



UPDATES IN FLEXOR TENDON REPAIR AT ZONE II

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ABSTRACT

This article reviews the history and current management concepts of flexor tendon lacerations. Classic and contemporary repair techniques are discussed. The most popular rehabilitation protocols are also reviewed.

KEY WORDS: Flexor tendon, injury, surgical repair

There was significant improvement in tendon repair over the last 20 years. Because of improvements in surgical technique, the material properties of suture, our understanding of the mechanisms of tendon repair and methods of aftercare, primary repair of flexor tendons has become the standard of care. Although results of primary flexor tendon repair have improved considerably there are still controversy about best methods of suture used and most effective postrepair protocol.

Current series often report good to excellent outcomes in 80 % of patients (1,2,3). In an effort to improve patient outcomes, researchers have recently focused on:

1. Improving the tendon strength at the repair site.
2. Decreasing tendon adhesions.
3. Increasing the motion at the repair site to improve tendon gliding and hand function.

IMPROVEMENT OF TENDON STRENGTH AT THE REPAIR SITE

According to current thinking, the aim of primary flexor tendon surgery is to use a method of repair which allows early movement without the repair rupturing, until such time as the healing tendon has sufficient strength to take over from the surgical repair. The primary problem is in bridging the enormous gap between the forces acting on flexor tendons during use (c. maximum 250N/25kg force) and the strength of the current repair techniques. At failure, older suture methods had a strength of 10 to 20 N (1-2 kg force), but newer designs achieve 50 to 80 N (5-8 kg force). In practice, lower loads are more relevant to the gap formation which restricts movement by allowing snagging of the repair on the tendon sheath edges. In the literature there is often quote the tensile force to produce a gap of 1 or 2mm at the repair site and an ultimate strength at which rupture occurs. In the clinical context, a gap is both deleterious to tendon gliding and to the final range of motion and power of the finger. How big a gap can be tolerated is not known but, probably, almost no separation is acceptable.

HISTORICAL OVERVIEW

Simpler core methods include the *Kessler repair* (Figure 1.) which was originally poorly described, and the Bunnell suture, which has been condemned as a cause of tendon ischaemia (Figure 2). Kleinert and his colleagues described a variant of the Bunnell repair (Figure 3.) which was quite different (4,5). Their report also included use of a peripheral running suture, the first of its type - and also introduced a new method of rehabilitation: three new variables in one study. Since the Louisville study, it has been difficult to consider core sutures without additional epitendinous suturing, and both ideas enjoy the multiple strand principle. Tsuge and his colleagues (6), offers an easy way of locking the suture and introducing two strands in one stitch (Figure 4.).

METHODS OF TENDON REPAIR WHICH INCREASE REPAIR SITE STRENGTH

CORE SUTURE

The goal of tendon repair is to accurately coapt the tendon ends using a suture method that is strong enough to allow a functional rehabilitation program. Believing that increased repair site strength allows early active digital range of motion and improved patient outcomes, numerous investigators have devised stronger tendon repair methods.

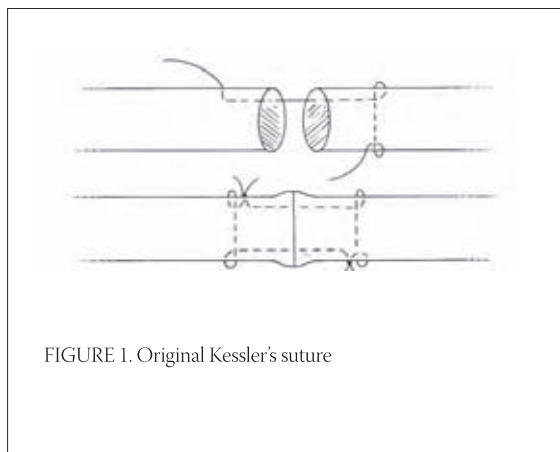


FIGURE 1. Original Kessler's suture

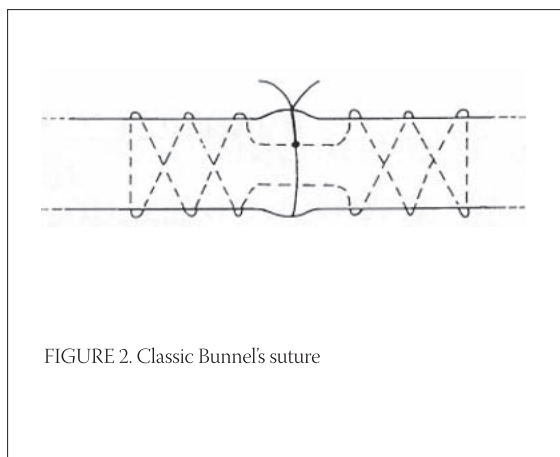


FIGURE 2. Classic Bunnell's suture

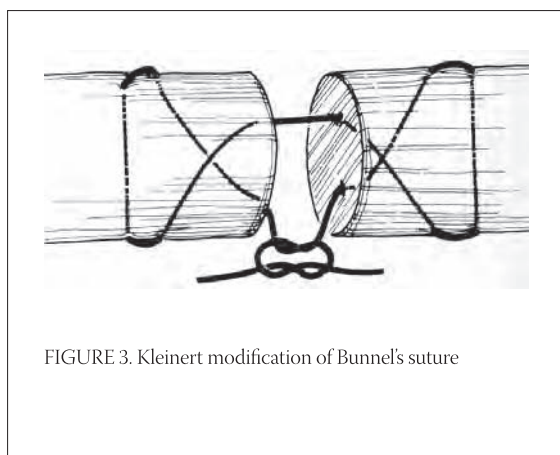


FIGURE 3. Kleinert modification of Bunnell's suture

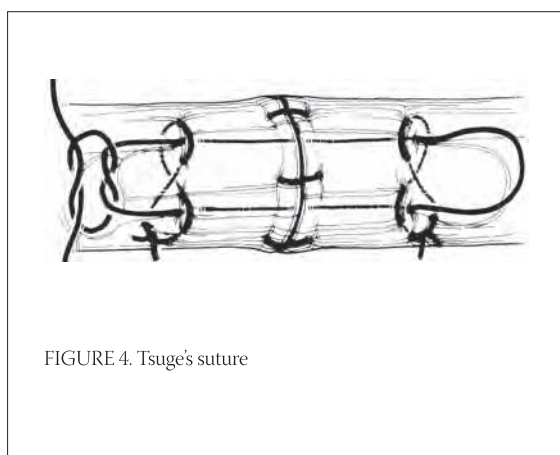


FIGURE 4. Tsuge's suture

Newer *multistrand*, *multigrasp* methods have been devised that are strong enough to allow rehabilitation programs that feature early active digital range of motion. *Strickland* uses combination of Tajima core suture and a matres core suture (7). This technique belongs to four strands suture (Figure 5a-d) Lim and Tsai six strands suture uses Supramed 4/0 as a suture material (Figure 6 a-h). In a study which was done by Gill et al. (8) it was shown significantly higher tensile strength than of Tsai six strand suture comparing to two strands (modified Kessler) and four strands (modified Tsuge). The 6-strand double-loop suture technique simplifies flexor tendon repair. It improves the repair's strength and its resistance to gapping without increasing tendon handling or bulk. This increased repair strength allows using a more aggressive rehabilitation program (1,2,3). The *Teno Fix* system, represents the first use of a surgical anchor system in soft tissue repair (9). Utilizing a small anchoring coil is inserted into a damaged tendon, gathering collagen fibers as it turns and harnessing the intrinsic strength of the tendon (Figure 7.). The system works by placing one anchor on each side of the repair site through a tenotomy 1,0 cm away from the cut edge. The tip of the preloaded installation instrument is placed into the tenotomy and the anchors are turned into tendon, in turn capturing collagen fibers. Although Tenofix system has been advertised as a very strong and secure, possibility of tendon rupture still exist. High costs of tendon repair using this technique, and fact that this system doesn't appear as much simpler as conventional techniques are reasons why it doesn't gain much popularity. This system is still in phase of initial clinical evaluation and no significant clinical experience has been cumulated yet to allow proper evaluation. Several investigators correlated repair site strength with the *gauge of suture*. Taras (10) and colleagues reported that 3-0 braided polyester sutures were 52 stronger than a 4-0 suture. These investigators conclude that significant increase in initial strength can be achieved simply by using larger suture caliber. Using a clinically relevant canine model, basic science investigators reporting on the gliding characteristics of multiple types of tendon suture methods found a significant improvement in gliding characteristics for suture methods with *internal placement*¹¹ of the suture knots and fewer external points of suture exposure. Chao et al. (12,13) found that *resection of one slip* of the FDS tendon significantly improved gliding resistance of the FDP tendon. The authors suggest that partial FDS resection may facilitate flexor tendon gliding beneath

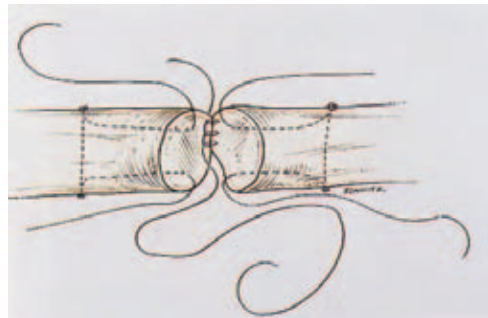


FIGURE 5a.

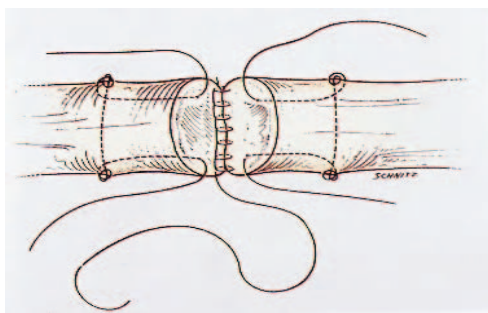


FIGURE 5b.

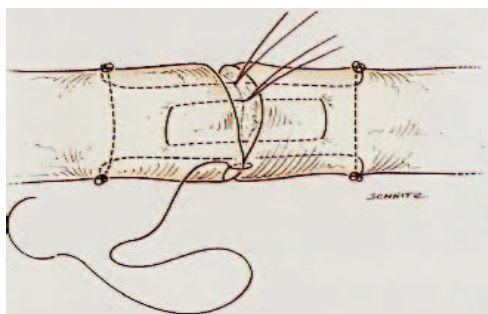


FIGURE 5c.

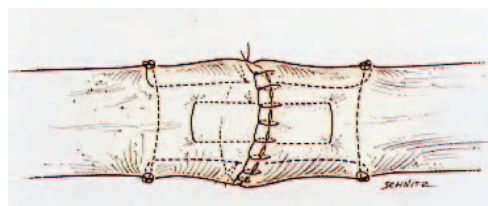


FIGURE 5d.

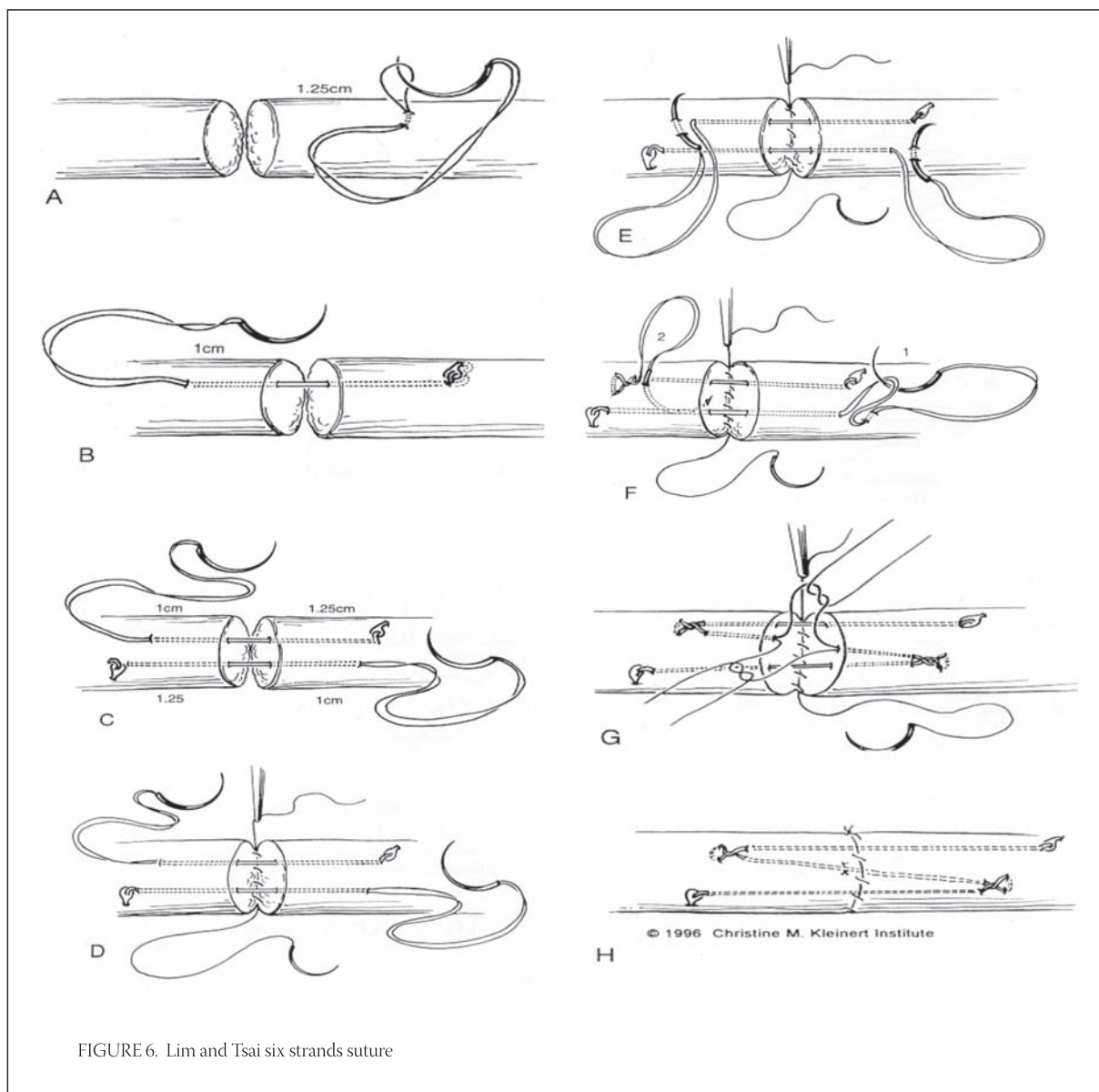


FIGURE 6. Lim and Tsai six strands suture

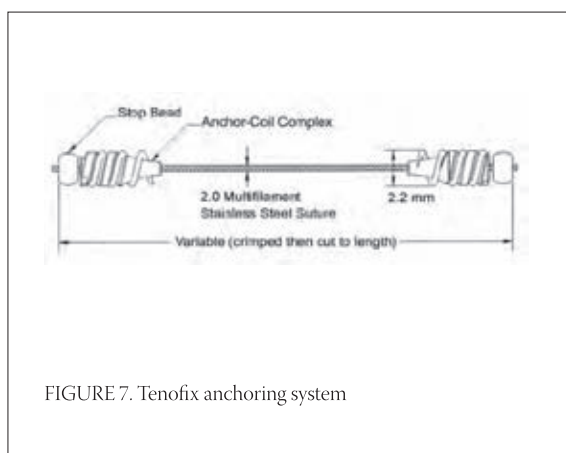


FIGURE 7. Tenofix anchoring system

the A2 pulley following tendon repair. Basic science investigators have also reported that increasing pulley size (*venting the pulley*) (14) by partial release improves gliding excursion and reduces resistance to motion.

Several basic science investigators have concluded that partial A2 pulley release can be done without significant loss of finger motion. Kwai Ben and Elliott reported a clinical study which employed a distal incision in the A2 pulley at the time of zone 2 flexor tendon repair. Prospective comparative trials which have focused on the effect of sheath repair have not demonstrated improvements in outcome for patients who undergo sheath repair (15,16). Current clinical recommendations are for careful intraoperative examination of the digit to ensure satisfactory tendon excursion through the pulley tunnels. Closure of the synovial sheath is no longer considered a necessity during primary flexor tendon surgery. A survey of the world literature shows that some hand centers prefer not to repair the sheath, while others advocate repair of the sheath whenever the initial injury allows. Comparison of the clinical outcomes after sheath repair with those in which the sheath was left

open shows identical results, as was reported by Saldana et al. (17) Despite the insignificance of closure of the sheath for finger function in this report, closure of the sheath in fresh, clean-cut tendon lacerations is not wrong and actually is still popular among hand surgeons. The most important aspect, however, that we should bear in mind is not to close the sheath in patients with sheath defects, fibrosis, or obvious tendon edema.

THE CIRCUMFERENTIAL SUTURE

The epitendon is the outermost layer of the tendon within the digital sheath. To use this layer for suturing a tendon seems practically impossible - one would always include some of the fibres from the tendon itself. Therefore, the concept of an epitendinous suture is not correct, as grasping only this superficial cell layer is impossible. A better terminology is to call this suture a circumferential suture, as it runs around the circumference of the injured tendon. Alternatively, it can be seen to grasp all sides of the circumference of the tendon. When *Kleinert* and co-workers⁴ presented their work they described the use of a simple continuous running circumferential suture to avoid bulging of the repair (Figure 8). In 1991, Pruitt et al. (18) showed the importance of the circumferential suture in preventing gap formation under cyclic stress testing. In 1994, Silfverskiold and Andersson (19) published their studies on a new type of circumferential suture which they named the "cross-stitch" suture (Figure 9). They described two configurations (see below) and found that the cross-stitch alone was as strong as a modified Kessler core suture with a simple circumferential suture. Since then variations of the cross-stitch has been tested in vitro and also have been compared to circumferential suturing with a *Halsted type* (Figure 10.) (20) of suture with somewhat conflicting results with respect to the final tensile strength.

CONFIGURATION AND STRENGTH

The simple running suture is the weakest circumferential suture but the quickest to perform. The cross-stitch described by Silfverskiold and Andersson and a circumferential suture using the Halsted configuration seems to be very similar in strength (19,20). The advantage of the cross-stitch technique is that need not be very exact in the clinical setting. Silfverskiold stated that the suture bite was placed 3 to 5mm from the cut edge. However, the addition of the cross-stitch totally eliminates the gap, making the repair smooth. While one can include as many cross-stitches across the tendon gap as one wishes, Kubota et al., (20) showed that a minimum of 4 strands increased the tensile strength.

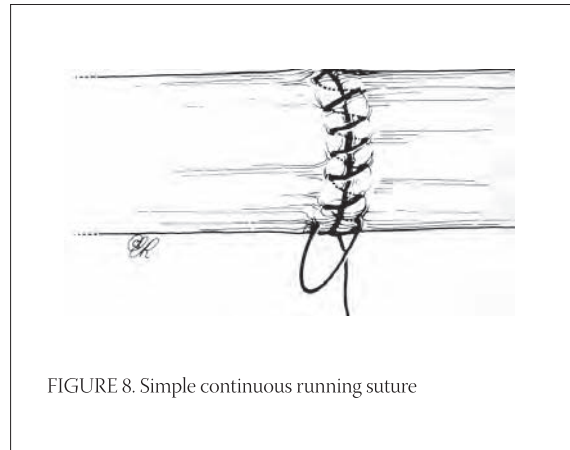


FIGURE 8. Simple continuous running suture

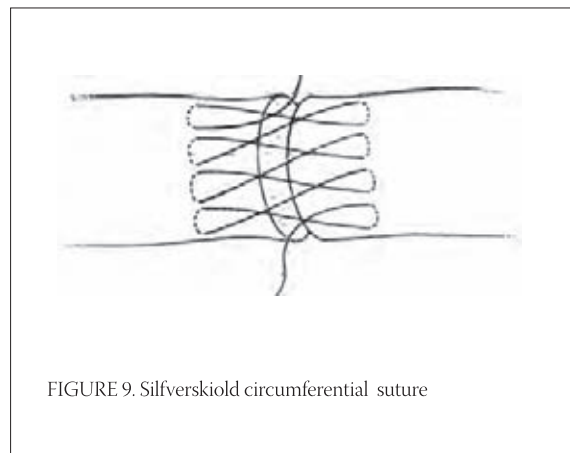


FIGURE 9. Silfverskiold circumferential suture

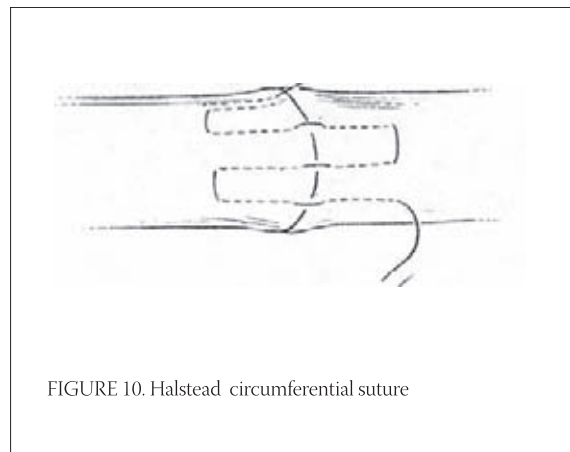


FIGURE 10. Halstead circumferential suture

In an ordinary tendon it is not difficult to include 4 or more strands. The disadvantage of the cross-stitch is that it may require a larger opening in the tendon sheath than is needed for a simple running circumferential suture. Another difficulty is performing the dorsal part of the circumferential suture in the region of A-4 pulley. Dorsally the surgeon has to negotiate the tails of vincula brevis, which we suggest to keep intact if possible.

DISTANCES AND DEPTH

The importance of the *distance* between the bites of the suture and the cut tendon surface has been studied

very little. Tang et al. (21) recently published a study on oblique tendon lesions and the importance of the placement of the core suture. They recommended that this distance is a minimum of 7mm. A corresponding study on circumferential sutures is lacking. Some authors do state the distance used in their studies and this varies from 3-5 to 6-8 mm. However, there is no study comparing the effect of variations of this distance on strength using the same material and configuration. Silfverskiold used a depth of 1 mm, which is a realistic figure (19).

METHODS TO LIMIT FORMATION TENDON ADHESIONS

Prevention of adhesions after flexor tendon surgery continues to be a significant focus for basic science researchers. Adhesion formation may be related to increase in cytokine concentration which upregulates injured and uninjured synovial sheath fibroblasts. Hyaluronic acid (HA) is a glycosaminoglycan that has previously been found to be present in the normal fluid of the synovial sheath. Histologic studies of the annular pulleys have demonstrated that the cells responsible for the generation of hyaluronic acid are the cells of the inner lamina of the pulley. Previous basic science studies have suggested that hyaluronic acid may limit adhesions formation following zone 2 flexor tendon repair (22,23). Recent investigators reported in a basic science study involving chickens found that an HA membrane applied circumferentially around the tendon repair site inhibited the formation of restrictive peritendinous adhesions (24). Hyaluronic acid limits the inflammatory response associated with flexor tendon injury and limits peritendinous adhesion formation without adversely affecting tendon repair. The insertion of polyvinyl alcohol shields (PVA) have been proposed as a method for limited peritendinous adhesion formation following flexor tendon repair. The material is thought to be effective by limited cellular survival on the surface of the membrane. The material is semi-permeable allowing passage of synovial fluid nutrients to the tendon repair site. Kobayashi and colleagues (25) have reported a basic science study evaluating the effect of PVA shields on tendon repair and the formation of peritendinous adhesions. They reported that PVA shields are effective in limiting peritendinous adhesion formation but are associated with a significant rate of repair site rupture and a decrease in repair site strength. Adcon T/N is an anti-adhesion barrier that is a re-

sorbable gel, composed of gelatin and a carbohydrate polymer. The application of this biomaterial has been shown to have some value in clinical studies (26). Golash et al. (27) reported in a prospective randomized study of an anti-adhesion barrier gel (ADCON T/N). In a prospective double blind randomized study, the application of one tube to ADCON (3.5gm) was followed by sheath closure at the time of flexor tendon repair. While the authors reported some benefit in sense of shorter period to achieve final range of motion from the application of ADCON T/N, a statistically significant improvement in function for the group treated with ADCON T/N has not been found. 5-Fluorouracil has also been proposed as an agent to diminish peritendinous adhesion formation following tendon repair. In an animal model Augustine et al. (28) that single dose only decrease significantly synovial reaction and postoperative technique (one touch technique). In two recent studies, tendon healing was not adversely affected by the application of 5FU. The application of 5FU was associated with fewer peritendinous adhesions but was not associated with an increased risk for tendon rupture (29). Investigators reporting an in vitro study of tendon cell proliferation and matrix metabolism concluded that certain non-steroidal anti-inflammatory medications can limit components of matrix metabolism for tendon explants. Kulick et al. (30) found that ibuprofen selectively increase intratendinous inflammation while minimizing peritendinous scarring. It is thought that TGF- β 1 contributes to the pathogenesis of excessive scar formation. In a rabbit model, Chang et al. (31) showed that intraoperative infiltration of neutralizing antibodies to the TGF- β 1 diminishes scar and adhesion formation.

METHODS THAT INCREASE MOTION AT THE REPAIR SITE TO IMPROVE HAND FUNCTION (REHABILITATION)

EARLY PASSIVE MOBILIZATION

If applied with care, early passive mobilization (starting within a few days of the repair) has been shown to produce superior results, apparently because early mobilization inhibits restrictive adhesion formation, promotes intrinsic healing and synovial diffusion, and produces a stronger repair site. Moreover, early passive motion prevents the decrease in tensile strength of repairs when compared to immobi-

lized tendons as reported Duran and Houser (34). There are two basic types of early passive mobilization protocols based on the work of Kleinert (32) and on that of Duran and Houser (34). Each protocol has many variations on these two approaches described in literature. In both approaches, a forearm-based dorsal blocking splint, applied at surgery, blocks the MP joints and wrist in flexion to place the flexor tendons on slack, and the IP joints are left free or allowed to extend to neutral within the splint. Dynamic traction maintains the fingers in flexion to further relax the tendon and prevent inadvertent active flexion. It may be provided by rubber bands, elastic threads, springs, or other devices. The traction is applied to the fingernail either by placing a suture through the nail in surgery or by gluing to the fingernail a dress hook, Velcro, a piece of soft leather or moleskin.

KLEINERT PROTOCOL

Since the publication by Kleinert (32) of his early mobilization regimen in the 1960s, this method has been that favoured throughout USA and Europe, although its popularity in the UK has fallen. Despite some centres producing very good results using “**Kleinert traction**”, many considered the original regimen to have significant problems both in terms of achieving poor distal interphalangeal (DIP) joint flexion and causing flexion contractures of the proximal interphalangeal joint (PIP). Modification of the regimen by adding a palmar pulley was introduced to improve DIP flexion. Strictly speaking, the regimen should be called an active extension/assisted flexion regimen rather than an active extension/passive flexion regimen. The original protocol is no longer used as originally described. More recent adaptations are summarized as following.

Early stage (from 0 to 3 weeks)

In the original Kleinert protocol, the dorsal blocking splint blocked the wrist in 45 degrees of flexion and the MP joints in 10 to 20 degrees. Rubber band traction was directed to the fingernail from the wrist or just proximal to the wrist. Every hour, the patient actively extends the fingers to the limits of the splint 10 times, allowing the rubber bands to flex the fingers.

Intermediate stage (from 3 weeks to 5 weeks)

The rubber band from the injured digit is attached to a wrist band from 3 weeks through 5 weeks. All active movement so the wrist and hand are encourage, although the injured digit is still tethered through 5 weeks. At five weeks, gentle active flexion may begin.

Late stage (starting at 6 weeks)

Resisted exercise begins. Several techniques have been described to help improve the total active range of motion.

Four-finger method. May et al. (33) describes an early passive mobilization protocol that is a variation of the Kleinert protocol they call the “four-finger” method. The dorsal splint extends only to the PIP joints to ensure that PIP extension is not limited, with the wrist at 30 – 45 degrees of palmar flexion, and the MP at 50 – 70 degrees of flexion. All four fingers are included in traction, even if not injured. A thicker rubber band is used to ensure maximum passive flexion, and manual pressure to all four fingers is used to attain the final degrees of passive flexion during exercise. Patients are instructed to use the uninvolved hand to decrease resistance from the rubber bands by pulling them distally during the active extension part of the exercises. The splint is removed at 4 weeks.

DURAN AND HOUSER PROTOCOL

The passive extension/passive flexion regimen of Duran (34) as originally described, is little used alone. However it is often combined with other regimes to increase PIP extension. Protected passive extension is the term often used, the proximal joints being placed in maximum flexion passively and the distal joints allowed to flex by tenodesis during passive extension of the affected joint.

Early stage (from 0 to 4.5 weeks)

The wrist is held in 20 degrees of flexion and the MP joints in a relaxed position of flexion. Duran and Houser determined through clinical and experimental observation that 3 to 5 mm of glide was sufficient to prevent formation of firm tendon adhesions; the exercises (6 to 8 repetitions twice a day) are designed to achieve this. With MP and PIP joints flexed, the DIP joint is passively extended, thus moving the FDP repair distally, away from an FDS repair. Then with DIP and MP joints flexed, the PIP is extended; both repairs glide distally away from the site of repair and any surrounding tissues to which they might otherwise form adhesions.

Intermediate stage (from 4.5 weeks to 7.5 or 8 weeks)

After 4.5 weeks, the splint is replaced with a wrist band to which rubber band traction is attached. Active extension exercises begin within the limitations imposed by the wrist band. Active flexion (blocking, FDS gliding, and fist-ing) is initiated on removal of the wrist band at 5.5 weeks.

Late stage (starting at 7.5 to 8 weeks)

Resisted flexion starts at 8 weeks. Blocking exercises are performed 4-6 times a day with 10 repetitions.

EARLY ACTIVE MOBILIZATION

Early active mobilization protocols are appropriate for alert, motivated patients who understand the exercise program and precautions. Clearly, whenever feasible, early active mobilization is preferable to early passive mobilization. The literature is growing rapidly (35,36,37,38) and contains a diversity of postoperative approaches. Based on studies indicating that early motion increases repair strength, most published protocols start motion at 24 to 48 hours after surgery. Halikis et al. (37), Gerard et al. (38) protocols use a dorsal blocking splint like those used for early passive mobilization protocols. Gerard also found (38) that early active motion doesn't compromise concomitant digital nerve injury regeneration.

BELFAST AND SHEFFIELD.

The most significant change in the last 15 years has been the advent of active flexion and extension regimes, following the work by Small et al. in Belfast (39). Variants of the Belfast regimen have now become the technique of mobilization used by the most units in the UK, less commonly in the rest of Europe, where it is only gradually becoming accepted and used. This method is the most cost effective in terms of materials and is more "user-friendly" for both patients and therapists although it appears, on first acquaintance, to have potentially more risk involved. In practice, however, this does not seem to be the case, with most units presenting rupture rates of around 5% which is the same rupture rate as those centers using Kleinert traction. Interestingly, non-compliant patients in the UK are often put back into Kleinert's traction.

Early Stage (Up to 4 to 6 weeks)

The postoperative splint maintains the wrist at 20-degree flexion and MP joints at 80 to 90 degrees of flexion, allowing full IP extension. The dorsal splint extends 2 cm beyond the fingertips to inhibit use of the hand. A radial plaster "wing" wraps around the wrist just proximal to the thumb to prevent the cast from migrating distally. On initiation of therapy, the postoperative dressing is debulked to allow exercise. Exercises, performed every 4 hours within the splint, include all digits and consist of two repetitions each of full passive flexion, active flexion, and active extension. The first week's goal is full passive flexion, full active extension, and active flexion to 30 degrees at the PIP joint and 5 to 10 degrees at the DIP joint. Active flexion is expected to gradually increase over the

following weeks, reaching 80 to 90 degrees at the PIP joint and 50 to 60 degrees at the DIP joint by the fourth week.

Intermediate Stage (Beginning at 4 to 6 weeks).

The splint is discontinued at 4 weeks if tendon glide is poor, at 5 weeks for most patients, or at 6 weeks for patients with unusually good tendon gliding (full fist developing within the first 2 weeks). Presumably, patients continue active flexion and extension exercises, and the program progresses from this point as it would for any tendon protocol, adding light resistance first attaining tendon glide, and then stepping up resistance (late stage) for strengthening, with full function expected by 12 weeks.

ACTIVE-HOLD/PLACE-HOLD MOBILIZATION (STRICKLAND)

This protocol introduced by Strickland (40) is an "active-hold" or "place-hold active mobilization" protocol. The digits are passively placed in flexion, and the patient then maintains the flexion with a gentle muscle contraction.

Early Stage (Up to 4 weeks)

A dorsal blocking splint is worn most of the time, with the wrist at 20 degrees of flexion and MP joints at 50 degrees. The exercise splint has a hinged wrist, allowing full wrist flexion, but wrist extension is limited to 30 degrees. Full digit flexion and full IP extension are allowed, but MP extension is limited to 60 degrees. Every hour, patients perform the Strickland version of modified Duran exercises (15 repetitions of PROM to the PIP and DIP joints and the entire digit) in the dorsal blocking splint, followed by 25 repetitions of place-hold digit flexion in the tenodesis splint. The patient extends the wrist actively with simultaneous passive digit flexion and actively maintains digit flexion for 5 seconds. The patient then relaxes and allows the wrist to flex and digits to extend within the limits of the splint.

Intermediate Stage (From 4 to 7 or 8 weeks)

Tenodesis splint is discontinued. Patient still wears dorsal blocking splint except for tenodesis exercises. The tenodesis exercises continue every 2 hours with 25 repetitions followed by 25 repetitions of active flexion and extension exercise for wrist and digits, avoiding simultaneous wrist and digit extension.

Late Stage (Starting at 7 to 8 weeks)

The splint is discontinued. Progressive resistive exercise is initiated. The patient gradually resumes activities of daily living, with no restrictions by 14 weeks.

CONCLUSION

The recent advances in zone II flexor tendon repairs a designed to increase the strength of the repair, provide safe and earlier range of motion exercises, reduce focal adhesions at the repair site and ultimately provide better function of the hand.

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