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Methods and Suture Materials for Flexor Tendon Repair

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Abstract

The current clinical methods of flexor tendon repair are remarkably different from those used 20 years ago. This article starts with a review of the current methods, followed by presentation of past experience and current status of six eminent hand surgery units from four continents/regions. Many units are using, or are moving toward using, the recent strong (multi-strand) core suture method together with a simpler peripheral suture. Venting of the critical pulleys over less than 2 cm length is safe and favours functional recovery. These repair and recent motion protocols lead to remarkably more reliable repairs, with over 80% good or excellent outcomes achieved rather consistently after Zone 2 repair along with infrequent need of tenolysis. Despite slight variations in repair methods, they all consider general principles and should be followed. Outcomes of Zone 2 repairs are not dissimilar to those in other zones with very low to zero incidence of rupture.

Keywords: Flexor Tendon, Repair, suture.

Introduction:

Avicenna, a Persian Arab surgeon, was the first to recommend tendon repair after laceration or rupture around the 10th century **(1).**

The first scientific research into the mechanism of tendon healing was performed by **John Hunter** in **(2)**, who explained that tendon healing occurred through callus formation, close to that seen in bone healing. Around **Salomon (3)** observed poor tendon healing of sutured canine flexor tendons and thus recommended that a defect in the tendon sheath to be left for better healing by allowing contact between the repaired tendon and the subcutaneous tissue**.**

In **1960s Verdan** divided the regions of flexor tendons into five zones. In **1990**, **Moiemen** and **Elliot (4)** subdivisions of zone 1 and Tang subdivisions of zone 2 were added to the existing zoning system to define more precisely the site of injuries and repairs. Such zoning and sub-zoning systems provide hand surgeons with the nomenclature to record tendon injuries, outcomes, and discuss the principles of treatment **(4).**

In **1969s**, **Kessler** and **Nissim (5)** introduced in a grasping technique called **Kessler.** Different authors have modified this technique to the point where the so-called “modified Kessler technique” bears little resemblance to the original description **(6).**

Two strand- repair techniques have been generally used in flexor tendon repair. The strength of the locking configuration of the modified Kesseler repair is strong enough to withstand the force of passive rehabilitation, but not early active motion, clinically seen as increased rupture rate. The modified pennington configuration has been introduced by ***Hatnaka*** and ***Manske*** (**7**) to increase repair strength.

The effect of increasing the number of strands by performing multiple similar but separated core suture has been in few configuration, the 4- and 6-srand modified ***Kessler (5)*, Tsuge(8)** and ***savag****e* repairs have demonstrated improved gap and ultimate force compared to the respective 2-strand techniques. Increasing the number of strands also improves the yield force and stiffness in the Pennington modified Kessler and savage repair. These improved biomechanical properties are probably due to both higher material strength and improved holding capacity of the repair technique of the tendon as the number of separated grasps increases along with the number of strands. Also double stranded sutures (i.e. loop or looped suture) have been used to perform multi-strand repairs. Most of these are multi-strand modification of the ***Tsuge(8)*** repair.

Barrie et al., (**9**) evaluated the influence of increasing the number of strands from four to eight by using either single or double stranded suture in the cruciate non-locked and cruciate cross-stitch locked configuration. Although the material strength increased, gap resistance did not improve.

Multiple-strand repair are technically demanding in clinical setting requiring multiple subsequent needles passes that increase tendon handling and easily lead to uneven of the strand. Thus multiple concomitantly passed suture strand have been investigated in the aim to improve the holding capacity with a simpler repair techniques. Two different coated braided polyester triple-stranded suture [the strand either remaining free (triple strand suture)or bound parallel to each other to form a ribbon-like structure (triple-stranded bound suture)] were developed and used in the Pennington modified Kessler configuration, thus producing two different 6-strand repairs with the technical performance of a two-strand repair. Both these 6-strand repairs reached improved stiffness, yield force, gap force, and ultimate force compared to the Pennington modified Kessler repair performed with conventional single-stranded suture. Furthermore the triple- stranded suture improved the strength of the repair compared to with the triple strand suture***(10).***

A modified six-strand looped (M-Tang) and a modified four-strand looped repair have become the methods of choice with a 90% excellent or good recovery rate by ***Strickland*** and ***Glogovac (11)*** criteria with combined protective active and passive motion for 3 weeks after surgery, with no repair rupture.

Different techniques have been illustrated in Figure (1) and table (1).

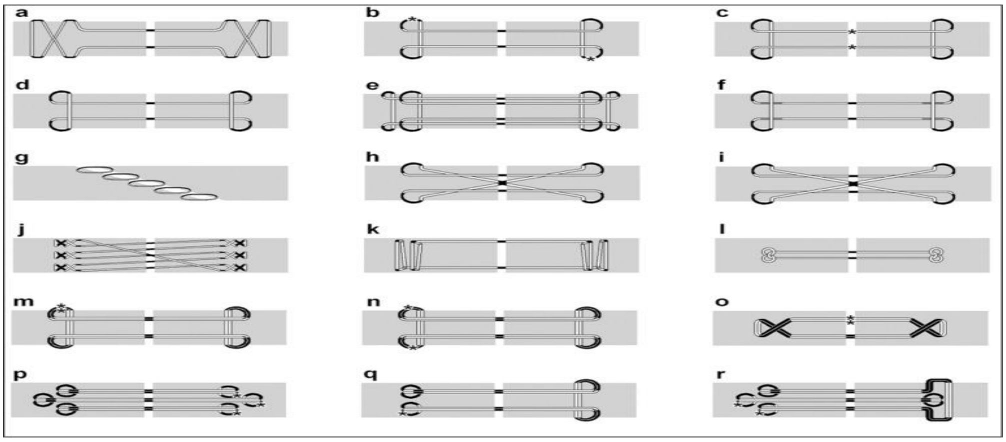

Figure 1 :Some of the joining techniques described in literature. Light Grey = Tendon. White = Suture internal of tendon. Black = suture external of tendon. Dark Grey = Suture external of tendon, dorsally placed (Only shown on figures f and k). *=placement of knot (only shown on figures b, c and m to r). Double strand suture used in repairs m to r. Adapted from8, 16–20. a. Bunnell; 2 strand, non-grasping anchor. b. Grasping Kessler; 2 strands, grasping anchor. c. Tajima; 2 strands, grasping anchor. d. Modified locking Kessler (aka. Pennington); 2 strand, locking anchor. e. Four strand double modified Kessler; 4 strands, locking anchor. f. Modified Pennington; 2 strand, locking anchor. g. Becker; Interrupted stitch joining oblique tendon ends. h. Grasping Cruciate; 4 strand, grasping anchor. i. Locking Cruciate; 4 strand, locking anchor. j. Savage; 6 strand, x-stitch anchor. k. Locking Lee; 2 strand, locking anchor with large purchase. l. Tsuge; 2 strand, anchor buried within tendon. m. Four strand Kessler repair. n. Four strand Kessler repair with knots on opposing sides. o. Four strand cross-lock repair. p. Tang. q. U-shaped four strand repair r. Six strand M-tang**. (12).**

Table 1: Studies of suturing techniques under axial tensile load (12).

Name	Epitenon suture	Force at fail (N)	load to 2mm gap (N)	Reference
Bunnell	none	22.563	15.696	Savage, 1985
Grasping Kessler	none	19.62	3.924	Savage, 1985
	none	22.09212		Lee, 1990
	6-0 nylon running	23.8 (SEM1.6)		Noguchi et al., 1993
	6-0 nylon running	26 (SEM2.4)		Noguchi et al., 1993
	6-0 nylon (ethicon) running suture	33.7 (SD4.7)	30.3 (SD8.6)	Tanaka et al., 2004
	6-0 Ethilon circumferential locking suture	31 (SD7)		Barrie et al., 2001
Tajima	6-0 nylon running	30.5 (SEM1.9)		Noguchi et al., 1993
Modified Kessler Locking AKA Pennington	none	34.44 (SD2.33)	22.56 (SD3.44)	Dogramaci et al., 2008
	6-0 Ethilon circumferential locking suture	32 (SD9)		Barrie et al., 2001
	6-0 nylon (ethicon) running suture	38.7 (SD5.1)	32.5 (SD5.3)	Tanaka et al., 2004
Four-strand double-modified Kessler	none	53.38 (SD8.09)	30.85 (SD1.90)	Dogramaci et al., 2008
Modified Pennington	6-0 nylon (ethicon) running suture	48 (SD3.9)	40.5 (SD5.5)	Tanaka et al., 2004
Becker	none	12.753	no gap up to ≈12.753, then failure	Savage, 1985
Grasping Cruciate	6-0 Ethilon circumferential locking suture	46 (SD12)		Barrie et al., 2001
Locking Cruciate	6-0 Ethilon circumferential locking suture	49 (SD13)		Barrie et al., 2001
Savage	none	67.1985	44.145	Savage, 1985
Locking Lee	none	43.164		Lee, 1990
	6-0 nylon running	37.6 (SEM1.5)		Noguchi et al., 1993
	6-0 nylon (ethicon) running suture	41 (SD3.5)	37.4 (SD9)	Tanaka et al., 2004
Tsuge	6-0 nylon running	27.3 (SEM1.4)		Noguchi et al., 1993

SD = Standard deviation. SEM = Standard error. N=Newton

Details of different techniques

Modified Kessler Suture

A modified Kessler suture **(Fig,2)** 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 **(13).**

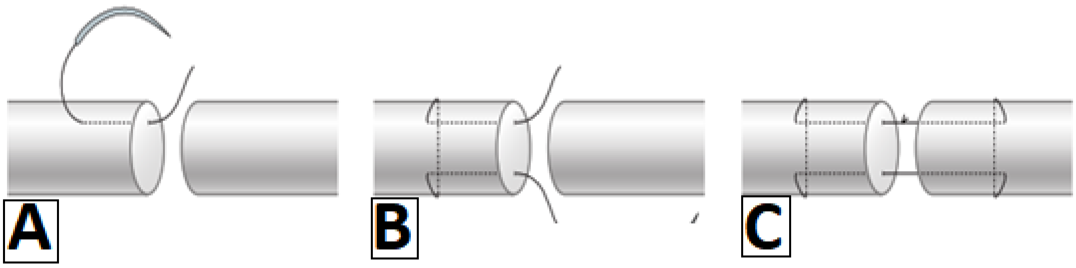

Figure (2): Modified Kessler suture technique (14).

Technique

- Move the needle through the cut surface of one side of the cut tendon for a distance of 1 cm through the tendon end and exit on the tendon surface. (Fig 2 a)
- transfer the suture transversely, take up a small portion of the tendon substance, and exit on the opposite side. (Fig 2 b)
- 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. (Fig 2 b,c)
- Tie the knot to the suture after sliding the tendon to allow approximation of the cut surfaces. (Fig 2 c) **(14).**

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 **(Fig 3) (15).**

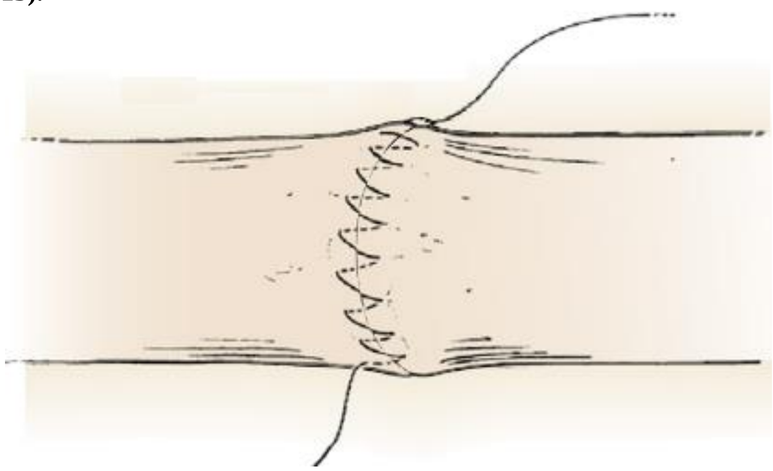

Figure (3): Epitendenous suture (16).

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. **(16)**

The continuous double knots technique and 4-strand -modiied Kessler technique :

The suture material used was polypropylene Size4–0 or 3–0 monofilament nonabsorbable single needle suture; only core sutures were used.

In the 4-strand modified Kessler group, the tendon was repaired using a modified Kessler technique for the first loop, Then a knot was made and the suture cut. After the first loop was done, the second loop of the modified Kessler technique was made without the subsequent suture from the first loop. Then a knot was made and the suture cut **(Fig. 4A-D) (17).**

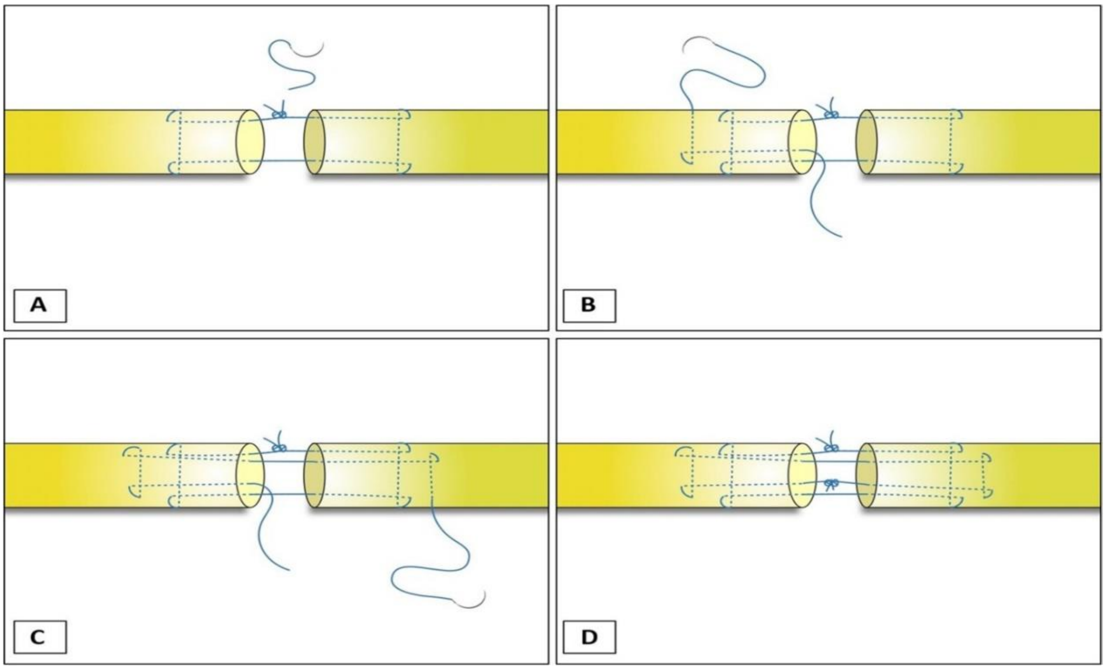

Figure (4): Showing the steps of 4 strand modified Kessler technique (17).

In the Continuous double knots technique:

1. The tendon was repaired by cross-locking suture in the proximal and distal part of the tendons (Fig. 5A). The cross-locking of the distal part of both tendon ends can be a practical technique to control and optimize the length of the tendon to reduce the gap. The cross-locking of distal part of both tendon ends can control the tendon gap well by experienced hand surgeon. After the knot was tied (Fig. 5B), the repair continued in the second loop without cutting the suture (Fig. 5C).

The final steps, suture knot of the second loop was tied to the first knot (Fig. 5D). A single hand surgeon did all the tendon repairs by two techniques.

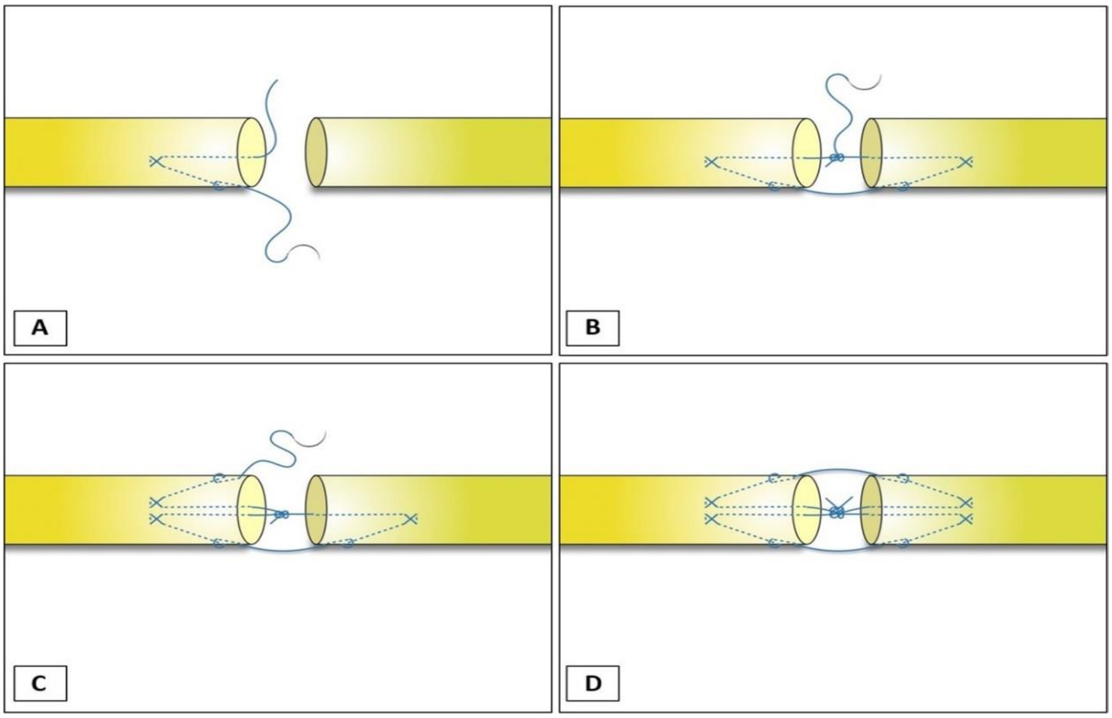

Figure (5): Showing the continuous double knots technique (17).

The cross sectional of flexor tendon after repair in both types is illustrated in figures a & b.

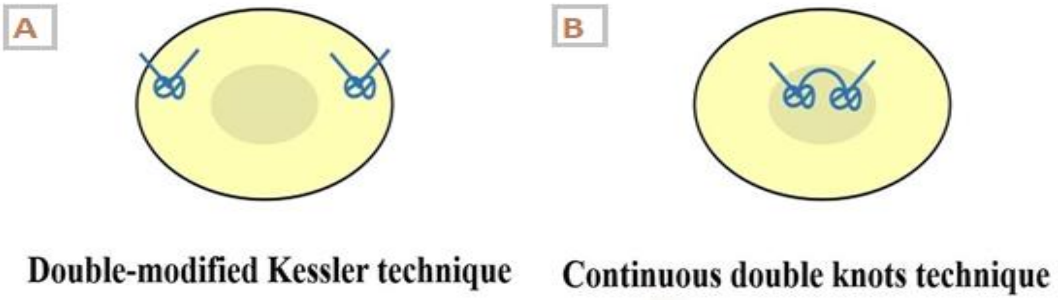

Figure (6): Showing the comparison of cross sectional of flexor tendon after repair by two 4-core suture techniques (17).

Non-grasping, grasping and locking

Suture anchoring has a significant impact on the strength of the repair **(18)** tendon's high tensile strength is attributed to its hierarchical arrangement of long parallel collagen fibres encased in a tough smooth layer, known as the epitenon **(19).** This is a biologically active layer that provides purchase strength but also prevents cells migrating out of the tendon **(20)**. Repairs which possess greater failure strength better exploit the aligned structure of the tendon and the high strength of the fibers and epitenon.

The strength of a given repair is attributed to how effectively it transmits axial tension into grip onto the tendon fibre bundles. Initial methods employed a non-grasping anchor aligned perpendicular to the fibre bundles, looped around a small portion of the epitenon **(Fig. 7-a)** such as the Bunnell technique. Upon failure the suture cuts between the fibres, thus the strength of the fibres is not exploited. The grasping method of anchoring, used in the grasping Kessler and Tajima techniques, has a suture loop around the epitenon and fibres. The loop tightens as the load is increased, which pinches onto the fibres **(Fig. 7-b).** The locking anchor improves on this method by creating a closed loop **(Fig. 7-c)** as employed in the locking Kessler and Locking

Lee sutures. The loop acts like a noose and tightens around the enclosed portion of fibres, thus resulting in a much more effective anchor **(12).**

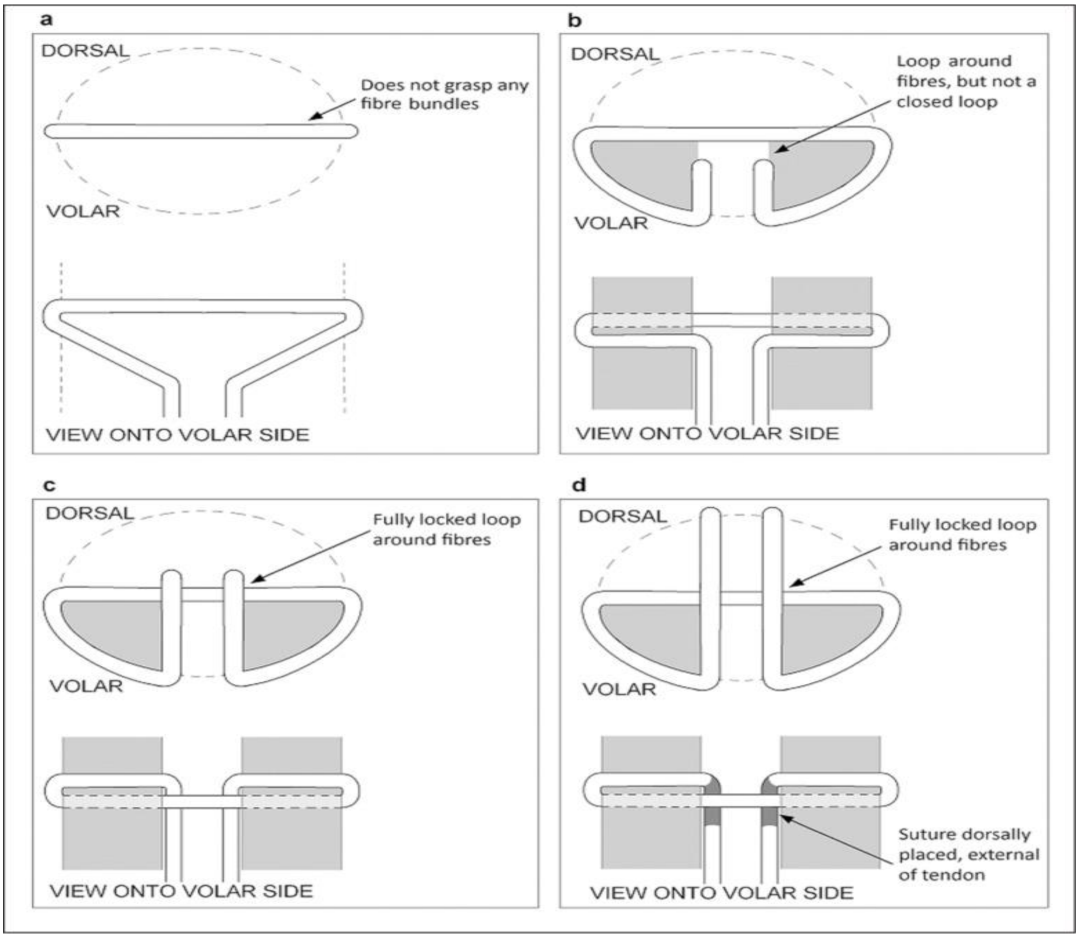

Figure 7: Four different suture anchoring methods. The portion of tendon fibres that the suture anchors around is shown in dark grey. The tendon outline is shown as a dashed in the cross sectional views. Dark grey represents suture which passes outside the tendon on the dorsal side. a. **Non-grasping** b. **Grasping.** c. **Locking (aka. Pennington Lock)** d.**Modified Pennington Lock (12).**

Suture Materials for Flexor tendons repair

The ideal suture material for flexor tendon repair should be strong enough, inextensible to prevent gaping, easy to use and knot, with good holding capacity, absorbable but maintains its tensile properties until tendon repair has achieved adequate strength, and have minimal tissue response ***(21).***

Earlier stainless steel was used as a core suture material due to its superior tensile strength and good tissue properties but was a banded because it was difficult to handle. A promising new metal suture, ***Nitionol*** (***NiTi***), has be introduced as possible new tendon repair material with high strength and stiffness comparable to those of stainless steel, but has better handling properties ***(22).***

Non absorbable synthetic material, especially coated braided polyester, monofilament nylon, and monofilament polypropylene, all have good biocompatibility and are today used in flexor tendon repair. Coated braided polyester is the most common core suture material. Tough nylon is also used especially in repair performed with looped suture. Monofilament polypropylene is mainly used in the peripheral sutures. Coated braided polyester suture demonstrates significantly higher tensile strength and stiffness compared to monofilament nylon and polypropylene suture and maintains its tensile properties in the body temperature, while the stiffness of both polypropylene and nylon suture has been shown to decrease significantly ***(*****23).**

The disadvantages of the coated braided polyester suture is the poor knot holding capacity requiring five square throws per knot to prevent slippage ***(24)***.

Also a braided polyblend polyethylene suture (fiberwire) has been introduced for flexor tendon repair. It has significantly higher ultimate force and stiffness compared to coat braided polyester, and monofilament nylon, and polypropylene sutures, and similar ultimate force but higher stiffness compared to braided stainless steel ***(25)****.mainly disadvantage is* poor knot-holding properties which requires at least six throws for optimal knot security **(26).**

Bioabsorbable suture materials have not been widely used in flexor tendon repair due to lack of sufficient tensile strength half-life and fear of increase tissue reaction and adhesion formation. In canine flexor tendon repair with active mobilization, the polydioxanone repair decreased significantly in strength already during the first two week and were significantly weaker compared to coat braided polyester repair during the six-week follow up ***(27).***

Furthermore, in biomechanical testing ex vivo, both polydioxanone and polyglycolide-trimethylene carbonate suture (**maxon)**have significantly higher elasticity compared to non-absorbable coated braided polyester suture making them biomechanically less suitable for flexor tendon repair. Histologically, an increased inflammatory reaction was found around the polydioxanone compared to polyester suture, but no influence on adhesion formation was detected ***(21).***

The bioabsorbable poly-L/D-lactide (***PLDLA)*** 96/4 has been suggested a novel suture candidate for flexor tendon repair with long enough tensile strength half-life of 10-13weeks in vitro and retaining over 75% of its tensile strength after 6 weeks of subcutaneous implantation in vivo. In rabbit Achilles tendon implanted PLDA suture demonstrated good biocompatibility with formation of a significantly thinner fibrous tissue and fewer inflammatory cells compared to polyglyconate suture(**maxon**) during a 12-week follow up ***(28).***

The biomechanical properties and knot holding capacity of the PLDA suture are good considering flexor tendon repair ***(24)***.

Polydioxanone(PDS) is is a synthetic, absorbable, monofilament suture made from a polymer of paradioxanone which Retains 74% of tensile strength at 2 weeks and 25% at 6 weeks. Absorbed at 6–7 months by hydrolysis Used where approximation of tissues needed for extended periods. Useful in infected tissues but Poor knot security and poor handling characteristics because of stiffness and memory.

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