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Original Article

ZM suture combined with early functional exercise can promote finger functional recovery in patients with finger flexor tendon rupture

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Abstract: Objective: To investigate the efficacy of ZM suture combined with early functional exercise in repairing flexor tendons and its impact on finger function recovery in patients. Methods: A retrospective analysis was conducted on 60 patients who sought medical treatment at the Orthopedics Hospital of Xingtai City from August 2019 to August 2022. Among them, 29 patients treated with the modified Kessler suture technique were assigned to the control group, while 31 patients treated with ZM suture technique were assigned to the observation group. Both groups of patients underwent early functional exercise after surgery and were followed up regularly for 6 months. Finger function, grip strength, pinch strength at 6 months after operation, upper limb function before and after treatment, visual analog pain scale (VAS) at 1 and 2 weeks postoperatively, quality of life, and incidence of complications were compared between the two groups. The risk factors affecting the prognosis of patients were analyzed. Results: At 6 months postoperatively, the observation group showed significantly better finger function, grip strength and grip strength ratio, and upper limb function compared to the control group (all $P<0.05$). The observation group had significantly lower VAS scores at 1 and 2 weeks postoperatively and a significantly lower incidence of complications compared to the control group, while their quality of life was significantly better than that of the control group (all $P<0.05$). The choice of treatment method is an independent risk factor affecting the prognosis of patients ($P<0.05$). Conclusion: The ZM suture technique combined with early functional exercise has significant efficacy in repairing flexor tendons, effectively promoting finger function recovery in patients. It is also associated with a high level of safety and warrants clinical application and promotion.

Keywords: ZM suture technique, early functional exercise, repair of flexor tendons, finger function

Introduction

Flexor tendon rupture is a prevalent injury seen in hand surgery, as it directly impacts finger flexion function and hinders patients' daily activities [1]. In clinical practice, the primary objective is to repair the ruptured tendons and facilitate hand function recovery. Currently, the conventional approach after flexor tendon repair surgery involves immobilizing the wrist, metacarpophalangeal, and interphalangeal joints in a flexed position using a plaster cast to minimize tension at the tendon ends. However, this immobilization frequently results in tendon adhesion and compromised finger flexion and extension function [2, 3]. To prevent tendon adhesion, early active functional exercise is considered the most fundamental and effective method. Nevertheless, the risk of tendon re-rupture poses a challenge during early active functional exercise after flexor tendon repair [4]. Traditional suture methods may have limitations in terms of tensile strength and suture thread stability at the tendon ends [5]. Therefore, modifying the traditional tendon suture methods is necessary to enhance the suture thread's ability to withstand tension during active finger flexion without obstruction.

The Kessler suture technique is a widely utilized method for repairing flexor tendon ruptures, renowned for its exceptional tensile strength and reliable suture placement [6]. However, as the suture knots are positioned within the ruptured tendon, it can lead to bulkiness at the repair site, increasing the difficulty of repairing the tendon sheath and raising the risk of postoperative complications, which may potentially affect finger function recovery [7]. The ZM suture technique, our latest advancement in suturing, focuses on the creation of suture loops at the ends of the flexor tendon. This innovative approach significantly increases the contact area between the suture thread and the tendon, resulting in improved suture stability and enhanced reliability of tendon healing. Nevertheless, the combined effect of the ZM suture technique and early functional exercise in the repair of flexor tendons has yet to be extensively studied, highlighting the need for further research and analysis in this area.

The main objective of this study was to observe the efficacy of the ZM suture technique combined with early functional exercise in the repair of flexor tendon ruptures, aiming to provide additional insights for the treatment strategy selection in patients with flexor tendon injuries.

Materials and methods

Clinical data

A retrospective analysis was conducted on 60 patients who visited the Orthopedics Hospital of Xingtai City between August 2019 and August 2022. Among them, 29 patients who underwent treatment using the Kessler suture technique were assigned to the control group, while 31 patients who underwent treatment using the ZM suture technique were assigned to the observation group. Inclusion criteria were as follows: (1) patients diagnosed [8] for the first time with finger flexor tendon rupture and who had not received treatment; (2) patients with complete clinical data. Exclusion criteria were as follows: (1) patients with concomitant dysfunction of other finger functions; (2) patients with significant impairment of vital organ functions such as liver or kidney; (3) patients with severe infectious diseases or immune dysfunction; and (4) pregnant or lactating patients. This study has been approved by the Orthopedics Hospital of Xingtai City's ethics committee and adheres to the principles of the Helsinki Declaration.

Treatment method

All patients underwent brachial plexus nerve block anesthesia, and a tourniquet was applied for hemostasis. Strict adherence to standard disinfection and draping procedures was followed. Deactivated and contaminated tissues at the wound site were meticulously cleared, ensuring optimal exposure of the tendon sheath and flexor tendon ends. Hemostasis was achieved using bipolar electrocoagulation.

Control Group: The conventional Kessler suture method was used for suturing: a 3-0 polyester tendon thread was horizontally passed through the tendon at a 5 mm position of the rupture, then crossed over to the opposite side of the ruptured tendon for suture, with a total of 2-3 stitches. No repairs were performed on the tendon sheath or surrounding tissues, and no sodium hyaluronate filling was applied.

Observation Group: The ZM suture method was used, with the specific procedure as follows: (1) Central suturing: Using a 3-0 TICRON polyester suture, the needle was inserted from the tendon end, with the entry point located on the palmar side of the flexor tendon in the avascular zone to minimize the impact on tendon vascularity. The suture was passed longitudinally through the tendon, exiting on the palmar side of the flexor tendon 10 mm above the needle entry point. Then, at the same horizontal level, the needle was inserted from the previous exit point and the suture was looped around the tendon twice (loop size being one-fourth of the tendon width and thickness). Subsequently, the suture was horizontally passed through the tendon and exited on the opposite side of the flexor tendon, followed by looping around the tendon twice. It was then passed longitudinally through the avascular zone of the tendon and exited from the stump, leaving a 10 cm suture tail before cutting. The same method was used to suture the other end of the flexor tendon, and a knot was tied at the tendon stump. (2) Peripheral suturing: Using a 5.0 TICRON polypropylene suture, the needle was inserted 8 mm from the tendon end and passed longitudinally through the tendon sheath for 4 mm before exiting. With the same needle, it was inserted 4 mm from the opposite end of the rupture and passed longitudinally through the tendon sheath for 4 mm before exiting. It was then transversely passed 2 mm across the tendon sheath, forming a continuous horizontal "S" appearance. This process was repeated 8 times, spanning the tendon end with the suture.

Both patient groups had early postoperative functional exercises. At 2-3 days after surgery, patients were guided to perform sequential movement exercises, including passive flexion of the metacarpophalangeal and interphalangeal joints to a fist position, followed by active extension to the limited position set by the orthosis. They also performed hold and maintain exercises, half-fist exercises, reverse locking exercises, and wrist circumduction while maintaining passive fist-gripping. The orthosis could be removed during exercise. Each exercise was repeated 30 times, four times a day. Patients were also instructed on limb elevation, centripetal massage, and application of elastic self-adhesive bandages for swelling control. Scar treatment and exercises involving more than half the range of motion for light fist-gripping started two weeks after surgery. At six weeks postoperatively, exercises involving full range of motion for active light fist-gripping, progressive resistance exercises, and interphalangeal joint locking exercises were introduced.

Primary observation indicators

(1) Assessment of postoperative finger function 6 months later using the Total Active Motion (TAM) system: TAM>220° is excellent, 201°-220° is good, 180°-200° is fair, and <180° is poor. The overall rate of excellence and goodness was calculated as the sum of the two rates. (2) Measurement of grip strength and pinch strength at 6 months postoperatively: The patient's upper arm is closely attached to the thoracic cage, with the elbow flexed at 90° and the forearm in a neutral position. Grip strength and pinch strength were measured using a dynamometer for both the affected and unaffected sides, and the ratio between the affected and unaffected sides was calculated. (3) Assessment of Disability of Arm Shoulder and Hand (DASH) [9]: The DASH upper extremity functional score was evaluated before and 6 months after treatment. This scale mainly assesses the patient's upper extremity symptoms and ability to engage in daily activities, with a score of 0 indicating normal upper extremity function and 100 indicating extreme limitation.

Secondary observation indicators

(1) Assessment of pain using the Visual Analog Scale (VAS) [10] at 1 week and 2 weeks postoperatively for both groups of patients. A higher score represents more severe pain. (2) Evaluation of the quality of life at 6 months post-treatment for both groups of patients using the SF-36 scale [11]. Higher scores in each assessment indicate better quality of life. (3) Recording and comparison of the incidence of complications between the two groups of patients, including incision infection, tendon adhesion, anastomotic swelling, and tendon rupture. (4) The risk factors affecting the prognosis of the two groups of patients were analyzed.

Statistical methods

The collected data were processed and analyzed using SPSS 20.0 software and GraphPad Prism 8 software for visualization. Independent samples t-test was used for between-group comparisons, paired t-test was used for within-group comparisons before and after treatment, data at different time points were compared using one-way analysis of variance. Chi-square test was used for categorical data. Multivariate logistic regression analysis was used to analyze the risk factors affecting the prognosis of the two groups of patients. A significance level of P<0.05 indicated a statistically significant difference.

Results

General data comparison

Subjects were comparable because there were no evident differences identified in gender, age, and BMI between the two groups (all P>0.05, **Table 1**).

Comparison of finger function between two groups at 6 months after operation

The observation group had a higher rate of excellent hand function at 6 months postoperatively compared to the control group, and the difference was statistically significant (P<0.05, **Table 2**).

Comparison of grip strength and pinch strength between the two groups of patients at 6 months postoperatively

The grip strength and pinch strength of the observation group were superior to those of the control group, but only the difference in grip

Table 1. Comparison of general data between the two groups

Variable	Observation group (n=31)	Control group (n=29)	X^2	P
Gender			0.007	0.935
Male	20 (64.52)	19 (65.52)		
Female	11 (35.48)	10 (34.48)		
Age (years)			0.010	0.919
≥35	10 (32.26)	9 (31.03)		
<35	21 (67.74)	20 (68.97)		
BMI (kg/m^2)			0.058	0.809
≥23	14 (45.16)	14 (48.28)		
<23	17 (54.84)	15 (51.72)		
Smoking history			0.183	0.668
Yes	22 (70.97)	22 (75.86)		
No	9 (29.03)	7 (24.14)		
Alcohol history			0.067	0.796
Yes	15 (48.39)	15 (51.72)		
No	16 (51.61)	14 (48.67)		
Injury site			0.051	0.821
Left hand	13 (57.41)	13 (56.86)		
Right hand	18 (42.59)	16 (43.14)		
Cause of injury			0.036	0.982
Cut wound	10 (32.26)	10 (34.48)		
Mechanical injury	12 (38.71)	11 (37.93)		
Others	9 (29.03)	8 (27.59)		

Table 2. Comparison of finger function between the two groups at 6 months after operation

Functional situation	Observation group (n=31)	Control group (n=29)	X^2	P
Excellent	20 (64.52)	13 (44.83)	-	-
Good	6 (19.35)	3 (10.34)	-	-
Fair	5 (16.13)	10 (34.48)	-	-
Poor	0	3 (10.34)	-	-
Excellent rate	24 (83.87)	16 (55.17)	5.876	0.015

strength (grip strength ratio) was statistically significant (P<0.05, **Table 3**).

Comparison of DASH scores before and after treatment in the two groups

Before treatment, there was no statistical difference in DASH scores between the observation group and control group (P>0.05). After treatment, both the observation group and control group showed a significant decrease in DASH scores compared to before treatment (all P<0.05). Furthermore, the DASH scores in the observation group were significantly lower than those in control group (P<0.05, **Figure 1**).

Comparison of VAS score in the two groups before operation and at 1 week and 2 weeks after operation

There was no significant difference in preoperative VAS score between two patient groups (P<0.05). However, postoperatively, both groups showed a significant decrease in VAS score compared to before treatment (both P<0.05). Postoperatively, the VAS scores in the observation group were lower than those of control group (all P<0.05). Additionally, the VAS scores at 2 weeks postoperatively were lower than those at 1 week postoperatively in both groups (P<0.05, **Figure 2**).

Table 3. Comparison of grip strength and pinch strength between the two groups of patients at 6 months postoperatively

Item	Observation group (n=31)	Control group (n=29)	X^2	P
Grip strength (kg)	21.65±1.39	15.97±1.4	15.76	<0.001
Grip ratio (%)	78.62±1.56	60.33±1.18	50.95	<0.001
Pinch strength (kg)	7.63±0.87	7.38±0.83	1.137	0.260
Pinch ratio (%)	69.73±1.53	69.23±1.84	1.147	0.256

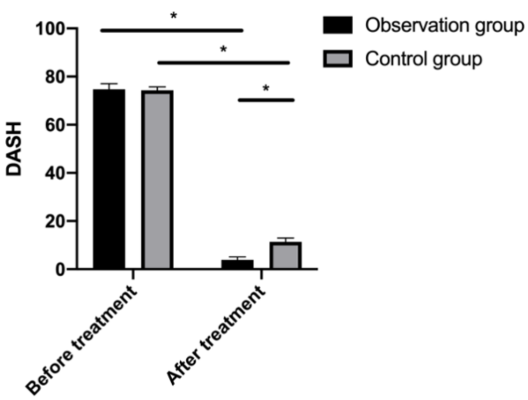

Figure 1. Comparison of DASH score in the two groups before operation and at 1 week and 2 weeks after operation. *, P<0.05. DASH, Disability of Arm Shoulder and Hand.

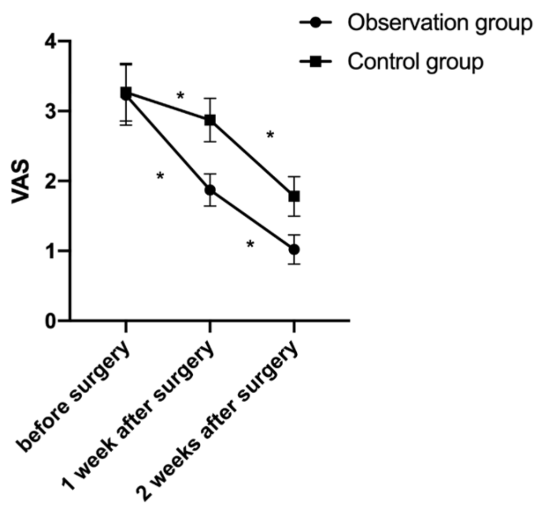

Figure 2. The VAS scores of the research group at 1 week and 2 weeks. *, P<0.05. VAS, visual analog pain scale.

Comparison of quality of life after treatment between the two groups

After treatment, all quality-of-life scores in the control group were evidently lower than those in observation group, indicating patients in the observation group were assessed with a better quality of life (P<0.05, **Table 4**).

Comparison of the incidence of postoperative complications between the two groups

The incidence of adverse reactions in the observation group was 5.56%, significantly lower than the incidence of adverse reactions in control group, which was 29.41% (P<0.05, **Table 5**).

Analysis of risk factors affecting patients' prognosis

According to the finger function of the patients after 6 months, they were divided into a good prognosis group of 42 cases (excellent + good) and a poor prognosis group of 18 cases (fair + poor). Through univariate analysis, it was found that age, injury site and treatment plan were the most important factors affecting the prognosis of the patients (**Table 6**). We then analyzed the patients through logistic regression analysis and found that the treatment plan was an independent risk factor affecting the poor prognosis of the patients (**Table 7**, P<0.05).

Discussion

Hand tendon injuries, frequently caused by crushing or saw injuries, can result in functional impairments. While flexion of the metacarpophalangeal joints may remain intact due to intact intrinsic hand muscles, extensor tendon ruptures at various locations can hinder proper extension and potentially lead to deformities [12]. In the treatment of finger flexor tendon ruptures, tendon repair plays a pivotal role by aiming to restore the smoothness of the tendon surface, preserve uninterrupted blood supply at the tendon ends, and provide sufficient tensile strength to facilitate early protective passive movements [13].

Table 4. Comparison of SF-36 score after treatment between the two groups

Item	Observation group (n=31)	Control group (n=29)	t	P
Social functioning	77.38±2.37	61.25±2.12	27.72	<0.001
Mental status	74.15±2.31	67.84±2.32	10.55	<0.001
Health status	91.33±1.81	82.8±2.23	16.32	<0.001
Emotional function	85.81±2.46	70.83±3.15	20.60	<0.001

Table 5. Comparison of the incidence of postoperative complications between the two groups

Complication	Observation group (n=31)	Control group (n=29)	X^2	P
Incision infection	1 (3.23)	3 (10.34)	-	-
Tendon adhesion	1 (3.23)	3 (10.34)	-	-
Bloated anastomotic stoma	0	2 (6.90)	-	-
Tendon rupture	0	1 (3.45)	-	-
Total incidence	2 (6.45)	9 (31.03)	6.048	0.014

Table 6. Univariate analysis of factors affecting the prognosis

Variable	Good prognosis group (n=42)	Poor prognosis group (n=18)	t/X^2	P
Gender			1.008	0.315
Male (n=39)	29 (69.05)	10 (55.56)		
Female (n=21)	13 (30.95)	8 (44.44)		
Age			3.994	0.046
≥35 (n=19)	10 (23.81)	9 (50.00)		
<35 (n=41)	32 (76.19)	9 (50.00)		
BMI (kg/m^2)			0.051	0.821
≥23 (n=28)	20 (47.62)	8 (44.44)		
<23 (n=32)	22 (52.38)	10 (55.56)		
Smoking history			0.230	0.610
Yes (n=44)	30 (71.43)	14 (77.78)		
No (n=16)	12 (28.57)	4 (22.22)		
Injury site			7.447	0.006
Left hand (n=26)	23 (54.76)	3 (16.67)		
Right hand (n=34)	19 (45.24)	15 (83.33)		
Treatment programs			12.61	0.001
Kessler suture (n=29)	14 (33.33)	15 (83.33)		
ZM suture (n=31)	28 (66.67)	3 (16.67)		

BMI, body mass index.

From a structural standpoint, fresh tendons primarily comprise a multitude of longitudinally arranged collagen fibers, accompanied by a smaller quantity of fusiform tendon cells. Additionally, a subset of collagen fibers is intricately twisted or interwoven to deter tendon separation and enable effective force distribution from various directions [14]. The composition and spatial arrangement of these components determine the biomechanical properties of tendons. When subjected to longitudinal stretching, most of the collagen fibers align parallel to the tendon's axis, arranging along the load direction and bearing the entire load, thereby exhibiting significant mechanical strength [15]. Nevertheless, the abundant longitudinal arrangement of collagen fibers in tendons renders them vulnerable to longitudinal splitting, which can result in suture pullout from the tendon ends. Meeting the demanding criteria of preventing suture pullout and ensuring resistance-free tension during active finger flexion places heightened demands on the suturing technique.

Table 7. Multivariate analysis of factors affecting the prognosis

Variable	B	S.E,	Wals	P	RR	95% C.I.	
						Lower limit	Upper limit
Treatment programs	0.622	0.114	3.024	0.002	1.726	1.329	1.995

Presently, it is widely acknowledged that employing a central locking suture to bear the primary stress within a region that does not compromise the tendon's blood supply, along with peripheral sutures to optimize the smoothness of the suture line, can yield a favorable and successful suturing outcome [16]. While ensuring the strength of tendon suturing, early rehabilitation training is beneficial in preventing tendon adhesion to surrounding tissues [17]. Building upon the Kessler method, we have developed the ZM suture technique, which incorporates both central locking sutures and peripheral sutures, for flexor tendon repair. To ensure the integrity of the sutures, we utilized 3-0 CRON polyester sutures and 5-0 CRON polypropylene sutures, while refraining from clamping the sutures with instruments. The study aimed to compare the effects of two suturing techniques on finger function, grip strength, pinch strength, and upper limb function in patients. The results demonstrated that the combination of the ZM suture technique with early functional exercises led to significant improvements in these outcomes. The central locking suture technique effectively secures the tendon bundles, augmenting their resistance against external forces. Moreover, the perpendicular orientation of suture forces at the gripping corners amplifies the friction between the sutures and the tendon, thus mitigating the risk of suture pullout. Consequently, these factors contribute to superior results during early functional exercises [18].

We further compared the post-treatment VAS scores, complication rates, and quality of life between the two groups of patients. The results showed that the observation group had significantly lower VAS scores and complication rates compared to the control group, and their quality of life was significantly higher. It is worth noting that in previous clinical studies on flexor tendon repair, the incidence of tendon re-rupture ranged from 0.9% to 5% [19-22]. In this study, no tendon re-rupture were observed in the observation group, demonstrating the excellent safety profile of the ZM suture technique. Specifically, the ZM suture technique, founded upon central suturing, incorporates peripheral sutures to achieve precise and smooth apposition of the tendon ends. This approach enhances intrinsic healing and imparts greater tensile strength, effectively preventing the formation of gaps between the tendon ends. In contrast, the conventional Kessler suture technique typically employs multiple locking loops on each side of the tendon ends. However, this technique does not yield significant improvements in the tendon's biological performance and may result in the loss of normal tendon tissue, potentially compromising tendon blood supply. Furthermore, the suture knots are positioned between the tendon ends, which can create gaps and hinder proper tendon healing [23]. Improving these factors contribute to reducing patient pain and complications while improving their quality of life.

In summary, the ZM suture technique combined with early functional exercises has shown significant effectiveness in repairing flexor tendons in the fingers. It effectively promotes the recovery of finger function in patients and has a high level of safety. Therefore, it is worth considering its clinical application and widespread use. However, this study also has certain limitations. First, because this is a small sample size study, our research conclusions need to be further confirmed. On the other hand, there are relatively few studies related to ZM suture technology, and there are no more similar studies at present. To support our research, we will carry out further large-sample research to further confirm our conclusions and promote the ZM suture method.

Disclosure of conflict of interest

None.

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