Int J Clin Exp Med 2020;13(2):1075-1083
www.ijcem.com /ISSN:1940-5901/IJCEM0102642

Original Article

The efficiency and safety of M-Tang stepped-lap repair on zone II and III flexor tendons

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Received September 22, 2019; Accepted January 8, 2020; Epub February 15, 2020; Published February 28, 2020

Abstract: Objective: To assess the efficiency and safety of M-Tang stepped-lap repair on zone II and III flexor tendon injuries. Methods: A retrospective study was conducted on 73 patients with zone II and III flexor tendon fractures who were randomly allocated to an experimental group (n=31) and a control group (n=42). In the experimental group, the patients were treated with M-Tang stepped-lap repair. The patients in the control group received double-Tsuge loop sutures. Finger function was estimated using the total active motion (TAM) scoring system at 3 months postoperatively. Meanwhile, the active motion of the wrist joints was measured. The excellent and good treatment rates and the active motion of the wrist joints were compared between the patients in the two groups. Differences in wound healing and complications, like limited flexion and extension and postoperative adhesion, were also compared. Results: The primary healing rate in the experimental group was significantly higher than it was in the control group (86.49% vs 64.58%, P<0.05). The excellent and good treatment rates in the experimental group were significantly higher than they were in the control group (91.89% vs 72.92%, P<0.05). The incidence of postoperative complications in the experimental group was lower than it was in the control group (3.23% vs 7.14%, P>0.05). Conclusion: M-Tang stepped-lap repair can achieve better primary healing and help to restore patients' hand function and wrist joint activity, which is worthy of clinical promotion.

Keywords: Flexor tendon injury, M-Tang suture, stepped-lap repair, double-Tsuge loop suture, hand function

Introduction

The hands are the most flexible organs of the human body. The risk of injury to the bare hands is high. The area between the distal interphalangeal joints (DIJ) and the digital arterial arch is Zone II. Zone III covers the area between the distal 1/3 of the middle section and DIJ. The location of the zone II and III flexor tendons is superficial and unprotected, resulting in a higher incidence of hand injuries [1, 2]. Moreover, the structure of the zone II and III flexor tendons is delicate and complex [2], leading to more difficult surgical repair and functional recovery. A standard surgical procedure concerning flexor tendon injury has not been established yet. In previous surgeries, the therapeutic effect was not satisfied. Postoperative tendon adhesion is an important factor in delaying functional recovery [3, 4]. There are many factors contributing to postoperative tendon adhesion. Peters et al. reported that tendon sheath end repair, the tendon sheath, and the trochlea are essential factors for postoperative tendon adhesion [5]. However, the suture method can directly affect the therapeutic effect and functional recovery of the flexor tendon [6].

It is difficult to suture the flexor tendon. A successful tendon suture not only cures the injured tendon without separation after dissection and obvious changes on the tendon surface, but it also minimizes the damage to the tendon. At present, the Kessler, Tsuge, and modified Kessler sutures are the three most widely used clinical suturing methods. The Kessler suture is disadvantaged by its short maintaining time of the mechanical properties and its poor anti-tension ability [7]. There is clinical evidence indicating that the therapeutic effect of the Tsuge suture is superior to the single-strand Kessler [8]. The Tsuge suture has higher mechanical properties and can form a triangle at the fractured tendon end. Therefore, it is not

easy to deform when it's subjected to force. However, the time necessary to maintain the postoperative anti-tension is short as well [9]. Fu et al. reported that the Tsuge and modified Kessler sutures could achieve a similar therapeutic effect [10]. However, suture methods with a higher endurance tension and with an easier and early functional rehabilitation still need to be explored.

In this study, the M-Tang stepped-lap repair and the double-Tsuge loop suture were applied to zone II and III flexor tendon injuries, and their therapeutic effects were compared to explore a better suture method for flexor tendon repairs.

Materials and methods

General information

This study was conducted in patients diagnosed with zone II and III flexor tendon fractures in Zhenjiang Ruikang Hospital from January 2014 to December 2018. In total, 73 patients (85 fingers) were enrolled according to the inclusion and exclusion criteria. Based on a random number table, the patients were allocated to an experimental group (31 patients, 37 fingers) or a control group (42 patients, 48 fingers). In the experimental group, the patients were treated with the M-Tang stepped-lap repair. The patients in the control group received a double-Tsuge loop suture.

Inclusion criteria: The fracture of the flexor tendon was caused by a cutting injury, and the flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) were completely broken; the lesion area was located in zones II and III; the onset time was less than 8 hours.

Exclusion criteria: The fracture of the flexor tendon was caused by a non-cutting injury such as a crushing injury; the patient's wound was severely infected; patients with a hand fracture or broken finger reconstruction; patients who had peripheral nerve injury; patients with diabetes or vital organ dysfunction.

This study was approved by the Ethics Committee of Zhenjiang Ruikang Hospital. All patients signed the informed consent form.

Methods

Suture materials and equipment: The suture materials were common 6-0 nylon sutures and 3-0 needle-ring nylon threads. The thread and needle of a 3-0 needle-ring nylon suture were of a high-strength nylon thread 3/8 arc. As for the materials, the thread was nylon 66; the needle was stainless steel; the composition of the silicon coating was 100% silicon. A surgical microscope GS-2000, which could magnify the images 6 times, was the equipment for suturing. Both the suture materials and equipment were produced by Ningbo Cheng-He Microsurgical Instruments Factory.

Double-Tsuge loop suture: In the first step, the needle was inserted vertically in the long axis of the tendon. The location was 1 cm away from the proximal end of the tendon, and the depth was 1/3 of the tendon diameter (2 mm, **Figure 1A**). In the second step, the needle was pushed out and plugged in a circle. After the insertion in parallel with the long axis of the tendon, the needle was penetrated through the tendon and brought out at the proximal end of the tendon (**Figure 1B**). In the third step, the symmetrical position of the proximal end of the tendon was chosen as the insertion location, while the needle was inserted in parallel with the long axis of the tendon and withdrawn from the distal end (**Figure 1C**). In the fourth step, the thread was cut and knotted (**Figure 1D**). In the fifth step, another symmetrical suture was completed as above (**Figure 1E**). Finally, the fracture was continuously sutured when the ends merged (**Figure 1F**).

M-Tang stepped-lap repair: Stepped dislocation of tendon anastomosis: A lengthened Z-shaped incision was made to observe and clean the wound using a conventional method. Then FDP and FDS were separated out. When the metacarpophalangeal joint (MPJ) flexed at 60°, a 1 cm stepped dislocation formed between FDP and FDS was the criterion for the resection of a certain length of FDP/FDS (**Figure 2A**). A length of 0.61 to 1.00 cm FDP/FDS was resected based on the angle formed among the MPJ, the proximal interphalangeal joint (PIPJ), and the distal interphalangeal joint (DIPJ). As a result, the FDS and FDP anastomoses were formed near the distal and proximal ends (**Figure 2B**, **2C**). The tendon near the distal end of the anastomosis was the resected tendon.

M-Tang stepped-lap suture: The tendon fracture was repaired using a 3-0 needle-ring nylon thread. First, a 3 mm incision initiated vertically

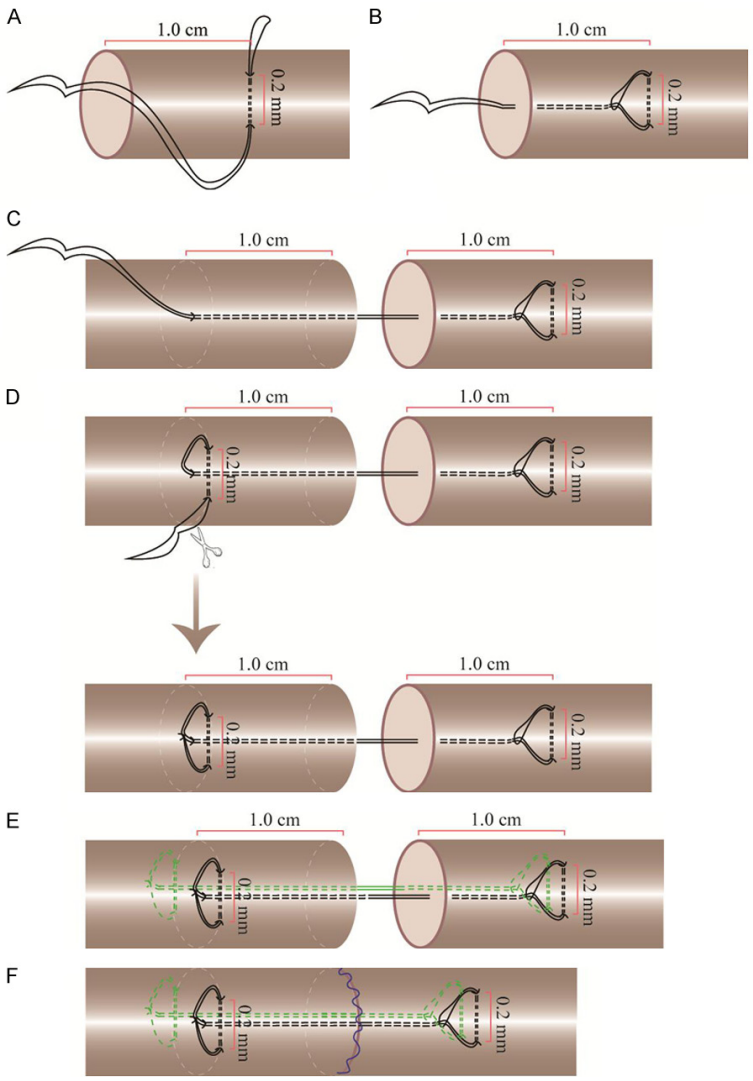

Figure 1. Diagram of the double-Tsuge loop suture. A. The needle is inserted to a 2 mm depth. B. The needle is brought out at the proximal end of the tendon. C. The needle is withdrawn from the symmetrical distal end of the tendon. D. The thread is cut and knotted. E. The trisection of the tendon width was achieved after the symmetrical suture. F. The fracture was continuously sutured using a 6-0 nylon thread.

from the 7 mm site of the proximal end of the tendon was made. The depth of the incision was 1/3 of the tendon diameter. The distances between the incision and the proximal and distal ends of the tendon were 5.5 cm and 8.5 cm, respectively (**Figure 3A**). Second, the 3-0 needle-ring nylon thread was inserted through the inner part of the incision and pulled out from the outer part. The thread was then inserted through the outside of the symmetrical point located at the same plane of the incision and pulled out from the inner part. As soon as the needle passed through the 3-0 needle-ring nylon thread, an M-Tang lock was developed by fastening the thread (**Figure 3B**). Third, the needle was inserted in parallel with the tendon and pulled out at 5 mm away from the distal end of the tendon. After passing through the center of the tendon, the needle was inserted laterally at 6 mm away from the distal end of the tendon and was then pulled out from the opposite side (**Figure 3C**). Fourth, a matching 3 mm incision located at the opposite side was made as before. After passing through the inner part of the tendon laterally, the needle was inserted 5 mm away from the end of the opposite side and was pulled out from the 3 mm incision. The needle was then inserted through the inner part of the incision and pulled out from the outer, and then it was inserted through the outer and pulled out from the inner. The second M-Tang lock was developed by fastening the thread (**Figure 3D**). Fifth, a 3 mm incision initiated from the dorsal center of the distal end of the tendon was made using another 3-0 needle-ring nylon thread and embed in the loop (**Figure 3E**). Finally, the needle inserted into the tendon laterally was pulled out at the incision of the proximal end of the tendon. The third M-Tang lock was then developed (**Figure 3F**). The 6-0 nylon thread was used for the continuous suture of the fracture, and an 8-shaped suture was applied for the repair of the tendon sheath. After the termination of hemostasis, the skin layers were closed one by one.

Postoperative rehabilitation: The elastic brace was fixed with a 30° angle between the MPJ and PIPJ, and a 0° angle between the PIPJ and DIPJ. The thin layer dressing was replaced regularly, while anti-infection was treated appropriately. On the first postoperative day, the drain-

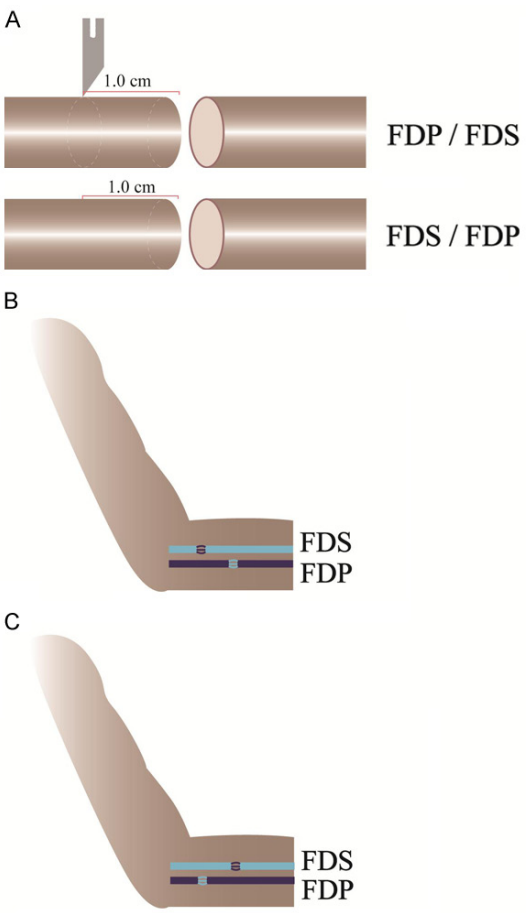

Figure 2. Diagram of the stepped dislocation of tendon anastomosis. A. The resection of a certain length of FDP/FDS. B. FDS anastomosis forms near the distal end. C. FDP anastomosis forms near the proximal end.

age was removed, and functional exercise like active extension and passive flexion of the interphalangeal joints was completed with the help of a professional physician. The exercise was performed daily in the morning, at noon and in the evening. The duration of each exercise was 0.5 h. After 2 to 3 weeks, the elastic brace was removed. The flexion and extension exercise of the injured finger joint, which was supported by the plaster, was performed in unmanned condition. In this period, other rehabilitation measures could be taken based on patients' condition.

Outcome measures

The primary and secondary healing rate. The primary healing: No complications like infection; only linear scars; no influence on the function. The secondary healing: The wound was infected, and the infection gradually reached the repaired scar tissue; after healing, the scars were large, resulting in the hinder of movement and even deformity [11].

The excellent and good treatment rate, which was estimated according to the TAM score at 3 months post-operation [12]. TAM was used to measure the MPJ, DIPJ, and PIPJ under flexed and extended state. TAM = (the MPJ flexion + the DIPJ flexion + the PIJ Flexion) - (limitation of the MPJ extension + limitation of the DIPJ extension + limitation of the PIJ extension). The TAM score was calculated as the TAM ratio of the injured finger to the contralateral corresponding finger: excellent (≥90%); good (≥75%); fine (≥50%); poor (<50%).

The active motions of the wrist joint were estimated at 3 months after surgery [13]. The active motions of the wrist joint under ulnar deviation, palm flexion, radial deviation and dorsal extension were measured using a ruler and protractor.

The complications like limited flexion and extension function, and postoperative adhesion were collected during a 1-year follow-up.

Statistical methods

All the data were analyzed using SPSS statistical software version 24.0 (SPSS Inc. Chicago, IL, USA). The enumeration data like the primary healing rate and the postoperative complications were calculated as number/percentage (n/%) The comparison were conducted using chi-square tests. The measurement data like the TAM and the active motion of wrist joint were calculated as the means ± standard deviations ($\bar{x}$ ± sd). Independent sample t tests were used for the comparisons between the two groups. The differences were considered statistically significant when the *P* value was less than 0.05.

Results

Basic data

As displayed in **Table 1**, there were no significant differences concerning age, gender, the number of hands and fingers, or the division of fingers between the two groups (all P>0.05).

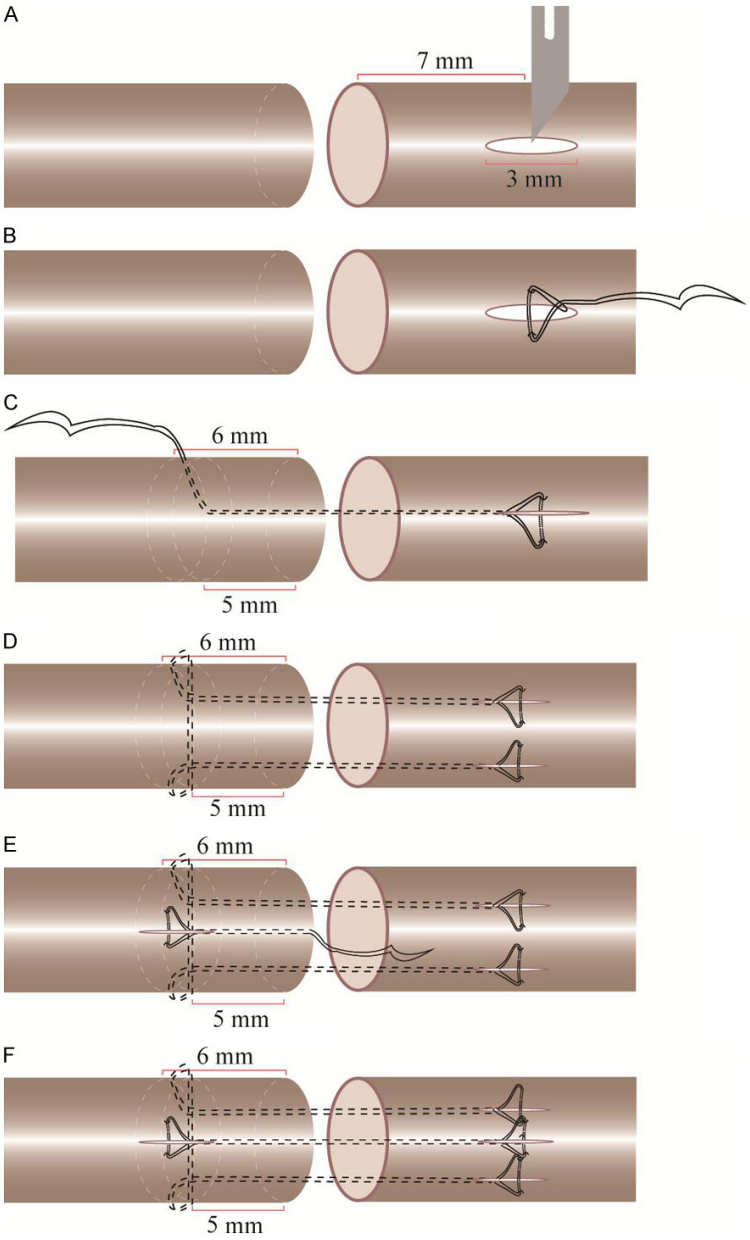

Figure 3. Diagram of M-Tang stepped-lap repair. A. A 3 mm incision is made. B. The M-Tang lock is developed. C. After passing through the center of the tendon, the needle is pulled out from the opposite side. D. The needle is inserted from the inner part of incision and pulled out from the outer part, and then it's inserted from the outer part and pulled out from inner part. E. Another 3-0 needle-ring nylon thread is embedded into the loop. F. The development of another M-Tang lock.

Comparison of the healing rate

As shown in **Table 2**, the primary healing rate in the experimental group was significantly higher than it was in the control group (86.49% vs 64.58%), while the secondary healing rate was significantly lower than it was in the control group (13.51% vs 35.42%).

Comparison of excellent and good treatment rate

The excellent and good treatment rates in the experimental group were significantly higher than they were in the control group (91.89% vs 72.92%, $P<0.05$, **Table 3**).

Comparison of the active motion of the wrist joint

As displayed in **Table 4**, the active motion of wrist joint in the experimental group was significantly higher than it was in the control group (all $P<0.05$).

Comparison of the postoperative complications

In the experimental group, no patients had troubles with their flexion and extension functions; only 1 patient had postoperative adhesions. As for patients in the control group, no one had problems in terms of their flexion and extension functions; only 2 patients suffered from postoperative adhesions. The incidence of postoperative complications in the experimental group was lower than it was in the control group (3.23% vs 7.14%, $P>0.05$). The details are shown in **Table 5**.

Discussion

Tsuge repair was first developed in the mid-1970s under the guidance of Tsuge, who was emeritus professor of plastic surgery in Hiroshima University [14]. The broken tendon and nerve are repaired using a loop suture. Many clinical studies have suggested that Tsuge repair is superior [15-18]: The procedure is simple and operational, resulting in a decreased learning cost; the blockage of blood flow is less, so the postoperative rehabilitation is quicker and better; the adhesion to surrounding tissue is less, minimizing the risk of func-

Table 1. Comparison of basic data

Group	Experimental group (n=31)	Control group (n=42)	χ^2 value	*P* value
Age (years)	36.98±11.37	39.26±10.95	0.860	0.393
Gender (n)			0.038	0.845
Male	23	32		
Female	8	10		
Hand (n)			0.372	0.542
Left	14	22		
Right	17	20		
Finger (n)			0.172	0.583
Thumb	3	4		
Index finger	12	16		
Middle finger	10	12		
Ring finger	7	10		
Little finger	5	6		
Division			0.041	0.840
Zone II	20	27		
Zone III	17	21		

Table 2. Comparison of the healing rate (n)

Group	Experimental group (n=31)	Control group (n=42)	χ^2 value	*P* value
Primary healing			5. 225	0.022
Number of fingers	32	31		
Healing rate	86.49%	64.58%		
Secondary healing				
Number of fingers	5	17		
Healing rate	13.51%	35.42%		

Table 3. Comparison of the excellent and good treatment rates (n)

Group	Excellent	Good	Fine	Poor	Excellent and good rate
Experimental group (n=31)	18	16	2	1	91.89%
Control group (n=42)	15	20	9	4	72.92%
χ^2 value	0.081	0.021	3.303	1.197	4.923
P value	0.776	0.884	0.069	0.274	0.026

Table 4. Comparison of the active motion of the wrist joint ($\bar{x}$ ± sd

Group	Experimental group (n=31)	Control group (n=42)	t value	*P* value
Ulnar deviation	32.38±7.56	27.46±8.26	2.642	0.010
Radial deviation	25.79±6.97	19.76±6.39	3.784	<0.001
Palm flexion	57.36±9.81	51.72±10.48	2.358	0.021
Dorsal extension	49.55±8.60	41.71±9.65	3.651	<0.001

tional recovery which is induced by postoperative tendon adhesion, and the suture is locked, which plays an important role in anti-slip and early rehabilitation. Tsuge repair has advantages in the case of a large number of tendon injuries. Pruitt et al. reported that the double-Tsuge loop suture has a more even anti-tension distribution of tensile force at the fracture site of the tendon [19]. The main reason is that the symmetrical distribution of the four sutures can moderately increase the tensile fracture load. The anti-tension strength of the double-Tsuge loop suture is higher than both the Kessler repair and the modified Kessler repair. An in vitro study reported by Kozono et al. indicated that the fatigue strength of the 6-bundle flexor tendon repair was higher than the 4-bundle. They also proposed that a double-Tsuge loop suture could not control the rotation of a tendon fracture and achieve an ideal suture strength [20]. However, this is an in vitro experiment. At present, the clinical application of 6-bundle flexor tendon repair is still being investigated.

In our study, the patients in the experimental group were treated using an M-Tang stepped-lap repair. The top three features of this technique were: stepped anastomosis, six-bundle sutures, and locked M-Tang loop. The advantages of M-Tang stepped-lap repair are closely related to its characteristics.

Table 5. Comparison of the postoperative complications (n)

Group	Experimental group (n=31)	Control group (n=42)	χ^2 value	*P* value
Limited flexion and extension	0	1		
Postoperative adhesion	1	2		
Rate of postoperative complications	3.23%	7.14%	0.528	0.467

Stepped anastomosis: the flexor tendon sheath is composed of the tendon fiber sheath and the synovial sheath. The synovial fluid secreted by the tendon synovial sheath provides nutrition for the tendon. The tendon fiber sheath plays an important role in the support and protection of the tendon synovial sheath [21]. The theory of exogenous healing posits that the removal of the partial tendon sheath can promote the entrance of peripheral blood vessels and cells into the tendon. Conversely, a complete tendon sheath may be detrimental for the repair of the tendon [22]. However, Eiken et al. provided more scientific evidence to reject this theory. They indicated that the complete tendon sheath could provide sufficient nutrition for the tendon and was an essential component of the tendon sliding mechanism. What's more, it could prevent postoperative tendon adhesion caused by the invaded granulation tissue. As a result, the repair of flexor tendon injury should focus on the promotion of endogenous repair and the inhibition of exogenous repair [23, 24]. In order to reduce the friction and edema of intraductal muscle ends, a stepped anastomosis was designed to perform the tendon end in different planes, so as to inhibit exogenous healing in some degree [25]. Moreover, the reduction of the tendon sheath and trochlear resection during operation could provide sufficient nutrition for the tendon, promoting tendon repair and reducing the risk of postoperative tendon adhesion [26].

Six-bundle sutures: Pruitt et al. and Kozono et al. reported that the 3-strand 6-bundle suture used in M-Tang stepped-lap repair could effectively increase the tensile fracture load and the anti-tension strength of the tendon end [19, 20]. Additionally, stepped anastomosis guaranteed the successful merger of the tendon ends. As a result, the overlap of the tendon ends was prevented effectively. The tendon had no local enlargement and little impact on the sliding mechanism. Moreover, the 3-strand 6-bundle suture formed a stable structure at the tendon end, realizing the flexible control of the tendon rotation.

Locked M-Tang loop: Many clinical studies have reported that the locked M-Tang loop used in the M-Tang stepped-lap repair was sutured in the same way as the double-Tsuge loop suture. The sutures applied in the M-Tang stepped-lap repair are completely wrapped by the tendon, so the tendon surface is smooth and friction is lessened, thus reducing the incidence of postoperative adhesion [27, 28].

In this study, we compared the efficiency and safety of M-Tang stepped-lap repair and the double-Tsuge loop suture. As a result, M-Tang stepped-lap repair displayed a higher primary healing rate. As for the TAM score and the active motion of the wrist joint, M-Tang stepped-lap repair showed more satisfying results. These were closely related to the three characteristics of M-Tang stepped-lap repair. However, there was no significant difference concerning safety between the two techniques.

However, there are some limitations to our study. Firstly, the sample size was insufficient. In order to provide a more accurate result of the therapeutic effect, we should further amplify the sample size. Secondly, biomechanical studies were not performed prior to this prospective study. Subsequent studies will concentrate on the collection of an evidence base on basic experiments. In addition, M-Tang stepped-lap repair is expensive. Meanwhile, it's highly challenging for the surgeons, especially in terms of the symmetry of the suture and the depth of the needle.

In conclusion, M-Tang stepped-lap repair has a better therapeutic effect and is safer on zone II and III flexor tendon injuries when compared to the double-Tsuge loop suture.

Disclosure of conflict of interest

None.

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