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ORIGINAL ARTICLE

Continuous Double Knots Technique Versus the 4-Strand Modified Kessler Technique for Flexor Tendon Repair

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ABSTRACT

Background: Flexor tendon injuries in the hand are common. surgeons, who are constantly striving for the optimal compromise between suture strength and early mobilization. This study aimed improving grip strength and total active movement in flexor tendon repair by utilizing and evaluating the efficacy of the continuous double knots technique versus the 4-strand modified Kessler technique regarding their clinical outcomes.

Methods: This comparative randomized clinical trial included 30 patients who sustained acute flexor tendon injury, divided into two groups: Group 1 underwent flexor tendon repair using the continuous double knots technique. Group 2; underwent flexor tendon repair using the 4-strand modified Kessler technique.

Results: 11 patients (73.3%) had good grip strength among group I in comparison to only 5 patients (33.3%) among group II (P=0.028). There were 7 patients (47%) among group I were very satisfied with the operation in comparison to only 2 patients (13%) among group II and there were 3 patients (20%) among group I were satisfied with the operation in comparison to only 2 patients (13%) among group II (P=0.025). As regards to functional outcome according to Strickland score among studied patients, 7 patients (46.7%) among group I were excellent in comparison to 4 patient (26.67%) among group II, which was statistically significant (P=0.046).

Conclusions: Using the continuous double knots technique then beginning early postoperative controlled active rehabilitation, leads to a better functional outcome, particularly in terms of total active motion, grip strength, as well as fewer complications.

Keywords: Flexor Tendon Repair; Continuous Double Knots Technique; 4-Strand Modified Kessler

INTRODUCTION

Hand trauma is common, and tendon injury which most commonly affects males between the ages of 20 and 29 is the most common injury to the hand and fingers. Primary end-to-end repair within 12 to 24 hours of injury is advised for acute flexor tendon injuries, which are more common than extensor tendon injuries [1].

Early passive mobility rehabilitation requires a primary end-to-end flexor tendon repair approach that is strong enough, as well as a number of studies on different suture techniques to improve tensile strength and efficacy for early motion and prevention of finger joint stiffness. For hand surgeons, who are always looking for the best combination of suture strength and early

mobilization, flexor tendon repair remains a challenge [2].

Although the modified Kessler technique is frequently used to repair flexor tendons, it has several drawbacks, such as weak grips and knot rupture. In order to overcome this shortcoming and boost the tensile strength of tendon healing, a number of novel approaches have been put f [3].

In order to improve the tensile strength of flexor tendon repair, Wongsiri and Liawrungrueang introduced a newly developed continuous double knots technique in 2021. They then applied the technique to pig flexors and compared its properties, including tensile strength, to the 4-strand modified Kessler technique [4].

This study aimed to improve grip strength and total active movement in flexor tendon repair by utilizing and evaluating the efficacy of the continuous double knots technique to repair flexor tendon injuries, and compare its properties, including grip strength and total active motion with the 4-strand modified Kessler technique, to estimate average operative time and the mean postoperative hospital stay and to estimate incidence of complications and patients' satisfaction, to our knowledge , this is the first study that conduct the latter technique in humans.

METHODS

The Plastic and Reconstructive Surgery Department of Zagazig University Hospitals conducted this prospective comparative randomized clinical trial study from March 2023 to September 2023 the course of 6 months. This study included 30 patients who sustained acute flexor tendon injury, divided into two groups: Group 1: underwent flexor tendon repair using the continuous double knots technique, their ages ranged from 16 to 60 years with mean 29.7±11.6SD. Most of the studied patients were males (86.7%) while (13.3%) were females. Group 2: underwent flexor tendon repair using the 4-strand modified Kessler technique, their ages ranged from 15 to 56 years with mean 27.8±10.7SD. Most of the studied patients were males (86.7%) while (13.3%) were females. The inclusion criteria were patients with sharp object injury, zone 3, 4, and 5 flexor tendon zones, and willingness to undergo surgery after receiving thorough information on the procedure. Patients with soft tissue injury, skin loss, tendon loss, and/or fracture of phalanges, patients with a history of previous tendon injuries or surgeries, patients with psychological and personality disorders, patients with local vascular compromise, and patients with any systemic disease that could affect rehabilitation were excluded. Approval was taken from the research ethical committee and the institutional review board (IRB# 191/5-3-2024) of Zagazig University's Faculty of Medicine. Every patient gave their consent to take part in the trial. The work was conducted in compliance with the World Medical Association's Code of Ethics (Declaration of Helsinki, 1964) and its subsequent unifications for human subject's research.

Every patient underwent a thorough demographic data of the patient was recorded according to age, sex, occupation, hand dominance and special habits of medical importance (alcoholism, smoking and drug abuse). General examination to detect any associated trauma and evaluate the medical condition of the patient. Routine laboratory investigations for preoperative assessment. Anteroposterior, lateral and oblique views of the digits were obtained. Standardized color digital photography and video recording of the site of injury.

Preoperative antibiotic was administered to all patients 1 hour before surgery. All patients were positioned in supine position on the operative table with

the upper limb resting on a table. The methods of anathesia of choice were general or regional anesthesia. Pneumatic tournique was applied around the mid-arm area and was inflated, after emptying of the hand and forearm veins, to a level of 100mmhg above each patient's systolic blood pressure. The surgical field was sterilized using Povidine iodine and the field is draped with sterilized towels. Operative technique was performed under 5X loupe magnification. Surgical incisions were done to provide adequate exposure of the field and the flexor tendons and with caution to avoid injury to neurovascular bundles and with good design to ensure viability of skin flaps and with consideration to the natural hand crease to avoid future scar contractures. In the palm, incisions along the course of or angled to flexion creases were used. In any case, it is important to avoid creating narrow skin flaps, because the tip of such a flap may not survive. After exposure of the surgical field, dissection for the flexor tendons was done and any retracted tendon end was retrieved either proximally or distally and any crushed tendon stump was trimmed and tendon ends were fixated at the surgical repair site with syringe needles. The suture material used was polypropylene Size 3–0 monofilament nonabsorbable single needle suture.

Tendon repair for patients in group A was performed using the Continuous double knots technique. The tendon was repaired using a cross-locking suture in both the proximal and distal regions of the tendons (Fig. 1A), and the distal part of both tendons was cross-locked to narrow the gap. After the knot was tied (Fig. 1B), the repair continued in the second loop without cutting the suture (Fig. 1C). Finally, the second loop's suture knot was attached to the first knot (Fig. 1D).

For tendon restoration, the Continuous Double Knots approach was selected. After the knot was tied (Fig. 1B), the repair proceeded in the second loop without severing the suture (Fig. 1C). The tendon was repaired by cross-locking the sutures in the proximal and distal regions of the tendons (Fig. 1A), and the distal part of both tendons was cross-locked to lessen the gap. In the last stage, the first knot was attached to the second loop's suture knot (Fig. 1D).

For patients in group B, the 4-strand modified Kessler was utilized. A knot was tied and the suture was removed after the tendon was repaired for the first loop using a modified Kessler procedure. Following the completion of the first loop, the second loop using the modified Kessler approach was created without the first loop's following suture. The suture was then severed when a knot was formed (Fig. 2 A–D).

After repair, the tourniquet was deflated and good hemostasis of the surgical field was done. Then wounds were closed using polypropylene Size 3–0 monofilament nonabsorbable simple interrupted or mattress sutures and drains were placed when needed **(Fig 3A).**

Povidineidione was placed on suture line after closure and non-adherent dressing was applied to the wounds then the hand and forearm were wrapped with soft pads.

Splinting: immobilization in a dorsal blocking splint with a slight flexion of the wrist (20°–30°), 50° flexion of the MCPJ and extension of the IP joints and exposure of finger tips were considered to monitor distal limb vascularity with caution not to make the crepe bandages around the splint tight (Fig 3B)

Postoperative care:

All patients were instructed to keep the upper limb in an elevated position using arm sling. All patients received analgesics, anti-edematous medications, and antibiotics for 2 weeks. Wound dressing was done every other day using saline, povidine iodine and alcohol. Patients were instructed to start passive physiotherapy by the 3rd day and to start controlled active physiotherapy by the

21st day. Patients were hospitalized for 24 hours, during which patients were monitored for any soaking of dressing, edema, pain and fingers' vascularity. Wound sutures were removed after 2 weeks and splints were removed after 6 weeks.

Follow up:

Patients were instructed upon discharge to follow up in our Outpatient clinic (OPC) weekly for one and a half month and monthly for 6 months during that period, measured by requesting the patient to squeeze the sphygmomanometer cuff while their arm was abducted, their elbow was flexed, their forearm was supinated, and their wrist was flexed by 30 degrees. Next, note the pressure you get when you squeeze the cuff and compare it to the hand that isn't hurt. Manual hand goniometry was used to record the measurements using a standard finger goniometer. The Total Active Movement (TAM) score, as established by the American Society for Surgery of the Hand (ASSH), was used to examine the results.

Statistical analysis

The statistical analysis of the collected data was conducted using IBM SPSS 23.0 for Windows (SPSS Inc., Chicago, IL, USA). The t-test was used for quantitative data that was regularly distributed, and the chi-square and Fisher's exact tests were employed for qualitative data. The Mann-Whitney test was applied to the skewed data. The p-value was significant at $P \leq 0.05$.

RESULTS

Table (1) showed that no statically significant differences between studied groups as regards demographic data (P >0.05). that most of the studied patients among group I had zone *V* zone of injury (40%) in comparison to (33.3%) among group II, with no statistically significant differences between the two groups (P >0.05As regards time of injury, there was no significant differences between the two groups (P >0.05). As regards operative time per tendon, there was statistically significant differences between the two studied groups, as group I has longer operative time (5.6±0.72 minutes) in comparison to group II (3.4±0. 5 minutes). (P=<0.001). There were 2 patients (13.3%) among group I and 4 patients (26.7%) among group II had associated nerve repair.

Table (2) showed that mean time to start physiotherapy among group I were 1.13 days ± 0.516 SD, while among group II were 1 day with no statistically significant differences between the two groups (P= 0.326). Also, mean time for mobilization against resistance were similar among the two studied groups. As regards Grip strength, 11 patients (73.3%) had good grip strength among group I in comparison to only 5 patients (33.3%) among group II (P =0.028).

As regards post-operative complications table 3 there were 3 patients (20%) among group I and 5 patients among group II had infections, those patients were treated medically and followed up and infection completely resolved within the period of 2 weeks with no need for surgical intervention. There were no significant differences between groups (P >0.05).

Table 4; showed that Patients satisfaction was significantly higher among group I in comparison to group II, as there were 7 patients (47%) among group I were very satisfied with the operation in comparison to only 2 patients (13%) among group II and there were 3 patients (20%) among group I were satisfied with the operation in comparison to only 2 patients (13%) among group II (P =0.025). As regards to functional outcome according to Strickland score among studied patients, 7 patients (46.7%) among group I were excellent in comparison to 4 patient (26.67%) among group II, which was statistically significant (P =0.046).

Table (1): Demographic and Clinical data among studied groups.

Variables		**Group I (n=15)**	**Group II (n=15)**	**P-value**
Age (years)	*mean±SD* *Range*	29.7±11.6 (16 – 60)	27.8±10.7 (15 – 56)	0.650
Sex	*Female* *Male*	2 (13.3%) 13 (86.7%)	2 (13.3%) 13 (86.7%)	1.000
Marital status	*Single* *Married*	9 (60%) 6 (40%)	11 (73.3%) 4 (26.7%)	0.439
Occupation	*Student* *Unemployed* *Employed*	5 (33.3%) 1 (6.7%) 9 (60%)	2 (13.3%) 2 (13.3%) 11 (73.3%)	0.403
Residence	*Rural* *Urban*	7 (46.7%) 8 (53.3%)	6 (40%) 9 (60%)	0.713
Special habits	*Free* *Smoker*	8 (53.3%) 7 (46.7%)	9 (60%) 6 (40%)	0.713
Dominant hand	*Right* *Left*	13 (86.7%) 2 (13.3%)	4 (26.7%) 11 (73.3%)	0.361
Clinical data among studied groups				
Zone of injury	*III* *IV* *V*	5 (33.3%) 4 (26.7%) 6 (40%)	4 (20%) 6 (40%) 5 (33.3%)	0.574
Time of injury (days)	*mean±SD* *Range*	1.27±0.458 (1 – 2)	1.60±0.737 (1 – 3)	0.148
Operative time per tendon (min.)	*mean±SD* *Range*	5.67±0.72 (4 – 7)	3.4±0.51 (3 – 4)	**<0.001**
Associated nerve repair	*No* *Yes*	13 (86.7%) 2 (13.3%)	11 (73.3%) 4 (26.7%)	0.361
Skin loss	*No* *Yes*	15 (100%) 0 (0%)	15 (100%) 0 (0%)	1.00

Table (2): Post-operative data among studied groups.

Variables		**Group I (n=15)**	**Group II (n=15)**	**P-value**
Physiotherapy start time (days)	mean±SD Range	1.13±0.516 (1 – 3)	1±0.0 (1 – 1)	0.326
Mobilization against resistance (days)	mean±SD Range	21±0.0 (21 – 21)	21±0.0 (21 – 21)	1.00
Grip strength	Bad Good	4 (26.7%) 11 (73.3%)	10 (66.7%) 5 (33.3%)	**0.028**

Table (3): Post-operative complication among studied groups.

Variables		Group I (n=15)	Group II (n=15)	P-value
Infection	*No* *Yes*	12 (80%) 3 (20%)	10 (66.7%) 5 (33.3%)	0.409
Tendon rupture	*No* *Yes*	15 (100%) 0 (0%)	15 (100%) 0 (0%)	1.00

Table (4): Patient satisfaction according to likert's scale and functional outcome according to strrickland score among studied groups.

Variables		Group I (n=15)	Group II (n=15)	P-value
Patients satisfaction	*Very dissatisfied* *Dissatisfied* *Neutral* Satisfied *Very satisfied*	0 (0%) 2 (13%) 3 (20%) 3(20%) 7 (47%)	0 (0%) 7 (47%) 4 (27%) 2(13%) 2 (13%)	**0.025**
Strickland Score	*Poor* *Fair* *Good* *Excellent*	2 (13.3%) 3 (20%) 3 (20%) 7 (46.7%)	4 (26.67) 5 (33.3%) 2 (13.3%) 4 (26.67%)	**0.046**

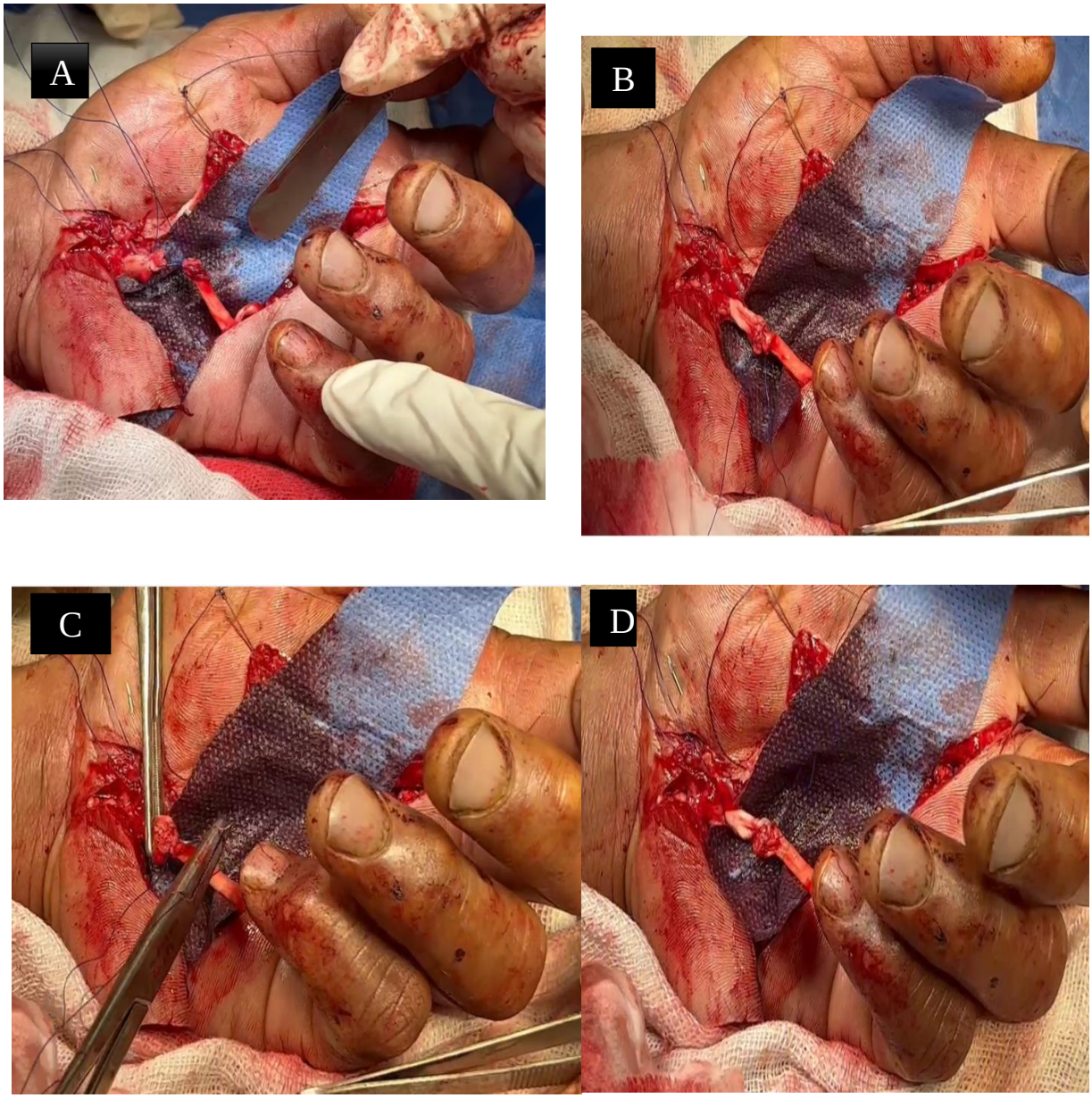

Figure (1): Group A, the Continuous double knots technique. **1A)** The tendon was repaired by cross-locking suture in the proximal and distal parts of the tendons. **2B):** the cross-locking of the distal part of both tendons were used to reduce the gap, after the knot was tied. **2C):** the repair continued in the second loop without cutting the suture. **2D):** suture knot of the second loop was tied to the first knot.

Figure (2): Group 2: the 4-strand modified Kessler technique. **A)** Approximation of 2 ends of flexor digitorum superficialis tendons. **B):** A modified Kessler loop was done and suture cut. **C):** A second loop of modified Kessler was done without suture from the first loop. **D):** two knots were made from each loop and suture cut.

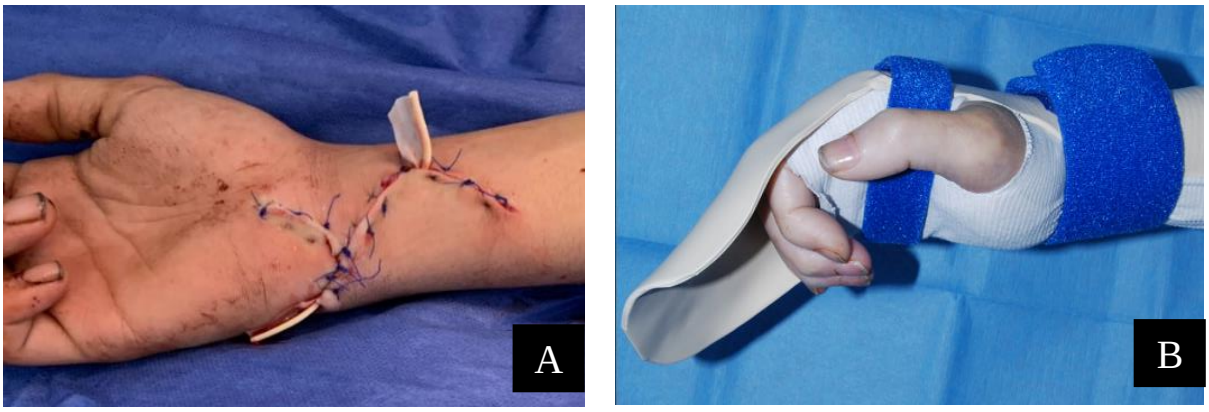

Figure (3): Wound closure and placement of soft drain. **B):** Dorsal blocking Splint.

DISCUSSION

To increase the tensile strength of tendon healing, numerous methods have been proposed. The number of suture strands crossing the repair site, the core suture purchase length, the anchoring technique, the lock diameter, and the core suture material all affect the initial strength of a repaired tendon. The suturing technique is also crucial for post-operative outcomes like motion restriction [3,5.6].

Despite this, there is still disagreement regarding the best surgical repair method that provide the patient with the best functional outcome to enable resuming a normal life [7].

The functional results of the continuous double knots approach and the conventional 4-strand double modified Kessler technique for healing flexor tendon injuries were evaluated in this study.

We found that there was no statistically significant difference between studied groups (group I & group II) as regard age, sex, occupation, Marital status, hand dominance, residency and smoking.

All patients were treated by primary repair within the first 3 days of injury, most of the cases were operated on in first two days 1.27 ± 0.45 days in group I versus 1.6 ± 0.73 days in group II with no statistically significant difference (p-value = 0.148) between studied groups.

Our results showed that most of the studied patients among group I presented with zone V injury (40%) in comparison to (33.3%) among group II, in which group the commonest presentation with zone IV injury (40%), with no statistically significant differences between the two groups (P >0.05).

This is in harmony with Dawood, [8] study, the commonest presentation among study subjects where zone V injury (37.5%), in a study conducted to compare the two-strand Kessler approach with the four-strand Cruciate procedure for repairing flexor tendon damage.

Contradictory to our study, in Sadek et al., [9] the authors assessed the efficacy of for the surgical treatment of acute zone II flexor tendon injury, the four-strand versus six-strand core suture technique, in our study we excluded zone II injuries from our study groups to eliminate the effect of adhesions and other complications, that commonly happen with zone II injuries, in assessing our studied techniques' results.

Although 20% of patients included in Elftatry et al, study in presented with zone V injuries, the majorty of patients included in that study presented with zone II injuries (75%) [7].

Following the principle of atraumatic techniques, we used to extend the original wound by doing Bruner zigzag incision, except when the original wound permitted optimum retrieval of the cut tendon, this meant escaping all possible further injury, gross and microscopic to the injured tendon during its retrieval. Earley and Milword, stated that enlarging the initial laceration using zigzag helped in exploring the wound and giving good access [10].

In all situations we selected polypropylene in the core suture (3/0) since the optimum suture material should be non-reactive, of small caliber, robust, easy to handle, and able to retain a decent knot. So, Polypropylene suits all our needs.

Wade et al. picked polypropylene because it is regularly used by surgeons, has comparable strength to nylon, stretches less and is more slippery. Its material can transmit loads that are significantly larger than its breaking force by the number of separate or continuous strands that cross the suture line [11].

The most commonly affected tendon in group I was Flexor pollicis longus. while the most commonly affected tendon in

group II was flexor digitorum superficialis of index.

In our study there was high statistically significant (p-value < 0.001) increased operative time per tendon in group I (5.6 ± 0.7 min) when compared with group II (3.4 ± 0.5 min). This could be due to the difficulty of the technique regarding the entry and exit of the needle, holding the suture and maintain the alignment of the two ends in comparison to the well oriented, experienced and widely used modified Kessler suture technique.

There were 2 patients (13.3%) among group I and 4 patients (26.7%) among group II had associated nerve repair.

Similar to our study, in Dawood et al., study, cases associated with major nerve injury were found in (22) cases (45.8%) [8].

Regarding postoperative data collected from our study, it shows that mean time to start physiotherapy among group I were 1.13 days±0.516 SD, while among group II were 1 day with no statistically significant differences between the two groups (P= 0.326). Also, mean time for mobilization against resistance were similar among the two studied groups.

However, in Dawood., study, the author started active mobility both for flexion and extension of digits for patients included in that study in the 7th post-operative day [8].

As regards Grip strength, 11 patients (73.3%) had good grip strength among group I in comparison to only 5 patients (33.3%) among group II (P =0.028).

Similar to our study, results of evaluating grip strength in Elftatry et al study showed that 80 % of cases have positive grip strength in the study group in which they used a 4-strand tendon repair technique [7].

Regarding post-operative complications found in our study there were 3 patients (20%) among group I and 5 patients among group II had infections, with no significant differences between groups (P >0.05). Those patients who suffered from infection were treated medically and followed up and infection completely resolved within the period of 2 weeks with no need for surgical intervention. We recorded zero cases of tendon rupture in our patients postoperatively.

In contrast to our study, in Heydari et al., study, out of 50 patients divided into two groups, there was a rupture in one case per group. Each group experienced two adhesion cases (8%). The authors attributed increased risk of adhesions with increase in number of affected digits [12].

We didn't face such complication in our study and that is mostly attributed to that in our technique we didn't use continuous sutures or epi-tendinous sutures as well as we included trauma zones III, IV and V and the previous authors included zone II injuries which is associated with higher incidence of such complications as mentioned in literature.

Regarding patients' satisfaction, it was significantly higher among group I in comparison to group II *(P =0.025).*

Regarding functional outcome according to Strickland score among studied patients, 7 patients (46.7%) among group I were excellent in comparison to 4 patient (26.67%) among group II, which was statistically significant (P =0.046).

And like our study, Dawood. study showed that total functional outcome was excellent in 27 out of 48 cases and when compared to the modified Kessler repair technique, the 4-strand cruciate repair technique performed noticeably better (P value 0.001) [8].

Also similar to our study, Elftatry et al, study in found that total active motion outcome was excellent in 50 % of patients in the group treated by 4-strand tendon repair, however, in the patients' group treated by modified Kessler technique the outcome was excellent in only 30 % of patients [7].

Conclusions:

We concluded that: In terms of motion range, grip strength, and the likelihood of complications, this study indicates that flexor tendon injuries can be successfully managed by four strands repair techniques. However, using the continuous double knots technique then beginning early postoperative controlled active rehabilitation, leads to a better functional outcome, particularly in terms of total active motion, grip strength, as well as fewer complications.

We recommend utilizing the continuous double knots technique in flexor tendon injuries repair regarding zones III, IV and V as a viable option to achieve optimal functional outcomes regarding optimizing motion quality, pinch and grip strength with minimal complications. We also recommend further studies including larger number of patients with long-term follow-up periods to clarify the most suitable option for flexor tendon repair.

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Conflict of interest: None.

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