An Overview about Different Techniques of Flexor Tendon Injury Management

Alshymaa Saeed Hemada Abd Elaal, Mohammed Salah Awad, Mohammed Ali Nasr

Plastic and Reconstructive Surgery Department, Faculty of Medicine, Zagazig University

Corresponding: **Alshymaa S. H.Abd Elaal**; Email: alshymaasaeed@gmail.com

Abstract

The intrasynovial flexor tendon's healing capacity has been a topic of extensive investigations and discussion for several decades. Before 1970, the digital flexor tendon was widely accepted as lacking intrinsic healing capacity. In subsequent decades, however, the intrinsic tendon healing capacity came to light in a series of experimental studies that demonstrated observation of the repair process in lacerated flexor tendons within the synovial sheath, identification of cellular activity and the ability of in vitro tendon cultures to generate matrix. Flexor tendon injuries are open in most cases, resulting from a sharp cut or a crush, but they can also present as closed injuries. Acutely lacerated flexor tendons in the hand and forearm should be treated primarily or at the delayed primary stage whenever possible. The best outcomes of flexor tendon repair came if a skilled surgeon did so within hours. A non-experienced surgeon should not patch the tendon injured in sensitive areas (such as zone 2). The preferred delay period is 4–7 days when the risk of infection can be properly assessed and edema has significantly decreased. Delay of repair after 3–4 weeks can cause myostatic shortening of the muscle tendon unit. In these late cases, tendon lengthening within the forearm muscles may relieve tension. After surgery, rupture of the repaired flexor tendons can be re-repaired if the rupture occurs within a few weeks to a month after surgery. Secondary tendon grafts can be the only option for ruptured cases where there is evident tendon end retraction or significant scarring. A modified Kessler suture can be used instead of the traditional Kessler grasping suture. An advantage of this suture is that the knot is left in the cut surface of the tendon. One possible disadvantage is the difficulty of sliding the tendon on some suture materials to achieve satisfactory approximation of the tendon ends. Modifications described subsequently may minimize the problem of exposed suture material.

Keywords: Different Techniques, Flexor Tendon Injury

DOI: 10.53555/ecb/2023.12.Si12.343

A clinical examination and X-ray study of the involved hand is extremely important for recognition of all aspects of an injury that has resulted in disruption of the digital finger flexors. Careful consideration to the history of the patient and the injury mechanism will alert the surgeon to the severity of the tendon damage and related injuries **(1).**

Flexor tendon injuries are open in most cases, resulting from a sharp cut or a crush, but they can also present as closed injuries.

Ultrasonography and magnetic resonance imaging are also used for diagnosing closed rupture, late presentation (or) recurrent ruptures after repair. Preoperative localization of retracted tendon ends allows more efficient &less traumatic tendon retrieval. Postoperatively used to distinguish tendon adhesions from tendon rupture.

Ultrasonography

Noninvasive imaging technique that is accurate in assessing flexor tendon integrity and location of cut ends. It is less reliable in the diagnosis of partial tendon laceration & differentiating adhesions from pseudo tendon formation **(1).**

Ultrasonographers must have musculoskeletal experience and a sound knowledge of hand anatomy because ultrasound examination is operator dependent. Dynamic studies are possible with ultrasound **(1).**

MRI

Noninvasive imaging technique that allows multiplanar imaging. However, it is expensive, not always available and does not permit dynamic flexor tendon examination. For hand imaging, specialized coils are preferred. It may be more useful than ultrasound examination for assessment flexor tendon injuries in the wrist and forearm where tissue depth is greater. It can differentiate postoperative adhesions from ruptures with 100% accuracy while only 60% accuracy of clinical examination. Identification of pulley ruptures with resultant bowstringing is possible. MRI will also locate retracted tendon ends. It may also be useful in partial tendon lacerations and the differentiation of isolated adhesion & Tendon Rupture **(1).**

Closed injuries occur with forced extension during active finger flexion. Chronic attrition as in rheumatoid disease, Kienbock disease, scaphoid nonunion, and distal radius fracture can also cause flexor tendon rupture **(2).**

Open injuries due to extensive trauma are frequently associated with neurovascular deficits. Alterations in the normal resting posture of the digits will help identify the loss of continuity of one or both flexor tendons. Lacerations on the palmar aspect of the fingers will always injury the FDP before severing the FDS, but the absence of the FDP function alone does not rule out the possibility of a nearly complete FDS injury **(2).**

Careful sensory evaluation of the palmar aspect of the distal phalanx will allow the examiner to identify injuries to the digital nerves and plan incisions for their exposure and repair. A deep wound with lacerations of both digital nerves strongly suggests injury of the digital arteries as well. In this era of microvascular surgical competence, there is no excuse for not repairing one, or both digital arteries in these complex injuries **(3).**

Complete lacerations of both the FDP and FDS tendons can be identified by loss of active finger flexion at PIPJ and DIPJ when the affected fingers are seen in a relatively extended position. To assess the continuity of the FDS tendon, the examiner holds the adjacent fingers in full extension. If the patient is unable to actively flex the PIPJ the FDS tendon is severed completely **(2).**

Variations in the FDS tendons of the little finger are common. In 30–35% of the little fingers, the FDS tendons are connected with that is of the ring or middle fingers. FDS tendon is absent in 10–15% of the little fingers. These patients have minimal or no PIPJ flexion of the little finger during testing. Weakness during resisted finger flexion indicates a possible partial tendon cut. If the patient can flex the DIPJ with blocking the PIPJ motion, it suggests no or only partial injuries to the FDP tendon **(3).**

To test the FPL tendon, the thumb MCPJ is maintained in a neutral position. The patient is asked to flex the IP joint. Loss of active flexion at the joint indicates complete severance of the FPL tendon **(3).**

<u>Treatment of Flexor Tendon Injury</u>

Timing of Repair:

Tendon repair has been classified into

1. Primary repair: within 12 hours.

2. Delayed primary repair: after 12 hours and within 10-14 days (or) before healing of the skin wound.

3. Secondary repair: from 2 to 4 weeks

4. Late secondary repair: after 4 weeks.

Acutely lacerated flexor tendons in the hand and forearm should be treated primarily or at the delayed primary stage whenever possible. The best outcomes of flexor tendon repair came if a skilled surgeon did so within hours **(1).**

Strickland found that after 4 weeks, muscle fibrosis, tendon contraction and proximal tendon end swelling occurs, that disrupts tendon glide through the pulleys. No clinical investigations actually validated the best time for primary repair. A non-experienced surgeon should not patch the tendon injured in sensitive areas (such as zone 2). The preferred delay period is 4–7 days when the risk of infection can be properly assessed and edema has significantly decreased. Delay of repair after 3–4 weeks can cause myostatic shortening of the muscle tendon unit. In these late cases, tendon lengthening within the forearm muscles may relieve tension **(4).**

After surgery, rupture of the repaired flexor tendons can be re-repaired if the rupture occurs within a few weeks to a month after surgery. Secondary tendon grafts can be the only option for ruptured cases where there is evident tendon end retraction or significant scarring **(4).**

Operative Technique

Brachial plexus block is usually appropriate, general anesthesia can also be used in serious related injuries and in situations where the patient is not cooperative. Arms and hands are scrubbed and wrapped. A tourniquet is placed on the upper arm. The wounds should be debrided and cleaned with antibiotic solution, devitalized tissues then should be excised. The hand is usually kept by an assistant to be adjusted during surgery. Loupe magnification is recommended **(5).**

On planning for the surgical exposure, the surgeon must consider that the severed flexor tendon ends will retract away from the injury site. Particularly when the digit is in flexion at the time of injury, the distal stumps of the severed tendons will come to lie a centimeter or more distal to the level of sheath disruption **(5).**

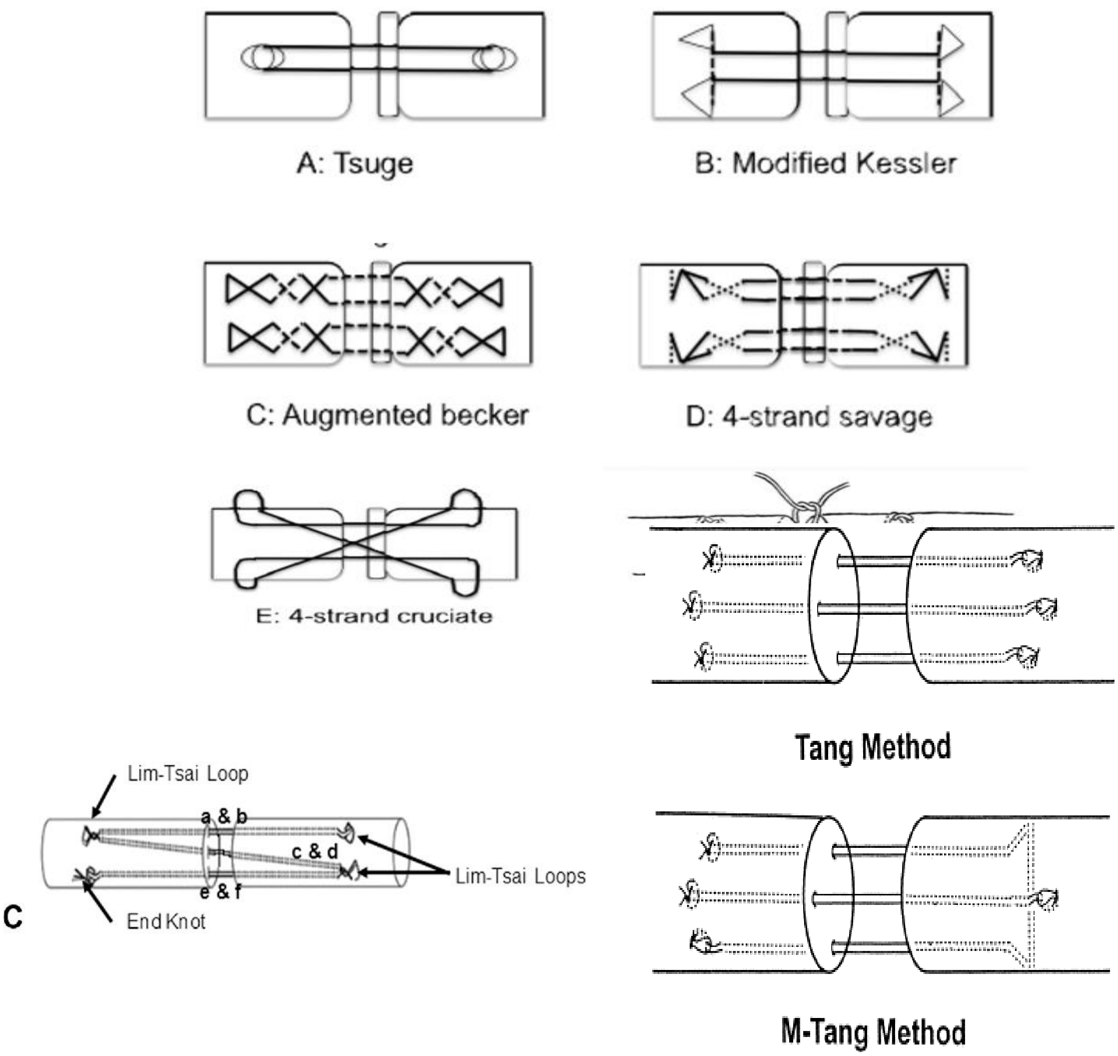
Although the incisions which should be used to expose the flexor tendons do not have a fixed rule, there is no advantage in attempting to perform these complicated repairs through existing unextended wounds or by small incisions along the length of the digit. Incisions should be selected that will not compromise the viability of skin flaps and that, when healed, will not create contracting or cosmetically ugly scars **(6)**

Brunner zigzag or midaxial incisions are often used, and the decision regarding which to use will be determined by the position, length, and direction of the original laceration, the need to gain access to the other injured structures, and the personal experience and preference of the surgeon **(6).**

Figure (1): Choices of incisions for exploring flexor tendon injuries, based on location of lacerations **(3).**

Surgical suture techniques vary among surgeons. The 2-strand modified Kessler method and Tsuge method are among the most widely used over the past 40 years.
Over the last 20 years a number of multistrand repair techniques have emerged, including 4-strand repairs such as cruciate, modified Savage, modified becker and Strickland; 6-strand repairs such as Savage, Lim-Tsai, Tang, M-Tang; and 8-strand repairs such as Winters – Gelberman methods.

Different multistrand suture techniques **(7).**
It is preferred to perform multistrand repairs, typically 4 or 6-strand repair methods when repairing lacerated tendons in zone 2 **(7).**
In the past 10 years, novel repair concepts have emerged and novel materials have been used. For example, new techniques involving a single needle passage carrying double or even triple strands into the tendon.



Fiber Wire also provides a strong suture material for tendon repairs. These methods are effective in enhancing strength with a minimal suture passage in the tendon **(8).**

Details of different techniques
Modified Kessler Suture
A modified Kessler suture can be used instead of the traditional Kessler grasping suture. An advantage of this suture is that the knot is left in the cut surface of the tendon. One possible disadvantage is the difficulty

of sliding the tendon on some suture materials to achieve satisfactory approximation of the tendon ends. Modifications described subsequently may minimize the problem of exposed suture material **(9).**

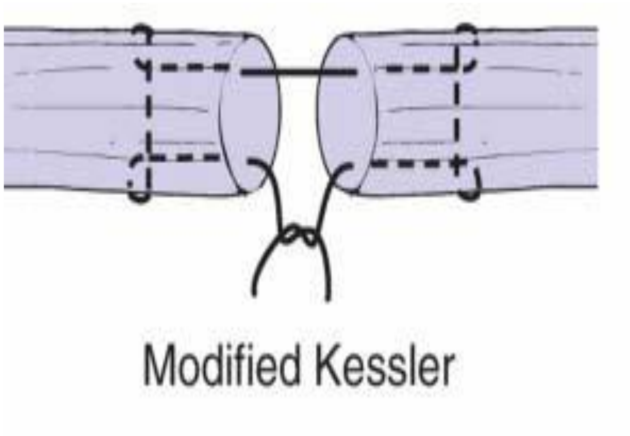


Figure (2): Modified Kessler suture technique **(9).**

Technique

• Move the needle through the cut surface of one side of the cut tendon and exit on the tendon surface.
• transfer the suture transversely, take up a small portion of the tendon substance, and exit on the opposite side.
• Move the needle through the cut surface to the other side of the cut tendon, then out and back with another locking maneuver to allow the suture to move through the cut surface.
• Tie the knot to the suture after sliding the tendon to allow approximation of the cut surfaces.

Epitendineous Suture

It is a method to augment repair site strength and to smooth the site of tendon repair. Diao et al have shown that there is some improvement in repair site strength by deepening the suture or by modifying the configuration. While circumferential suture can increase the repair site's initial and early postoperative strength, it remains an adjunct to the core tendon suture. In some cases, placing the circumferential suture first (at least in the most dorsal aspect of tendon repair) may facilitate tendon orientation and facilitate placing and tensioning of the core suture **(10).**

Closure of the synovial sheath is no longer considered essential for tendon repairs after debate in the 1980s and early 1990s. It is now agreed that avoiding compression or constriction to the edematous tendons by the sheath or annular pulleys after surgery is very important to tendon healing. With major pulleys and a majority of the sheath intact, leaving a part of the synovial sheath open has no significant adverse effect on tendon function and healing.

On the other hand, incision of a single annular pulley (A1, A3, or A4) or a vital portion (up to two-thirds of its length) of the A2 pulley does not affect the tendon gliding significantly when all other pulleys or the synovial sheath are intact. In addition, such a release can be helpful for tendon healing and gliding: as constrictions on edematous tendons are released **(4).**

When the repair is considerably delayed (3 weeks after injury), the A2 pulley usually collapses or is even embedded within scars. It is better to excise a portion of the A2 pulley to shorten this pulley.

The release usually needs to include a part of the adjacent synovial sheath. The total length of the sheath pulley release is about 2 cm in adults, which decompresses tendon gliding, but does not lead to functional disturbance **(4).**

Whether or how to repair the FDS tendon when both flexor tendons are injured is a subject of diverse opinions, particularly in the areas covered by the A2 pulley or distal to it. Few reports have discussed it specifically. Repair of one slip of the FDS is also feasible. In the area of the A2 pulley (zone 2C) it is advisable to remove the FDS locally in cases of extreme peritendinous damage, when the tendons appear edematous, and in cases of delayed primary repair. When performing the delayed repair, the FDS tendon in zone 2C is almost impossible to be repaired, since some degree of collapse or narrowing of the A2 pulley is unavoidable and tendons are always edematous **(4).**

In zone 2B, where the FDS tendon is bifurcated into two slips, better to use two Tsuge repairs separately in each tendon slip; when the laceration is close to the insertion, the tendon slips are anchored to the phalanx.

Treatment of the FDS tendon in zone 2D is straightforward, identical to that of the FDP tendon, except that the FDS is flatter and 4 or less strands are used **(11).**

In deciding surgical options relating to both the FDS and the pulleys, we seek to decrease the gliding contents appropriately (by not repairing or excising the FDS tendon) or enlarge the sheath (when both tendons are repaired primarily or only the FDP tendon is repaired at the delayed stage) **(4).**

The underlying idea is that the fibro-osseous digital flexor sheath tunnel is comparable to a tight fascial compartment of extremities; the edematous and healing tendons are easily compromised. The release of tendon compression to prevent overloading it during movement could be more vital to treatment success than having adequate surgical strength **(4).**

Brunelli and monini technique:

Brunelli and Monini described a technique which theoretically shifts the point of maximum stress from the tendon site to the tendon insertion site. The original technique of Brunelli and Monini consists in creating a slipknot using two needles 3–0 or 4–0 nylon monofilament suture. The needle enters transversally through the proximal stump at 1 cm proximal to the cut edge and as close as possible to the dorsal aspect of the tendon. Then, the needles reenter symmetrically the tendon 0.5 cm distally and exit through the cut edge. The needles enter the distal stump and run longitudinally to exit through the tendon insertion and finger pulp, where the suture is tied on a button. The stumps are maintained aligned by applying a 8–0 or 9–0 epitendinous running suture **(12).**

Modified Brunelli pull out technique:

The tenorrhaphy is done with a 3–0 monofilament nonabsorbable single needle suture (first modification of the original technique). The second modification in the Brunelli and Monini technique is represented by the distal approach of the suture insertion through the finger pulp, instead of beginning the suture at the proximal tendons' stump. The completion of the slipknot is similar to the original technique. After passing through the distal stump, the suture exists and is tied over on the finger pulp. The third modification is represented by using a 5–0 absorbable circumferential running suture **(12).**

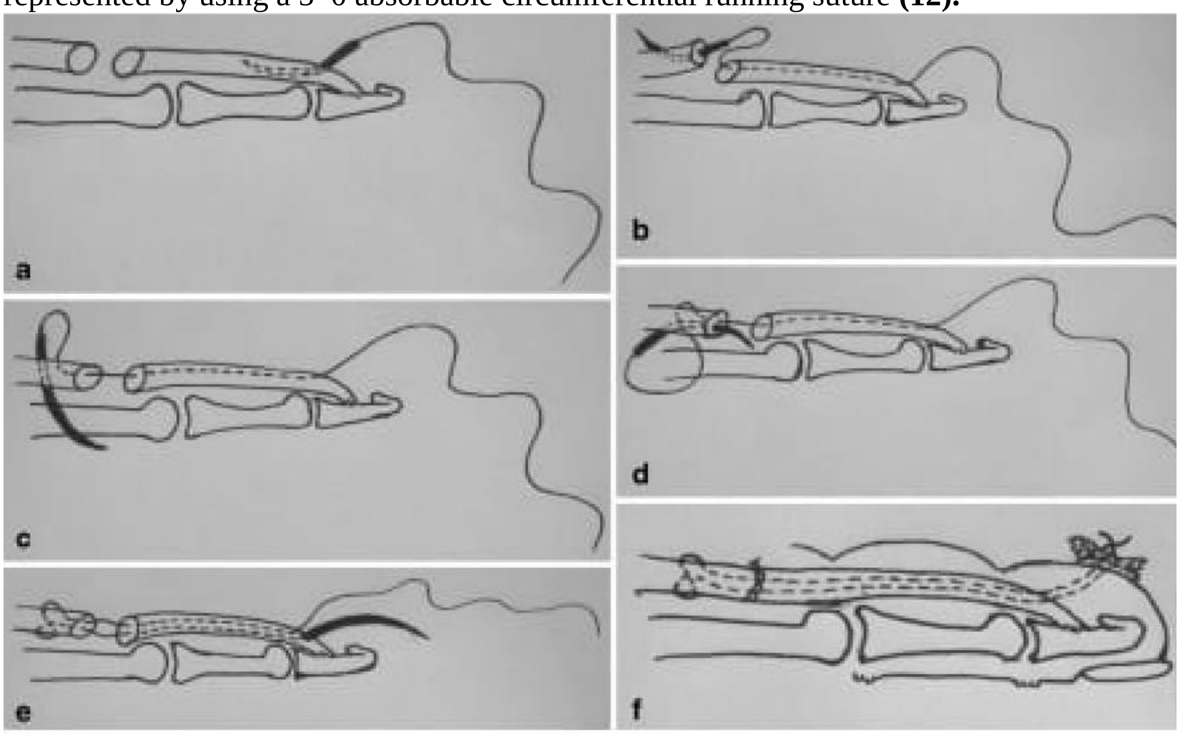


Figure (3): Modified Brunelli pull out technique **(12).**

Injuries in children

Flexor tendon repairs in children have a better prognosis than those in adults. As children may be less compliant with instructions to limit movement, the repaired digits are usually immobilized for 3–3.5 weeks after surgery. Elhassan *et al.* reported that early postoperative motion and immobilization did not affect outcomes in children aged 2–14 years with injuries in zones 1 and 2 **(13).**

Postoperative care

Immobilization program

Postoperatively, the immobilization program using total immobilization is the most conservative approach to rehabilitation after a flexor tendon repair. the immobilization program is suggested for the following reasons: children and adults who are unable to understand and proceed with a complex mobilization protocol, injuries related to the adjacent structures, such as fracture, and health conditions that affect tissue healing, such as rheumatoid arthritis.

Collins and Schwarze developed an early progressive resistance program for the immobilized repaired tendon. The immobilization cast or dorsal blocking splint positions the wrist and MCPJ in flexion and the IPJ in full extension. In general, the cast is removed after 3–4 weeks and is replaced by a dorsal blocking splint **(14).**

The patient begins passive flexion with the wrist held in 10° of extension and gentle differential tendon gliding exercises.

During this phase, the difference between the digital total active motion (TAM) and total passive motion (TPM) is evaluated. A 50° (difference indicates dense adhesion formation, which would lead the therapist to initiate early progressive resistance beginning with blocking exercises.

Figure (4): FDP and FDS blocking exercises **(14).**

At 4–6 weeks the dorsal protective splint is discontinued during the day, but the patient is advised to wear the splint when outdoors and during sleep for protection. Gentle active wrist and digital extension begins, together with blocking and fisting exercises. At this phase, if extrinsic flexor tightness is noted, a forearm based splint holding the wrist and digits in comfortable maximum extension is worn at night. Considerable

resistive training usually starts at 6–8 weeks. Timing and load strength of which depends on the extent of the adhesion formation **(15).**

Controlled motion programs

Studies have shown that early controlled forces applied to the healing tissues improve recovery of tensile strength, decrease adhesions, improve tendon excursion, and promote intrinsic healing. Controlled motion rehabilitation protocols have been developed mainly for flexor tendon repairs in zone 2 but are also used for zones I, III, IV and V **(10).**

Kleinert and Duran – Houser protocols were the most common from 1970 to the 1990s.The protocols have evolved and the methods presently used in many clinics are combined active and passive regimens **(10).**

The modified Kleinert method

In the 1960s, Kleinert and associates introduced a controlled active extension–passive flexion motion protocol that was popularized in the late 1970s and 1980s. The wrist was held in palmar flexed with a dorsal protective splint with 30–40° wrist flexion, 50–70° MCPJ flexion, and the IP joints are allowed full extension. Rubber bands are attached to the tip of the injured finger and secured to the volar forearm. Patients are allowed to extend the fingers actively and the fingers are brought back to flexion passively by the tensed rubber bands.

Kleinert method **(3).**

The elastic flexion pull acts as the repaired flexor tendon unit without flexor muscle contraction. Active extension of the digit is performed to the limits of the dorsal blocking splint. Because of flexion contractures at the PIPJ and loss of active DIPJ motion, two modifications became standard: a palmar pulley was added at the level of the MCPJ to improve DIPJ flexion, and at night the elastic traction is detached and the fingers strapped into extension within the splint to prevent PIPJ flexion contractures. In recent years, some surgeons have advised to abandon rubber band

Duran–Houser method

This is a controlled passive finger flexion protocol without traction of rubber bands using a similar dorsal protective splint. It was introduced by Duran and Houser in the 1970s **(16).**

The program was designed in response to their measurement that 3–5 mm of tendon glide would prevent restrictive adhesion in zone 2. Passive DIPJ extension with PIPJ and MCPJ flexion glides the FDP away from the FDS suture sites. Passive PIPJ extension with MCPJ and DIPJ flexion was found to glide both tendons away from the injury site.

A dorsal splint is applied with the wrist in 20° flexion, the MCPJ in 50° flexion, and the IPJ are allowed in full extension. Patients undergo 10 passive DIPJ extensions with PIPJ and MCPJ flexions and 10 passive PIPJ extensions with MCPJ and DIPJ flexions within the splint hourly through the first 4 weeks,. This protocol decreased the frequency of PIPJ contracture seen with Kleinert's rubber band traction.

Strickland and Gettle modified this protocol by adopting a Duran-like protocol, later known as the "Indianapolis method **(5).**

This protocol consists of two splints, **the dorsal-blocking splint** (used during periods of rest and passive motion, with the wrist at 20–30° of flexion, MCPJ in 50° of flexion, and IP joints in neutral position) and a **tenodesis splint** (used when performing place and hold exercise). The latter hinged wrist splint permits the wrist position to be varied between flexion and extension. With the tenodesis splint, the patient passively flexes the digits while actively extending the wrist. The patients passively push their fingers into a passive composite fist with the wrist extended and hold for 5 seconds. Then the patients relax the wrist and let it descend into flexion. Patients are instructed to exercise 25 times per waking hour. The tenodesis splint is removed four weeks after surgery, while the dorsal blocking splint remains and the patients are permitted active digital flexion and extension. A week later an active composite fist is added to the program followed by an active extension of the wrist and digits. When both flexor tendons are repaired in the digital sheath, the two tendons should be practiced for differential motion. Shifting finger postures from straight, hook, and fist positions generates differential gliding between the two tendons **(5).**

Early active motion

In the late 1980s and early 1990s, protocols containing early active tendon motion components emerged. One necessity is that the tendon repairs should be robust enough during motion to withstand stress. In 1989, the Belfast surgeons devised an active motion protocol, which was later known as the **"Belfast method." (17).**

Postoperatively, a splint is applied from the elbow to the fingertips with the wrist in mid flexion, the MCPJ at slightly less than 90° flexion, and the IP joints straight. The light dressing is removed from the digits, and exercises are begun 48 hours post-operative. The exercises, under observation, consist of two passive movements accompanied by two active movements and are conducted at intervals of 2 hours. During the first week, the PIPJ is actively flexed through about 30° and the DIPJ through 5–10°.

In subsequent weeks, the range of active motion is gradually increased. The splint is removed by the sixth week and IP joints blocking exercises are initiated. Variants of the Belfast method have been reported. In one of the variants – the **"Billericay regimen"** – the wrist and the MCPJ are kept in a splint at 30° flexion, and the splint is removed by the fifth week. The patient is instructed to perform 10 repetitions of the active finger flexion exercise hourly **(18).**

Mechanical properties of tendon (19).

As implied by its name derived from the Latin tendere, ''to stretch'' the tendon serves to conduct tension. The primary responsibility for this property is collagen: its stress – strain curve is virtually identical to tendon curve. The collagen structure of parallel fibers with strong crosslinks is ideal for tension bearing. The mechanical properties of the tendon can be illustrated by analysis of its stress–strain curve.

This curve consists of three regions: a toe region with the start slope, a linear region, and a failure region. The toe area, the initial loading step, is due to the uncrimping of collagen at the molecular level, and grossly to tendon tightening before stress sets in. For a given load (or stress) the linear region shows a constant elongation (or strain). This slope, or ratio of stress to strain, represents a fundamental property of tendon: its Young's modulus of elasticity. The final region includes areas of irreversible changes, including the yield point (the point at which the material begins elongating with a decrease in load) and the failure point (the point at which the material's integrity breaks down). Ultimate strain, the deformation at which the material fails, has been calculated to range in human tendon as an increase of 9%–35% of initial length **(19).**

Simple linear analysis of tendon mechanics neglects its rate and time-dependent properties, most importantly its viscoelasticity. The two main parameters of viscoelasticity are creep and stress relaxation. Creep is the time-dependent tissue elongation under a constant stress characterized by an initial large elongation followed by elongation in smaller amounts. *Stress relaxation* is the concomitant decrease in load exhibited as the tissue is subjected to constant elongation. Monleon et al studied the viscoelastic behavior of flexor tendons in the hand and reported their viscoelastic relationship, with the stress-strain relationship **(19).**

The viscoelastic properties of the tendon can be visualized using a diagram in which the elastic property is represented as a spring, with displacement directly proportional to force, and the viscous property as a dashpot, which increases

The mechanical behavior of tendon changes over the course of repeated loads. During cycling, there is a tendency for creep to continue elongating the tissue and, during unloading, for friction to prevent the tissue from returning to its original length. Over time there is progressively less difference between the successive amounts of elongation. There is a disparity between the upswing (loading) and downswing (unloading) of each cycle. This area between the limbs of the cycle is termed hysteresis and represents the energy absorbed by the tissue within each cycle **(19).**

Various other behavioral, physiological and pathological factors may affect the mechanical properties of the tendon. Exercise promotes collagen synthesis and influences the length of collagen fibrils, increasing the tendon's strength **(20).**

Animal experiments have shown that exercise results in an increased concentration of collagen, increased tendon weight, increased maximum stress and decreased maximum strain. While the long-term effects of exercise on the tendon appear to be positive, patients may develop periods of weakness during training which require rest to allow the tendon to adjust morphologically **(21).**

Similarly, stress-shielding experiments have shown that immobilization periods lead to decreases in the tendon modulus of elasticity and tensile strength; the longer the duration of the immobilization, the greater the decrease **(22).**

Patient age also may contribute to tendon quality. Tendon cross-sectional area increases until skeletal maturity; consequently, the elastic modulus of tendon is highest at maturity and declines in old age **(23).**

The crimp angle also decreases with age, reflected by a decrease in the toe region of the stress–strain curve. Aging is accompanied by decreased tendon collagen, proteoglycan, and water content, resulting in the tendon becoming smaller, weaker, and more prone to injury **(20).**

Disease states such as diabetes affect tendon health. One in vivo study showed a glucose induced increase in collagen cross linking. Compared to normal tendon, the tendon treated with a glucose solution showed an increase in maximum load, elastic module, energy to yield, toughness and significantly less deformation than the control subjects **(24).**

The effect of external modalities used to augment tendon healing has been evaluated in several animal models with varying results. Studies of healing rabbit tendons reported increased strength using ultrasound and electrical stimulation **(24).**

Similar studies were performed on chicken tendon using pulsed electromagnetic fields reported decreased strength and increased peritendineous adhesions **(25).**

.

References

1. Kannan N. (2009): "Prognostic indicators affecting functional outcome in Zone 2 flexor tendon repairs." PhD diss., Stanley Medical College, Chennai; 25-27.
2. Shapiro LM and Kamal RN. (2020): Evaluation and Treatment of Flexor Tendon and Pulley Injuries in Athletes. Clin Sports Med; 39:279-97.
3. Neligan PC. (2013): Plastic surgery hand and upper extremity. 3rd ed. Vol 6. London, New York: Elsevier Saunders; 179.
4. Tang J, Amadio P, Guimberteau J and Chang J. (2012): Tendon Surgery of the Hand. 1st ed. Philadelphia, Pa. Saunders Elsevier; 240.
5. Strickland JW and Cannon NM. (1993): Flexor tendon repair: Indiana method. Indiana Hand Center Newsletter; 1:1-9.
6. Taras JS, Skahen JR, James R, et al. (1996): The double-grasping and cross-stitch for acute flexor tendon repair: applications with active motion. Atlas Hand Clin; 1:13-28.
7. Allam MW, Bahaa El Din A, Abdel Latif EA and Khater AM. (2020): Comparative Study in Primary Repair of Flexor Tendon Injuries Between Two Strands Tendon Repair and Four Strands Tendon Repair. EJPRS; 44:217-21.
8. Griffin M, Hindocha S, Jordan D, Saleh M and Khan W. (2012): Suppl 1: An Overview of the Management of Flexor Tendon Injuries. Open Orthop J; 6:28.
9. Terry CS and James H. (2008): Campbell's Operative Orthopaedics, 11th (ed.); Elsevier Health Sciences; 3854.
10. Boyer MI, Ditsios K, Gelberman RH, Leversedge F and Silva M. (2002): Repair of flexor digitorum profundus tendon avulsions from bone: an ex vivo biomechanical analysis. J Hand Surg (Am.); 27:594-8.
11. Paillard PJ, Amadio PC, Zhao C, Zobitz ME and An KN. (2002): Pulley plasty versus resection of one slip of the flexor digitorum superficialis after repair of both flexor tendons in zone 2: a biomechanical study. JBJS (Am.); 84:2039-45.
12. Georgescu AV, Matei IR, Capota IM, Ardelean F and Olariu OD, (2011): Modified Brunelli Pull-Out Technique in Flexor Tendon Repair for Zone II: A Study on 58 Cases. HAND; 6(3):276- 81. doi:10.1007/s11552-011-9345-5).
13. Elhassan B, Moran SL, Bravo C and Amadio P. (2006): Factors that influence the outcome of zone 1 and zone 2 flexor tendon repairs in children. J Hand Surg (Am.); 31:1661-6.
14. Collins DC and Schwarze L. (1991): Early progressive resistance following immobilization of flexor tendon repairs. J Hand Ther; 4:111-6.
15. Sueoka SS and LaStayo PC. (2008): Zone 2 flexor tendon rehabilitation: a proposed algorithm. J Hand Ther; 21:410-13.
16. Duran RJ and Houser RG (1975): Controlled passive motion following flexor tendon repairs in zones 2 and 3. JAAOS: Symposium; 105–14.
17. Small JO, Brennen MD and Colville J. (1989): Early active mobilization following flexor tendon repair in zone 2. J Hand Surg (Eur.); 14:383-91.
18. Elliot D, Moiemen NS, Flemming AF, Harris SB and Foster AJ. (1994): The rupture rate of acute flexor tendon repairs mobilized by the controlled active motion regimen. J Hand Surg (Eur.); 19:607-12.
19. Pradas MM and Calleja RD. (1990): Nonlinear viscoelastic behaviour of the flexor tendon of the human hand. J Biomech; 23:773-81.
20. Patterson-Kane JC, Wilson AM, Firth EC, Parry DA and Goodship AE. (1998): Exercise-related alterations in crimp

morphology in the central regions of superficial digital flexor tendons from young thoroughbreds: a controlled study. Equine Vet J; 30:61-4.

21. Lin TW, Cardenas L and Soslowsky LJ. (2004): Biomechanics of tendon injury and repair. J Biomech; 37:865-77.

22. Yamamoto E, Hayashi K and Yamamoto N. (2000): Effects of stress shielding on the transverse mechanical properties of rabbit patellar tendons. J Biomech Eng; 122:608-14.

23. Cherdchutham W, Becker CK, Spek ER, Voorhout WF and Weeren PR. (2001): Effects of exercise on the diameter of collagen fibrils in the central core and periphery of the superficial digital flexor tendon in foals. Am J Vet Res; 62:1563-70.

24. Gum SL, Reddy GK, Stehno-Bittel L and Enwemeka CS. (1997): combined ultrasound, electrical stimulation, and laser promote collagen synthesis with moderate changes in tendon biomechanics. Am J Phys Med Rehabil; 76:288-96.

25. Robotti E, Zimbler AG, Kenna D and Grossman JA. (1999): The effect of pulsed electromagnetic fields on flexor tendon healing in chickens. J Hand Surg (Eur.); 24:56-8.