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Research Article

Efficacy Comparison of Various Repair Techniques for Flexor Tendon Injuries: A Systematic Review and Meta-Analysis

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ABSTRACT

Background: Flexor tendon injuries are potentially disabling, as flexor tendons are essential to hand function, playing a vital role in all types of grip, including power grip and fine pinch grip. However, there has been no consensus regarding the most effective repair technique for this pathology.
Methods: A systematic search was conducted based on PRISMA guidelines to identify relevant studies through PubMed, Google Scholar, and Cochrane. A total of 9 studies (266 tendons from 108 patients) were included.
Results: In comparison between Modified Kessler and Four-stranded Cruciate technique, Four-stranded Cruciate Suture produces higher 2 mm gap strength (I2= 93%, P< 0.00001), higher ultimate strength (I2= 99%, P=0.02), and better Functional Outcome as measured by Strickland Criteria (I2=0%, P< 0.0001). In comparison between the 2-Stranded and the 4-Stranded Kessler technique. The 4-Stranded Kessler technique produces higher 2 mm gap strength (I2= 98%, P=0.02) and higher ultimate strength (I2= 60%, P<0.00001).
Conclusion: Current systematic review and meta-analysis suggest that the 4-stranded cruciate repair technique has better strength and functional outcome than the modified Kessler, especially in zone II and III injuries. Four-stranded Kessler is also proven to have better strength compared to the two-stranded Kessler.

Keywords: Biomechanics; Cruciate; Flexor tendon; Kessler; Tendon repair

INTRODUCTION

Flexor tendons are essential to hand function, playing a vital role in all grip types, including power grip and fine pinch grip. The studies of flexor tendon injuries showing a 7% occurrence in hand injuries.[1] Flexor tendon injuries frequently occur through division in deep lacerations of the fingers, palm, or forearm.[2] Flexor tendon injuries commonly occur in young, active people.[3,4] Several approaches to flexor tendon injury had 70-90% of successful repair rates.[5] The most common mechanism of finger flexor tendon disruptions reported in children is

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cut by glass.[6] Superior function obtained in the repair of sharply incised tendons instead of crushing injuries is a well-known fact.[7]

Flexor tendon injuries of the hand are commonly encountered problem, affecting both gender and different age groups due to varying types of injurious agents, sometimes associated with fractures of phalanges and/or nerve or vessel injuries that could result in significant functional disabilities that have a negative impact on working ability and lifestyle.[2]

Flexor tendon injuries are commonly encountered and the surgical repair still represents a challenging problem. According to Strickland, the characteristics of an ideal primary flexor tendon repair are easily placed in tendon, secure knots, smooth junctions, minimal gapping, minimal interference with tendon vascularity, and sufficient strength throughout healing to permit application of early motion stress.[8] Re-establishing normal hand and wrist function with a normal range of finger and wrist movement and normal grip strength remains one of the most difficult goals to achieve. Furthermore, tendon repair complications like tendon rupture, gapping, adhesions, and joint stiffness are influenced by factors, including age, mechanism, level of injury, repair technique, and the rehabilitation protocol.[6,9,10]

As far as we observe, there has not been any meta-analysis to objectively compare the repair strength and outcomes of some commonly used repair techniques (Modified Kessler vs. Four-stranded Cruciate technique and Two-stranded Kessler vs. Four-stranded Kessler Technique).

MATERIAL AND METHODS

The study design was a systematic review and meta-analysis over numbers of randomized controlled trials and non-randomized comparative studies. A systematic search was conducted to identify relevant studies up to the 2020 publication year through PubMed, Google Scholar, and Cochrane database based on PRISMA guidelines (Figure 1). The keywords used were:

- “Modified Kessler” AND “Cruciate” AND “Flexor Tendon” AND “Strength”
- “Modified Kessler” AND “Cruciate” AND “Flexor Tendon” AND “Outcome”
- “Two-stranded Kessler” AND “Four-stranded Kessler” AND “Flexor Tendon” AND “Strength”

Those data were then manually scanned and reviewed by authors with the inclusion criteria: (1) the studies included a comparative design for the modified Kessler vs. Cruciate repair and Two-stranded Kessler vs. Four-stranded Kessler, (2) Outcomes discussed are repair strength (2 mm gap and ultimate strength) and functional outcome based on Strickland Criteria. Exclusion criteria were crush injuries, lack of adequate skin cover, a concomitant

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fracture or chondral lesion, replantation, extensor tendon injury in the same digit, and previous hand trauma. Table 1 describes the PICO method for defining the inclusion and exclusion criteria.

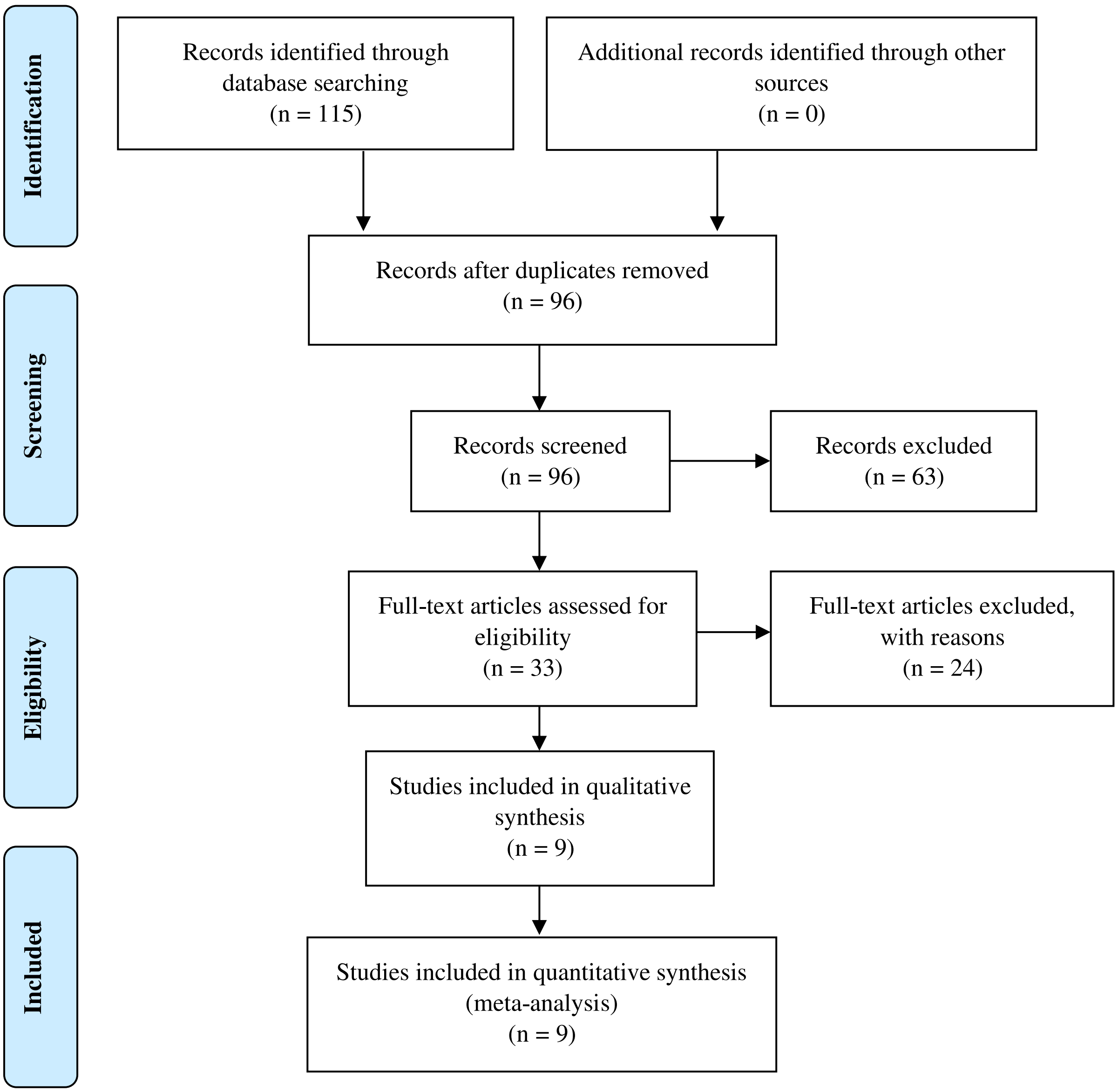

Figure 1. Flow chart showing article selection

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Table 1. PICO Table Describing Inclusion and Exclusion Criteria

Study Component	Inclusion	Exclusion
Population	• Any age • Any sex • Human or animal studies • In vivo or in vitro studies • Injury in flexor tendons	• Crush injuries, lack of adequate skin cover, • A concomitant fracture or chondral lesion, replantation, and extensor tendon injury in the same digit, • Previous hand trauma
Intervention and Comparison	• Modified Kessler vs. Four-stranded Cruciate • Two-stranded Kessler vs. Four-stranded Kessler	• Other methods of treatment • Studies with only one method of treatment (non-comparative studies)
Outcome	• 2 mm gap strength • Ultimate strength • Functional outcome based on Strickland Criteria	No outcome mentioned or different outcomes
Publication	• Studies published in English in peer-reviewed journals	• Duplicate publications of the same study that do not report on different outcomes • Meeting presentations or proceedings
Study Design	• Randomized controlled trials and non-randomized comparative studies	• Review articles • Abstracts, editorials, letters • Case reports

Abbreviations: PICO, Population-Intervention-Comparison-Outcome

The data extraction was collected under basic characteristics, and the main outcomes presented the final functional outcome and biomechanical outcome. In each study, the mean difference (MD) for continuous outcome and odds ratio (OR) for dichotomous outcome with a 95% confidence interval (CI) was calculated using Review Manager (RevMan) [Computer program, Version 5.3. Copenhagen: The Nordic Cochrane Centre, the Cochrane Collaboration, 2014]. Fixed effect model was used when the heterogeneity was <50%, whereas random effect model was used when the heterogeneity was >50%.

RESULTS

A total of nine studies (266 tendons from 108 patients) were included, divided into five meta-analyses. Nine studies are Prospective Randomized Controlled Trial (Level I evidence) (Table 2).

A study was to develop and test in vitro a new flexor tendon suture technique repaired using 1 of 4 suture techniques (the modified Kessler, the Strickland, the modified 4-strand Savage Cruciate 4-strand repairs). Each repair was tested using a slow-test machine and displacement control at two mm/s. Force applied, the resultant gap and ultimate tensile strength were recorded, and statistical comparisons were

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performed using a two-tailed Student's t-test with the level of significance set at p 5.05.

Table 2. Studies included in the analysis

No.	Reference	Journal	Study Design	Level of Evidence
1.	McLarney et al. (1999)	The Journal of Hand Surgery	Randomized Controlled Trial (Cadavers)	I
2.	Barrie et al. (2000)	The Journal of Hand Surgery	Randomized Controlled Trial (Cadavers)	I
3.	Tang et al. (2001)	Plastic and Reconstructive Surgery	Randomized Controlled Trial (Cadavers)	I
4.	Waitayawinyu et al. (2008)	The Journal of Hand Surgery	Randomized Controlled Trial (Cadavers)	I
5.	Navali et al. (2008)	The Journal of Hand Surgery	Randomized Controlled Trial (Humans)	I
6.	Shaikh et al. (2018)	Surgical Medicine Open Access Journal	Randomized Controlled Trial (Humans)	I
7.	Karjalainen et al. (2012)	The Journal of Hand Surgery	Randomized Controlled Trial (Cadavers)	I
8.	Dogramaci et al. (2008)	HAND	Randomized Controlled Trial (Sheep)	I
9.	Yalcin et al. (2011)	Acta Orthopaedica et Traumatologica Turcica	Randomized Controlled Trial (Cadavers)	I

In another study, functional outcome was better in 4 strands cruciate repair with excellent result in 66.6%, good in 29.1% and fair in 4.1%, as compared to modified Kessler technique in which excellent results were found in 45.8%, good in 37.5%, fair in 12.5% and poor in 4.1% of cases. A better functional result was achieved in 4 strands cruciate repair, especially in zone II, with excellent results in 33.3%, good in 50%, and fair in 16.6% of cases, as compared to modified Kessler repair with no excellent results, 33.3% good, 50% fair and 16.6% poor results.

Another study, implemented repairs on 40 flexor digitorum profundus (FDP) tendons acquired from fresh frozen cadavers. The tendons were divided into five groups of 8 tendons each. The 2-strand modified Kessler suture technique was used in the first group, the 4-strand Strickland suture technique in the second group, the 4-strand modified Kessler (without epitenon suture) suture technique in the third group, and the 4-strand modified Kessler (with epitenon sutures) suture technique in the fourth group. The remaining eight intact tendons were set aside as the control group. The ultimate tensile strength of the 2-strand modified Kessler group was determined as 39.89±9.65 Newtons (N), the ultimate tensile strength of the 4-strand Strickland group was 39.64±9.14 N, the ultimate tensile strength of 4-strand modified Kessler group (without epitenon suture) was 50.29±11.24 N, the ultimate tensile strength of 4-strand modified Kessler group (with epitenon suture) was 54.47±6.83 N, and the ultimate tensile strength of the control group was 119±17.59 N.

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Table 3. Studies included in the analysis

No.	**Reference**	**Patient Characteristics**			**Injury Site/Zone**	**Duration of Surgery (minutes)**		**Follow Up Period**
		Sample Size	**Age (years)**	**Sex**		**Modified Kessler**	**Four-Stranded Cruciate**	
1	McLarney et al. (1999)	20 tendons from 14 cadavers: Kessler: 10 Cruciate: 10	NA	NA	Index, long, and ring finger flexor profundus tendons	3 ± 0.5	4 ± 1	NA
2	Barrie et al. (2000)	20 tendons from 21 cadavers: Kessler: 10 Cruciate: 10	NA	NA	Index, long, and ring finger flexor profundus tendons	NA	NA	NA
3	Tang et al. (2001)	Kessler: 10 Cruciate: 10	NA	NA	NA	6.2 ± 0.5	9.0 ± 0.5	NA
4	Waitayawinyu et al. (2008)	Kessler: 7 Cruciate: 7	72 (54-91)	NA	NA	NA	NA	NA
5	Navali et al. (2008)	32 tendons in 29 patients: Kessler: 16 Cruciate: 16	34 months (11–46 months)	NA	Zone 2 FDP lacerations	NA	NA	11 months (8–18 months)
6.	Shaikh et al. (2018)	140 tendons in 44 patients. Kessler: 70 Cruciate: 70	28.05 ± 10.42	M: 28 (63.64%) F:16 (36.36%)	Thumb: 8 (5.7%) Index finger: 24 (17.1%) Middle finger: 44 (31.4%) Ring finger: 42 (30%) Little finger: 22 (15.7%)	NA	NA	8 weeks
7.	Karjalainen et al. (2012)	Kessler: 10 Cruciate: 10	NA	NA	Flexor digitorum profundus tendons from the index, middle, and ring fingers	NA	NA	NA

Abbreviations: NA, Not Available

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Table 4. Modified Kessler vs. Four Stranded Cruciate

No.	Reference	Tensile Strength		Functional Outcome	
		Modified Kessler	Four-Stranded Cruciate	Modified Kessler	Four-Stranded Cruciate
1	McLarney et al. (1999)	2 mm gap: 22 ± 3.5 Ultimate: 28 ± 2.8	2 mm gap: 44 ± 4 Ultimate: 55 ± 3.1	NA	NA
2	Barrie et al. (2000)	2 mm gap: 14 ± 2 Ultimate: 39 ± 6	2 mm gap:37 ± 2.3 Ultimate: 70 ± 8	NA	NA
3	Tang et al. (2001)	2mm gap: 21.2 ± 4.0 Ultimate: 24.7 ± 3.0 Elastic modulus: 3.1 ± 0.3 Energy to failure: 0.09 ± 0.02	2mm gap: 37.4 ± 3.8 Ultimate: 46.3 ± 3.8 Energy to failure: 4.5 ± 0.3 Energy to failure: 0.26 ± 0.04	NA	NA
4	Waitayawinyu et al. (2008)	2mm gap: 39 ± 12 Ultimate: 56 ± 6	2mm gap: 96 ± 12 Ultimate: 107 ± 12	NA	NA
5	Navali et al. (2008)	• NA	• NA	• Satisfactory: 14 (87.5%) • Fair: 2 (12.5%)	• Satisfactory: 15 (93.75%) • Fair: 1 (6.25%)
6.	Shaikh et al. (2018)	• NA	• NA	• Satisfactory: 20 (28.6%) • Fair: 50 (71.4%)	• Satisfactory: 46 (65.7%) • Fair: 24 (34.3%)
7.	Karjalainen et al. (2012)	• Stiffness: 7 ± 3 • Ultimate: 39 ± 6	• Stiffness: 2.75 ± 1.2 • Ultimate: 20 ± 3	• NA	• NA

Abbreviations: NA, Not Available.

Table 5. 2-Stranded Kessler vs. 4-Stranded Kessler

No.	Reference	Sample Size	Injury Site/Zone	Tensile Strength	
				2-Strand Kessler	4-Strand Kessler
1	Barrie et al. (2000)	20 tendons from 21 cadavers: 2-Kessler: 10 4-Kessler: 10	Index, long, and ring finger flexor profundus tendons	2 mm gap: 14 ± 2 Ultimate: 39 ± 6	2 mm gap: 26 ± 2 Ultimate: 66 ± 11
2	Dogramaci et al. (2008)	20 tendons: 2-Kessler: 10 4-Kessler: 10	Flexor digitorum profundus tendons of forelimbs	2 mm gap: 22.56 ± 3.44 Ultimate: 34.44 ± 2.33	2 mm gap: 30.85 ± 1.9 Ultimate: 53.38 ± 8.09
3	Yalcin et al. (2011)	16 tendons from 7 cadavers: 2-Kessler: 8 4-Kessler: 8	Index, middle, and ring fingers of 14 hands	Ultimate: 39.89±9.65	Ultimate: 54.47±6.83

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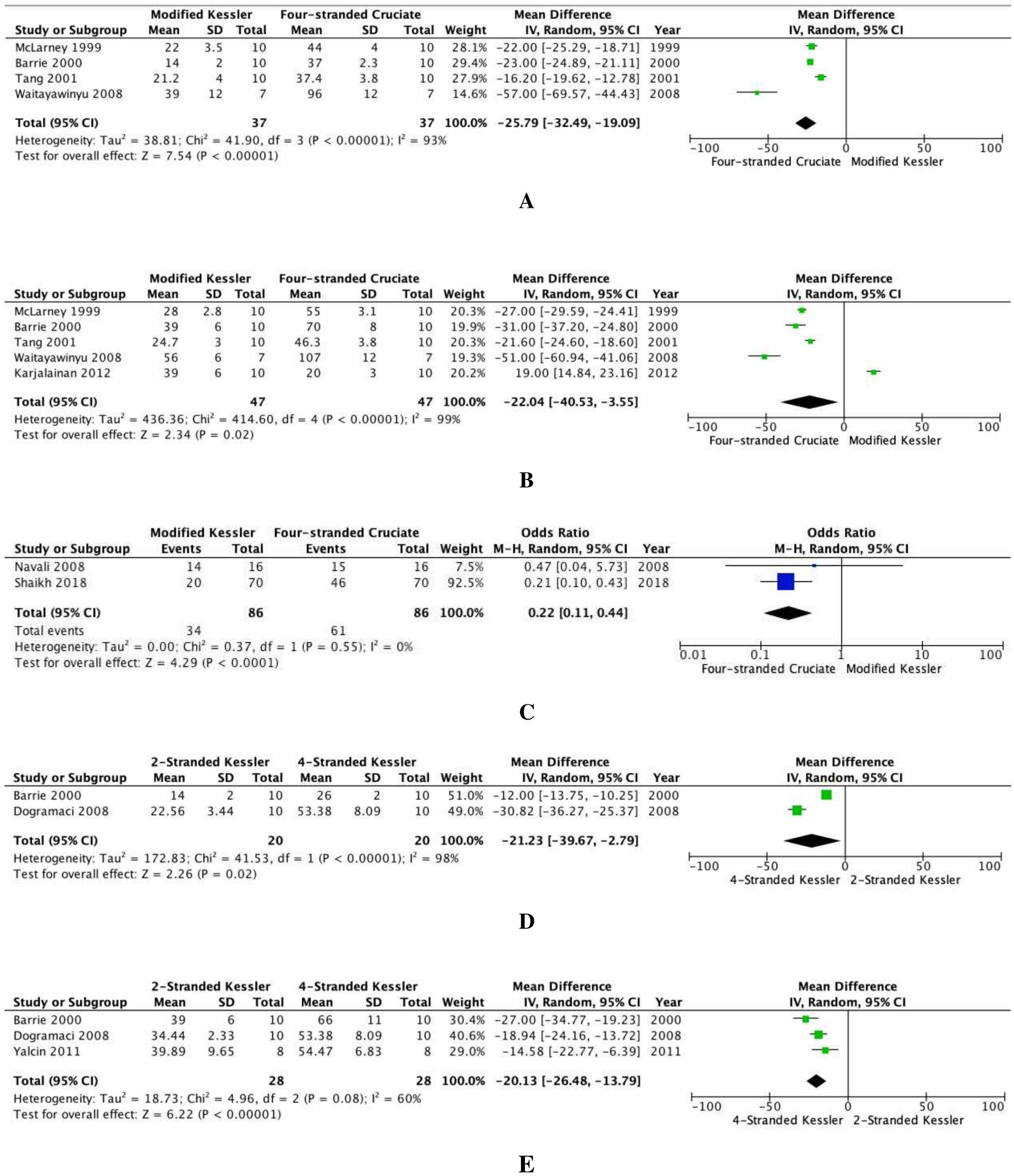

Figure 2. Forest Plot for 2 mm Gap Strength **(A)**, Forest Plot for Ultimate Strength **(B)**, Forest Plot for Functional Outcome **(C)**, Forest Plot for 2 mm Gap Strength **(D)**, Forest Plot for Ultimate Strength **(E)**

In zone III, 4 strand cruciate technique showed a better functional outcome with 77.7% excellent and 22.2% good results compared to 55.5% excellent and 44.4% good results found in Modified Kessler repair. Zone V showed almost comparable results between the two types of repairs.

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The tensile strength of 4-strand modified Kessler group (with epitenon suture) group was significantly higher ($p<0.05$) than 2-strand modified Kessler group. The tensile strength of the 4-strand modified Kessler group (without epitenon suture) was also significantly higher ($p<0.05$) than 2-strand modified Kessler group. No significant difference was observed between the tensile strengths of the 2-strand modified Kessler and 4-strand Strickland group ($p>0.05$).

In comparison between Modified Kessler and Four-stranded Cruciate technique, Four-stranded Cruciate Suture produces higher 2 mm gap strength (4 studies with 74 samples, $I^2= 93\%$, $P< 0.00001$), higher ultimate strength (5 studies with 94 samples, $I^2= 99\%$, $P=0.02$), and better Functional Outcome as measured by Strickland Criteria (2 studies with 172 samples, $I^2=0\%$, $P< 0.0001$).

DISCUSSION

The flexor tendons are strong, smooth cords that connect the forearm muscles to the bones in the fingers and thumb. There are two to each finger and one for the thumb. Tendons run inside tunnels at the wrist and in the fingers, and they bend the fingers in the manner of a bicycle brake cable. Tendons can be damaged by any cut across the wrist or hand's palmar surface, especially at the finger creases where the tendons lie just under the skin. Occasionally, the tendon is detached from the bone by a violent pulling injury to the finger. Each hand's specific movement relies on the finely tuned biomechanical interplay of the intrinsic and extrinsic musculotendinous forces.[11,12]

Flexor tendon injuries commonly occur in young, active people. The most common mechanism of finger flexor tendon disruptions reported in children is cut by glass. Superior function obtained in the repair of sharply incised tendons as opposed to crushing injuries is well-known. Restoring digital function after a flexor tendon injury continues to be one of the greatest challenges in the field of hand surgery.[13] Advances in the understanding of tendon anatomy, nutrition, healing, and postoperative rehabilitation have generated an evolution of techniques that have enhanced the results of flexor tendon repair.[14] The surgical repair technique for zone two flexor tendon injuries has been debated extensively through the years, but adhesion formation, suture rupture, and suture locking on the pulley edge remain possible consequences of a poor repair. Although increasing the repair strength through increasing the number of strands crossing the repair site to allow active postoperative mobilization without increasing the risk of rupture is logical, it can compromise tendon gliding function.

The cruciate suture technique was nearly twice as strong as 2 mm gap formation compared with the Kessler, Strickland, and Savage repairs. Ultimate tensile strength was also significantly stronger for the Cruciate technique than the Kessler, Strickland, or Savage repairs. The technique was significantly faster to perform than

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the Savage or Strickland repairs and was comparable in repair time to the 2-stranded Kessler repair. The new suture technique's design allowed the tendon repair to be completed with the ease and speed of a 2-strand technique but bestowed on the repair strength that exceeded current 4-strand techniques. Besides that, the tensile strength of 4-strand sutures, with or without epitenon sutures, is significantly higher than the tensile strength of 2-strand sutures. All suture techniques applied had sufficient tensile strength to promote early mobilization.[14,15] Four strand core sutures have a better result with a lower tendon rupture rate than two strand core sutures. Other facts stated in literature are that the zone with the worst results was zone II, and Kleinert splints had better results than static splints.[16-18]

This study has several limitations: (1) The heterogeneity of the studies included is high. (2) Due to the limitation of studies, animal studies and in vitro studies are also included. This may contribute to the heterogeneity of the studies involved. However, to our knowledge, this study is the first to formulate a meta-analysis on this matter. It is hoped that this study might be influential for future study, conducting well-designed trials with a larger amount of samples.

CONCLUSION

Current systematic review and meta-analysis suggest that the 4-stranded cruciate repair technique has better strength and functional outcome than the modified Kessler repair technique. The Four-stranded Kessler technique is also proven to have better strength compared to the two-stranded Kessler technique.

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