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Review 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 and fine pinch grips. 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 a comparison between the Modified Kessler and 4-stranded Cruciate techniques, the Four-stranded Cruciate Suture produces a higher 2 mm gap strength ($I^2 = 93\%$, $p < 0.00001$), higher ultimate strength ($I^2 = 99\%$, $p = 0.02$), and better Functional Outcome as measured using the Strickland Criteria ($I^2 = 0\%$, $p < 0.0001$). In a comparison between the 2-Stranded and the 4-Stranded Kessler technique, the 4-Stranded Kessler technique produces a higher 2 mm gap strength ($I^2= 98\%$, $p =0.02$) and higher ultimate strength ($I^2= 60\%$, $p <0.00001$).
Conclusion: The current systematic review and meta-analysis suggests that the 4-stranded cruciate repair technique has better strength and functional outcomes than the modified Kessler, especially in zone II and III injuries. The 4-stranded Kessler is also proven to have better strength compared to the 2-stranded Kessler.

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

INTRODUCTION

Flexor tendons are essential for hand function, playing a vital role in all grip types, including power and fine pinch grips. Studies indicate that flexor tendon injuries comprise 7% of all hand injuries. These injuries can result in significant functional impairment, including difficulty with activities of daily living, work, and recreational activities. Prompt and appropriate treatment is essential to minimize functional loss and optimize recovery.[1] These injuries frequently occur due to deep lacerations of the fingers, palm, or forearm.[2] Young, active individuals are particularly susceptible to flexor tendon injuries.[3,4] Several surgical approaches to flexor tendon injury have reported successful repair rates of 70-90%.[5] In children, the most common mechanism of finger flexor tendon disruption is a glass cut, often resulting from accidental falls or playing with broken glass. This type of injury is particularly concerning due to the sharp nature of the cut, which can sever the tendon cleanly, leading to significant functional loss if not treated promptly. In addition to glass cuts, other common mechanisms of injury in children include lacerations from knives, scissors, or other sharp objects, as well as sports-related injuries.[6] It is well-established that superior functional outcomes are achieved in the repair of sharply incised tendons compared to crush injuries.[7]

Flexor tendon injuries of the hand are a common problem that can affect people of all ages and genders. These injuries can occur due to a variety of causes, including lacerations from sharp objects, crush injuries, and sports injuries. The severity of the injury can vary widely, from simple lacerations to complex injuries involving multiple tendons, nerves, and blood vessels. In some cases, the injury may also be associated with fractures of the bones in the hand or wrist. Flexor tendon injuries can have a significant impact on a person's ability to perform daily activities, work, and recreational activities. The extent of the functional impairment depends on the severity of the injury, the number of tendons involved, and the location of the injury. In severe cases, the injury can lead to permanent loss of hand function. The prompt and appropriate treatment of flexor tendon injuries is essential to minimize functional loss and optimize recovery. The treatment of flexor tendon injuries typically involves surgical repair followed by a period of rehabilitation. The specific surgical technique used will depend on the type and severity of the injury. The rehabilitation process is essential for restoring hand function and preventing complications, such as stiffness and contractures.[2]

The surgical repair of flexor tendon injuries remains a challenging problem. Strickland outlines the characteristics of an ideal primary flexor tendon repair, including ease of placement, secure knots, smooth junctions, minimal gapping, minimal interference with tendon vascularity, and sufficient strength throughout healing to permit early motion stress.[8] Re-establishing normal hand and wrist function with a full range of motion and normal grip strength is a challenging goal. Complications such as tendon rupture, gapping, adhesions, and joint stiffness can occur. These complications are influenced by factors such as age, injury mechanism, level of injury, repair technique, and rehabilitation protocol.[6,9,10]

To our knowledge, there has not been a meta-analysis that objectively compares the repair strength and outcomes of some commonly used repair techniques (Modified Kessler vs. 4-stranded Cruciate technique and 2-stranded Kessler vs. 4-stranded Kessler technique).

MATERIAL AND METHODS

Study Design

This study employed a systematic review and meta-analysis of randomized controlled trials and non-randomized comparative studies.

Search Strategy

A systematic search was conducted according to the PRISMA guidelines (Figure 1) to identify relevant studies published up to 2020.[11] The following databases were searched: PubMed, Google Scholar, and Cochrane.

Keywords

The following keywords were used:

- "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"

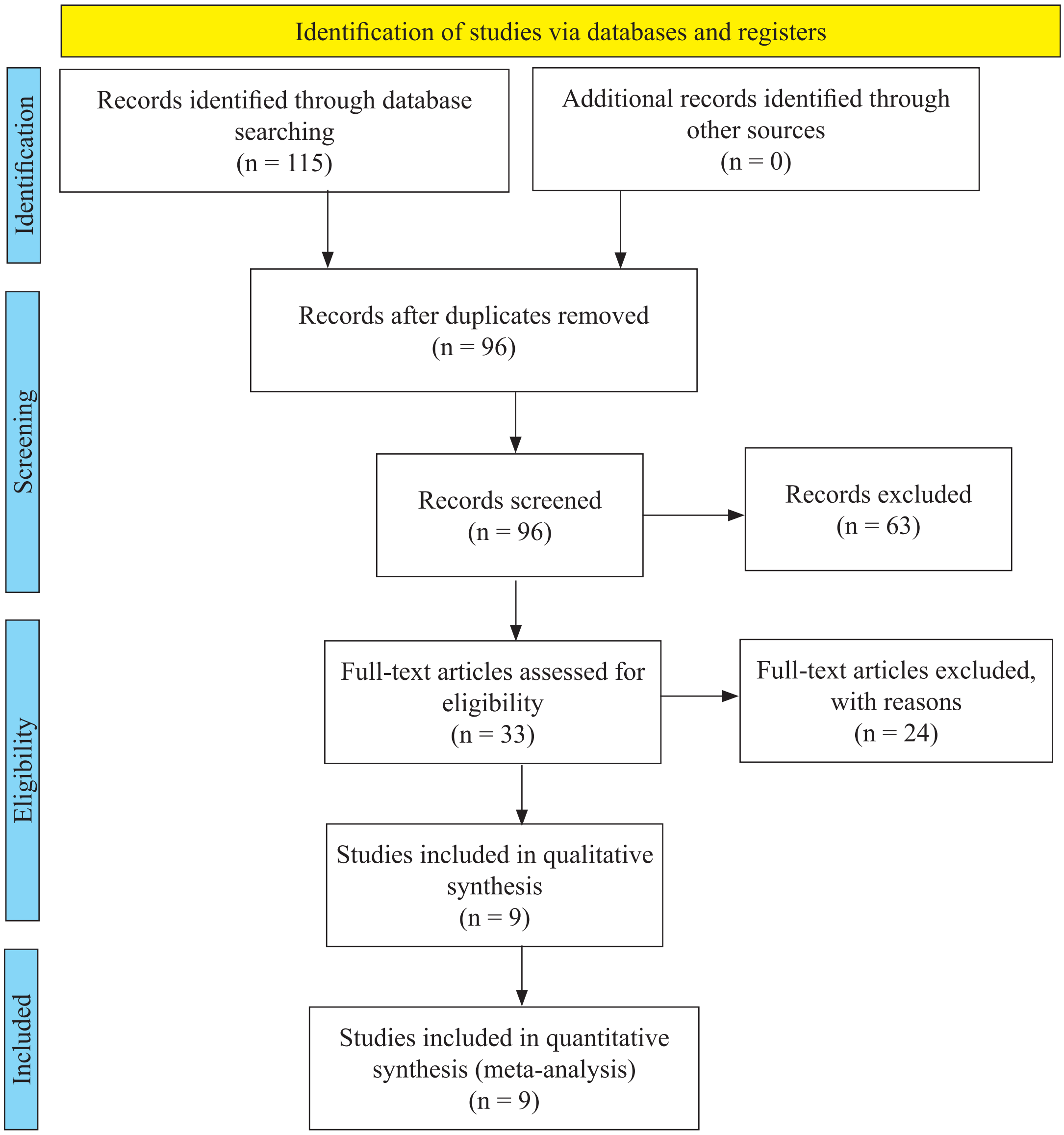

Figure 1. Flow chart showing article selection

Inclusion Criteria

The inclusion criteria were: 1) Studies with a comparative design evaluating Modified Kessler vs. Cruciate repair or Two-stranded Kessler vs. Four-stranded Kessler techniques; and 2) Studies reporting outcomes related to repair strength (2 mm gap and ultimate strength) and functional outcomes based on Strickland Criteria.

Exclusion Criteria

The exclusion criteria were: 1) Crush injuries; 2) Lack of adequate skin cover; 3) Concomitant fracture or chondral lesion; 4) Replantation; 5) Extensor tendon injury in the same digit; 6) Previous hand trauma

Table 1 provides a detailed description of the PICO method used to define the inclusion and exclusion criteria.

Data Extraction and Analysis

The data extraction included the basic study characteristics. The main outcomes consisted of the final functional and biomechanical outcomes. For each study, the mean difference (MD) for the continuous outcomes and odds ratio (OR) for the di-

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

Table 2. Studies included in the analysis

No.	Reference	Journal	Study Design	Level of Evidence
1.	McLarney et al. (1999)[11]	The Journal of Hand Surgery	Randomized Controlled Trial (Cadavers)	I
2.	Barrie et al. (2000)[12]	The Journal of Hand Surgery	Randomized Controlled Trial (Cadavers)	I
3.	Tang et al. (2001)[2]	Plastic and Reconstructive Surgery	Randomized Controlled Trial (Cadavers)	I
4.	Waitayawinyu et al. (2008)[13]	The Journal of Hand Surgery	Randomized Controlled Trial (Cadavers)	I
5.	Navali et al. (2008)[6]	The Journal of Hand Surgery	Randomized Controlled Trial (Humans)	I
6.	Shaikh et al. (2018)[10]	Surgical Medicine Open Access Journal	Randomized Controlled Trial (Humans)	I
7.	Karjalainen et al. (2012)[9]	The Journal of Hand Surgery	Randomized Controlled Trial (Cadavers)	I
8.	Dogramaci et al. (2008)[14]	HAND	Randomized Controlled Trial (Sheep)	I
9.	Yalcin et al. (2011)[15]	Acta Orthopaedica et Traumatologica Turcica	Randomized Controlled Trial (Cadavers)	I

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)[11]	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)[12]	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)[2]	Kessler: 10 Cruciate: 10	NA	NA	NA	6.2 ± 0.5	9.0 ± 0.5	NA
4	Waitayawinyu et al. (2008)[13]	Kessler: 7 Cruciate: 7	72 (54-91)	NA	NA	NA	NA	NA
5	Navali et al. (2008)[6]	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)[10]	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)[9]	Kessler: 10 Cruciate: 10	NA	NA	Flexor digitorum profundus tendons from the index, middle, and ring fingers	NA	NA	NA

Abbreviations: NA, Not Available

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)[11]	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)[12]	2 mm gap: 14 ± 2 Ultimate: 39 ± 6	2 mm gap:37 ± 2.3 Ultimate: 70 ± 8	NA	NA
3	Tang et al. (2001)[2]	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)[13]	2mm gap: 39 ± 12 Ultimate: 56 ± 6	2mm gap: 96 ± 12 Ultimate: 107 ± 12	NA	NA
5	Navali et al. (2008)[6]	• NA	• NA	• Satisfactory: 14 (87.5%) • Fair: 2 (12.5%)	• Satisfactory: 15 (93.75%) • Fair: 1 (6.25%)
6	Shaikh et al. (2018)[10]	• NA	• NA	• Satisfactory: 20 (28.6%) • Fair: 50 (71.4%)	• Satisfactory: 46 (65.7%) • Fair: 24 (34.3%)
7	Karjalainen et al. (2012)[9]	• 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)[12]	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)[14]	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)[15]	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

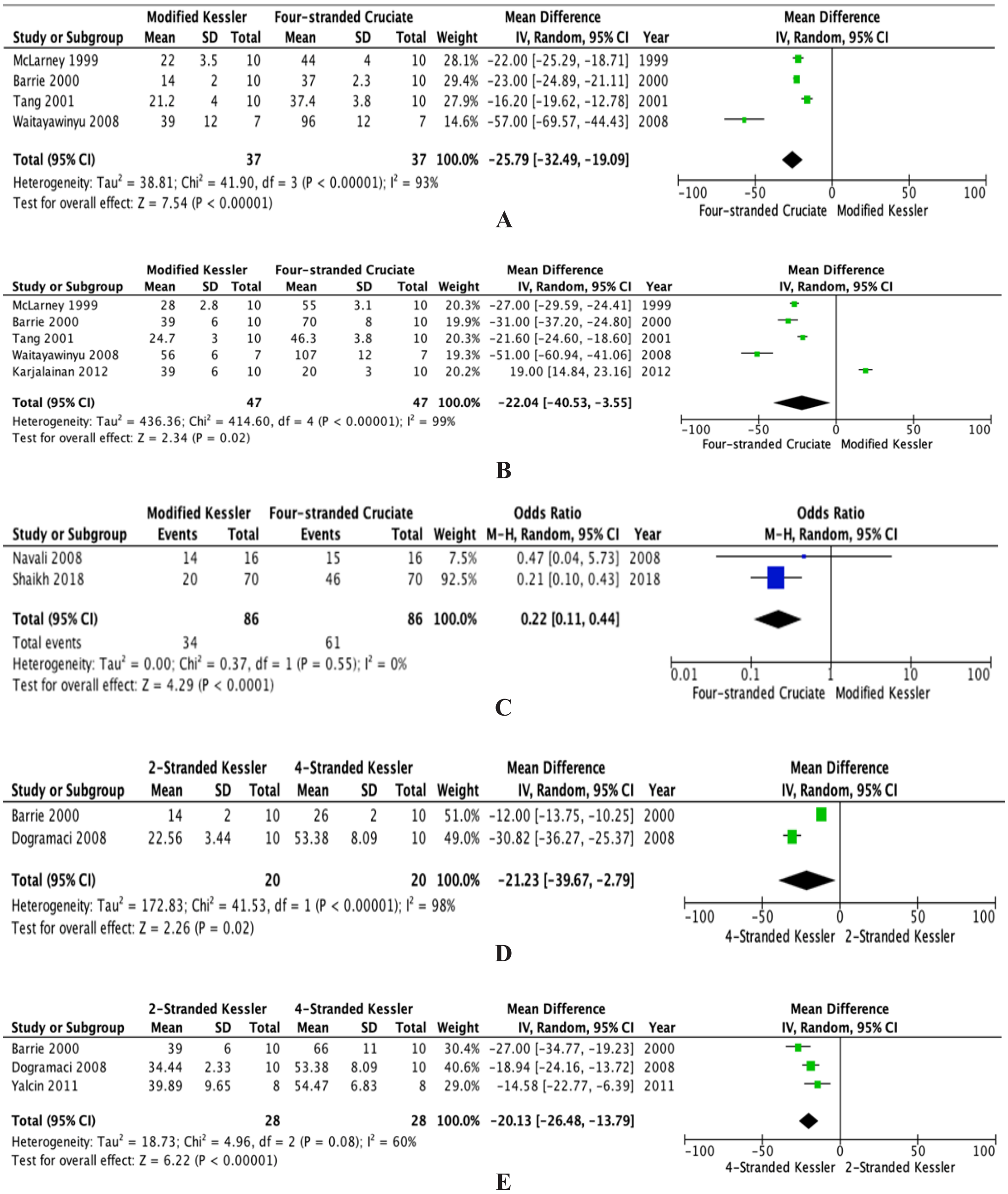

Figure 2. (A) Forest plot for 2 mm gap strength, (B) Forest plot for ultimate strength, (C) Forest plot for functional outcome, (D) Forest Plot for 2 mm gap strength, and (E) Forest plot for ultimate strength.

chotomous outcomes with 95% confidence intervals (CI) was calculated using Review Manager (RevMan) [Computer program, Version 5.3. Copenhagen: The Nordic Cochrane Centre, the Cochrane Collaboration, 2014]. A fixed-effect model was used when the heterogeneity was < 50%, and a 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 5 meta-analyses. Nine studies were a 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 and Cruciate 4-strand repairs). Each repair was tested using a slow-test machine and displacement control at two mms. Force applied, resultant gap, and ultimate tensile strength were recorded, and statistical comparisons were performed using a two-tailed t-test with a level of significance set at $p < 0.05$. Table 3 presents an overview of the seven studies included in the analysis, detailing patient characteristics, injury specifics, surgical duration, and follow-up periods.

In another study, functional outcome was better in the 4-strand Cruciate repair with excellent results in 66.6%, good in 29.1% and fair in 4.1%, compared to the 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 the 4-strand Cruciate repair, especially in zone II, with excellent results in 33.3%, good in 50%, and fair in 16.6% of cases, compared to the modified Kessler repair with no excellent results, 33.3% good, 50% fair and 16.6% poor results Table 4.

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 sutures) suture technique in the third group, and the 4-strand modified Kessler (with epitenon sutures) suture technique in the fourth group. The remaining 8 intact tendons were set aside as the control group. The ultimate tensile strength of the 2-strand modified Kessler group was determined to be 39.89±9.65 Newtons (N), while the ultimate tensile strength of the 4-strand Strickland group was 39.64 ± 9.14 N, the ultimate tensile strength of the 4-strand modified Kessler group (without epitenon sutures) was 50.29±11.24 N, the ultimate tensile strength of the 4-strand modified Kessler group (with epitenon sutures) was 54.47±6.83 N, and the ultimate tensile strength of the control group was 119±17.59 N (Table 5).

In zone III, the 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 the Modified Kessler repair. Zone V showed almost comparable results between the two types of repair.

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

In a comparison between the Modified Kessler and 4-stranded Cruciate technique, the 4-stranded Cruciate Suture produces a 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 using the Strickland Criteria (2 studies with 172 samples, $I^2 = 0\%$, $p < 0.0001$) (Figure 2).

DISCUSSION

The flexor tendons are the 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 the 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 intrinsic and extrinsic musculotendinous forces.[11,12]

Flexor tendon injuries commonly occur in young, active individuals. The most common mechanism of finger flexor tendon disruption in children is a laceration from glass, often resulting from accidental falls or playing with broken glass. This type of injury is particularly concerning due to the sharp nature of the cut, which can sever the tendon cleanly, leading to significant functional loss if not treated promptly. In addition to glass cuts, other common mechanisms of injury in children include lacerations from knives, scissors, and other sharp objects, as well as sports-related injuries. Sharply incised tendons tend to heal more quickly and with less scarring than crush injuries, which can damage the surrounding tissues and make it more difficult for the tendon to heal properly. The degree of functional loss after a flexor tendon injury depends on the severity of the injury, the number of tendons involved, and the location of the injury. In severe cases, the injury can lead to permanent loss of hand function.

The prompt and appropriate treatment of flexor tendon injuries is essential to minimize functional loss and optimize recovery. The treatment of flexor tendon injuries typically involves surgical repair followed by a period of rehabilitation. The specific surgical technique used will depend on the type and severity of the injury. The rehabilitation process is essential for restoring hand function and preventing complications, such as stiffness and contractures.[14] 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.[15] 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 as the 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 the 2 mm gap formation compared to 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 the Savage or Strickland repairs, and was comparable in repair time to the 2-stranded Kessler. The new suture technique's design allowed the tendon repair to be completed with the ease and speed of the 2-strand technique while bestowing on the repair strength that exceeded the current 4-strand techniques. Additionally, the tensile strength of the 4-strand sutures, with or without epitenon used, is significantly higher than the tensile strength of 2-strand sutures. All suture techniques applied had sufficient tensile strength to promote early mobilization.[15,16] Four strand core sutures have a better result with a lower tendon rupture rate than 2-strand core sutures. Other facts stated in literature are that the zone with the worst results was zone II, and that Kleinert splints had better results than static splints.[17-19]

This study has several limitations. The heterogeneity of the included studies is high. Due to the limitations of the available studies, animal and in vitro studies have been included, potentially contributing to the heterogeneity. However, to our knowledge, this study is the first to conduct a meta-analysis on this topic. It is hoped that this study will be influential for future research, encouraging well-designed trials with larger sample sizes.

CONCLUSION

The current systematic review and meta-analysis suggest that the 4-stranded cruciate repair technique has better strength and functional outcomes than the modified Kessler repair technique. The 4-stranded Kessler technique is also proven to have better strength compared to the 2-stranded Kessler technique.

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CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

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