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Features of surgical treatment for primary injury to the flexor tendons of the three-phalangeal fingers in the second zone: a retrospective cohort study

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Abstract

Introduction Three-phalanx finger flexor tendon injuries in the fibrous-osseous canals of the fingers represent a complex orthopedic problem requiring multifaceted treatment. The functional outcome of flexor tendon reconstruction depends on the surgical strategy, timely provision of necessary rehabilitation support, and patient compliance. Failure to adopt a comprehensive approach to treating patients with this injury often leads to poor clinical and functional outcomes.

The **purpose** was to determine key surgical and rehabilitation factors that have impact on the outcomes of primary reconstruction of the flexor tendons of the three-phalangeal fingers in the second zone.

Materials and Methods We analyzed the postoperative results of 100 patients who underwent primary reconstruction of the deep flexor tendon of one three-phalangeal finger after damage to both flexor tendons in zone 2 according to the Verdan classification. These included finger function using the Strickland criteria and the Boyes – Lister scale, and clinical and functional assessment of the limb using the validated DASH and MHQ scales. The impact of patient morphological characteristics, anatomical topography of the injury, surgical strategy, and rehabilitation protocol on postoperative outcome was assessed.

Results A statistically significant improvement in function was found according to the Strickland criterion with a surgical incision size not exceeding 1.5 phalanx lengths ($p < 0.05$). Functional results with the use of a four-thread 3/0 intrasegmental suture and a six-thread 3/0 suture according to the Strickland criterion and the Boyes Lister scale were statistically significantly better ($p < 0.05$). Poor results according to the Strickland criterion were observed statistically significantly more often in the absence of rehabilitation than with any type of rehabilitation ($p < 0.05$). Suture ruptured more frequently without rehabilitation ($p < 0.001$) than if rehabilitation with a hand therapist was provided.

Discussion The obtained results both differ from the published ones in the literature and confirm some parameters. The use of four- or six-thread 3/0 tendon suture configurations and a rehabilitation protocol with a specialist improves functional outcomes in the treatment of flexor tendon injuries of the triphalangeal fingers and reduces the risk of suture rupture. Combined flexor tendon and digital nerve injuries do not show functionally significant differences compared to isolated tendon injuries.

Conclusion A retrospective cohort analysis identified key surgical and rehabilitation factors that influence the outcomes of primary zone 2 flexor tendon reconstruction of the three-phalangeal fingers: the configuration and caliber of the intra-articular suture, the size of the surgical incision, and the availability and type of rehabilitation provided. These factors significantly had a significant impact on the clinical and functional outcomes of treatment.

Keywords: flexor tendons, tendon suture, tendon treatment

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INTRODUCTION

Primary reconstruction of the flexor tendons of the fingers following their injury in the area of fibrous-osseous canals remains a pressing orthopedic problem due to the high incidence of poor functional outcomes in the postoperative period [1, 2]. To achieve good function after tendon suture is possible with comprehensive treatment, which includes an appropriate surgical strategy, early rehabilitation support from a specialist (a hand rehabilitation physical therapist), and high patient compliance [3, 4].

One of the challenges in tendon reconstructive surgery remains the high incidence of suture failure in the early postoperative period, often due to the use of double-thread axial configurations [5]. According to current data, to prevent ruptures, the number of intrasegmental threads used in suture should be at least four [6]. Minimal invasiveness and the choice of surgical approach are among the significant surgical factors determining the success of rehabilitation and functional outcome. Extensive approaches, as well as the lack of precision technique for exposure of flexor tendons from the osteofibrous canal, contribute to the formation of extensive adhesions and scars. This complicates the recovery process and increases the risk of tendon suture failure [7–9].

Early active rehabilitation should be performed by a specialized therapist in hand rehabilitation. Without a rehabilitation protocol, poor results occur in 100 % of cases [10]. Currently, various rehabilitation protocols exist for treating patients with flexor tendon injuries, which are selected individually for each clinical case [11–13].

A significant challenge in achieving good functional outcomes in the management of flexor tendon injuries is low patient compliance. Failure to comply with postoperative recommendations and rehabilitation protocols is associated with long-term disability, as well as a high portion of patients with low socioeconomic status in the structure of injuries to this anatomical region [14, 15]. Analysis of factors that affect rehabilitation outcomes reveals a paradoxical relationship: patient adherence to treatment increases proportionally to the severity of the injury. However, even when only one finger is injured, low compliance often undermines the surgeon's efforts, necessitating the search for new approaches to managing this group of patients [16]. In addition to the above factors, patient compliance is also affected by different insurance status, race, and bad habits [17–19].

The functional outcome of reconstruction in injuries of finger flexor tendon zone 2 depends on a large number of factors that arise at each stage of the treatment process. This clinical study was conducted to analyze surgical outcomes, identify key risk factors critical to the treatment of this patient cohort that influence long-term functional outcomes, and highlight the most significant aspects of flexor tendon treatment.

The **purpose** was to determine key surgical and rehabilitation factors that have impact on the outcomes of primary reconstruction of the flexor tendons of the three-phalangeal fingers in the second zone.

MATERIALS AND METHODS

Study design A single-center retrospective cohort study conducted according STROBE recommendations.

Ethical approval The study was approved by the ethics committee of the Vreden National Medical Research Center of Traumatology and Orthopedics (Protocol No. 4, September 20, 2024). Informed consent for the processing of personal data and inclusion in the study was obtained from all patients.

Conditions and terms The study included data from a retrospective analysis of medical case records, clinical examinations, and instrumental studies of 100 patients after primary suture of the deep flexor tendon of one triphalangeal finger. All patients underwent urgent surgical care at the Vreden National Medical Research Center of Traumatology and Orthopedics between 2022 and 2023.

Inclusion criteria: patients with injury to the superficial and deep flexor tendons of one triphalangeal finger in zone 2 according to the Verdan classification who underwent primary reconstruction of the deep flexor tendon.

Exclusion criteria: injury to both neurovascular bundles of the finger; injury more than 24 hours old; patients with congenital malformations of the hand, a history of severe hand injuries (mine-explosive, gunshot, etc.), systemic diseases, including autoimmune diseases.

Methods of data collection and analysis

To evaluate long-term results of surgical treatment, patients were clinically and instrumentally examined in an outpatient setting, and interviewed using standard questionnaires. Finger function was assessed by measuring the range of motion in the proximal and distal interphalangeal joints of the finger using the Boyes-Lister scale and Strickland criteria, as well as the validated Disability of the Arm, Shoulder, and Hand (DASH) and Michigan Hand Outcomes Questionnaire (MHQ). The length of the surgical incision was measured using an orthopedic ruler along the axis of the finger being examined. The length of half a phalanx was equal to 0.5 units of measurement, while the length of one phalanx was equal to 1 unit of measurement. Grip strength was measured using an electronic dynamometer.

Description of medical intervention

All surgical procedures were performed by surgeons experienced in treating patients with digital flexor tendon injuries. The procedure was performed in the operating room, with the patient in the supine position and the injured upper limb supported on a side table. The procedure was performed under conduction anesthesia in the brachial plexus area or local infiltration anesthesia. After placing a tourniquet in the middle third of the arm, the primary wound was extended proximally and distally using a Bruner Z-shaped approach or a mid-lateral approach. The proximal and distal ends of the deep flexor tendon were brought into the wound, and the tendon was sutured using monofilament or polyfilament suture material with a thread of 3/0 or 4/0 with various intrasegmental suture configurations (two-, four-, or six-thread). An adapting suture was then applied. In cases of injury to the proper digital nerve, epineural suturing was performed using 8/0 or 9/0 monofilament sutures under optical magnification. Repair of the latter was performed individually at the surgeon's discretion. Skin suturing was performed using 3/0 or 4/0 monofilament sutures. After applying an aseptic dressing, the upper limb was immobilized in a plaster cast in physiological flexion of 30° at the wristand flexion at the metacarpophalangeal joints at 30–45° along the dorsal surface from the distal phalanges of the second through fifth fingers to the middle third of the forearm.

Statistical processing of the findings

The database was created using the Excel spreadsheet program of the Microsoft Office suite (Microsoft, USA). Statistical processing of the data was performed using SPSS Statistics (IBM, USA).

The distribution type of the quantitative variable values was tested using the Shapiro–Wilk test. The test results revealed that none of the quantitative variables followed the normal distribution law. For this reason, and given the small number of observations in the samples formed for the comparative and exploratory analysis, nonparametric statistical methods were used. The quantitative variables were described using the median (Me), interquartile range (Q1; Q3), and extreme sample values (min–max). These descriptive statistics are presented as Me [Q1; Q3] (min–max). For qualitative variables, absolute frequency values and proportions expressed as a percentage are presented.

Comparative analysis of quantitative variables was performed using the Mann-Whitney test when comparing two independent groups, and the Kruskal-Wallis test when comparing three or more independent groups. In the latter case, when statistically significant differences between groups

were identified, a Dunn post-hoc test with a Bonferroni correction for multiple comparisons was performed on the p-value. Correlation analysis with the calculation of the Spearman correlation coefficient (ρ) was used to assess the presence of a relationship between two quantitative variables.

A comparative analysis of qualitative variables was performed by constructing contingency tables and then calculating the Pearson χ^2 test. If the applicability conditions of the Pearson χ^2 test were violated (the presence of zero values of empirical frequencies in cells, the presence of cells with expected frequencies less than 5), the exact tests were applied: Fisher's (for four-field contingency tables) or Fisher-Freeman-Halton's (for multi-field contingency tables). If statistically significant differences between event frequencies were detected in the case of multi-field contingency tables, post-hoc tests were performed, consisting of pairwise comparisons of proportions using the Z-test. A Bonferroni correction for multiple comparisons was also applied to the obtained p-values.

To assess the influence of significant predictors identified during the preliminary analysis on the Strickland and Boyes tests, ordinal regression was used. The applicability of this model was tested using a parallel lines test. Model validity was confirmed at a p value > 0.05. To estimate the proportion of variance in the dependent variable explained by the model, Nigelkirk's pseudo R2 was calculated. This indicator can take values from 0 to 1, where higher values correspond to better model quality. The results of ordinal regression are presented as coefficient estimates, *p* values, and odds ratios (ORs) with corresponding 95 % confidence intervals (95 % CI).

The study of the joint relationship of thread thickness and axial suture type with the Strickland, Boyes-Lister, DASH and MHQ indices was performed using a two-way nonparametric rank analysis of variance (ART-ANOVA) with post-hoc testing using Student's t-test on equalized ranks with Bonferroni correction.

The critical level of significance for this study was chosen to be $\alpha = 0.05$, that is, at $p < 0.05$ the null hypothesis was rejected.

Patients

The baseline clinical and demographic characteristics of 100 patients included in the study are presented in Table 1.

Table 1

Clinical characteristics of patients

Parameter	Number of patients (*n* = 100)	
	n	%
Gender: males	68	68
Non-dominant hand injury	56	56
Finger V injury	56	56
Mechanism of injury: knife	64	64
A cut wound with smooth edges	68	68
Associated nerve injury	18	18
Location of the wound in the PIP joint area	46	46

Note: PIP — proximal interphalengeal joint

RESULTS

In most cases, interventions were performed under local infiltration anesthesia (82 %) using the Bruner Z-shaped approach (79 %). The most commonly used configuration was a four-thread axial suture (59 %) and a 3/0 suture thread (70 %). Monofilament suture material was used in 65 % of cases. Ligament injuries occurred in 20 patients (20 %). The average incision size was two units, or the length of two phalanges. Immobilization lasted an average of four weeks.

Fifty-six patients (56 %) consulted a hand rehabilitation therapist, while 21 patients (21 %) did not undergo rehabilitation. The average total range of motion of the interphalangeal joints of the injured finger was 110°, which is considered satisfactory according to the Strickland criteria. Poor results were more common according to the Boyes-Lister Scale and the Strickland criteria. However, the average DASH (20) and MHQ (75) questionnaire scores showed good results. Suture rupture occurred in 16 % of cases. The most common contractures were in the proximal interphalangeal joint (30 %). Handgrip strength averaged 26 kg on the injured upper limb side and 27 kg on the uninjured one.

The comparison of patient characteristics such as gender, age, hand dominance, and the number of the injured finger with the results of the Strickland criteria and the Boyes-Lister scale found no statistically significant differences ($p > 0.1$).

The comparison of surgical factors such as nerve injury, traumatic agent, type of surgical approach with the results of the Strickland criteria and the Boyes-Lister scale found no significant statistical differences ($p > 0.1$).

The comparison of the category of surgical approach size with the obtained results of the Strickland criteria found statistically significant differences (Table 2).

Table 2

Comparison of the size of surgical approach by the number of phalanges with the Strickland criterion

Approach size by number of phalanges		Критерий Strickland				Total
		Poor	Fair	Good	Excellent	
1.5	*n*	7	1	8	7	23
	%	18.9	4.3	28.6	58.3	23.0
2.0	*n*	20	15	14	4	53
	%	54.1	65.2	50.0	33.3	53.0
2.5	*n*	10	7	6	1	24
	%	27.0	30.4	21.4	8.3	24.0
Total	*n*	37	23	28	12	100
	%	100.0	100.0	100.0	100.0	100.0

Pearson's χ^2 criterion: 14.060; $p = 0.029$.

Excellent results according to the Strickland criterion were statistically significantly more frequent with approach of 1.5 phalanx ($p = 0.002$) than with 2.0 ($p = 0.028$*) and 2.5 ($p = 0.050$*) phalanges. For the remaining compared pairs of proportions, statistically significant differences were not revealed ($p > 0.05$*).

[1]The comparison of the type of axial suture in combination with the thread thickness with the obtained functional results of the Strickland criterion and the Boyes-Lister scale, there was a statistically significant difference between the configurations of a two-thread 3/0 suture and a four-thread 4/0 suture ($p = 0.0203$ — Strickland; $p = 0.0469$ — Boyes-Lister), as well as a two-thread 3/0 suture and a six-thread 3/0 suture ($p = 0.0094$ — Strickland; $p = 0.0440$ — Boyes-Lister). The functional results with a four-thread 4/0 suture and a six-thread 3/0 suture were statistically significantly better than the use of a two-thread 3/0 suture.

The comparison of the type of rehabilitation protocol with the functional results of the Strickland criterion and the Boyes-Lister scale, statistically significant differences were obtained.

Poor results according to the Strickland criterion were statistically significantly more common if rehabilitation was not performed than with any type of rehabilitation (rehabilitation in a clinic — $p = 0.036$*; hand rehabilitation specialist — $p < 0.001$*; independently on one' own — $p = 0.005$*).

* *p* values are given taking into account the Bonferroni correction for multiple comparisons.

Also, poor results according to the Strickland criterion were statistically significantly more common if patients performed rehabilitation independently than with a hand rehabilitation specialist ($p = 0.005$*).

Good results according to the Strickland criterion were statistically significantly more frequent if rehabilitation was with a hand rehabilitation specialist ($p = 0.010$*) than if done on one's own.

Excellent results were achieved only if rehabilitation was done with a hand rehabilitation specialist (Table 3).

Table 3

Comparison of the type of rehabilitation protocol in relation to the functional outcome according to the Strickland criterion

Rehabilitation type		Strickland criterion				Total
		Poor	Fair	Good	Excellent	
No rehabilitation	*n*	20	1	0	0	21
	%	54.1	4.3	0.0	0.0	21.0
At the clinic	*n*	3	3	0	0	6
	%	8.1	13.0	0.0	0.0	6.0
With a rehabilitation specialist	*n*	6	12	26	12	56
	%	16.2	52.2	92.9	100.0	56.0
On one's own	*n*	8	7	2	0	17
	%	21.6	30.4	7.1	0.0	17.0
Total	*n*	37	23	28	12	100
	%	100.0	100.0	100.0	100.0	100.0

In the absence of rehabilitation, poor results according to the Boyes criterion were statistically significantly more frequent ($p = 0.003$*) than fair ones.

If rehabilitation was done with a hand rehabilitation specialist, good results according to the Boyes criterion were statistically significantly more frequent than poor ($p < 0.001$*) and fair ($p = 0.001$*) results.

Poor results according to the Boyes criterion were statistically significantly more frequent if rehabilitation was not performed ($p < 0.001$*) or was performed independently ($p = 0.005$) than if rehabilitation was done with a rehabilitation specialist.

Excellent results were achieved only if rehabilitation was performed under supervision of a hand rehabilitation specialist (Table 4).

Table 4

Comparison of the type of rehabilitation in relation to the functional outcome according to the Boyes–Lister scale

Rehabilitation type		Strickland criterion				Total
		Poor	Fair	Good	Excellent	
No rehabilitation	*n*	18	3	0	0	21
	%	51.4	13.0	0.0	0.0	21.0
At the consultation clinic	*n*	3	3	0	0	6
	%	8.6	13.0	0.0	0.0	6.0
With rehabilitation therapist	*n*	6	10	22	18	56
	%	17.1	43.5	91.7	100.0	56.0
On one' own	*n*	8	7	2	0	17
	%	22.9	30.4	8.3	0.0	17.0
Total	*n*	35	23	24	18	100
		100.0	100.0	100.0	100.0	100.0

* *p* values are given taking into account the Bonferroni correction for multiple comparisons.

No statistically significant differences were found for comparison of the type of rehabilitation and the development of interphalangeal joint contractures ($p = 0.216$). However, statistically significant differences were found comparing the type of rehabilitation and the rate of tendon suture rupture (Table 5). Tendon suture rupture occurred more frequently in the absence of rehabilitation ($p < 0.001$*) than in rehabilitation with a hand therapist.

Table 5

Comparison of the type of rehabilitation protocol in relation to tendon suture rupture incidence

Type of rehabilitation		Suture rupture		Total
		no	yes	
No rehabilitation	*n*	12	9	21
	%	14.3	56.3	21.0
At the consultation clinic	n	5	1	6
	%	6.0	6.3	6.0
Physical therapist	n	53	3	56
	%	63.1	18.8	56.0
On one's own	n	14	3	17
	%	16.7	18.8	17.0
Total	n	84	16	100
	%	100.0	100.0	100.0

DISCUSSION

This retrospective study conducted a multivariate analysis of outcomes after primary surgical reconstruction of the flexor tendons of the three-phalangeal fingers. Factors that did not affect the clinical and functional results were interpreted. Injury to the proper digital nerves in combination with injuries to the flexor tendons on one finger and their simultaneous restoration did not correlate with a reduced range of motion, thus, it can be accomplished by performing an epineural suture without the use of nerve grafting, which is confirmed by data from foreign sources [20, 21]. Gender and age of patients were not statistically significant factors. This suggests that patients of both sexes, young and elderly, have similar levels of compliance and potential for functional recovery. Hand dominance and the number of the injured finger also had no relationship with the functional results obtained. High-quality data on the effect of hand dominance on postoperative outcome in adult patients are practically not presented in the literature. However, a group of authors reports functionally better results in pediatric patients if injury to the flexor tendons was on the dominant hand [22].

Our study identified the main predictors associated with poor functional outcomes. These include the use of a double-thread suture configuration, regardless of the thread size, and the absence of rehabilitation. If present, these predictors increased the risk of poor results and tendon suture ruptures. The absence of rehabilitation or its implementation in an outpatient setting, although not statistically significantly different from rehabilitation by a specialized specialist, tended to increase the extension deficit in the interphalangeal joints. The obtained results regarding the intrasegmental suture configuration are inconsistent with previously published studies [23, 24]. Regarding the use of a specialized rehabilitation protocol performed by a hand rehabilitation therapist, there are scientific studies confirming the obtained results [10, 25].

Due to its anatomical and technical complexity, as well as the need for early rehabilitation supervised by a specialist, surgical treatment of digital flexor tendons in the second zone should follow the well-known "one-shot surgery" concept: a technically reliable, minimally invasive final surgical

* *p* values are given taking into account the Bonferroni correction for multiple comparisons.

intervention. Key surgical and rehabilitation factors identified in this study are recommended for achieving high functional outcomes.

Study limitations The retrospective design of the study restricts the ability to establish cause-and-effect relationships. Some data on intraoperative details and the rehabilitation protocol were obtained from medical records which carries a risk of incomplete data. The single-center nature of the sample may not allow the generalization of the results to other institutions. The relatively small sample size (n = 100) reduces statistical power for analyzing rare outcomes. These limitations should be considered when interpreting the results.

CONCLUSION

The statistical analysis of this retrospective group of patients has revealed significant functional differences in the category of intrasegmental suture configuration and suture material size, as well as a correlation between functional outcomes and rehabilitation interventions. Patient's gender, age, hand dominance, surgical approach type, and combined tendon and proper digital nerve injury did not significantly differ in the postoperative period.

Conflict of interests *The authors declare no conflict of interest.*

Funding source *The study was conducted without additional funding.*

Ethical approval *The study was approved by the institutional ethics committee of the Vreden National Medical Research Center of Traumatology and Orthopedics (protocol no. 4, dated September 20, 2024).*

Informed consent *Informed voluntary consent to participate in the study and process personal data was obtained from all patients.*

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