Flexor tendon suturing techniques

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Introduction:
Over the past 100 years, there have been a vast amount of progress and innovations in the treatment flexor tendon injuries. Its management continues to be an area of maximum amount of scientific work in the field of hand surgery with a progressive increase published literature year after year.[1]Knowledge of flexor tendon repair is important as it happens to be one of earliest skills learned by hand surgeons during training.[1] In spite of the bewildering amount of research shown in the last 50 years, the ideal repair and result continue to evade us.[1] Systematic analysis have shown wide variations in study design and reporting of outcomes comparing a 2-strand with multistrand technique of repair due to which superiority of newer methods still remains to be proven.[2] However, with growing evidence, more and more surgeons are moving towards multistrand repair using new generation suture materials. A brief outline is presented on the various techniques of end to end primary suturing of flexor tendons commonly seen in general practice.

Current basis for suturing techniques
Flexor tendon healing occur in three stages: inflammatory, fibroblastic and remodeling. (Myer and Fowler) In the first week a mass of clot forms at site of injury which encourages recruitment of proinflammatory cells and cytokines.[3] By the third week (fibroblastic stage) the fibroblasts rapidly proliferate, producing immature and unorganized type III collagen.[3] **During this stage, the site is soft and weak**.[3] This was shown by Mason and Allen in canine flexor tendon repairs where they demonstrated **decreased tensile strength for first three weeks** postoperatively.[4] Based on this fact, the concept of immobilization during the first three weeks got established[4] In the subsequent remodeling stage at 6 to 8 weeks, type I collagen fibers are reorganized to increase the strength of the tendon structure[3] However, injured tendons that are immobilized, will heal with adhesions which is well established in the remodeling

stage[3,4] Unfortunately, in the region of the tendon sheath such adhesions will invariably lead to loss of movement.[4] This concept of **extrinsic healing** of flexor tendon was further justified by Peacock and Potenza who suggested that tendon had no repair potential and that healing occurred only by granulation tissue originating from the neighboring tissues.[4,5] Experiments in the 70s by Lundborg, Mathew and Richards showed the **intrinsic healing** potential which established the fact that tendons can still heal without adhesions.[4,5] To prevent adhesions early mobilization was necessary. Studies have proven that the strength of the healing tendon is directly related to the volume of stress applied to it. Tendons which were mobilized were found to be stronger than immobilized ones 2 to 3 weeks after the repair. Early motion regimes increase tensile strength, decreases adhesion formation, and improves tendon gliding.[6]

In order to encourage early mobilization, the tendon repair should be strong enough to resist gap formation. Presence of gap promotes adhesions. Schuind et al have shown tendon forces up to 35 N during active unrestricted finger motion.[7,8] Therefore, a surgically repaired tendon should withstand cyclical forces under both linear and curvilinear load conditions of least 40 N to resist gap formation.[8] In vivo studies has shown that the gap formation can happen if the load is as low as 20N which is close to the strength of two strand repairs.[4,8] In this regard it is important to achieve a repair which allow mobilization in a safe zone. This zone of rehabilitation represents the difference between the force to initiate unloaded digital flexion and the gapping force.[4] Hence in flexor tendon repair the goal should be to use a high strength, low-friction suture material and construct, like the 4 strand and 6 strand core suture repairs which can withstand forces up to 60N permitting early active mobilization to get the best possible outcomes.[4,8]

Nomenclature

The repair technique generally consists of a **core suture** and a **peripheral suture**.

Core suture: Core suture are ones which captures significant intrasubstance bundles of tendon fibres.[9] There exist enormous variations in the design, geometry, materials used for the core suture in flexor tendon repair. A Good example of this confusion which exist in literature is the Kessler's repair and its modifications. Sebastin et al have written an exhaustive historical review of this technique pointing out the subtle differences in the original and the modified design of this technique.[10] Core suture technique are divided either according to the number of strands passing through the repair site (2-

strand, 4-strand, 6-strand) or by type of tendon–suture junctions (grasping, locking, and mixed grasping-locking repairs).[8] A core suture has three components: the **transverse**, **longitudinal** segment and the **Link** connecting them.[10](figure 1) The link refers to the site where the suture forms a "locking" or "grasping" configuration between transverse and longitudinal segment to encompass the tendon substance or between two longitudinal components.[10] **Locking** refers to an arrangement that tightens the suture around a bundle of tendon fibers when tensile forces act at the repair ends (Figure 2).[8] On the other hand, **Grasping** represent a design that holds the tendon fiber bundles but does not tighten around their substance and tends to pull through the fibers when tensile forces are acting at the repair ends (Figure 2).[8] This component has now been questioned for erroneous terminology and in clinical situation it is difficult to predict whether grasping or locking loop has been achieved.[10, 11]
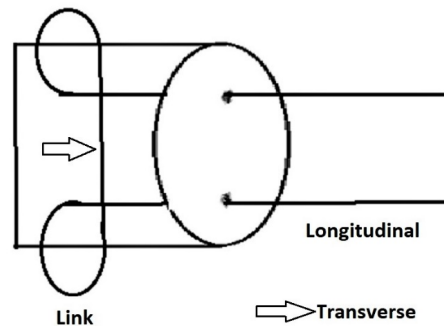
Figure 1: Showing the components of the core suture. The arrow represents the transverse component.
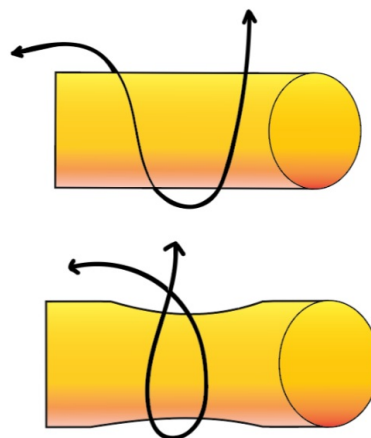
**Figure 2**: Showing the grasping and locking configuration.

Sebastin et al have proposed a simplified classification based on number of strand passing across the repair site, the knots and the type of hold on the tendon fibres (sliding Vs anchored).[10] For

example, the popularly used Modified Kessler which actually represents the Pennington's modification of Kirchmayer's repair would be classified as 2-strand 1-knot sliding repair.[10] In contrast the original Kessler's grasping technique is grouped as 2-strand 2-knot anchored repair.[10]

2-strand repairs:

Bunnell's, Mason- Allen's, Kleinert's, Original Strickland's and Tsuge's have been one of the most well quoted 2 strand repairs.[5,8-12] The various modifications of Kessler's sutures still continue to be one most popular sutures practiced in India and worldwide.[10,12] (figure 3-5)

a)

b)

c)

d)
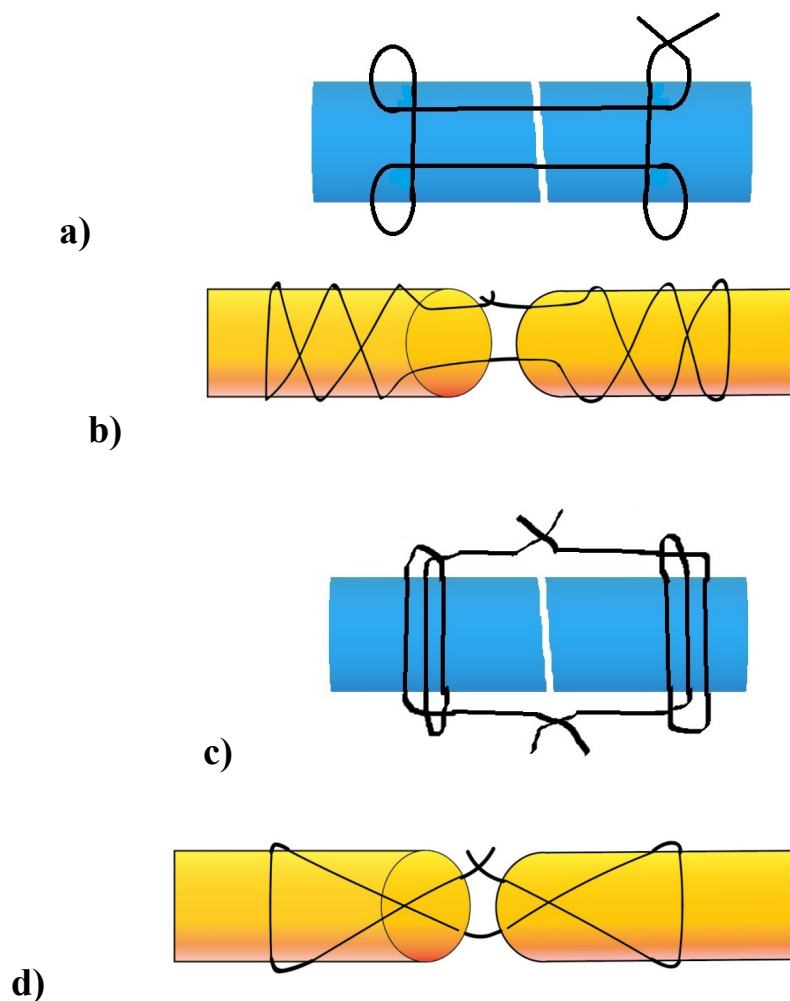
Figure 3: The earlier generation of 2 strand repairs – from 1900 till 1960s.a) Kirchmayer's (1917),   b) Bunnell's technique(1922), c) Mason Allen(1941), d) Kleinert (1962)


a)

b)

c)

d)

e)
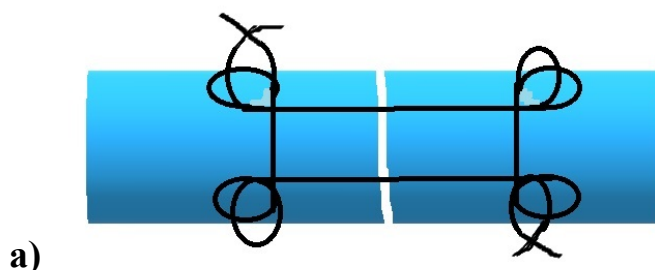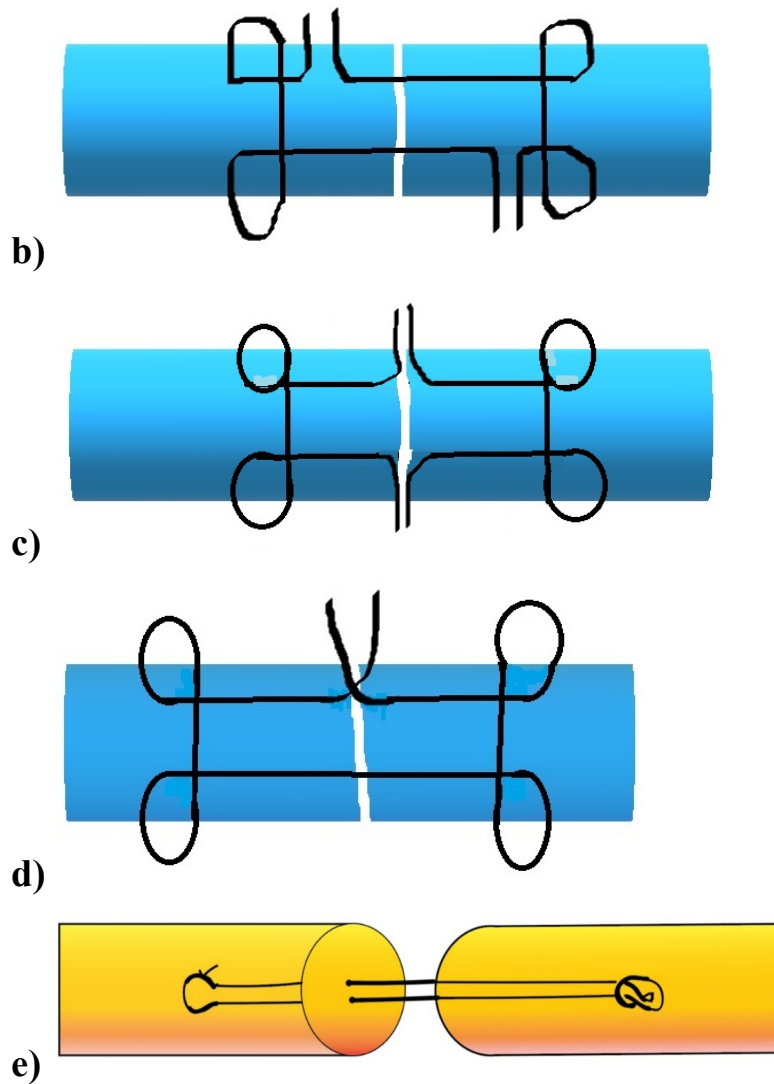
Figure 4: The next generation in 1970s were markedly influenced by Kessler(a) and its modifications: Urbaniak(b), Tajima (c), Pennington(d)(which is actually a modification of Kirchmayer's 2 strand technique), Tsuge's (e) original 2 strand was the other different technique

4-strand repairs:

The 4-strand repairs currently represent the one basic requirements for an early active mobilization program and rehabilitation. The most popular techniques have been those of Modified Strickland and Tsuge, Becker's and the double Kessler's technique.[1,5,6,8-13]

a)

b)

c)

d)
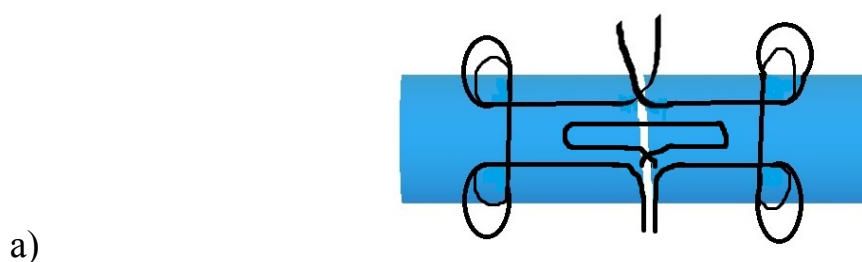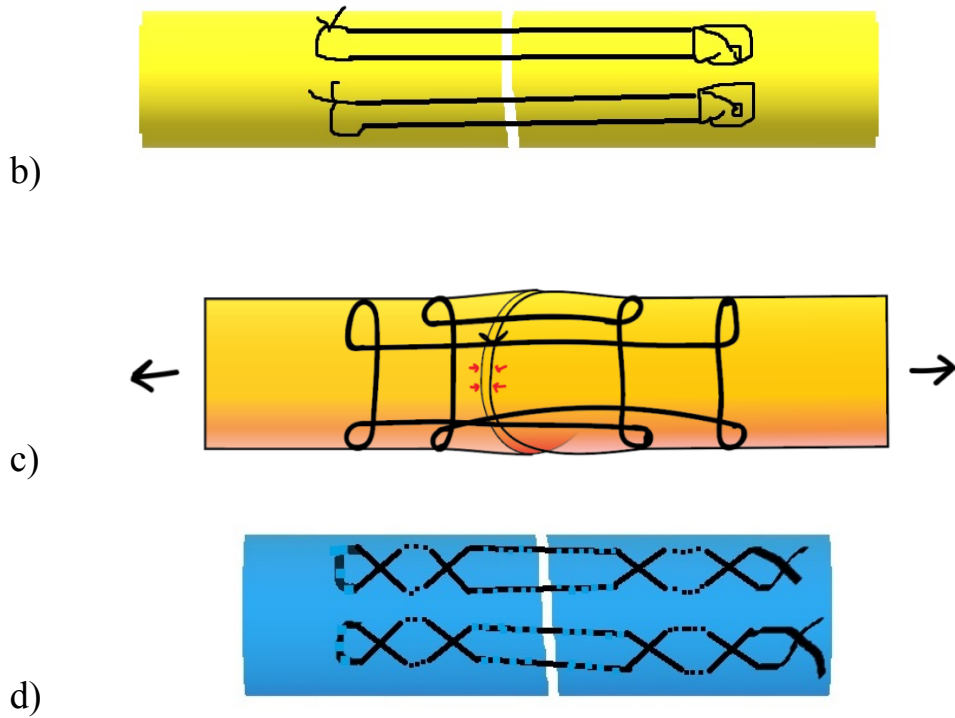
Figure 5: The development of 4 strand repair in the 1980s a) showing the Strickland's technique extensively used in the West; note the anchored repair with 3 knots. b) showing the Tsuge's 4 strand repair popular in the Far East: this is also an anchored repair c) the Double Kessler: the above one shows the Lin's modification with asymmetric configuration: the red arrow shows the compression across the cut ends with distraction load which adds further strength to the repair on active mobilization. d) Becker's technique is popularly used for repair of the FDS at zone 2.

Cruciate repairs:

A major disadvantage with Kessler-type repairs have been shown to be risk of gap formation with tendon loading. Tension at repair site leads to shortening of the transverse components, tendon buckling, and change in the angle of the Kessler loop relative to the longitudinal axis of the tendon. This leads to modification of the Kessler loop to form a U-shaped construct leading to elongation of the tendon repair and a gap develops.[11] The transverse component, is not seen in a cruciate-type repair. This can withstand the longitudinal axial forces more efficiently and hence is less likely to elongate. In view of this biomechanical advantage and ease of application 4-strand cruciate repairs have become very popular.[11] The Adelaide repair is the best example of this technique.[9,11,13](Figure 6)
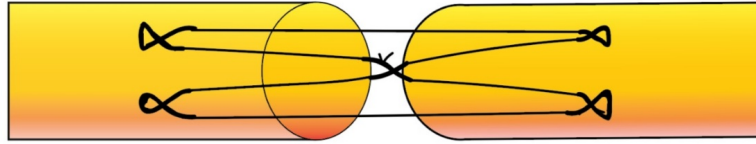
Figure 6: Showing the Adelaide repair (cross locked cruciate repair)

6-strand repair:

The most well described techniques have been those of Tang's modification of Tsuge and M-Tang whereas the cruciate 6-strand technique of Savage and Lim-Tsai have also been well tested.[8,9,11,13] Al-Qattan introduced his six strand 'figure of eight' technique which had longitudinal sutures only in its construct without any transverse or locking components. It had shown excellent to good results in 98% in the authors' cases series of 50 patients.[11,15] (figure 7)
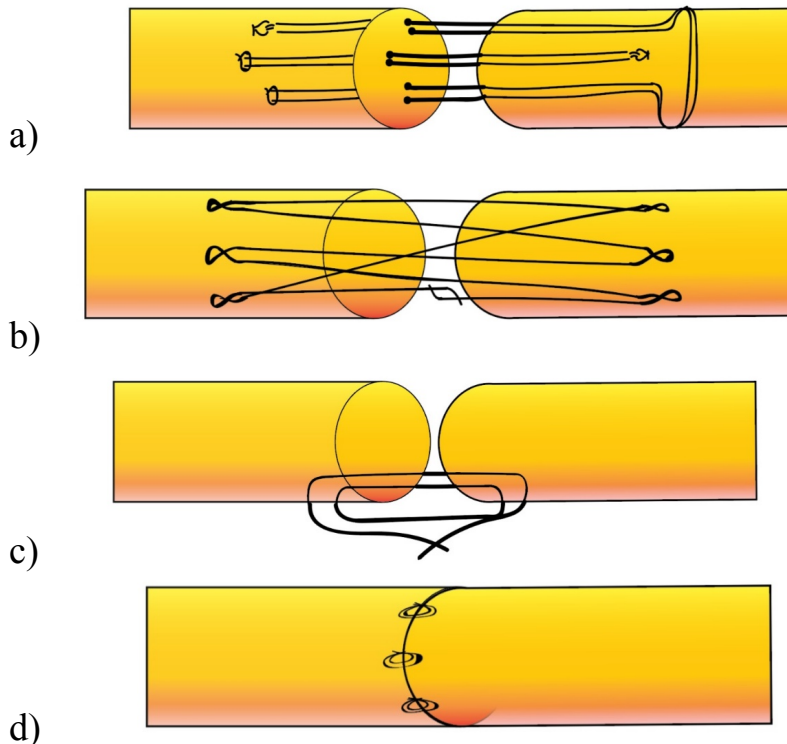

a)

b)

c)

d)

Figure 7: a) showing the M- Tang technique, b) modified Savage technique, c) Al Quattan's technique: note the figure of eight configuration: 3 similar sutures are passed on the anterior aspect(d)

8-strand repair:

The Winters-Gelberman technique uses a double-stranded suture of 4-0 or 3-0 with a design involving multiple locking loops and resembles a double Pennington configuration making it an 8-core repair.[13,14]

Peripheral suture:

Peripheral suture represents lighter sutures at the surface of the

tendon.[8] The concept of peripheral suture was first described by Verdan and later popularized by Kleinert as a technique of smoothening the repair.[5,9] This is generally done with 5-0 or 6-0 sutures. It was later shown to have dramatic mechanical benefits.[9] Literature has shown this suture to add significantly to the strength of repair, from 10 to 50 percent.[6] In a systematic review based on 39 studies on complications of flexor tendon repairs, Dy et al have shown that the addition of an epitendinous suture lowered the rate of reexploration by 84%.[13,16] Peripheral sutures include simple running, interrupted, locking running, horizontal mattress, interlocking horizontal mattress, Silfverskiöld's cross stitch and locking cross-stitch have been described.[5,6,8-13](figure 8)
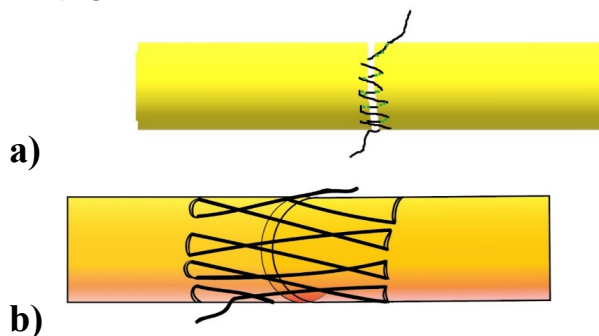

Figure 8: Showing 2 commonly described peripheral sutures. a) simple continuous(after Kleinert) and b) Silverskiold's technique.

Important factors in repair technique influencing outcomes:

1) **Volar versus Dorsal Location of the Core Suture**

Earlier workers had advocated the placement of core suture in a more volar location with the aim of preserving the blood supply which was supplied through the dorsal vincula.[6] However, there is no literature evidence to corroborate these suggestions.[6] This was found by Soejima et al who observed no difference in the vascularity of the tendon if the core suture is placed volarly or dorsally.[6,17] On the contrary Aoki et al. showed that the volar location of the suture increases the work of flexion.[6,18]

2) **Number of suture strands:**

Strengths of core sutures have been studied extensively in literature and based on many in vitro studies it is now well accepted, that an increase in suture number across the repair site proportionately increases failure or fatigue strength, resistance to gap formation during cyclic loading.[1,3-6,8-11,14,19] Repair with use of a 4-0 nylon suture for a 2-strand, 4-strand and 6-strand each have shown to have an increasing strength of about 25 N, 45 N and 70 N respectively.[8] Currently, a 2-strand suture are considered to

have inadequate strength and not safe for active tendon motion exercises.[8] Strickland have shown that that anything above a four-strand repair will permit active range-of-motion protocols in the rehabilitation phase of tendon healing.[6] This maintains the strength and under select conditions a modest increase in strength and stiffness at repair site.[19]

3) **Suture Material and its Calibre:**

Currently monofilament nylon (Ethilon) and polypropylene (Prolene) continues to enjoy widespread popularity as cheap, durable with strong knot characteristics. However new generation materials like braided polyester(Ethibond) has been shown to have a better tensile strength and stiffness and are now widely available in India. Ticron, Supramid, Fibrewire have been widely used in the West and offer better strength when compared to the traditional nylon and polypropylene sutures. Taras et al have reported considerable increases in repair strength when suture caliber was increased from 5-0 to 2-0. 3-0 and 4-0 sutures have been the most commonly used sutures.[6,12,20] 3-0 suture are recommended for their greater strength although a 4-0 sutures have been found to be equally strong when used in a 4-strand locked cruciate core stitch.[11] A 2-0 suture has increased bulk and is less commonly used whereas a 5-0 suture is only used for peripheral sutures.

4) **Suture configuration**

The superiority of a locking over grasping configuration remains controversial as there are studies which do not show its benefits.[8,11] The locking configuration has a marginal advantage in having a better tensile strength and gap resistance than the grasping suture in the first three weeks following repair.[19] The locks has been suggested to be 2mm in diameter and perpendicular to the longitudinal axis of the tendon.[6,19] Cruciate type designs have become popular for the reasons mentioned earlier.

5) **Aggressive pulley-venting**

Traditionally the preservation A4, A2 pulleys for fingers and oblique pulley for thumb have been suggested to be vital to prevent bowstringing. However, in the 90s, Savage, Tang and other workers showed that preservation of this pulley was no longer sacrosanct and they could be divided provided the other pulleys are intact.[5,9,11] Subsequently complete division of A4, oblique pulleys and partial division up to 2/3 of A2 pulley

became popular.[11]Venting significantly removes the danger of a bulky repair getting stuck at the rim of pulley or constricted within its narrow space and increasing the resistance to glide.[11,21] More recent development has now suggested that even the A2 pulley can be completely divided along with the C1 pulley without any significant loss of function.[21-23] (figure 9)
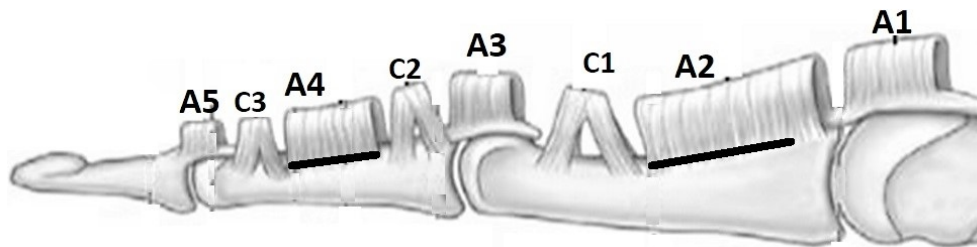
Figure 9: Apart from the other pulleys, current recommendation suggests venting (black line) can be done for A4(complete) and A2(2/3) pulleys provided the adjacent pulleys are left intact. The key is to ensure safe excursion of the repaired site.

6) **Purchase of the suture:**
In vitro animal studies have suggested that the optimal purchase length is in the range of 7mm to 10mm ensures adequate strength of the repairs and resistance to gap formation.[11,19] (figure 10)
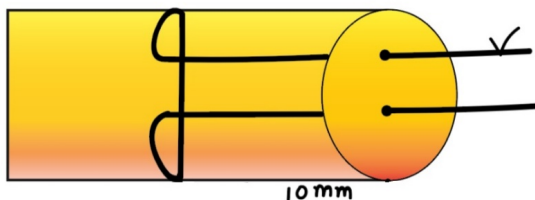
Figure 10: The optimum purchase distance should be 1cm.

7) **Tensioning of the sutures**
Adding tension to the suture equalizes the load on the strands of the repair which prevents gapping during early active motion of the tendon. Wu and Tang have demonstrated that 10% of tendon shortening significantly decreased the gap formation without an obvious increase in bulk of repair.[11,21] Loose repair of tendon has been shown in in vitro studies to gap easily during testing of active motion. (figure 11)
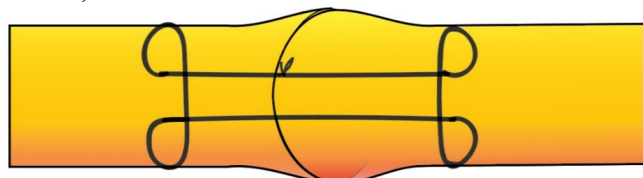
Figure 11: Note the repair has to be sutured with tension to add to the bulk of repair.

   8) **Peripheral suture:**

Peripheral suture augmentation of core sutures placed deep into the tendon has been found to have 80% greater strength than those placed superficially through the epitenon and tendon surface.[19] Similarly, peripheral suture placed 2 mm away from the cut end were found stronger by 37% than those with a 1-mm distance suture.[19] Hence it is beneficial to put peripheral suture and this should be placed deep in the tendon and far from the cut end to improve the repair strength.[19]
The simple running peripheral suture is easy to apply and hence remains popular and most commonly used. The other more complex techniques are difficult to place and may interfere with gliding of the tendons.[11] Recent studies have now shown that peripheral sutures are not necessary in the presence of strong core suture.[21,22]

   9) **Knots**

Knots happens to be the weakest areas of a suture construct and therefore placing them outside and away from the site of repair with as few knots as possible improves repair strength.[3,19] However, other studies have not shown to decrease tensile strength with intratendinous knot which may even encourage tendon healing.[19] The number of knots has shown to alter the repair strength.[9,11,19] It is thought that all strands carry equal load in repairs with one knot, whereas in two knots, differential loading of the strands lead to increased risk of early failure.[11]

Summary:

The primary goal in Flexor tendon repair is to restore original full range of movement of the digits. This requires the knowledge of the normal sequence of healing of tendons and its close interaction with its surrounding milieu. An ideal healing would be seen when early mobilization is encouraged which is due to intrinsic healing within the substance of the tendon. In the first four weeks the repaired structure is biologically weak and early mobilization carries the risk of gap formation. Gap formation encourages extrinsic healing which leads to adhesions and subsequent loss of motion and rupture. Hence it is mandatory to place a biomechanically strong suture construct which prevents gap formation. The enormous amount of basic

science work and clinical research done in the last five decades has guided us to get some consensus on achieving good function after flexor tendon repair. This involves a minimum of four strand core repair with 3-0 or 4-0 suture which is applied with a purchase distance of 10mm and some tensioning. A simple running peripheral suture adds significantly to the strength of repair. Venting of pulleys is now strongly advocated including those of A2 and A4 to prevent resistance to tendon gliding with early mobilization.

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