IFSSH Scientific Committee on Flexor Tendon Repair

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Trends in Flexor Tendon Surgery over the last 10 years

The results of flexor tendon repair in the hand have improved over the years, which is the result of a combination of improved surgical techniques and better rehabilitation. Further improvements may be on the way. Traditionally, to reduce muscle force on the repair, the wrist has been splinted in flexion after flexor tendon injuries. Now this practice has been called into question. There is debate about many details of technique. The central tenet of modern flexor tendon surgery is to repair and move divided flexor tendons within a few days of injury. The possibility of reducing the effect of adhesions on movement of the repaired tendon has been considered periodically but it remains to be proven whether, by drugs or other means, this can be useful routinely following flexor tendon repair. Like many other parts of hand surgery, when one looks more closely, one discovers that much that seemed fully understood is far from understood and what we have assumed to be based on hard fact often rests on opinion. Nevertheless, the results of flexor tendon repair in the hand have improved over the last twenty years, as a result of a combination of improved surgical techniques and better rehabilitation. This report examines trends in both.

Rehabilitation regimes

Splinting and wrist position

At the present time, flexor tendon repairs are mobilised by most surgeons in a dorsal blocking splint as an additional safeguard against tendon rupture, with a definitive dorsal thermoplastic splint being applied 24-72 hours after surgery, whatever the technique of rehabilitation. While the interphalangeal joints are invariably allowed to fully extend, the precise angles to which the wrist and MCP joints may extend in these splints vary from unit to unit. The degree of standardisation of splint construction possible in clinical practice probably belies such precision in print and the variability of the statements in the literature would suggest that the precise degree to which these joints are allowed to extend may not be of great significance. The degree of flexion of the wrist is probably less significant than previously believed. In an unpublished series of patients in Chelmsford/UK, 50 patients mobilised in the neutral wrist position had no increase in tendon ruptures with the same percentage of good and excellent results as this unit had reported previously with the wrist in the flexed position. Many units now splint the wrist in this position.

A paper presented to the American Society for Surgery of the Hand (ASSH) [1] compared the results of similar flexor tendon repairs, treated after surgery with splints that either did or did not immobilize the wrist. Both splints blocked finger metacarpophalangeal joint extension at 30°. Both passive and active finger motion exercises were performed by the patients while wearing the splints. At both six and twelve weeks after injury, the short-splint group had significantly ($p < 0.05$) better interphalangeal joint motion; at the twelve-week point, it was better by about 10°. Rupture rates were similar in the two groups. On the basis of this study, it may be reasonable to consider changing the traditional wrist-immobilization splinting regimen when treating patients with flexor tendon lacerations in the fingers. Peck et al [2] compared the outcomes of patients with uncomplicated zone II flexor tendon repairs who had been rehabilitated using either the traditional forearm-based splint or the Manchester short splint (splint with no wrist component). It demonstrated similar rupture rates between the two groups (short arm splint: 4.4% after 3 and 6 weeks; long arm splint: 3.9% after 1, 8 and 10 weeks) comparable to published levels using four-strand repair techniques and indicated that the use of a shorter splint appears to be safe for the rehabilitation of these injuries.

Time of Splinting

Whatever the method of rehabilitation, there has been relative consensus of opinion about the length of rehabilitation, although the source of the timing of the various stages of this assisted recovery is obscure. Whichever technique of early mobilisation is used, flexor tendon repairs are currently mobilised in dorsal splints with no active grasping with the fingers for 4-5 weeks. There follows a period of 3-4 weeks of gradual increase of activity with the splint only being worn at night and in public places, where the fingers might be accidentally pulled into extension. Full use of the hand for light activities and therapy to correct failures of finger extension begins only after 8 weeks, with heavy grasping activities being avoided for 12 weeks. Patients return to sedentary manual activities at 8 -10 weeks and to heavy manual labour at 12 weeks after surgery. Although suggestions of shortening of the period of splinting are sometimes aired in meetings, they have not yet appeared in print. An interesting finding of the recent unpublished work in Bern/Switzerland (see below) was that the ruptures occurred later following multi-strand repairs (average rupture time 47(range 24-80) days) than reported previously with two-strand repairs, after which rupture commonly occurred in the first four weeks [9]. While this may reflect particular aspects of management in this unit, it, nevertheless, should suggest caution over moving to a shortened splinting period and suggests a need for further investigation.

Many of the recent papers described how active motion protocols aim to increase early tendon excursion to prevent adhesion formation and to produce increased motion [3-7].

Active/passive Rehabilitation protocols and functional outcome

One review analysis [3] showed that in passive motion rehabilitation, the overall complication rate was 13%, with 4% from rupture and 9% from decreased motion. Active motion rehabilitation showed an overall 11% complication rate, with 5% from ruptures and 6% from decreased motion. Rupture rate in early active motion articles did not reveal statistical difference between 4-strand, 2-strand or 6-strand repair. Overall, there was not a statistically significant difference when comparing total complications between passive versus active protocols. However, while passive protocols had a statistically significant lower risk of rupture, they also had a significantly higher risk of decreased post-operative range of motion compared to early active motion protocols.

Trumble et al [4], who produced level I evidence directly comparing active place-and-hold therapy with passive motion. The study showed greater interphalangeal joint motion, significantly smaller flexion contractures, and higher patient satisfaction with early active motion without increased risk for repair rupture. They reported a 3% rupture rate.

Frueh et al [5] compared early passive mobilization (EPM) with controlled active motion (CAM) after a 4-strand flexor tendon repair in zones 1 and 2 in 159 digits. There was a statistically significant difference between the TAM values of the EPM (n=87; TAM 170°) and the CAM (n= 14; TAM 200°) protocols 4 weeks after surgery but not at 12 weeks (TAM 220°). Rupture rates were 5% (CAM) and 7% (EPM), which were not statistically different.

More recently, there has been some question as to whether early, limited arc active motion might have some benefit over place and hold exercise, but this has not been studied formally. Of the ongoing rehabilitation controversies, possibly the one most often discussed is which is the best of the active mobilization techniques today: Kleinert (active extension-passive flexion), now often amalgamated with that of Duran-Houser, or Early Active Mobilization (active extension-active flexion). If one looks at both techniques closely, one realizes that both are moving towards freer movement and both are pushing repairs ever harder during the early post-operative period, making this discussion an unproductive exercise. The questions begged by this trend to mobilise earlier and harder are how far we can go along this track without increasing the rate of tendon rupture and do we need to follow this path, rather than which is the best regimen for doing this. It also has to be borne in mind that many units repairing flexor tendons have insufficient therapists and are unlikely to acquire more in the current economic climate. Early active mobilisation is the cheapest and least therapist dependent method of rehabilitation. The papers published in this century increasingly report mobilisation by early active motion, which may reflect these economic benefits rather than any functional benefit.

Surgical Considerations

At the time of writing, there is no 'best' suture material or 'best' suture technique and the choice of each in anyone unit, country or area of the world is more often determined by opinion, historical precedence and availability of particular materials than by science.

Number of strands core suture techniques and functional outcome

The 'best' of core sutures still remains to be identified, with surgeons publishing their results during the last ten years following 4-strand or 6-strand core suture repair reporting an average of 5.4 (range 0-17)% repair ruptures. **(Table 1)** Critical analysis of the rupture rates in clinical papers written during the last twenty years fails to show a consistently significant reduction in rupture of repairs, despite the laboratory evidence that four and six strand suture techniques are stronger than two-strand repairs. Most reported series of primary flexor tendon repairs in zone 2 of the fingers, which has been the testing ground of flexor tendon surgery for fifty years, include a rupture rate of approximately 5%, whatever method of core and circumferential suturing is used.

A recent meta-analysis demonstrated no significant difference in rupture rates between 2-strand and multi-strand repairs. [6] This meta-analysis also showed a trend but no statistical significance that early active motion using a 4-strand core suture repair technique had a lower risk for rupture (2%) compared to those using a 2-strand technique (6%).

In another review [7], no difference in functional outcomes between 2- and multistrand core suture flexor tendon repairs could be shown. A comparison of 2-strand (755 digits vs 656 digits) versus multistrand (664 digits vs 145 digits) showed no significant difference in outcomes (Strickland Criteria group vs ASSH criteria group) The repair technique was also examined in zone 2 in the 2-strand repair group with modified Kessler (634 digits) versus other techniques (110 digits); no significant difference was found in either outcomes or rupture rate. There was a rupture rate of 3.9% (2-strand repair group: 4.3%, multistrand repair group: 3.2%). There was a trend for a lower rupture rate in the multistrand repair group but without statistical significance.

Even if rupture rates have slightly decreased over the last 10 years there remains great variation in results between different units, with some studies having higher rupture rates despite multistrand repair and other case series using two-strand sutures without any rupture. [8] (Table 1)

Table 1: *Flexor tendon repair studies from 2002-2014*

Reference	**Patients / Digits / Tendons, Zone II**	**CAM/Kleinert***	**Suture Repair (digits)**	**Outcome**	**Rupture rates**	**Comments**
Hatanaka H, 2002	6/7 tendons	Active mobilization,	FDP: 2-0 loop, epit. 6-0 FDS: 4-0 loop Tang, epit. 6-0; 2 strand	Strickland 86% good-excellent	1 (14%) after 6 weeks	
Klein L, 2003	35/40 tendons Zone I-III	Active motion, dorsal blocking splint, rubber band traction 5 weeks	Tajima, Kessler, Core 3-0/4-0, epit. 6-0; 4 strand	Strickland 95% good-excellent Zone II 88% goode-excellent Zone I,III	1 (2.5%) after 4.5 weeks	
Braga-Silva J, 2005	82/136 tendons	Active mobilization	Modified Kessler, 3-0, epit. 5-0; 2 strand	IFSSH and Strick-land criteria: Long fingers: 98% good– excellent (Strickland); 82% good (IFSSH)	5 (7.4% long-finger, 3.6% thumb) after 2 weeks	
Chai SC, 2005	8/15/28 tendons, only 25 repaired	Dynamic traction, passive motion	Supramid 6 strand (9); modified Kessler 2 strand(16)	Strickland 93% good-excellent	0	Multiple digits mixed results
Hung LK, 2005	32/46 : 24 in Zone II I,II,III,V	Early active mobilization: passive flexion, then active flexion	Modified Kessler— 4-0 nylon with 6-0 nylon epitendinous 2 strand repair	ASSH: 71% good–excellent in zone II	2 ruptures in zone II (8.3%) 6 weeks and 1 week after repair 1 rupture in zone III(4.5%)	
Su BW, 2005	67/85 29/34Tenofix 38/51 Control	Modified Kleinert, active Flexion at 4 weeks	TenoFix anchors, 2-0 stainless steel sut., epit. 6-0 (34); 3-0 cruciate, epit. 6-0 (51); 4-strand	Strickland: 67% good–excellent TenoFix 70% good–excellent control	TenoFix: 0 Control: 9 (17.6%) 6 weeks after repair	

Chan TK, 2006	16/21/31 tendons	3 wk active extension/passive flexion, 2 wk active flexion without resistance, 2 wk active flexion with resistance	FDP: modified Kessler—4-0 nylon with 6-0 nylon epitendinous FDS: horizontal mattress sutures 2-strand repair	Buck-Gramcko: 81% good-excellent	1 (4.8%) 1 week after repair	Multiple digits mixed results
Yen CH, 2008	20 patients	Active extension, active place-and-hold—10 patients Kleinert method—10 patients	4-0 Prolene core sutures plus 6-0 Prolene circumferential sutures 4-strand repair	Mayo Wrist Score: Active motion: 70% good–excellent Kleinert splint: 0% good–excellent	Active place and hold: 0 Kleinert splint: 1 (10%) 5 weeks after repair	
Hoffmann G, 2008	71/77	46/51 early active mobilization; 25/26 modified Kleinert's regimen	6-strand double loop polyamid (4-0), modified 2 strand Kessler suture 4-0 Prolene, both epit. 5-0 Prolene	Strickland: EAM: 39/50 good-excellent (78%) Mod.Kleinert: 9/21 good-excellent (43%)	EAM: 1/51(2%) Mod.Kleinert 3/26 (11%) between 4-8 weeks after surgery	28% vs 38% needed extension splints
Kitis A, 2009	192/263 digits	Group 1: modified Kleinert (Washington regimen)— 98/137 digits) Group 2: controlled passive movement (CPM)—94/126 digits	Modified Kessler— 4-0 nylon with 6-0 nylon epitendinous 2-strand repair	Buck-Gramcko: Group 1: 87% excellent total active movement, 89% grip strength, Group 2: 75% excellent total active movement, 81% grip strength,	Modified Kleinert: 0 CPM: 1 (0.8%) in second week after repair	Modified Kleinert: 16 extension deficits CPM: 26 extension deficits
Saini N, 2010	75 digits Zone II-V	Modified Kleinert's regimen and Silfverskiold regimen: active extension with initial active flexion and later passive flexion	Modified Kessler— 3-0 or 4-0 polypropylene core suture and epitendinous stitch 2-strand repair	Louisville: 82% good–excellent	2 (3%)	2 contractures (3%)

Trumble TE, 2010	103/119 digits	Passive motion—51 patients with 58 digits Active motion with place- and-hold—52 patients with 61 digits	FDP: Strickland method—2 core sutures of 3-0 polyester and 6-0 Prolene epitendinous FDS: simple Kessler with 3-0 polyester 4-strand repair	Strickland: Active motion: IP joint motion 156° ± 25°, 94% good–excellent Passive motion: IP joint motion 128° ± 22°, 62% good–excellent	Passive motion: 2 (3.8%) Active motion: 2 (3.7%) 3/4 ruptures in small digits	Six patients with multiple-digit injuries had overall worse outcomes in both groups
Bal S, 2010	31/78 Zone II (14/25) Zone V (17/53)	Modified Kleinert protocol	Modified Kessler— 3-0 Prolene with epitendinous 5-0 Prolene 2-strand repair	ASSH: 52% good–excellent in zone II 83% good–excellent in zone V	2 zone II (8%) 1 zone V (1.9%) after 4-8 weeks	
Sandow MJ, 2011	53/73 Zone I, II	Early active Mobilization; dorsal splint 20° wrist extension, 80° MCP flexion, IP joint 0° extension for 6 weeks, place and hold; buddy taping for 4 weeks	4-strand single cross grasp 3-0/4-0 polyester or 4-0 nylon or 4-0 polypropylene; epitendinous repair 5-0/6-0 nylon/ polypropylene	Strickland: 71% good-excellent, 34% fair, 15% poor	3 zone II (4.6%) after 2-4 weeks	Follow up 65/73 tendons
Starnes T, 2012	21/24 patients (sharp injuries) 13/17 patients (saw injuries)	Early active mobilization protocols (17/21 in the sharp group [81%]; 8/13 in the saw group[62%]); 5%/8% modified Duran protocol	4-strand core suture and epitendinous suture	Strickland: 30% good-excellent results in saw group; 46% in sharp group	0 in the sharp group 1 in the saw group (5.8%)	9/17 in saw group secondary surgery (3/24 in sharp group)
Frueh FS, 2014	132/159	Early passive motion (EPM): 138; Controlled active motion (CAM): 21 Dorsal splint in 10° wrist flexion, 40° MCP flexion, IP joint 0° for 5 weeks, then 3 weeks at night with active blocking exercise and passive flexion	85% 4-0/3-0 polyester braid; 4-strand; 15% 2-strand or 6-strand; epit. 6-0	ASSH: 54% good-excellent EPM 65% good CAM	EPM 10 (7%) CAM 1 (5%)	29 patients reoperated (tenolysis)

In a review by Elliot et al. [9] the rupture and re-repair rate was evaluated between 1989-2003. The decrease of the rupture rates has been seen to decrease in reports of more recent years, typically after 2005 but remained between 2-7%. [9] With increased repair strength, the rate of ruptures seem to occur later than in the review by Elliot. Our own experience (University Hospital Bern) in a recent unpublished series of 147 flexor tendon repairs between 2011-13 using a six strand repair and early active flexion protocol [10,11] with flexion of the wrist in 30° for 4 weeks demonstrated a surprisingly high rupture rate of 10%. The average of rupture time was at 46.7 days (24-80) after primary repair. (Table 2) In 3 patients, there was a history of a fall causing the rupture, 1 patient suffered from a connective tissue disease, while 6 times no rupture cause could be defined. In 6 cases the FDS tendon was resected (indicating perhaps a more difficult repair?). Eleven of the ruptured tendons had been treated with early active flexion protocol while 5 followed a classic Kleinert regime (active extension, passive flexion). Exceptionally, in 2 of 16 ruptures, a 4 strand and not a 6 strand repair was performed. This rupture rate is in contrast to another published series including 51 flexor tendon repairs with the same repair technique (6-strand Lim Tsai and epitendinous running suture) and an early active flexion protocol, which recorded a rupture rate of 2%. [10,11]

Table 2: *Rupture delay after primary repair from 1989-2003 in comparison to 2011-13*

Time after primary repair of rupture (weeks)	No of mechanical ruptures (Elliot 2006)	No of mechanical ruptures (Vögelin 2014, unpublished)
<1	8	-
1-2	23	-
2-3	11	-
3-4	8	1
4-5	6	1
5-6	2	4
6-7	2	2
7-8	1	1
8-9	1	-
9-10	-	1
11-12	-	1
Average (days)	18 (3-61)	46.72 (24-80)

Unpublished recent data from Chelmsford also suggests no improvement in rupture rate despite a move towards four and six strand core sutures. There is also some evidence that suture material has a deleterious effect on tenocyte activity and, hence, a possibility that increasing amounts of suture material increase this effect [12]. So, perhaps, we are, unwittingly, making tendon repair breakdown more likely as we put more foreign suture material into the tendon and simply putting in more complex sutures is possibly not the answer, or not the only answer.

Inserting these more complicated sutures may have another cost: they are more difficult to insert and make an already complicated procedure even more so. Bearing in mind that most primary flexor tendon surgery is carried out by trainee hand surgeons world-wide, this may prove a serious disadvantage to their use. An alternative approach has become increasingly popular in the Far East using a single suture repair with a looped double strand nylon suture. Tang and his colleagues [13] still could not avoid the inevitable small rupture rate in their early clinical study, but its simplicity at a time when the Western approach may be becoming too complicated.

Over the past 10 years, surgeons have reported good to excellent results in 80% or more of the tendons that underwent 4-strand or 6-strand core suture repair, with 0% to 17% repair ruptures, on average 5.4%. (Table 1) This period saw the first widespread use of multi-strand core suture repairs, but in most reports disruption is still seen after 5 weeks during early active motion. There are reports of no repair ruptures in some case series, but, despite all of the progress in surgical technique and rehabilitation protocols, the rupture rate has not disappeared yet. (Table 1) Nevertheless, most repairs are probably done currently with four-strand core sutures, although the literature in the last ten years includes more papers using two strand than multistrand repairs.

The Circumferential Suture

In the latter years of the last century, the tendon repair was commonly completed using a continuous circumferential over-and-over suture, usually of 5/0 or 6/0 monofilament nylon or polypropylene. This was originally introduced to tuck in ragged parts of the tendon edges to allow easier gliding. This is particularly so along the deep surface of the tendon repair after completing the core suture, especially in the tight confines adjacent to the A4 pulley. Placing sutures along the 'back wall' of the repair prior to completing the core suture, a technique commonly used with simple circumferential suturing to avoid bunching of the repair, is very much more difficult with the complex circumferential sutures. Although elaboration of the circumferential suture raised the possibility of dispensing with the core suture entirely, the pendulum of clinical activity has swung back more recently to increasing the core suture strength, with simple circumferential over-and-over suturing being the commonest finishing suture in current use.

The Sheath

The period of closing the tendon sheath completely has passed. The repaired tendons, which are inevitably greater in diameter than the original tendon, are more likely to suffer restriction of their free movement if the sheath has been closed. However, even with a policy of simply laying the sheath back, catching of some repairs on the main pulleys remains a problem. Elliot [14] and Tang [13] have pointed out that repairs snagging on pulleys treated by early mobilisation will either restrict movement of the finger or cause the repair to snap and suggested that judicious venting of the A2 and A4 pulleys is often necessary to achieve free movement of the repair. This does not allow bow-stringing of the tendons provided most of the sheath is intact [8,9]. Wide-awake surgery [15] makes this factor more obvious to the operating surgeon. In all tendon surgery, surgeons should consider the diameters of the pulleys and how the tendon fits inside them. It is crucial to always leave room to accommodate edema and swelling of the tendons which have undergone surgery.

An independent analysis which compared venting of the pulley system and early active mobilization in 114 digits with no venting and passive flexion-active extension mobilization in 335 digits showed a trend toward an improvement in the incidence of excellent outcomes in those fingers with appropriately vented pulleys, but this difference was not statistically significant. [7] The A2 pulley can be vented partly, up to 50% of its length, to allow tendon motion during tenolysis, provided that remaining elements of the sheath are intact (for proximal A2 release, the A1 pulley and for distal release A3). It appears as well that the A4 pulley can be safely vented, if the A3 and A5 pulleys are intact. [16] In all tendon surgery, surgeons should consider the diameters of the pulleys and how the tendon fits inside them. It is crucial to always leave room to accommodate edema and swelling of tendons that have been operated on. [7]

Improving the results of tendon repair by biological and biophysical interventions.

Investigators have studied the effect of added lubricants on reducing adhesion formation for many years [17-29]. Results have been inconsistent, perhaps related to the residence time of the lubricant preparation. Higher molecular weight formulations appear to have better clinical results in some studies, but not uniformly. Fixing a lubricant to the tendon surface has a large effect on reducing adhesions, but at the cost of delaying healing, at least in animal models. Adding stem cells within the repair site can to some extent reverse this problem, again in animal models, but there have been no clinical reports on the use of stem cells to aid flexor tendon healing [28]

Conclusions

Over the last 10 years, repair strength (4-and 6-strand repair) and newer suture materials (double loop polyester, supramid or tenofix) have been improved as well as active mobilization rehabilitation protocols including a change of wrist position by modification of splints to reduce the work of flexion during active flexion. Despite all of these modifications, tendon ruptures have not been eliminated, although they may seem to occur later, after 4-10 weeks, rather than at 2-4 weeks, as was often noted in past studies. This might suggest that the stronger repair may prevent earlier ruptures but raises the question as to whether stronger repairs and earlier mobilization may slow healing somehow, due either to the bulk of the multistrand repairs or to gapping that proceeds more slowly to rupture with a multistrand repair than it might with a 2-strand suture. The near future will show whether a change of wrist position and avoiding place and hold positions in the controlled active motion protocols will improve the results, or whether application of lubricants [29] will help to avoid gapping and rupturing of the tendons while maintaining full interphalangeal joint motion.

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Historical landmark references

Mason ML, Allen HS (1941). The rate of healing of tendons. An experimental study of tensile strength. Ann Surg 1941:**113**:424-59

- *The fundamental need to mobilise repaired flexor tendons early to avoid adhesion and loss of tendon gliding is now generally accepted, as is the fact that healing of the flexor tendon, at least in the digits, does not necessitate the formation of adhesions. Experimental evidence would also suggest that this early movement encourages more rapid tendon healing under the influence of longitudinal forces (Mason and Allen, 1941; Gelberman et aI, 1981).*

- *The principle of the core sutures in common use is that the suture grips the tendon at a distance from the cut ends to prevent the suture pulling through the tendon fibres when subject to longitudinal tension during mobilisation in the first few weeks after repair, at which time the tendon ends soften (Mason and Allen, 1941).*

Urbaniak JD, Cahill JD, Mortenson RA. Tendon suturing methods: analysis of tensile strengths. In Hunter JM, Schneider LH eds, Symposium on Tendon Surgery. St Louis: Mosby, 1975:70-80

- *The softening of the tendon ends eliminates any advantage of strength of different suture materials (Urbaniak, 1975).*

Kirchmayr L. Zur Technik der Sehnennaht. ZBL Chir 1917:**40**:906-7

Kessler I, Nissim F. Primary repair without immobilisation of flexor tendon division within the digital sheath. Acta Orthop Scand 1969:**40**;587-601

- *Until the beginning of this century, the commonest core sutures used in Europe and the United States of America were the two-strand Tajima and Strickland modifications of the suture originally described in 1917 by Kirchmayr and re-described in 1969 by Kessler and Nissim.*

Savage R. In vitro studies of a new method of flexor tendon repair. J Hand Surg Brit 1985:**10**:135-41

- *Following the laboratory work of Savage in 1985, showing that a six strand Kirchmayr/Kessler-type of core suture was very much stronger than two-strand repairs, there has followed two decades of intense activity to find a four- or six-strand suture which achieves a similar strength but is more easily placed within the cut tendons than the Savage suture and a multitude of four and six strand core sutures have been described and tested, mostly in vitro* ***(Tables 1 and 2).***

- *Savage reported one rupture in 31 fingers with zone 2 complete flexor divisions repaired with a six strand suture, a rupture rate of 3%.*

Savage R, Risitano G. Flexor tendon repair using a "six strand" method of repair and early active mobilisation. J Hand Surg Brit 1989:**14**:396-9

- *The degree of flexion of the wrist in a splint is probably less significant than previously believed. In fact, the extreme flexion advocated in early papers is almost a Phalen test position and can have the same effect on the median nerve as this test, particularly when* *associated with the considerable local oedema of a zone 5 injury. Savage (1988) suggested that flexion of the wrist did not achieve less tension on flexor tendon repairs distal to the wrist because any relaxation of the flexor muscles was countered by increased tension on, and spontaneous firing of, the extensor muscles applying force to the repairs in the opposite direction. He suggested that the position achieving least tension on repairs in the fingers and palm was the 'resting position' in which we commonly splint hands, with the wrist in slight extension.*

Harris SB, Harris D, Foster AJ, Elliot D. The aetiology of acute rupture of flexor tendon repairs in zones 1 and 2 of the fingers during early mobilization. J Hand Surg Brit 1999:**24**:275-80

- *Harris et al., reported 17 ruptures (4%) in a series of 397 fingers with zone 2 complete flexor divisions using a two strand modified Kessler core suture, suggesting that other factors than the core suture configuration may infuence the rupture rate of any one unit.*

Tsuge K, Ikuta Y, Matsuishi Y. Intra-tendinous tendon suture in the hand. Hand 1975:**7**:250-5

Tsuge K, Ikuta Y, Matsuishi Y. Repair of flexor tendons by intratendinous suture. J Hand Surg 1977: **2**:436-40

Tang JB, Shi D, Gu YQ, Chen JC, Zhou B. Double and multiple looped suture tendon repair. J Hand Surg Brit 1994:**17:**699-703

Tang JB, Gu YT, Rice K, Chen F, Pan CZ. Evaluation of four methods of flexor tendon repair for postoperative active mobilisation. Plast Reconstr Surg 2001:**107**:742-9

- *Inserting these more complicated sutures may have another cost: they are more difficult to insert and make an already complicated procedure even more so. Bearing in mind that most primary flexor tendon surgery is carried out by trainee hand surgeons world-wide, this may prove a serious disadvantage to their use. An alternative approach has become increasingly popular in the Far East, where Tsuge described a single suture repair with a looped double strand nylon suture which acts to grip the tendon on either side of the division in a manner which is akin to a single, large epitendinous suture (Tsuge et al, 1975, 1977). This was elaborated by Tang, who suggested using three Tsuge sutures spaced evenly around the circumference of the tendon (Tang et al, 1994, 2001).*

Wade PJF, Wetherell RG, Amis AA. Flexor tendon repair : significant gain in strength from the Halsted peripheral suture technique. J Hand Surg Brit 1989:**14**:232-5

Lin GT, An KN, Amadio PC, Cooney WP. Biomechanical studies of running suture for flexor tendon repair in dogs. J Hand Surg Am 1988:**13**:553-8

- *However, it became evident that the circumferential suture has considerable strength and is much more significant than the tidying role originally ascribed to it (Wade et at, 1986; Lin et al, 1988).*

Kubota H, Aoki M, Pruitt DL, Manske PR. Mechanical properties of various circumferential tendon suture techniques. J Hand Surg Brit 1996:**21:**474-80

- *A further problem of increasing the elaboration of this suture on the surface of the tendon is increasing resistance to free gliding of the tendon within the tendon sheath (Kubota et al, 1996) and it was never established which of the new circumferential sutures provided*

the most useful balance between additional strength and increased resistance to movement.

Gelberman RH, Amilf D, Gonsalves M, Woo S, Akeson WH. The influence of protected passive mobilisation on the healing of flexor tendons : a biochemical and microangiographic study. Hand 1981:**13**:120-8

- *The fundamental need to mobilise repaired flexor tendons early to avoid adhesion and loss of tendon gliding is now generally accepted, as is the fact that healing of the flexor tendon, at least in the digits, does not necessitate the formation of adhesions. Experimental evidence would also suggest that this early movement encourages more rapid tendon healing under the influence of longitudinal forces (Mason and Allen, 1941; Gelberman et aI, 1981).*

Duran RH, Houser RG. Controlled passive motion following flexor tendon repairs in zones II and III. In American Academy of Orthopaedic Surgeons Symposium on Flexor Tendon Surgery in the Hand, Hunter JM, Schneider LH eds, St.Louis:Mosby,1975:105-14

- *Mobilising primary flexor tendon repairs completely passively in both directions (passive extension – passive flexion) , either by a therapist or by the patient with his/her other hand, was introduced by Duran and Houser in 1975 and embraced by Strickland and his colleagues in Indianapolis (Strickland and Glogovac, 1980). Although the original authors had a 15% rupture rate and only 53% of the digits achieved a good or excellent range of motion in the second paper, this technique has been used widely, particularly in ther United States.*

Strickland JW, Glogovac SV. Digital function following flexor tendon repair in Zone II : a comparison of immobilisation and controlled passive motion techniques. J Hand Surg 1980:**5**:537-43

- *Mobilising primary flexor tendon repairs completely passively in both directions (passive extension – passive flexion) , either by a therapist or by the patient with his/her other hand, was introduced by Duran and Houser in 1975 and embraced by Strickland and his colleagues in Indianapolis (Strickland and Glogovac, 1980). Although the original authors had a 15% rupture rate and only 53% of the digits achieved a good or excellent range of motion in the second paper, this technique has been used widely, particularly in ther United States.*
- *The Tajima modification buries a single knot in the centre of the tendon. The Strickland modification uses a separate suture in each tendon end and buries two knots. These repairs were mostly made with a 3/0 or 4/0 monofilament polypropylene or braided polyester suture material, with both materials being of adequate strength and each having relative benefits. Both remain the commonly used materials.*

Silfverskiöld KL, May EJ. Flexor tendon repair in zone II with a new suture technique and an early mobilization program combining passive and active flexion. J Hand Surg Am 1994:**19**:53-60

- *The series reported by Sifverskiold and May, in 1994, from Gothenburg in Sweden, has probably the best results reported from a civilian unit, to date, in the world. It actually combines features of Kleinert, Duran-Houser and Belfast mobilizations.*