through a medial incision. The ankle may then be casted in plantar flexion for 6-8 weeks. If the Achilles is avulsed off the calcaneus, it can be repaired using large bone anchors or with sutures passed through drill holes in the calcaneus. Acute closed ruptures can be treated open or closed with equally good results in recent literature studies.

Krachow suture is shown below. Many now add a second suture to give four strands for both Achilles tendon and biceps tendon repairs.
Summary:

Tendon injuries require early identification and repair. Even in major centers excellent results are difficult to achieve with flexor tendon injuries in the hand since these require special and frequent therapy sessions and exceptional patient compliance. Any severe trauma or crushing type injury further compromises the final result. If therapists are not available to follow the patient on a bi-weekly or weekly basis, then the surgeon must learn basic therapy techniques described above in order to care for his patients.

Because of the poor results with limited range of motion after tendon injuries in remote locations, the authors feel the suture technique described above using a silk suture with a Bunnell core suture, an additional horizontal mattress or other core suture as a Kessler, a locking epitendinous suture and the therapy protocol for one week in the hospital has the best chance for giving the patient a functional hand. The patient must not be discharged within the first week no matter how well the wound is healing. Editor’s Note: See Hand Therapy Chapter, Chapter 32.

Nerve Injuries

All major nerves that can be identified should be repaired. Identification requires knowledge of anatomy and as mentioned before, it is important that the surgeon always has an anatomy book in the operating theatre. Immediate direct repair or with nerve grafts is best. Even after a few days, dissection of nerve ends may be difficult. If one must delay repairing a nerve because of severe contamination, severe crushing injury, nerve avulsion or loss, or inadequate surgical skills, then the ends should be tagged with 2-0 or 3-0 non-absorbable suture, as Prolene or nylon, and ends left long. Ideally this should be with a blue, black or green suture that will be easily recognized during a second stage. Nerve repairs can easily be disrupted after repair and during repair of other structures. Therefore the author often repairs these after tendons are repaired unless they are deep in the wound.

The surgeon must perform a careful exam with each injury. Glass injuries are especially deceiving as the direction glass penetrates is sometimes difficult to determine. An injury on the radial side may damage the ulnar nerve.

The following chart shows the last muscle innervated by each nerve and the exam to determine the function of that muscle. The autonomous sensory zone—where there is no
overlapping of sensory innervation—is shown. There are other ways to exam each muscle but the pointing of the index finger—radial nerve, snapping of thumb and fingers—median nerve and crossing of fingers—ulnar nerve gives an easy and quick motor exam.

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Last muscle</th>
<th>Autonomous Innervated</th>
<th>Sensory Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial</td>
<td>Extensor Indicus</td>
<td>Dorsal 1st web space</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(EIP)Point with Index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>Abd. Pollicis Brevis</td>
<td>Volar surface index</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(AbPB) Snap fingers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulnar</td>
<td>First Dorsal interosseous</td>
<td>Volar surface small</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1st DI) Cross fingers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Below are the findings when each nerve is injured at each level in the upper extremity.

**Findings when Radial Nerve injured:**

<table>
<thead>
<tr>
<th>Level</th>
<th>Motor Loss</th>
<th>Sensory Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above elbow</td>
<td>Loss of wrist/finger ext</td>
<td>Dorsum of hand, radial side</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow</td>
<td>Finger ext, weak wrist ext</td>
<td>same</td>
</tr>
<tr>
<td>Mid-forearm</td>
<td>none</td>
<td>same</td>
</tr>
<tr>
<td>Wrist</td>
<td>none</td>
<td>same</td>
</tr>
</tbody>
</table>

Radial nerve injuries at and above the elbow will result in a wrist drop and inability to extend the fingers at the MPJ. No muscles in the hand are innervated by the radial nerve.

**Findings when Median Nerve injured:**

<table>
<thead>
<tr>
<th>Level</th>
<th>Motor Loss</th>
<th>Sensory Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above elbow</td>
<td>T, I, L flexion</td>
<td>Volar T, I, L, ½ R</td>
</tr>
<tr>
<td></td>
<td>Weak pronation</td>
<td>Thenar eminence.</td>
</tr>
<tr>
<td></td>
<td>Thumb abduction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>T=Thumb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I=Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L=Long</td>
</tr>
<tr>
<td>Mid-forearm</td>
<td>Thumb abduction</td>
<td>same</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T=Thumb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I=Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L=Long</td>
</tr>
<tr>
<td>Wrist</td>
<td>Thumb abduction</td>
<td>Volar T, I, L, ½ R</td>
</tr>
<tr>
<td></td>
<td>(thenar wasting)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>T=Thumb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I=Index</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L=Long</td>
</tr>
</tbody>
</table>
Findings when Ulnar Nerve injured:

<table>
<thead>
<tr>
<th>Level</th>
<th>Motor Loss</th>
<th>Sensory Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above elbow</td>
<td>FDP S,R</td>
<td>Volar surface</td>
</tr>
<tr>
<td></td>
<td>Intrinsic</td>
<td>S, ½ R</td>
</tr>
<tr>
<td></td>
<td>No claw</td>
<td></td>
</tr>
<tr>
<td>Below elbow</td>
<td>Intrinsic</td>
<td>Same</td>
</tr>
<tr>
<td></td>
<td>Claw</td>
<td></td>
</tr>
<tr>
<td>Wrist</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td></td>
<td>Froment’s sign</td>
<td></td>
</tr>
</tbody>
</table>

It is unusual just to have nerve injuries without muscle or tendon injuries. Often the surgeon will determine at exploration if the loss of function is due to a nerve or muscle injury.

The nerves in the upper extremity that should be repaired are the median, ulnar, radial, superficial radial, superficial ulnar nerve and digital nerves.

Repair Technique

Epineural repair is recommended. It is important to align the nerve as near normal as possible. This is not always easy but in larger nerves one can align by the direction of the cut, by the location of blood vessels, and fascicular size and pattern. Often the nerve ends need sharp trimming but only after one has determined the alignment from the original injury. (For example, it is easy to determine the alignment of an obliquely cut nerve when it is first inspected rather than later when it has been divided transversely for repair.) This is best done by a new sharp blade against a sterile wooden tongue depressor but any flat surface will do. Herniating, protruding fascicles must also be trimmed back. Larger nerves should be repaired with 6-8 interrupted sutures. Smaller nerves are repaired with 2-4 sutures and digital nerves with 1 or 2 sutures. In the larger nerves, the first sutures are best placed 180° from each other and left long for manipulation of the nerve. It is often easiest to flip the nerve over and repair the deep surface first. After repair it is important to splint the extremity so that tension may be taken off the repair. Three weeks immobilization is usually sufficient. It is ideal if these repairs can be carried out under loupe magnification but it is understood that many do not have these. Larger nerves may be repaired with 4-0 to 6-0 monofilament non-absorbable suture. Digital nerves should be repaired with the smallest non-absorbable suture available, i.e. 6-0 to 8-0.

Specific Nerves:

- Median, Ulnar and Radial Nerves in the Arm or Upper Forearm
  These nerves should be aligned as best possible using the guidelines above.
  - With the radial nerve around the elbow, one should try and identify the sensory portion of the nerve above and below the laceration so that the motor fascicles may be approximated. The radial sensory nerve at this level provides
sensation to the dorsum of the hand on the radial side, but the radial motor fascicles innervate all the extensor muscles of the hand and fingers.

- The ulnar nerve may need to be transposed anterior to the medial epicondyle to remove tension on the repair. This is almost always necessary with ulnar nerve injuries near the elbow. Though the nerves are divided into definite and specific fascicles at this level, not random as once thought, still it is best just to do one's best in aligning the nerve, especially without magnification.

♦ At the wrist
- The superficial radial and ulnar nerves and palmar cutaneous branch of the median nerve should be repaired to prevent neuromas. These are small and difficult to see without loupes.
- The ulnar nerve topography at the wrist has two distinct fascicular groups with the motor group ulnar to the sensory group until Guyon’s canal where it passes deep or dorsal to the sensory fascicular group. Attempt should be made to approximate the motor fascicular group.
- The median nerve topography is a little more complex with the motor fascicles. In the mid-forearm the anterior interosseous nerve is posterior or dorsal and is usually distinct. At the wrist the motor branch to the thenar muscles is volar and radial. The motor branch should be carefully identified distally and then dissect proximally to the injury site. By first identifying the motor branch distally, the motor fascicles in the proximal nerve end can be better identified. If one has a nerve stimulator this will help identify the distal motor fascicles. The distal muscles will respond to stimulation for 48-72 hours.

♦ Hand
- Digital nerves should be repaired especially on the radial side of each finger and both sides of the thumb. These are repaired after tendons are repaired with 1-2 sutures of the smallest monofilament non-absorbable suture you have and can see.

Nerve Palsy

Injuries with resulting paralysis of the major nerves to the hand are common. Often the diagnosis is missed at the time of the injury. When patients present late with upper extremity nerve palsy, it is usually easy to determine which nerve is involved. On the other hand when there has been severe damage to muscles as well as nerves, the diagnosis may not clear.

Radial nerve injuries above the elbow will have a classic wrist drop whereas those below the elbow will not have a wrist drop; however, they will have weakness in extension of the thumb and fingers. Median nerve injuries at any level will lead to thenar wasting and loss of thumb palmar abduction and opposition. Ulnar nerve injuries above the elbow will not produce the typical “claw” deformity since the long flexors to the small and ring fingers are also paralyzed. When the injury is in the mid-forearm or wrist, there is typical claw deformity of the small and ring but not of the index and long since the lumbrical muscles to the index and long are innervated by the median nerve. A complete claw deformity is seen in injuries to the median and ulnar nerves in the distal forearm and wrist. Ulnar nerve injuries at any level will lead to muscle wasting between the fingers, interossei palsy, and...
in the first web space, first dorsal interosseus. There are other findings and tests found in the major textbooks.

**Late repair of nerves**

Nerves may be repaired directly or with nerve grafts. For muscle reinnervation, the sooner the better. Delayed repair will often still give protective sensation. Except in the very young, reinnervation of intrinsic muscles rarely occurs unless the injury is sharp and near the site of innervation in the hand. In addition the repair must be performed soon after injury. Late nerve repairs should be carried out but with the understanding that muscle function will unlikely return with a delay of 6 months unless the injury is very close to the site of innervation. Radial nerve injuries at the elbow have been repaired late with return of some motor function since the site of innervation for some extensor muscles is close to the elbow. It is recommended that tendon transfers also be done at the same time when a radial nerve is repaired late, >6 months. Late repair of median and ulnar nerves may be done for protective sensation.

The treatment for nerve palsies with tendon transfers is beyond the scope of this book. Major textbooks have detailed descriptions of the various types of reconstruction. The motor losses that require tendon transfers include the following:

Radial nerve—wrist drop and thumb/finger extension at MPJ  
Median nerve—thumb opposition  
Ulnar nerve—finger extension at IPJs with correction of claw and thumb/index pinch

**Vascular Injuries**

Brachial artery injuries should be repaired. Injuries to the radial and ulna arteries should be repaired if there is any evidence of ischemia. Certainly when both arteries are divided at least one should be repaired. Repair with 5-0 or 6-0 monofilament suture. If one artery is divided, then it should be repaired if there is any evidence of ischemia. One can verify collateral flow through the palmar arch by appearance, checking capillary refill and if available using a Doppler to determine if there is arterial flow throughout the hand. Visualizing capillary refill is often the only method of determining flow if one does not have a Doppler.