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ORIGINAL ARTICLE

Four-Strand Modified Kessler versus Cruciate Technique for Repair of Zone Two Flexor Tendon Injuries: A Randomized Controlled Trial

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ABSTRACT

Background. This is the first double-blinded randomized study in which the four-strand modified Kessler and the four-strand cruciate technique were compared in a series of zone II flexor tendon injuries in patients of working age (19–60 years old).

Objective. To compare the functional outcomes of zone II flexor tendon repair with the four-core modified Kessler versus the four-core cruciate technique done at our institution's Hand Clinic.

Methodology. This double-blinded randomized controlled trial was conducted from September 2022 to August 2023. The sample population consisted of eight fingers of eight patients who sustained traumatic zone II flexor tendon lacerations. Statistical analysis was made between the functional outcomes using the Strickland formula at the fourth, sixth, and eighth weeks, and the FIL-DASH (Disabilities of the Arm, Shoulder, and Hand - Filipino translation) score at the third, and sixth months postoperatively.

Result. At weeks four, six, and eight post-operatively, Strickland scores in the four-strand cruciate group were significantly higher than those in the four-strand modified Kessler group (p <0.02, p <0.03 and p <0.02). FIL-DASH scores at three and six months did not differ significantly between the groups.

Conclusion. The four-core cruciate technique resulted in significantly better short-term functional outcomes than the four-core modified Kessler technique. More studies are needed to improve on these findings.

Keywords. Modified-Kessler, cruciate, functional outcome, FIL-DASH, double-blinded randomized controlled trial, flexor tendon injury

INTRODUCTION

Traumatic flexor tendon injuries are common causes of emergency room visits and require surgical treatment to restore function and prevent long-term disability.[1-3] These injuries are often caused by lacerations from sharp objects, crush injuries, and sports-related trauma.[4] Surgical repair of flexor tendons is challenging due to the need for precise fusion of transected ends, postoperative mobilization to prevent adhesions, and the risk of re-rupture.[5-7] Early post-operative mobilization reduces the risk of contracture, expedites the healing process, and enables patients to regain full mobility with enhanced grip strength, enabling prompt return to work.[8,9]

A widely recognized technique for tendon repair is the four-strand modified Kessler stitch, which was derived from the two-strand Kessler suture.[10] This method is initiated in the middle of the cut tendon end and a modified Kessler core is inserted that will pass through only one lateral half of the tendon; thus, apposing only the lateral half of the tendon. The same suture of the modified Kessler core is continuously inserted into the

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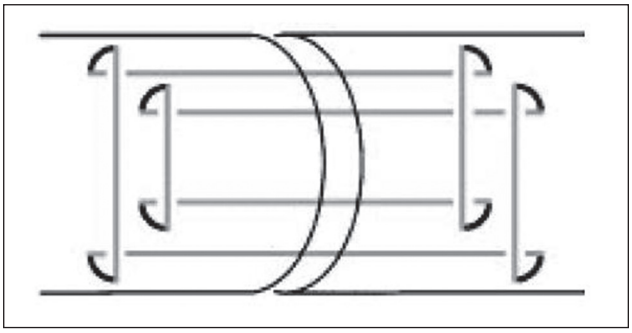

Figure 1. Four-strand modified Kessler tendon repair.

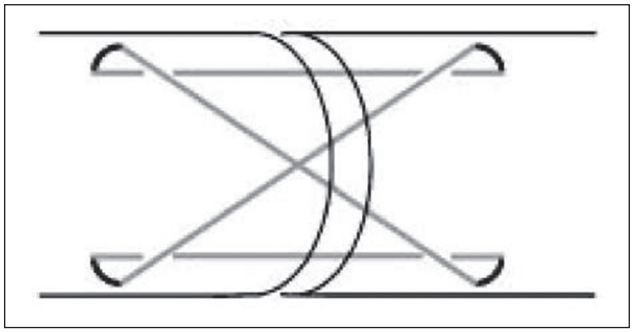

Figure 2. Four-strand cruciate technique tendon repair.

unopposed half of the cut tendon ends, which completes four strands.[10] The final phase is done through a double knot to connect the gap between the tendons (Figure 1). Meanwhile, the four-strand cruciate technique is done by making a 2 mm slit on the side of the tendon and 1 cm from the tendon edge.[11] The needle is inserted through the slit passing through the severed tendon edge and longitudinally passing out of the tendon edge. This is followed by the passing of the needle into the corresponding severed tendon edge and going longitudinally out of the side of the tendon. The suture is further reintroduced a few mm distal to the exit point without locking and directed crosswise to move out in the middle of the tendon laceration site. The suture is reinserted into the opposite tendon segment in a crossing fashion and exits on the opposite tendon 1 cm from the laceration site. This is followed by the reinsertion of the suture without locking passing longitudinally across the laceration site. Finally, this is passed back moving through the middle of the laceration site to move out next to the free tendon edge (Figure 2).[11]

The choice of repair method depends on factors such as the timing of the repair, the extent of the injury, and the surgeon's preference. Primary repair is preferred within three weeks of injury, while secondary repair or tendon grafting may be necessary for older injuries.[12] Despite advancements in surgical techniques, there is no consensus on the best approach, and surgeons often rely on their experience and the specifics of each case.[13-15] The goal of repair is to minimize gaps, maintain tendon vascularity, secure suture knots, and provide adequate strength for healing.[14,15] Overall, surgical repair of flexor tendon injuries requires a tailored approach based on the individual patient's needs and the specifics of the injury.

In a recent study on adult sheep tendons, a six-strand (three figure-of-8 sutures) cruciate repair, a 10-strand (six figure-of-8 and cruciate) repair using a combined technique (four figure-of-8 and 10-strand sutures) were compared. Biomechanically, the combined repair was the most robust in terms of both gap and failure (single cyclic tensile).[16]

This paper aimed to compare the functional outcomes of patients with zone II flexor injuries who underwent surgery in a tertiary government hospital using the two suturing techniques, namely the four-strand modified Kessler and cruciate techniques.

METHODOLOGY

Study design

A double-blind randomized controlled trial was conducted. Each eligible patient was assigned a patient reference number by the primary investigator. A patient reference number assigned as "odd" served as the control group (Arm A: Four-strand core modified Kessler Technique) while patient reference numbers that were "even" served as the experimental group (Arm B: Four-strand cruciate Technique).

In the postoperative evaluation of patients using Strickland's evaluation system[17] and Disabilities of the Arm, Shoulder, and Hand - Filipino translation (FIL-DASH),[18] both the patient and the team of evaluators (one orthopaedic resident who did not perform the procedure and one hand specialist) were blinded to the repair technique.

Participant selection

Inclusion Criteria

- patients aged 19 to 60 years
- isolated clean laceration on any finger or thumb of either hand (dominant or non-dominant) with a zone II flexor tendon injury of both flexor digitorum superficialis and flexor digitorum profundus tendons needing repair
- no comorbidities

Exclusion Criteria

- grossly contaminated or infected wounds
- multiple injuries other than flexor tendon injury
- crushing injury of flexor tendon
- intraoperative identification of non-zone II flexor tendon injury
- comorbidities

Sample size

Sample size could not be computed a priori due to lack of the required inputs from previous studies for sample size calculation.

The actual sample size achieved was four patients per arm. This comprised the total number of patients enrolled in the study. There was a zero dropout rate.

The final sample size of four patients per arm achieved statistically significant results at a 5% level of significance for all time points (weeks four, six, and eight). Moreover, statistical power achieved by the said sample size was 73, 78, and 91%, for outcome measurement at weeks four, six, and eight.

Data collection

The assigned procedure was explained and informed consent was taken by the principal investigator for each eligible patient. Participants were randomly assigned to the two arms based on an odd-even scheme of the patient reference number. Arm A underwent four-strand modified Kessler repair and Arm B underwent four-strand cruciate repair. One surgeon (the primary investigator) performed both procedures. Non-absorbable, braided, sterile (Ethibond 5-0) sutures were used for both techniques. Each method was followed by repair of epitenon with continuous running sutures using a non-absorbable nylon suture (Ethilon 4-0). Postoperatively, rehabilitation was done following the Belfast technique, which includes a dorsal blocking splint for six weeks with early active and passive mobilization facilitated by a single JBLMGH rehab therapist. All patients were evaluated postoperatively at four weeks, six weeks, and eight weeks for assessment of total active motion. A comparison was made between the two methods using the Strickland evaluation methodology as outlined in the following equation.

$$\text{Strickland} = \{[(\text{activeflexionPIP+DIP}) - (\text{extensiondeficitPIP+DIP})]/175°\} \times 100\%$$

The Strickland scores are classified as follows; Excellent: 85% to 100%, Good: 70% to 84%, Fair: 50% to 69%, Poor: <50%.

The functional outcomes were evaluated by a single team of evaluators (one orthopaedic resident who did not perform the procedure and one hand specialist). Range of motion and tendon excursion were measured using a standard finger goniometer and data was measured using the Strickland evaluation system.

Furthermore, functional outcome was also evaluated in the third and sixth months using FIL-DASH scoring. The main part of the FIL-DASH is a 30-item disability/symptom scale concerning the patient's health status during the preceding months. The items ask about the degree of difficulty in performing different physical activities because of the arm, shoulder, or hand problem (21 items), the severity of each of the symptoms of pain, activity-related pain, tingling, weakness, and stiffness (five items), as well as the problem's impact on social activities, work, sleep, and self-image (four items). Each item has five response options. The scores for all items are then used to calculate a scale score ranging from 0 (no disability) to 100 (most severe disability). The score for the disability/symptom scale is called the DASH score. In this study, the Filipino version (FIL-DASH) was used.

Data analysis

The baseline characteristics were summarized using frequency distributions. The baseline comparability of groups was determined through Fisher's exact tests. An independent t-test was used to compare the outcomes in the two groups. A $p \leq 0.05$ was taken as statistically significant.

DASH scores were used to evaluate patients at the third and sixth months postoperatively. At least 27 of the 30 items of the questionnaire were answered. The computation and transformation of scores were based on the standard scoring guide as shown below. A higher score indicates greater disability. The standardized response mean was calculated as the mean change scores divided by the standard deviation of the change scores.

$$\text{DASH disability/symptom score} = \{[(\text{sum of n responses})]/n - 1\} \times 25,$$

where n is equal to the number of completed responses.

Ethical considerations

The study was conducted in compliance with the ethical principles outlined in the Declaration of Helsinki and the National Ethical Guidelines for Health and Health-Related Research of 2017. Prior to study initiation, there was a review and approval of the study protocol and informed consent and subsequent amendments by the Jose B. Lingad Memorial General Hospital Research Ethics Committee (JBLMGH REC), a Level 2 Philippine Health Research Ethics Board (PHREB) – accredited research ethics committee.

There was no direct benefit for the subjects joining this study. However, the results of the study may have indirect benefits. This study will be published and may serve as references for future studies on this topic.

Before a subject's participation, the investigator obtained written informed consent after explaining the aims, methods, anticipated benefits, and potential risks of the study. The informed consent was signed and personally dated by the subject and the person who conducted the informed consent discussion. One copy of the signed informed consent was given to the subject. Furthermore, participants could withdraw anytime from the study. Disclosure of potential conflicts of interest was discussed regularly.

The investigator preserved the confidentiality of all subjects taking part in the study. The investigator ensured that the subject's anonymity was maintained. The risk to the subject's privacy was minimal and no sensitive information was obtained. All data were encoded using a password-protected Excel spreadsheet. A code number was assigned for each patient and recorded in a separate password-protected spreadsheet. Only the primary investigator had access to this

file. After encoding, all data collection forms were kept in a secured cabinet. The researchers intended to adhere fully to the provisions of the Data Privacy Act of 2012.

RESULTS

A total of eight patients (four patients per arm) participated in this study. The two groups were found to be comparable at baseline (i.e. no significant differences were noted in the two groups in terms of age, gender, handedness and affected digit; $p > 0.05$) (Table 1).

At four weeks post-operatively, two patients in the four-strand modified Kessler Technique group had good functional outcomes based on Strickland's Evaluation System and the other two patients had fair functional outcomes. On the other hand, one patient in the four-strand cruciate Technique had excellent functional outcomes, two patients had good functional outcomes and one patient had fair functional outcomes. There were significant differences in the Strickland scores between the groups favoring the cruciate technique at weeks four, six, and eight ($p < 0.05$) (Table 2).

In terms of FIL-DASH, the cruciate group had lower mean scores (indicating less disability) at months 3 and 6 but the differences were not statistically significant ($p > 0.05$).

Table 1. Baseline characteristics of the patients

		Four-strand modified Kessler technique n = 4	Four-strand cruciate technique n = 4	p^F
Age	19–30 years old 31–45 years old	2 2	2 2	1.00
Gender	Male Female	3 1	2 2	1.00
Handedness	Dominant Non-dominant	3 1	3 1	1.00
Affected Digit	Index Finger Middle Finger Ring Finger Small Finger	1 2 1 0	0 1 2 1	1.00

*F = Fisher's exact test, 2-tailed

Table 2. Comparison of functional outcomes of patients who underwent four-strand modified Kessler technique and four-strand cruciate technique

Functional Outcome based on Strickland Scores	Four-strand modified Kessler technique n = 4 (%) Mean ± SD	Four-strand cruciate technique n = 4 (%) Mean ± SD	p^a
Week 4	62.00 ± 9.90	77.25 ± 6.65	0.02*
Week 6	71.25 ± 11.06	87.25 ± 3.95	0.03*
Week 8	81.00 ± 8.68	95.50 ± 1.29	0.02*
Functional Outcome based on FIL-DASH	**Four-strand modified Kessler technique (Mean ± SD)**	**Four-strand cruciate technique (Mean ± SD)**	p^b
Month 3	5.63 ± 2.20	4.60 ± 1.75	0.25
Month 6	2.48 ± 1.65	1.25 ± 1.44	0.15

*Significant difference at α = 0.05
a = one-tailed independent t-test assuming unequal variance
b = one-tailed independent t-test assuming equal variance

DISCUSSION

Regaining full function of the finger after a flexor tendon laceration is one of the most difficult tasks in the field of hand surgery. Improvements in technique and post-operative care have achieved reliable flexor tendon repairs, optimizing digital motion and functional outcomes. The surgical repair of zone two flexor tendon injuries has been the subject of considerable discussion. However, adhesion formation, suture rupture, and fixation of sutures on pulley edges remain potential consequences of inadequate repair.[6]

Theoretically, increasing the number of sutures that cross the repair site can reduce the likelihood of rupture. Core sutures with more strands crossing the repair site have a higher degree of tensile strength compared to those with a similar design but fewer strands.[3]

The advantages of multi-strand suture techniques demonstrated in vitro do not necessarily translate into improved outcomes in vivo. Numerous studies have indicated that multi-strand techniques may possess a higher degree of in vitro gliding resistance. In a 2001 study conducted by Zhao et al., gliding resistance and adhesion formation were compared between two-strand modified Kessler and a four-strand Becker repair in a dog model. The two techniques were selected due to their relatively low gliding resistances and their respective postoperative mobility protocols. The study found that the gliding resistance of the Kessler group was significantly less than that of the Becker group, with the gliding resistance being significantly lower at three and six weeks post-operatively. Therefore, it was suggested that gliding resistances may be more significant than the strength of the suture, provided a post-operative low-force gliding protocol is employed.

Our study was designed to compare the functional outcome of zone II tendon repair with four-strand modified Kessler as compared to the four-strand cruciate technique. Many studies have investigated this in animal and in vitro models, but this is the first double-blinded randomized study in which the four-strand modified Kessler and four-strand cruciate technique have been compared in a series of zone II flexor tendon injuries in patients of working age (19–60 years old).

A similar study conducted with a prospective case-control design by Dawood found better functional results in four-strand 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.[19] Navali et al., found that four-strand suture repair prevented tendon ruptures and achieved excellent and good functional results in 90% of cases.[3]

In the present study, no ruptures were encountered during early postoperative rehabilitation. The four-strand cruciate technique yielded significantly better Strickland scores at weeks four, six, and eight (Table 2). A single knot is required for

this repair, which has been shown to have several advantages. While each additional knot has been demonstrated to reduce the strength of the suture material, a single knot results in a reduced tendon manipulation during the repair favoring significant difference during evaluation. The suture repair limbs that run along the contours of the tendons promote anatomical alignment and proper placement. If the suture can glide at the non-locking corners, this method balances the stress across all four strands of the repair. The other four-strand repair methods tested were dual-strand, which unevenly distributes stress across the multiple sutures, resulting in a final tensile strength that is only as high as the initial failure point of the suture.[11]

Thanks to the simplicity of design, ease of execution, and superior mechanical properties of the four-strand cruciate technique, it is a good choice for flexor tendon repair.

CONCLUSION

The four-strand cruciate technique provides better functional outcomes than the four-strand modified Kessler technique. Using the right surgical technique helps patients recover faster, return to work earlier, and provide for their families. Further studies on more patients are needed to add to the strength of these findings.

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STATEMENT OF AUTHORSHIP

All authors certified fulfillment of ICMJE authorship criteria.

AUTHORS DISCLOSURE

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