Flexor tendon injuries

Pearls

I. History
- Galen popularized notion that tendons contained nerves discouraging surgery on tendons
- Bunnell described need for proper atraumatic repair
- Verdan described technique of primary tendon repair
- Secondary tendon grafting popular until Kleinert reports good results of zone II repair, better than previous reports
- Further modifications made to suture material and placement of core strands

II. Anatomy
- Flexor digitorum profundus
    - Dual innervation from AIN and ulnar nerve
    - Primary flexor of DIP joint
    - Assists with MCP and PIP flexion
    - Shares common muscle belly in forearm
- Flexor digitorum superficialis
    - Functions as flexor of PIP joint
    - Assists with MCP function
    - Individual muscle bellies in forearm
    - FDS absent (25%) or underdeveloped to small finger commonly
    - Innervated by median nerve
- Flexor pollicis longus
    - Flexion of thumb at IP joint
    - Most radial structure within carpal tunnel

        - Innervated by AIN
- Flexor carpi radialis
    - Primary wrist flexor
    - Inserts at base of second metacarpal
    - Closest structure to median nerve
    - Innervated by median nerve
- Flexor carpi ulnaris
    - Primary wrist flexor
    - Inserts at base of 5th metacarpal, pisiform and hook of hamate
    - Innervated by ulnar nerve
- Camper's chiasm
    - Located at level of proximal phalanx where FDP splits FDS tendon
- Pulley system
    - 5 annular pulleys
        - A1, A3 and A5 arise from volar plate over MP, PIP and DIP joints respectively
        - A2 and A4 over proximal and middle phalanx respectively from periosteum and help prevent bowstringing
        - 3 cruciate pulley
            - Collapsible and flexible
            - Annular pulleys approximate each other during flexion
        - Thumb
            - Two annular pulleys
            - One oblique pulley
                - Most important to prevent bowstrings
- Nutrient supply
    - Diffusion through synovial sheaths
    - Direct vascular perfusion

III. Patient History and physical examination
- Traumatic injuries often caused volar laceration
- Also may be result of forced extension of a flexed digit

IV. Surgical strategies
- Placement of core sutures approximately 10mm from end of tendon
- Four core strands needed for early active range of motion protocol
- Epitendinous suture adds additional strength
- Proper gliding essential to function and venting of pulleys may be necessary

V. Post operative protocol
- Forearm based dorsal splint made for protection
- Early active range of motion demonstrated to be superior in terms of post operative range of motion than Kleinert or Duran protocols but has higher risk of rupture

I. History

Animal experimentation in the seventeenth century first detailed in the seventeenth century detailed healing and complete recovery in a canine model of achilles tendon repair. Tendon healing was found to be by fibroblastic response. The level of the fibroblastic response was related the level the amount of trauma which resulted in greater adhesions. In 1916 Leo Mayer described the blood system of the tendons and in 1970 Hunter established that blood supply to the tendon was directly from the vincular system. Manske and colleague help establish the dual nutrient supply of tendons with the blood supply and diffusion within the synovial sheath and that the diffusion is a more effective pathway.

One of the first to describe the importance of avoid adhesions was Erich Lever who advocated for careful suturing and early motion 6 days after surgery. Sterling Bunnell in 1918 published his landmark article in which he emphasized the importance of atraumatic technique and in 1922 he described it even further with the importance of sharp instruments, good lighting and comfortable working position.

Avicenna is credited for performing the first operation on a tendon. Galen had stated that tendons were compromised of both ligaments and nerves and this dogma was persistent until 1752 when Albrecht von Haller published his work on the sensibility and irritability of various tissue of the body and demonstrated the insensibility of tendons. Bunnell's initial attempts of primary repair resulted in failure because of lack of adequate suture

materials and techniques. This resulted in abdandonment of primary repair in favor of wound repair with delayed tendon grafting. Verdan had come to the conlusion that primary repair of flexor tendons was possible and described a technique of coaptation and immobilization using transfixion pins across the proximal and distal tendon ends. In the late 1950's Harold Kleinert began his 10 year of zone II flexor tendon repair with a modified Bunnell core suture with a running epitenon stitch using a 6-0 suture. This was combined with an aggressive program of postoperative rehabilitation with dynamic protective splinting. Further modifications evolved with suturing technqiues. James Hunter further advanced tendon grafting with use of implants for tendon sheath reconstruction and further elaborated on flexor tendon anatomy with respect to the pulley system, vincular, synovial and vascular structures.

II. Anatomy

The muscle belly of the flexor digitorum profundus (FDP) originates from the palmar and medial aspect of the upper part of the ulna and from the ulnar side of the interosseous membrane. The four tendons of the FDP pass under the transverse carpal ligament and enter the palm where, at the level of the meta- carpal, the lumbrical muscle originates from the radial side of the tendon. Throughout its course from the muscle to the palm, there are several intertendinous fibers that tether the tendons to each other.

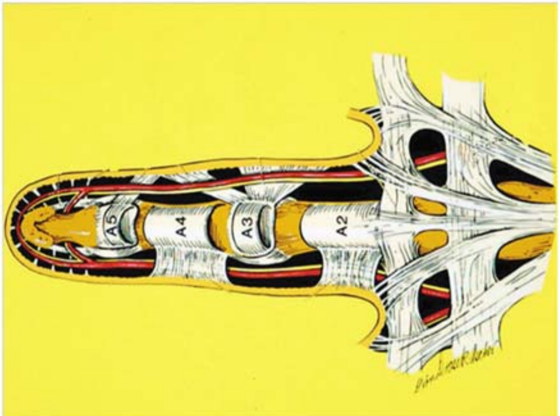
The muscle belly and tendon of the FDP to the index finger may be completely separate from the rest of the muscle and tendons, allowing it to act independently.

The muscle belly of the flexor digitorum superficialis (FDS) is palmar and superficial to the FDS muscle belly. The FDS muscle arises from the medial epicondyle, the coronoid process and from the volar aspect of the proximal radius. At the distal forearm four broad and flat tendons arise from the muscle. Approaching the carpal tunnel, the FDS tendons to the middle and ring finger lie more superficial to the FDS tendons to the index and small fingers Occasionally, the FDS to the small finger may be absent.

The FDS and the FDP enter the fibrous sheath just proximal to the metacarpophalangeal joints. Just after entering the fibrous sheath, at the proximal part of the proximal phalanx, the FDS tendon becomes flatter and splits into two parts through which the FDP tendon passes. This area of separation of the FDS tendons is known as the *bifurca*. Each flat slip of the FDS encircles the FDP tendon, rotating 180 degrees in the process. The two slips then interdigitate and unite with each other to form *Camper's Chiasma*.

The internal fibrous structure of the FDS from the bifurca to the chiasma is quite complex. At the bifurca, the tendon divides into two, each slip rotating 90 degrees and passing dorsal to the FDP. As it does so, each slip divides into two. The lateral slips continue on rotating another 90 degrees and then inserting onto the middle phalanx in a broad insertion distal to the palmar plate of the PIP joint. The medial slips interdigitate with each other forming the *Camper's Chiasma* dorsal to the FDP tendon, each of the medial slips then joining the contralateral lateral slip to reach insertion into the base of the middle phalanx·

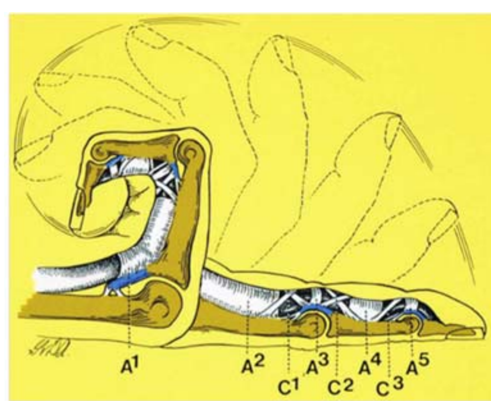
The area of Camper's chiasma has rich dorsal vascular supply through the vincula brevia (short vincula). The vincula longae (long vincula) may also penetrate through to the FDS tendon in this region.



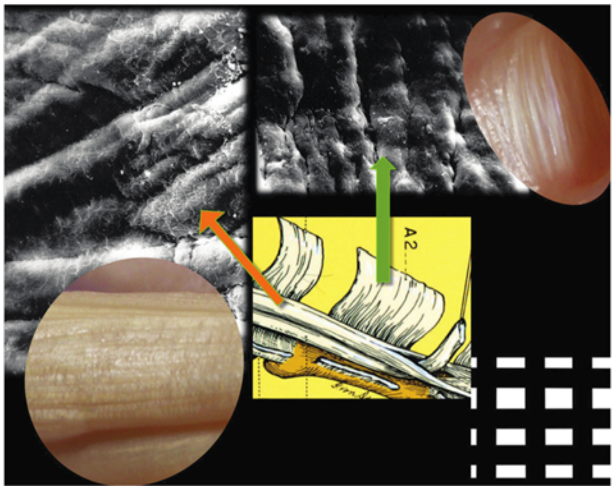
The tendon of the FDP passes through the area of the Camper's chiasma and after exiting the fibrous sheath distal to the distal interphalangeal joint. The shape of the FDP tendon changes throughout. At the level where the FDS passes around the FDP, the tendon narrows. On reaching the PIP joint, the tendon widens again. The tendon narrows to pass through the A4 pulley and then fans out on reaching its insertion at the terminal phalanx. There is a groove on the palmar part of the central portion of the FDP tendon. This groove seems to start at a random point on the tendon and deepens as the tendon goes distally. Nearing its insertion the tendon almost splits into two halves.

There is considerable morphological difference between a loaded and unloaded palmar portion of the FDP tendon. The fiber direction changes from wider treads in the unloaded position to narrower treads in the loaded position. This change in fiber configuration has been compared to treads on modern vehicle tires helping to channel synovial fluid towards the edges.

This arrangement along with the general collagen arrangement on the palmar aspect of the FDP and the dorsal surface of the annular pulleys have led to the postulation of a "synovial pump" that helps to push synovial fluid into the volar aspect of the tendon thus nourishing it. Scanning electron microscopy has shown that the collagen arrangement on the palmar aspect of the FDP is longitudinal whereas the collagen arrangement on the deeper surface of the annular pulley is transverse. In the loaded finger, when the two



surfaces interact closely, they form a crisscross latticework that traps synovial fluid and forces that fluid onto the palmar surface of the tendon .

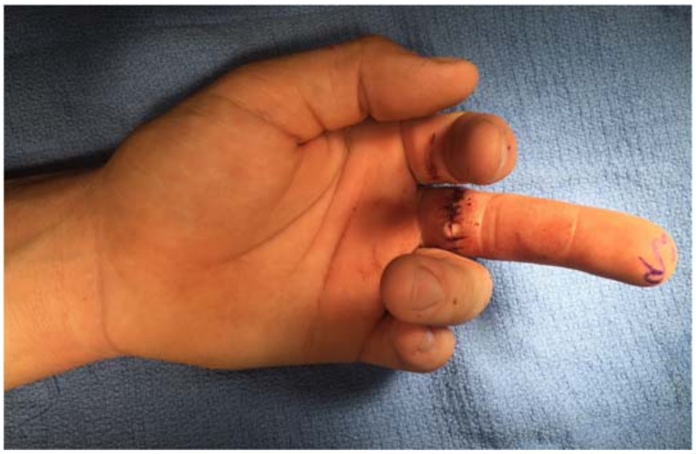


For many years, considerable conjecture has been expanded on the relationship between the FDS and the FDP tendons and the role of the bifurcation and coming together of the FDS around the FDP. One of the oldest hypotheses is that the bifurca forms a pulley like sling to constrain the FDP to the proximal phalanx thus increasing its efficiency. The other hypothesis is that the bifurca and chiasma form a frictionless tunnel for the FDP. There is an argument based on the fiber arrangement of the chiasma that the FDS at the bifurca and chiasma acts like "Chinese finger trap" on the FDP tendon. It may add to the FDP pull or it may play a role in the synovial fluid circulation and tendon nutrition.

III. Patient history and physical examination

As with any injury a proper history should be obtained with any hand injury. In particular with flexor tendon injuries, laceration are common and it is important to understand the mechanism. Patients may reports numbness in the digits which should raise concern for neurovascular injury. The object causing the laceration should be noted and depending on the object it may require a tetanus booster. The location of the laceration should also be noted because it will impact healing potential. Another mechanism of injury is a forced extension of a flexed digit.

The first step of physical examination. A finger with a flexor tendon injury will be found in an extended position in the resting position and not follow the normal cascade. Also the color and capillary refill shold be noted on initial inspection for possible vascular injury. If there is any doubt of vascularity, pulse oximetry and doppler can be used as adjunts in the examination.



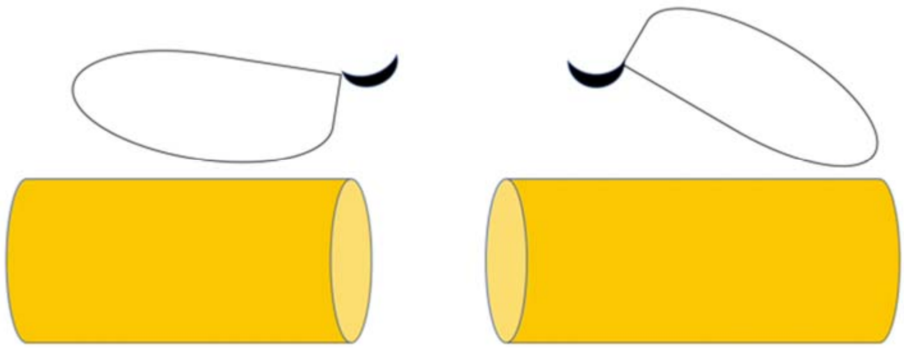
The flexor digitorum superficialis tendon can be tested in each digit while holding the remaining digits in extension whole asking the patient to flex the finger in question. Isolated flexion of the proximal interphalangeal joint should be seen. In the small finger the flexor digitorum superficialis tendon is often underdeveloped or undersized – comparison to the uninjured limb can help establish the expected baseline. The integrity of the flexor digitorum profundus tendon can be assessed by immobilizing the PIP joint and asking the patient to flex at the distal interphalangeal joint. Partial tendon injuries can be difficult to discern because pain may be a limiting factor.

Tenodesis effect can also aid in the diagnosis of flexor tendon injuries and is useful in obtunded patients. As the wrist is brought into extension and the fingers should fall into flexion. With a. flexor tendon injury, the finger will remain in extension.

IV. Surgical strategies

Initial management of the flexor tendon injuries depends on the vascularity of the digit. If the finger is perfused then the digit may irrigated with gross debris removed and closed. IF a partial tendon injury involving less than 50% of the tendon is seen then the patient may be allowed to undergo early mobilization. If the perfusion of the digit has been compromised then the patient should be taken promptly for vascular repair with tendon repair at the same time.

There are multiple configurations for suture repair of flexor tendons however there are a few overarching principles. Strickland described the fundamentals of tendon repair which include easy placement of sutures in the tendon, secure sutures knots, smooth juncture of the tendon ends, minimal gapping at the repair site, minimal interference with tendon vascularity and sufficient strength through healing to permit application of early motion stress. Strength of the repair is proportional to the number of core sutures. Core sutures. Should. Be placed about 10mm from the tendon edge. An



epitendinous suture is a peripherally based stitch that improves the biomechanical strength of the repair 10-50%, minimizes gapping and helps reduce the cross sectional area of the repair. It was first introduced by Verdan in 1960. A systemic review found that adding an epitendinous suture decreased rate of reoperation by 84%.

Knots are the weakest component of the construct and can be either internal or external within the repair site. Studies have shown that internal knots had decreased strength compared with external knots at day zero of the repair however 6 weeks after the repair there was no difference in tensile strength. There I also suggestion that internal. Knots may stimulate tendon healing. Locking loops also increase tensile strength by grasping the tendon and minimizing the sliding of the suture material through the tendon.

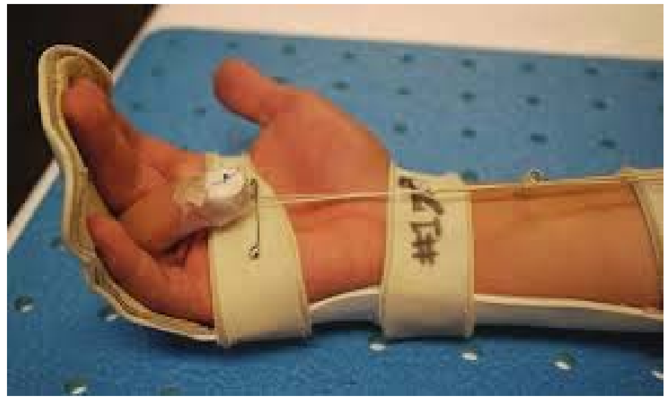
Different zones of flexor tendon injuries require different considerations. Zone I is defined as the region from the FDP tendon to the insertion of the FDS tendon and may be result of a laceration or an avulsion. In the case of the avulsion there may be a bone fragment from the distal phalanx which may or may not be attached to the flexor digitorum profundus. If the fragmnent is large enough screw fixation may be possible. If not K-wires may be used or the fragment may be re-approximated with the repair with pull out sutures. A pull out repair should be performed with a monofilament suture such as a 3-0 prolene and placed in a non-locking manner and then passed through the sterile matrix of the nail with keith needles and tiest over cotton and a button. Suture is removed at 6 weeks typically. If there is a laceration and the distal stump is at least 1cm in length then a direct repair may be possible.

Zone II is defined as the proximal aspect of the A1 pulley to the insertion of the FDS tendon. This zone historically has been difficult to management because of increased risk of adhesion formation, difficulty accommodating. Two tends in tight fibrooseeeous tunnel, catching and triggering of the repaired tendon under the A2 pulley and repair site ruptures from poor vascular supply. Repairs should be done ideally within 7-10 days to minimize contractures. An extensive exposure may be needed because the lacerated tendons can retract proximally to the PIP joint when the vinculum longus remains intact or into the palm where the lumbrical insertion distally into the extensor mechanism prevents it from going into the wrist. Bruner incisions should be used to avoid contractures. Repairs should be performed with at least four core strand sutures and an epitendinous suture to provide sufficient strength for early active motion protocols. Previous dogma emphasized the importance of the A2 and A4 in preventing bowstringing and often great lengths were taken to preserve these structures. Recent research has demonstrated the importance in gliding after repair and that venting of the pulleys to allow for gliding is acceptable and may not necessarily result in bowstringing.

Zone III extends from the distal aspect of the carpal ligament to the A1 pulley. Prognosis is better than zone II injuries because of the absence of the tendon sheath. Release of the A1 pulley may be needed to prevent impingement. Repair occurs in the same manner as zone II.

Zone includes the area within the carpal tunnel and zone V is the area proximal to the transverse carpal ligament and ends at the musculotendinous junction. Lacerations in this area may involve multiple tendons with damage to neurovascular structures. Release of the carpal tunnel may be necessary. If bowstringing is present the transverse carpal ligament may be need to be closed with Z-lengthening.

IV. Rehabilitation



After surgery patients are immobilized and protected with a forearm based dorsal blocking splint with entire hand position in the intrinsic plus position. Early mobilization is thought to help prevent adhesion formation, reduce edema and prevent joint contractures by increasing excursion. Early active protocol consists of place and hold flexion and active extension within a dorsal blocking splint and tenodesis exercises. Place and hold exercises begin 7 to 10 days postoperatively. Dorsal blocking splint is removed at about the 4 week mark. The Kleinert protocol involves attaches rubber bands to the

patient's fingers – the patient actively extends the fingers within the confines of the orthosis. Elastic bands passively flex the fingers to the palm. The modified Duran protocol involves a dorsal protective splint with 40-50 degrees of flexion at the metacarpophalangeal joint and 20 degrees flexion to 20 degrees extension at the wrist. The ROM protocol involves full passive flexion of the fingers followed by active extension. The Durant and Kleinert protocols have a decreased risk of rupture but decreased postoperative digit ROM compared with active motion protocols.