# Flexor Tendon Repairs: Techniques, Eponyms, and Evidence

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The evolution in surgical technique and suture technology has provided an abundance of options for flexor tendon repairs. Multiple biomechanical studies have attempted to identify the best surgical technique based on suture properties, technical modifications, and repair configurations. However, the burgeoning amount of research on flexor tendon repairs has made it difficult to follow, and no gold standard has been determined for the optimal repair algorithm. Therefore, it seems that repairs are usually chosen based on a combination of familiarity from training, popularity, and technical difficulty. We will discuss the advantages, disadvantages, and technical aspects of some of the most common core flexor tendon repairs in the literature. We will also highlight the nomenclature carried through the years, drawings of the repairs referred to by that nomenclature, and the data that support those repairs. *(J Hand Surg Am. 2014;39(9):1846–1853. Copyright © 2014 by the American Society for Surgery of the Hand. All rights reserved.)*

**Key words** Flexor tendon injuries, repair, zone II, load to failure, repair site gapping, surgical technique.



Although there are multiple surgical techniques for zone II flexor tendon repairs, no consensus has been achieved on what is the gold standard. Strickland described the *ideal* repair as having the following characteristics: (1) easy suture placement, (2) secured knots, (3) smooth end-to-end tendon apposition, (4) minimal to no gapping at the repair site, (5) avoiding injury to tendon vasculature, and (6) having enough strength for early active postoperative motion.[1] In reality, no technique has completely filled these criteria.

What has been established is that with current suture technology, multiple core suture strands ($\geq 4$) crossing the repair site result in a stronger repair that is able to tolerate early postoperative active motion rehabilitation protocols. Repair strength is further increased by the use of higher suture caliber and stiffer suture materials. The addition of an epitendinous stitch improves biomechanical strength of repairs, minimizes gapping, and helps reduce cross-sectional area, which in turn decreases gliding friction. Knots are also the weakest component of the repair, and their location matters. Pruitt et al showed in an *in vivo* canine study that placement of internal knots was inferior to outside knot placement in terms of overall biomechanical strength at day 0. However, internal knots demonstrated equivalent tensile strength at 6 weeks compared to external knots.[2] In terms of gliding friction from external knot placement, Momose et al also demonstrated that 2 lateral sided knots had more friction than 1 volar-sided or 1 lateral-sided knot.[3]

However, there is great variability among the repair configurations, and it is easy to confuse different eponyms for the classic (eg, Kirchmayr, Kessler, etc), modified classic (eg, Pennington, Tajima, etc), and modern repairs (eg, Winters-Gelberman, Lim-Tsai, etc). Various repairs over time have assumed multiple eponyms and descriptions, creating confusion

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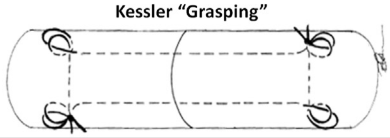
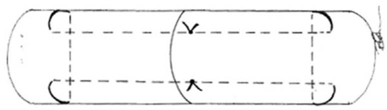
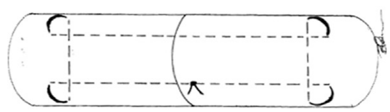
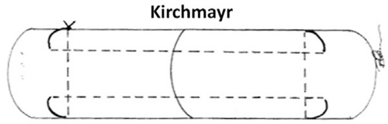
| Technique<br>2-Stranded Core Repairs | # Core Strands<br># Knots & Location<br># Sutures | Suture Size/Type | 2 mm Gapping Load (N)<br>(unless otherwise stated) | Failure Load (N) | Epitendinous Suture |
|---|---|---|---|---|---|
| Kessler "Grasping"<br> | • 2<br>• 2 External Knots<br>• 2 Sutures | No recent articles discussing the original form of the Kessler "Grasping" Repair | | | |
| Tajima "Modified Kessler"<br> | • 2<br>• 2 Internal Knots<br>• 2 Sutures | 4-0 Braided Nylon | 30 (initial) | 32 | Yes |
| Pennington "Modified Kessler"<br>Single Repair<br> | • 2, 4<br>• 1-2 Internal Knots<br>• 1 Suture<br>• Modification: Double repair using 1-2 sutures or double stranded suture | 3-0 FiberWire® Single | 54 | 65 | Yes |
| | | 4-0 Ethibond®<br>a)Single<br>b)Doubled | a)14<br>b)26 | a)39<br>b)66 | Yes |
| | | 3-0 Ticron™<br>a)Single<br>b)Doubled | a)21<br>b)57 | a)35<br>b)68 | Yes |
| Kirchmayr<br> | • 2<br>• 1 External Knot<br>• 1 Suture | No recent articles discussing the original form of the Kirchmayr repair | | | |

**FIGURE 1:** Two-stranded flexor tendon repairs. The repair and biomechanical data for common 2-stranded repairs depicted above include the original Kessler repair, Tajima modified Kessler, Kirchmayr repair, and Pennington repair. The Pennington has historically and erroneously been called a *modified Kessler* in many studies and is likely a modification of the Kirchmayr repair.[4–8]



in the literature. A recent historical review article by Sebastin et al describes this dilemma and proposes a conventional naming system based on core suture strands, number of knots, and type of repair.[4] In their article, they astutely highlight the confusion associated with the term *modified Kessler*, which actually refers to repairs that modify the 2-strand Kirchmayr repair, not the Kessler repair as originally described.[4]

More recently, improvements in suture design and technology have renewed interest in barbed suture and stainless steel wire in flexor tendon repairs.

## 2-STRAND REPAIRS

We present the biomechanical data for common 2-strand repairs, such as the Pennington and Tajima *modified Kessler* repairs, in Figure 1.[4–8] As discussed by Sebastin et al, these modifications are likely alterations of the Kirchmayr repair, not the original Kessler grasping repair.[4] The major differences in technique deal with knot placement and type of loop used to pass the suture through the tendon, which are outlined in the figures. The Pennington stitch has been commonly referred to as the *modified Kessler* and is doubled to create 4-core stranded repairs with either double-stranded suture, separate placement of 2 separate Pennington repairs leading to 2 knots, or continuous passage of suture to stack repairs adjacent to each other with 1 knot.

## 4-STRAND REPAIRS

With current suture technology, 4-strand repairs are the "minimum" number of core strands necessary for early motion exercises. We will discuss variations of the cruciate repair; Massachusetts General Hospital (MGH) repair, otherwise referred to as the augmented Becker repair; and the Strickland repair (Fig. 2).[6,7,9–17]

### Cruciate repairs

Cruciate repairs are one of the most commonly performed repairs in flexor tendon surgery and are commonly the control repair in numerous studies evaluating different repair configurations. The original cruciate repair designed by McLarney et al was a grasping (nonlocking) repair technique. However, locking configurations have been shown to be biomechanically superior to grasping (nonlocking) configurations.[9]

Croog et al compared the biomechanics of different locking cruciate configurations: simple lock, circle

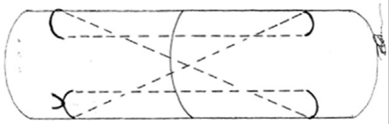
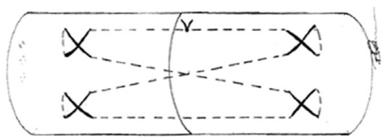
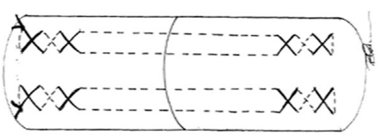
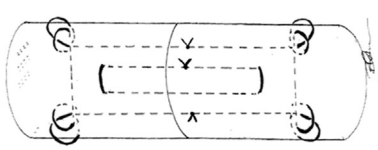
| Technique<br>4-Stranded Core Repairs | # Core Strands<br># Knots & Location<br># Sutures | Suture Size/Type | 2 mm Gapping Load (N)<br>(unless otherwise stated) | Failure Load (N) | Epitendinous Suture |
|---|---|---|---|---|---|
| Non-Locking Cruciate<br>(Simple)<br> | • 4<br>• 1 Internal or External Knot<br>• 1 Suture | 4-0 Surgidac™ | 44 | 56 | Yes |
| | | 3-0 Fiberwire® | 34<br>75 | 54<br>87 | No<br>Yes |
| | | 4-0 Ethibond® | 37 | 70 | Yes |
| Cross-Lock Cruciate<br>(Cross-Stitch or Adelaide)<br> | • 4<br>• 1 Internal Knot<br>• 1 Suture<br>• Modification: ⬆ cross lock length to maximize biomechanical strength | 3-0 Fiberwire® | 67<br>92 | 79<br>119 | No<br>Yes |
| | | 3-0 Fiberwire® | 59 | 85 | Yes |
| | | 3-0 Ticron™<br>a)2 mm cross lock<br>b)4 mm cross lock | a)55<br>b)62 | a)72<br>b)71 | No |
| | | 3-0 Fiberwire® | 96 | 107 | Yes |
| | | 4-0 Ethibond® | 35 | 70 | Yes |
| | | 4-0 Ethibond® | N/A | 64 | Yes |
| MGH<br>(Augmented or Modified Becker)<br> | • 4<br>• 2 External Knots<br>• 2 Sutures<br>• Modification: 2 Internal Knots | 3-0 Ethibond®<br>3-0 Fiberwire®<br>4-0 Fiberwire® | 34<br>43<br>39 | 49<br>56<br>52 | Yes |
| | | 4-0 Fiberwire®<br>Modified MGH | 55 | 65 | Yes |
| | | 3-0 Fiberwire® | 70 | 99 | Yes |
| | | 3-0 Ethilon®<br>3-0 Ethibond®<br>3-0 Fiberwire® | 48<br>58<br>60 | 69<br>82<br>124 | Yes |
| Indiana (Strickland)<br> | • 4<br>• 3 Internal Knots<br>• Core Stitch Tajima Modified Kessler + Horizontal Mattress<br>• 3 Sutures | 4-0 Surgidac™ | 23 | 35 | Yes |
| | | 3-0 Fiberwire® | 45 | 52 | Yes |
| | | 3-0 Surgilon™ | 42 | 48 | Yes |
| | | 4-0 Ethibond® | N/A | 46 | Yes |
| | | 3-0 Ethilon®<br>3-0 Ethibond®<br>3-0 Fiberwire® | 39<br>43<br>43 | 50<br>49<br>53 | Yes |

**FIGURE 2:** Four-stranded flexor tendon repairs. The repair and biomechanical data for common 4-stranded repairs include the non-locking cruciate (also called simple cruciate), cross-lock cruciate (also called cross-stitch cruciate or Adelaide repair), MGH (also called Augmented or Modified Becker repair), and Indiana (also called Strickland) repairs.[6,7,9–17]

lock, and cross-lock cruciate repairs.[10] They found the cross-lock (commonly also referred to as cross-stitch) configuration was biomechanically the most superior with and without an epitendinous stitch in terms of 2-mm gapping and ultimate load to failure.[10]

In a head-to-head comparison of a cross-lock cruciate repair to the Strickland repair, Vigler et al demonstrated that the cross-lock cruciate had a significantly smaller increase in work of flexion and a higher ultimate load to failure than the Strickland repair.[11]

Peltz et al also showed that a 4-mm cross-lock was slightly better than a 2-mm cross-lock in terms of 2-mm gapping, although not statistically significant enough to prefer one over the other in terms of surgical technique.[12]

Advantages of the cross-lock cruciate repair include its biomechanical strength compared with other 4-strand repairs and the use of a single suture to complete the repair. Although the cross-lock pattern can be tedious, overall the cruciate configuration is easier to place than other repairs requiring dual-suture configurations or multiple suture passes through the tendon.

Disadvantages of the cross-lock cruciate repair include exposed suture on the surface of the tendon, increased tissue handling from placing the cross-locks, and the need to make sure tendon ends are well approximated when the cross-locks are placed, the reasoning being that, unlike some other gliding repairs, additional tensioning of the repair cannot be easily achieved at the time of final knot tying.

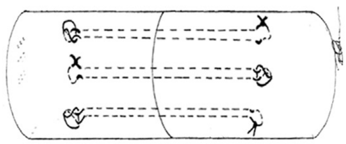
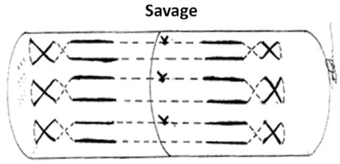
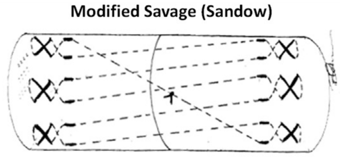
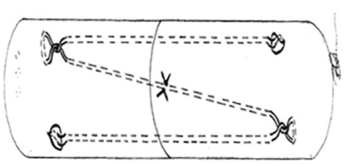
| Technique 6-Stranded Core Repairs | # Core Strands # Knots & Location # Sutures | Suture/Size Type | 2mm Gapping Load (N) (unless otherwise stated) | Failure Load (N) | Epitendinous Suture |
|---|---|---|---|---|---|
| Tsuge (Tang Modification)  | • 2, 4, 6<br>• 2, 4, 6 External Knots (one 2-core repair = starting anchor knot + final tied knot)<br>• 1, 2, 3 Double Stranded Sutures<br>• Modifications Double or triple core repair M-Tang (6-strand) U-Tang (4-strand) | 4-0 Supramid®<br>a) Triple Tang<br>b) M-Tang | a) 45<br>b) 46 | a) 59<br>b) 62 | Yes |
| | | 4-0 Supramid®<br>a) Double Tang<br>b) U-Tang | a) 37<br>b) 37 | a) 45<br>b) 43 | Yes |
| | | 4-0 Supramid®<br>a) Double<br>b) Triple | a) 41 (Initial)<br>b) 56 (initial) | a) 48<br>b) 64 | Yes |
| | | 4-0 Supramid®<br>Double Modified | N/A | 60 | Yes |
| | | 4-0 Supramid®<br>a) Single<br>b) Double | a) 18<br>b) 24 | a) 22<br>b) 46 | Yes |
| | | 4-0 Supramid®<br>Triple Tang | 45 | 60 | Yes |
| Savage  | • 2, 4, 6<br>• 1, 2, 3 Internal Knots<br>• 1, 2, 3 Sutures | 4-0 Surgidac™<br>4-strand | 21 | 32 | Yes |
| | | 4-0 Ethibond®<br>6–strand | 56 | 124 | Yes |
| | | 3-0 Ticron™ 4-strand<br>4-0 Ticron™ 4-strand<br>4-0 Ticron™ 6-strand | 56<br>36<br>63 | 68<br>56<br>76 | Yes |
| Modified Savage (Sandow)  | • 6<br>• 1 Internal Knot<br>• 1 Suture | 4-0 Ethilon® | 37 | 58 | Yes |
| Lim-Tsai  | • 6<br>• 1 Internal Knot and 2 Starting Anchor Knots<br>• 2 Double-Stranded Sutures | 4-0 Supramid® | 28 | 49 | Yes |
| | | 4-0 Supramid® | 40 | 51 | Yes |
| | | 4-0 FiberLoop®<br>4-0 Tendo-Loop (Braided Polyester)<br>4-0 Supramid® | 35 (1 mm)<br>18 (1 mm)<br>17 (1 mm) | 97<br>52<br>47 | No |

**FIGURE 3:** Six-stranded flexor tendon repairs. The repair and biomechanical data for common 6-stranded repairs include the Tang Modified Tsuge, Savage, Sandow Modified Savage, and Lim-Tsai repairs. The Tsuge repair by itself is a 2-strand repair but is commonly augmented to 6 strands to increase the overall strength. The Tsuge and Lim-Tsai repairs require double-stranded sutures.[5,7–9,16,18–22]

## Massachusetts General Hospital (Modified Becker)

The MGH repair, otherwise known as the modified or augmented Becker repair, is a 4-core repair with a running cross-lock loop configuration using 2 separate sutures secured with 2 separate knots on the outside of the tendon.

Moriya et al demonstrated higher load to failure and 2-mm gapping using an MGH repair with either Ethibond (Ethicon, Somerville, NJ) or Fiberwire (Arthrex Inc., Naples, FL) when compared to a modified Kessler repair using the same suture material. However, the gliding resistance was significantly higher using the MGH repair compared to the modified Kessler repair.[13] In a follow-up study, Moriya et al made a technical modification, burying the knots of the MGH repair (eg, modified MGH repair), and found a higher ultimate load to failure and 2-mm gapping compared to the standard MGH repair. Interestingly, there was still a slightly higher gliding resistance.[14]

Advantages of the MGH repair include biomechanical strength in terms of superior load to failure and 2-mm gapping compared to classic repair constructs such as the *modified Kessler* configurations and Strickland method. As shown biomechanically, this repair would be most advantageous when using a suture with a lower gliding friction. Also, the MGH repair has a larger suture purchase based on its configuration, which contributes to better biomechanical stability.

Disadvantages include exposed suture on the surface of the tendon, with the cross-lock configuration creating increased work of flexion due to friction and potential for increased adhesions, as well as potential weaknesses with the placement of 2 knots. Use of the

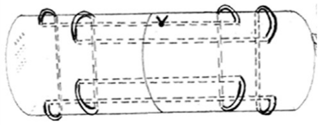
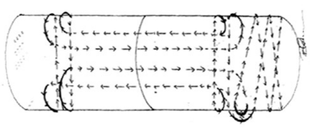
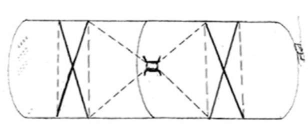
| Technique<br>8-Stranded Core Repair<br>Alternative Repair Options | # Core Strands<br># Knots & Location<br># Sutures | Suture Size/Type | 2 mm Gapping Load (N)<br>(unless otherwise stated) | Failure Load (N) | Epitendinous Suture |
|---|---|---|---|---|---|
| Winters-Gelberman<br> | • 8<br>• 1 Internal Knot<br>• 1 Double-Stranded Suture | 3-0 Braided Nylon<br>4-0 Braided Nylon | 40<br>41 | 77<br>69 | Yes |
| | | 4-0 Polyfilament Caprolactam | 45<br>*Estimated | 82 | Yes |
| Knotless Barbed Suture<br> | • 2-8<br>• Knotless<br>• 1 Bi-directional Barbed Suture<br>OR<br>• 1 Self-Locking Uni-Directional Barbed Suture<br>• Variable Configurations | 2-0 Polypropylene Quill™<br>a) 3-strands<br>b) 6-strands | N/A | a) 36<br>b) 88 | No |
| | | 2-0 Polydiaxonone Quill™<br>4-strand | 32 | 50 | No |
| | | 3-0 Glycolic Carbonate V-Loc™<br>a)2-strand<br>b)4-strand | N/A | a) 38<br>b) 146 | No |
| | | 0 Polypropylene Quill™<br>4-strands | 63 | 72 | No |
| | | 2-0 Polybutester V-Loc™<br>4-strands | 47 | 56 | No |
| Multifilament Stainless Steel<br>(MFSS)<br> | • Variable<br>• Knot Crimp or Internal Knot<br>• Variable Number of Sutures<br>• Variable Configurations | 3-0 MFSS<br>2-strand | N/A | 108 | Yes |
| | | 4-0 MFSS<br>• 6-strand Savage<br>• Cross-Stitch Cruciate<br>3-0 MFSS<br>• Cross-Stitch Cruciate | 82<br>60<br>78<br>*Estimated | 98<br>78<br>92<br>*Estimated | Yes |

**FIGURE 4:** Eight-stranded repair (Winters-Gelberman) and alternative suture repair options. The repair and biomechanical data for the 8-stranded Winters-Gelberman and newer, alternative suture repairs using knotless barbed suture and multifilament stainless steel. The barbed and stainless steel sutures can be used in a variety of repair configurations.[15,24–31]



modified MGH repair could avoid exposed knots by burying them, but even then, buried knots in the repair site can be a point of weakness during the immediate postoperative period.[2,3] The numerous placements of cross-locks also could become difficult for smaller tendons and FDS tendons, ultimately increasing the tissue handling of the injured tendon.

### Strickland

The Strickland method, also known as the Indiana Hand method, is a 4-core nonlocking (grasping) repair (Tajima *modified Kessler* and horizontal mattress) supplemented by a running-locking epitendinous stitch. The original configuration design by Strickland uses the grasping knot technique seen in the original Kessler grasping stitch.

Advantages of this repair are its biomechanical strength compared to other 2-core repairs and ability to be used for early motion exercises.

Disadvantages are that this repair has been shown to be inferior to many newer techniques in terms of biomechanical strength. The increased number of knots (3 internal knots) also increases points of weaknesses in the construct, although most repairs fail by either suture rupture or pullout.

## 6-STRAND REPAIR

We will discuss common 6-core repairs including the double-stranded suture repairs (Lim-Tsai and Tsuge) and single suture repairs (Savage and Modified Savage). These are depicted in Figure 3.[5,7–9,16,18–22]

### Lim-Tsai and Tsuge

The Lim-Tsai repair is a 6-core repair that uses 2 double-stranded sutures. At approximately 1 cm from the repair site, a superficial locking stitch is placed to cinch the suture down to the tendon. A core stitch is placed through to the opposite side, where a cross-lock stitch is placed. Then the suture is brought back through to the center of the repair. Another identical suture configuration also is placed with a double-stranded suture starting on the opposite side. After this is completed, a knot is tied in the center of the repair, completing the 6-core repair.

The Tsuge repair is a 6-core repair that also uses a double-stranded suture. By itself it is a 2-core stitch, but this repair can be augmented by placing multiple core stitches to increase repair strength and is commonly referred to as the Tang modification of the Tsuge repair. The repair is started by using a double stranded suture that is cinched onto itself to secure the stitch to the tendon. Then a longitudinal throw is passed across to the other side of the tendon, where one end of the double-stranded suture is cut to free the needle end. A locking stitch with the free needle is placed by passing the needle transversely to the other side, where the stitch is tied down.

Advantages of both these repairs are their superior biomechanical strength compared to other 2- and 4-core stranded repairs. The Tsuge repair by itself is not stronger but, when modified as a 6-core repair, can provide a stronger repair construct.

A disadvantage of the Lim-Tsai is the placement of 2 separate sutures, which increases tissue handling. Modifications of the Lim-Tsai stitch include using a single-looped suture instead of 2 separate sutures. The standard Lim-Tsai stitch also uses an intratendinous knot that can affect overall strength. Disadvantages of the Tsuge stitch include the necessity to use multiple repair constructs to match the biomechanical strength of the 4-core or higher repairs. Each Tsuge 2-core repair contains 2 knots, with a 6-stranded repair requiring 6 knots. Modifications by Tang decreased the number of overall knots (U-Tang, M-Tang) without sacrificing biomechanical strength.[18,19]

### Savage repair

The Savage technique is a popular configuration for flexor tendon repairs. The repair can be done as separate segments in a 2-core, 4-core, or 6-core suture configuration but would require 1, 2, and 3 knots, respectively. However, a modification by Sandow and McMahon utilized a 6-core configuration with 1 suture and 1 knot.[23] Savage describes the placement of anchor points on each end that have a longitudinal component that exits the tendon and then is passed obliquely and transversely to create a cross-lock. Then another longitudinal pass is made and brought through the tendon to the other side, where the process is repeated. If using the Sandow modification, 6 consecutive anchor points in sequence are created and then secured with 1 internal knot.

Advantages of this technique include its stout biomechanical strength and, in cases of the Sandow modification, placement of one knot. Once the first anchor points are set, the tendon length should be set and the repair should be completed without any further bunching at the repair site.

Disadvantages of this technique likely include its meticulous placement of multiple longitudinal passes and cross-locks. The repair time will also likely be increased compared to other 4-core or 6-core double-stranded repair configurations.

## 8-CORE REPAIR

### Winters-Gelberman

The Winters-Gelberman repair is an 8-core repair using a double-stranded suture (Fig. 4).[15,24–31] The configuration involves multiple locking loops and resembles a double Pennington configuration. In a biomechanical comparison by Nelson et al comparing the Winters-Gelberman repair to a double-stranded 4-core modified locking Kessler, the Winters-Gelbmerman repair was superior in all measurements with or without an epitendinous stitch.[24]

Osei et al recently compared a 3-0 and 4-0, 4-strand modified locking Kessler to a Winters-Gelberman repair using 4-0 double-stranded suture. Overall, they found that the Winters-Gelberman repair was still stronger using a 4-0 double-stranded suture than a 4-strand modified locking Kessler using 3-0 suture, indicating that increasing suture caliber may not necessarily compensate for using more core strands.[25]

The advantage of this repair is its stout biomechanical strength compared to common 4-core and 6-core repairs. This repair will be most useful in larger tendons able to withstand 8-strands. This repair uses an easily replicated configuration based on the Pennington repair.

Disadvantages of this repair include its potentially increased bulk with 8-core strands, increased tissue handling with increased suture passes, and technical difficulty, especially in smaller tendons.

## ALTERNATIVE SUTURE REPAIRS

### Stainless steel

Gordon et al recently compared a 3-0 multifilament stainless steel wire suture to a 4-0 cross-stitch cruciate Fiberwire repair, both supplemented by an epitendinous stitch. They found the ultimate tensile strength to be similar between both repair constructs; however, no raw data were provided. The stainless steel suture was on average 5 minutes faster, needed less surgical exposure by 1.5 cm without C1 and A3 pulley resections, and had significantly less frictional force than Fiberwire. The 2-mm gapping load was also determined as higher than Fiberwire; however no raw data were provided.[26] In another comparative biomechanical study, it was shown that the 4-0 stainless steel repairs in either a Savage or cross-lock cruciate configuration were significantly stronger than 4-0 Fiberwire in the same configurations.[27]

The technical aspects of this repair include using a crimp system to secure the stainless steel suture. In their technique, a single-stranded suture with needles at both ends is placed at the end of the tendon and a single

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cross-lock stitch is placed. This is repeated for the other tendon end and the free suture ends in the center of the repair are secured with a crimp buried in the center of the tendon. The gap at the repair site is supplemented by volar only interrupted epitendinous stitches.

Advantages of this repair include the potential to avoid taking down more soft tissue structures than other standard repairs; the decreased repair time, which can be useful in injuries with multiple digits; and that the repair can be knotless. Disadvantages include unknown long-term potential complications with the wire and crimp mechanism and technical difficulties with the crimp system.



### Barbed suture

The recent interest in barbed suture has focused on the unidirectional nature of the barbs, which allow a stronger interaction between the suture and the tendon, as well as knotless fixation (Fig. 4).

Parikh et al compared multiple suture materials using a simple-locked cruciate technique to a 3- and 6-core barbed suture technique in a novel configuration. Overall, there was a statistically significant difference in terms of ultimate load to failure and cross-sectional area (repaired/native) between the 6-core barbed suture and the simple-locked cruciate repairs.[28]

Marrero-Amadeo et al compared a 4-core 2-0 barbed repair in a *modified Kessler* configuration to the Strickland repair and found no statistically significant differences in terms of ultimate load to failure and 2-mm gapping.[15]

Zeplin et al compared 2- and 4-core modified Kirchmayr-Kessler repairs using either a 3-0 barbed suture or a 3-0 PDS (Ethicon) suture. The ultimate load to failure was very similar for both repairs in the 4-core repairs; however, no gapping data were presented.[29]

McLellan et al compared a 2-core *modified Kessler* and 4-core Savage using 3-0 Ethibond to a 4-core 0-diameter barbed suture repair that combined the *modified Kessler* and Savage techniques used for the other repairs. Overall, the 4-core Savage repair was similar to the knotless barbed repair in terms of 2-mm gapping and ultimate load to failure. The change in cross-sectional area for barbed repairs was significantly smaller compared to the other 2 repair techniques.[30]

Joyce et al compared a 4-core cross-stitch cruciate repair (Adelaide) using a 3-0 Prolene (Ethicon) to a 2-0 barbed suture repair in a cross-stitch cruciate configuration. They found a statistically significant difference in the 2-mm gapping loads and change in cross-sectional area using the barbed suture repair.[31]

Advantages of barbed suture include its knotless fixation (eliminating one mechanism of variability and potential source of failure) and comparable biomechanical strength. The reduction in cross-sectional area is also advantageous for early postoperative motion. Faster surgical time using barbed suture has not been well evaluated clinically, but based on the fact that it is knotless, it can be an advantage during polytrauma cases.

Disadvantages of barbed suture include the inability to "reverse" the repair if there are any erroneous suture passes. The unidirectional barbs lock the stitch in the tendon when passing the suture, making it difficult to pull back the suture without damaging the healthy tendon fibers. Another often-overlooked technical issue while handling barbed suture is its increased affinity to "catch" on objects in the operative field such as field sponges while passing the suture. Exposed barbs on the outside of the tendon are also at risk of catching on the surrounding tissue and pulleys, which may increase adhesion formation and restrict motion. With current barbed suture technology, one must drop one suture caliber to equal an equivalent suture tensile strength (eg, a 2-0 barbed = 3-0 nonbarbed). Also, current barbed suture technology is not available in stronger composite materials (eg, Fiberwire, Maxbraid, Orthocord, Supramid, etc.) and therefore may require more strands across the repair site to give an equivalent overall strength.

## COMPLICATIONS

Complications of flexor tendon repair are predominantly postoperative adhesions, rupture, and decreased total active motion, perhaps due to bulky repairs or poor gliding through the pulley system.

In a recent systematic review of 39 studies meeting inclusion criteria, Dy et al discuss the complication rates after flexor tendon repairs and reported a reoperation rate of 6%, rupture rate of 4%, and adhesion formation rate of 4%. The majority of repairs in the studies were "modified Kessler" repairs and the majority of those included an epitendinous stitch. Based on their data mining, the addition of an epitendinous stitch decreased the rate of reoperation by 84%.[32] Based on the amount of continued flexor tendon research aimed at improving strength and decreasing adhesions, there may be an underrepresentation of the general clinical sense surgeons have with respect to potential complications or reduced digital function.

## REFERENCES

1. Strickland JW. Development of flexor tendon surgery: twenty-five years of progress. *J Hand Surg Am.* 2000;25(2):214–235.
2. Pruitt DL, Aoki M, Manske PR. Effect of suture knot location on tensile strength after flexor tendon repair. *J Hand Surg Am.* 1996;21(6):969–973.

3. Momose T, Amadio PC, Zhao C, Zobitz ME, An KN. The effect of knot location, suture material, and suture size on the gliding resistance of flexor tendons. *J Biomed Mater Res*. 2000;53(6):806−811.
4. Sebastin SJ, Ho A, Karjalainen T, Chung KC. History and evolution of the Kessler repair. *J Hand Surg Am*. 2013;38(3):552−561.
5. Labana N, Messer T, Lautenschlager E, Nagda S, Nagle D. A biomechanical analysis of the modified Tsuge suture technique for repair of flexor tendon lacerations. *J Hand Surg Br*. 2001;26(4): 297−300.
6. Waitayawinyu T, Martineau PA, Luria S, Hanel DP, Trumble TE. Comparative biomechanic study of flexor tendon repair using FiberWire. *J Hand Surg Am*. 2008;33(5):701−708.
7. Barrie KA, Wolfe SW, Shean C, Shenbagamurthi D, Slade JF, Panjabi MM. A biomechanical comparison of multistrand flexor tendon repairs using an in situ testing model. *J Hand Surg Am*. 2000;25(3):499−506.
8. Viinkainen A, Goransson H, Huovinen K, Kellomaki M, Rokkanen P. A comparative analysis of the biomechanical behavior of five flexor tendon core sutures. *J Hand Surg Br*. 2004;29(6):536−543.
9. Mclarney E, Hoffman H, Wolfe SW. Biomechanical analysis of the cruciate four-strand flexor tendon repair. *J Hand Surg Am*. 1999;24(2):295−301.
10. Croog A, Goldstein R, Nasser P, Lee SK. Comparative biomechanic performances of the locked cruciate four-strand flexor tendon repairs in an ex vivo porcine model. *J Hand Surg Am*. 2007;32(2):225−232.
11. Vigler M, Palti R, Goldstein R, Patel VP, Nasser P, Lee SK. Biomechanical study of cross-locked cruciate versus Strickland flexor tendon repair. *J Hand Surg Am*. 2008;33(10):1826−1833.
12. Peltz TS, Haddad R, Scougall PJ, Nicklin S, Gianoutsos MP, Walsh WR. Influence of locking stitch size in a four-strand cross-locked cruciate flexor tendon repair. *J Hand Surg Am*. 2011;36(3):450−455.
13. Moriya T, Zhao C, Yamashita T, An KN, Amadio PC. Effect of core suture technique and type on the gliding resistance during cyclic motion following flexor tendon repair: a cadaveric study. *J Orthop Res*. 2010;28(11):1475−1481.
14. Moriya T, Larson MC, Zhao C, An KN, Amadio PC. The effect of core suture flexor tendon repair techniques on gliding resistance during static cycle motion and load to failure: a human cadaver study. *J Hand Surg Eur Vol*. 2010;37(4):316−322.
15. Marrero-Amadeo IC, Chauhan A, Warden SJ, Merrell GA. Flexor tendon repair with a knotless barbed suture: a comparative biomechanical study. *J Hand Surg Am*. 2011;36(7):1204−1208.
16. Angeles JG, Heminger H, Mass DP. Comparative biomechanical performances of 4-strand core suture repairs for zone II flexor tendon lacerations. *J Hand Surg Am*. 2002;27(3):508−517.
17. Miller B, Dodds SD, deMars A, Zagoreas N, Waitayawinyu T, Trumble TE. Flexor tendon repairs: the impact of FiberWire on grasping and locking core sutures. *J Hand Surg Am*. 2007;32(5): 591−596.
18. Wang B, Xie RG, Tang JB. Biomechanical analysis of a modification of Tang method of tendon repair. *J Hand Surg Br*. 2003;28(4):347−350.
19. Cao Y, Tang JB. Biomechanical evaluation of a four-strand modification of the Tang method of tendon repair. *J Hand Surg Br*. 2005;30(4):374−378.
20. Gill RS, Lim BH, Shatford RA, Toth E, Voor MJ, Tsai TM. A comparative analysis of the six-strand double-loop flexor tendon repair and three other techniques: a human cadaveric study. *J Hand Surg Am*. 1999;24(6):1315−1322.
21. Xie RG, Zhang S, Tang JB, Chen F. Biomechanical studies of 3 different 6-strand flexor tendon repair techniques. *J Hand Surg Am*. 2002;27(4):621−627.
22. Gan AWT, Neo PY, He M, Yam AKT, Chong AKS, Tay SC. A biomechanical comparison of 3 loop suture materials in a 6-strand flexor tendon repair technique. *J Hand Surg Am*. 2012;37(9): 1830−1834.
23. Sandow MJ, McMahon MM. Single-cross grasp six-strand repair for acute flexor tenorrhaphy. Modified Savage technique. *Atlas Hand Clin*. 1996;1:41−64.
24. Nelson GN, Potter R, Ntouvali E, et al. Intrasynovial flexor tendon repair: a biomechanical study of variations in suture application in human cadaver. *J Orthop Res*. 2012;30(10):1652−1659.
25. Osei DA, Stepan JG, Calfee RP, et al. The effect of suture caliber and number of core suture strands on zone II flexor tendon repair: a study in human cadavers. *J Hand Surg Am*. 2014;39(2):262−268.
26. Gordon L, Matsui J, McDonald E, Gordon JA, Neimkin R. Analysis of a knotless flexor tendon repair using a multifilament stainless steel cable-crimp system. *J Hand Surg Am*. 2013;38(4):677−683.
27. McDonald E, Gordon JA, Buckley JM, Gordon L. Comparison of a multifilament stainless steel suture with FiberWire for flexor tendon repairs-an in vitro biomechanical study. *J Hand Surg Eur*. 2013;38(4):418−423.
28. Parikh PM, Davison SP, Higgins JP. Barbed suture tenorrhaphy: an ex vivo biomechanical analysis. *Plast Reconstr Surg*. 2009;124(5): 1551−1558.
29. Zeplin PH, Zahn RK, Meffert RH, Schmidt K. Biomechanical evaluation of flexor tendon repair using barbed suture material: a comparative ex vivo study. *J Hand Surg Am*. 2011;36(3):446−449.
30. McClellan WT, Schessler MJ, Ruch DS, Levin LS, Goldner RD. A knotless barbed flexor tendon repair techniques using a bidirectional barbed suture: an ex vivo comparison of three methods. *Plast Reconst Surg*. 2011;128(4):322e−327e.
31. Joyce CW, Whately KE, Chan JC, Murphy M, O'Brien FJ, Carroll SM. Flexor tendon repair: a comparative study between a knotless barbed suture repair and a traditional four-strand monofilament suture repair. *J Hand Surg Eur Vol*. 2014;39(1):40−45.
32. Dy CJ, Hernandez-Soria H, Ma Y, Roberts TJ, Daluiski A. Complications after flexor tendon repair: a systematic review and meta-analysis. *J Hand Surg Am*. 2012;37(3):543−551.