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ARTICLE

Comparing the outcomes of fingertip-to-palm and fingertip-to-forearm two-stage flexor tendon reconstruction for isolated flexor digitorum profundus tendon injuries

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ABSTRACT

Flexor tendon injuries of the hand have devastating consequences when primary tendon repair fails or left untreated in the first place. Flexor tendon reconstruction is a substantial treatment option to obtain functional digit. In this study, we aimed to compare the functional outcomes and technical feasibility of fingertip-to-palm and fingertip-to-forearm tendon reconstruction methods. Thirty-five patients were divided into two groups according to the proximal attachment site of the free tendon grafts. Group I consisted of 18 patients whose tendon grafts were placed from fingertip-to-palm (zone III). Group II consisted of 17 patients whose tendon grafts were placed from fingertip-to-forearm (zone V). The mean of 39.6 months (range, 6–52 months) of follow-up with complete clinical data were obtained for all the cases. The mean length of the tendon grafts used in group I and group II was 9.7 ± 1.4 cm and 15.9 ± 1.2 cm, respectively. Significantly shorter tendon grafts were needed in group I ($p < 0.001$). Both mean DASH score and mean Michigan score were significantly improved postoperatively in both groups ($p = 0.0001$, $p = 0.0001$), but there was no significant difference between two groups based on postoperative DASH score ($p = 0.112$) and Michigan score ($p = 0.151$). No statistically significant difference was observed between two groups in terms of Strickland's scores ($p = 0.868$). This study demonstrates that comparable results can be obtained with fingertip-to-palm and fingertip-to-forearm staged tendon reconstructions. Fingertip-to-palm tendon reconstruction seems to be more advantageous when multiple flexor tendon injuries aimed to be reconstructed, in which requirement of tendon graft can be fulfilled with less donor site morbidity.

Abbreviations: DASH: disabilities of the arm, shoulder and hand

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Flexor tendon injury; staged reconstruction; tendon graft; palm; zone III

Introduction

Flexor tendon injuries of the hand are the most challenging injuries which have devastating consequences if left untreated, or if the treatment is delayed. The management of late-presenting neglected injuries or patients having failed primary tendon repair depend on chronicity and pattern of the injury, and patients' particular functional demands. Flexor tendon reconstruction is a substantial treatment option for patients having sensate and well vascularized digits without intractable fixed contractures, and willingness to comply with the extensive rehabilitation protocol [1]. Although, the indications for single-stage tendon reconstruction are limited, it may be performed in patients having unscarred flexor tendon sheath and adequately functional pulley system. In more severely injured digits, two-stage reconstruction described by Hunter and Salisbury should be considered as the treatment option [2]. There are several surgical methods described for two-stage flexor tendon reconstruction. Although the intended results are similar, there are certain modifications between the methods regarding the tendon graft donor site, attachment method and site of the free tendon graft. There is no common consensus on the level of proximal attachment of the tendon graft. In the literature, it has been stated that proximal attachment can be performed at the palm (zone III) or distal forearm (zone V) depending on the extent of the injury, existing scarring, but mostly on the surgeon's preference [3]. There are a small number of studies which report the results of the fingertip-to-palm tendon reconstruction, but it is difficult to compare the results of these studies due to usage of different evaluation methods [4–8].

The aim of this study was to compare the functional outcomes and technical feasibility of fingertip-to-palm and fingertip-to-forearm tendon reconstruction methods.

Materials and methods

Fifty-three patients who underwent two-stage flexor tendon reconstruction for isolated zone II flexor digitorum profundus (FDP) tendon injury between January 2013 and December 2020 were reviewed. Eighteen patients who were under 16 years of age at the time of initial surgical treatment (three patients), who had previous surgeries other than flexor tendon injury at the same limb (five patients), who had previous or concomitant contralateral hand injuries that can distort the comparison (two patients), and who had incomplete clinical data (eight patients) were excluded from the study.

Thirty-five patients were divided into two groups according to the proximal attachment site of the free tendon grafts. Group I consisted of 18 patients whose tendon grafts were placed from

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fingertip-to-palm (zone III) and group II consisted of 17 patients whose tendon grafts were placed from fingertip-to-forearm (zone V). Patients' demographic data were collected using hospital data system. Mechanism of injury, associated injuries, involved digit, dominant hand, tendon graft donor site, tendon graft attachment technique, time elapsed since injury, interval between two stages, and the complications were recorded.

University of Health Sciences Baltalimanı Bone Diseases Training and Research Hospital Ethics Committee Approval was obtained for this retrospective cohort study (number: 69-437, date: 31 March 2021). Informed consent was obtained from all patients for their demographic and clinical data to be used.

Evaluation of results

Grading of the injured digits according to Boyes' Preoperative Classification System, concomitant injuries and their management were obtained from patients' medical files [9].

Preoperative and postoperative Disabilities of the Arm, Shoulder and Hand (DASH) score, Michigan Hand Outcomes Questionnaire (MHQ) and Visual Analog Scale (VAS) for pain were evaluated.

LaSalle and Strickland method was used to compare the overall results of two groups. This method compares preoperative passive interphalangeal joint motion with postoperative active interphalangeal joint motion. After the initial assessment, according to percent of return of motion, patients were grouped as following: 75–100% as excellent; 50–74% as good; 25–49% as fair; and 0–24% as poor [4]. All range of motion (ROM) measurements were performed by using finger goniometer. We evaluated patients' flexion and extension of metacarpophalangeal (MCP), proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints of involved digit. We calculated total active motion (TAM) by subtracting total extension deficit of the MCP, PIP and DIP joints from the total active flexion of the same joints [10].

Hand grip strength and pinch strength of the operated finger against the thumb were measured using Jamar dynamometers (JA Preston Corporation, Clifton, NJ). Measured strengths of the operated hand were compared with the contralateral hand.

Length of the tendon graft used was calculated by subtracting the length of the resected portion of the tendon graft after the final tenorrhaphies from the initial length of the harvested tendon graft. The duration of the operation was compared between the two groups.

Surgical technique

Hand surgery operations are performed by two surgical teams in our tertiary hand surgery center. With the similar indications, first team prefers the palm (zone III) for the proximal attachment of the free tendon graft, and the second team prefers the distal forearm (zone V) in the two-stage flexor tendon reconstruction procedure.

At the first stage, Bruner-type incision was applied, and concomitant injuries of neurovascular structures and pulleys were identified. Required neurovascular repairs and pulley reconstructions were performed in this stage. In group I, digital nerve repair was performed in four patients and pulley reconstruction was performed in two patients. In group II, digital nerve repair was performed in three patients, artery repair was performed in one patient, and pulley reconstruction was performed in one patient. In both groups, scarred FDP tendon is meticulously excised, and at least 2 cm of proximal FDP stump distal to the lumbrical muscle origin was preserved. Flexor digitorum superficialis (FDS) tendon is not sacrificed in any patient. Dacron-reinforced silicone tendon prosthesis was advanced through the pulley system and smooth gliding of the prosthesis was controlled. The silicone prosthesis was sutured to distal remnant of the FDP tendon with nonabsorbable suture material. In group I, proximal end of the prosthesis left free in the palm, and in the distal forearm in group II. No splints were used, and free finger movements were initiated in patient who had no neurovascular repairs and pulley reconstructions. Passive ROM exercises were started after the third week in patients who underwent additional surgical procedures.

Second stage was planned to be performed after 12 weeks when the injured digit could be passively flexed to touch the palm. Bruner-type incision at the distal phalanx was used to reveal the distal stump of the FDP and the distal end of the tendon implant and the connecting sutures were divided. Cautious dissection was held not to harm the pseudosheath proximal to the DIP joint or to injure any of the pulleys. The proximal end of the implant was retrieved through the forearm or palm incision. Tendon stripper is employed to harvest the grafts. The tendon graft is sutured to the proximal end of the implant and pulled through the new tendon sheath. Palmaris longus tendon was used as tendon graft in 28 patients (80%) and plantaris tendon was used in seven patients (20%). Tenorrhaphy was applied to the FDP tendon of the involved digit in group I. In group II, common profundus tendon mass was used as a motor for 3rd, 4th and 5th digits, whereas the involved digit's independent profundus tendon was used as a motor for the 2nd digit. Graft fixation was achieved distally using a grasping suture passed volar to dorsal through drill holes in the distal phalanx and secured on a button. Nonabsorbable sutures were used to suture the FDP tendon remnant on the distal phalanx to the tendon graft as reinforcement. The proximal tendon graft is secured in the palm or distal forearm with a Pulvertaft weave technique, secured with nonabsorbable suture. If palm-to-fingertip graft is used, the proximal juncture is made just distal to the lumbrical origin. Intraoperatively, restoration of the natural digital cascade has been confirmed.

The postoperative splint was applied with the wrist in 30° of flexion, MCP joints in 70° of flexion, and interphalangeal joints fully extended. Early passive ROM exercises initiated at first week postoperatively, followed by gentle place-and-hold exercises at third week postoperatively. At sixth week splint was removed and gradual stretching and strengthening exercises were initiated.

Statistical analysis

Statistical analysis was performed with NCSS 2007 Statistical Software (Number Cruncher Statistical System, Kaysville, UT). In the evaluation of the data, besides descriptive statistical methods (mean, standard deviation), the distribution of variables was evaluated with the Shapiro–Wilk test of normality. Paired *t*-test was used for comparison of normally distributed variables, unpaired *t*-test was used for comparison of paired groups. Chi-square test was used for comparison of qualitative data. The results were evaluated at the significance level of $p < 0.05$.

Results

Of the 35 patients, nine were female and 26 were male with a mean age of 28.5 (range, 16–51 years). The mean of 39.6 months (range, 6–52 months) of follow-up with complete clinical data were obtained for all the cases. There were no significant

Table 1. Patient demographics.

	Group I ($n = 18$)	Group II ($n = 17$)	p Value
Age (years)	26.8 ± 10.5	30.3 ± 10.9	0.337[a]
Sex (n)			0.627[b]
Male	14 (78%)	12 (71%)	
Female	4 (22%)	5 (29%)	
Mean follow-up (months)	42.9 ± 22.1	31.4 ± 17.2	0.096[a]
Surgical side (n)			**0.009**[b]
Right	12 (67%)	17 (100%)	
Left	6 (33%)	0 (0%)	
Dominant hand (n)			0.109[b]
Right	15 (83%)	10 (59%)	
Left	3 (17%)	7 (41%)	
Involved digit (n)			0.581[b]
Index	4 (22%)	1 (6%)	
Long	0 (0%)	1 (6%)	
Ring	5 (28%)	6 (35%)	
Little	9 (50%)	9 (53%)	
Boyes' grade	3.1 ± 1.3	3.1 ± 1.2	0.994[a]

[a]Unpaired t-test.
[b]Chi-square test.
Values in bold indicate that they are statistically significant.

Table 2. Preoperative and intraoperative data of the patients.

	Group I ($n = 18$)	Group II ($n = 17$)	p Value
Time-to-surgery (weeks)	14.7 ± 11.2	15.6 ± 7.1	0.287[a]
Duration between two stages (weeks)	19.1 ± 6.5	19.5 ± 8	0.983[a]
Graft harvest site (n)			0.892[b]
Palmaris longus	14	14	
Plantaris	4	3	
Length of the used tendon graft (cm)	9.7 ± 1.4	15.9 ± 1.2	**0.001**[a]
Duration of the surgery (min)	205.5 ± 40.8	196.2 ± 37.6	0.351[a]

[a]Unpaired t-test.
[b]Chi-square test.
Values in bold indicate that they are statistically significant.

differences in patient demographics between two groups except group I had significantly higher number of patients with left hand injury ($p = 0.009$). There was no significant difference between two groups with respect to severity of the injuries according to Boyes' classification ($p = 0.994$) (Table 1).

The mean length of the tendon grafts used in group I and group II was 9.7 ± 1.4 cm and 15.9 ± 1.2 cm, respectively. Significantly shorter tendon grafts were needed in group I ($p = 0.001$). Duration of the surgical procedure (total of both stages) in group I and group II was 205.5 ± 40.8 min and 196.2 ± 37.6 min, respectively, and there was no significant difference between both groups ($p = 0.351$) (Table 2).

No statistically significant difference was observed between the postoperative Strickland score averages of group I and group II ($p = 0.868$). Total percentage of patients having excellent or good results according to Strickland's score in group I was 83%. Fingertip-to-forearm staged tendon reconstruction had 82% good to excellent results. An average of 37.5° increment in TAM was observed in group I after the procedure, whereas the mean improvement of TAM was 35.6° in group II. There was no significant difference between the two groups in terms of postoperative TAM ($p = 0.352$) (Table 3).

Both mean DASH score and mean Michigan score were significantly improved postoperatively in both groups ($p = 0.0001$, $p = 0.0001$). As the patients were grouped according to the proximal attachment site of the tendon graft, there was no significant difference between two groups based on postoperative DASH score ($p = 0.112$) and Michigan score ($p = 0.151$). Scores distributed according to surgical technique are shown in Table 4.

In group I, pinch strength of the involved digit against the thumb was 90%, and grip strength was 92.2% of the contralateral hand at the final follow-up visit. In group II, pinch strength of the involved digit against the thumb was 92.1%, and grip strength was 95.3% of the uninvolved hand. There was no significant difference between two groups based on postoperative grip strength and pinch strength ($p = 0.311$ and $p = 0.610$, respectively) (Table 4).

In group I, rupture of the distal attachment of the silicone prosthesis was observed in two patients, and the first stage was repeated in these patients. Wound infection was observed in one patient, and this patient was treated with local debridement and antibiotic administration. Tenolysis was performed in two patients due to flexion contracture after the second stage. The first stage was repeated because a rupture developed at the distal connection point of the implant in one patient in group II. Tenolysis was performed in one patient due to flexion contracture. One patient developed limitation of flexion in the adjacent fingers and was interpreted as a quadriga effect, which was improved with rehabilitation.

Discussion

In this study, functional outcomes of FDP tendon reconstructions with proximal fixation of the tendon graft at the wrist or palm were compared. No difference was found between the clinical results of the two methods. However, in the fingertip-to-palm group, average of 6.2 cm shorter tendon graft was used. We assume this will be advantageous especially in multiple tendon reconstructions.

Initially, staged tendon reconstructions were the primary treatment for zone II 'no man's land' flexor tendon injuries. However, later they have been used successfully for delayed and complicated flexor tendon injuries [2]. Tendon reconstructions in zone II can be performed in one or two-stage. The superiority of these two methods over each other is controversial in the literature [11]. There are some authors who recommend single-stage tendon reconstruction instead of two-stage tendon reconstruction, even in complicated cases [12]. On the other hand, we consider that to name tendon reconstruction surgeries as single or two-staged is indeed a misnomer. As LaSalle and Strickland stated, secondary procedures like tenolysis are frequently required after tendon reconstructions [4]. In our clinical practice, we prefer two-stage reconstruction, which we believe reduces the risk of adhesion, and we inform patients about the additional surgeries which will be required.

Tendon reconstruction outcomes have been reported using TAM, Buck-Gramcko's Scale, Strickland's score and Schneider's grading [13]. Each of these systems uses different criteria to measure outcomes. Nevertheless, two-staged reconstructions are recommended by most of the authors as these operations yield satisfactory results. Finsen stated that, 15 excellent and six good results were obtained in 43 patients when graded according to Buck-Gramcko's Scale [14]. Wilson et al. stated that excellent motion with few complications can be obtained following delayed two-stage tendon grafting in patients with flexor profundus avulsions. They reported that mean TAM improved from 166° to 244°, and all patients had 220° or greater TAM [8]. Beris et al. reported the rate of good and excellent results according to Buck-Gramcko's Scale was 82% in 22 digits of 20 patients who undergone two-stage tendon reconstruction. They achieved 189° mean TAM postoperatively, and that was 71% of the contralateral respective finger [15]. Coyle et al. stated that they obtained mean 206° of TAM at involved finger with two-staged reconstructions

Table 3. Preoperative and postoperative total active motion (TAM), metacarpophalangeal (MCP), proximal interphalangeal (PIP) and distal interphalangeal (DIP) active range of motions.

Joint		Group I ($n = 18$)	Group II ($n = 17$)	p Value[a]
DIP active motion (°)	Preoperative	0 ± 0	0 ± 0	–
	Postoperative	25 ± 8.4	27.1 ± 8.8	0.485
	p Value[b]	**0.0001**	**0.0001**	
PIP active motion (°)	Preoperative	76.9 ± 7.3	78.2 ± 6.6	0.588
	Postoperative	86.1 ± 9.2	89.1 ± 6.9	0.283
	p Value[b]	**0.004**	**0.0001**	
MCP active motion (°)	Preoperative	80.8 ± 8.9	85.9 ± 5.9	0.059
	Postoperative	84.2 ± 7.11	83.5 ± 7.4	0.797
	p Value[b]	0.264	0.308	
TAM	Preoperative	157.8 ± 10.2	164.1 ± 8	0.069
	Postoperative	195.3 ± 15.1	199.7 ± 12.4	0.352
	p Value[b]	**0.0001**	**0.0001**	

[a]Unpaired t-test.
[b]Paired t-test.
Values in bold indicate that they are statistically significant.

Table 4. Functional outcomes of patients who underwent fingertip-to-palm and fingertip-to-forearm staged flexor tendon reconstruction.

	Group I ($n = 18$)	Group II ($n = 17$)	p Value[a]
DASH score			
Preoperative	38.9 ± 10.7	39.9 ± 8.7	0.755
Postoperative	10.5 ± 4.3	13.1 ± 5.1	0.112
p Value[b]	**0.0001**	**0.0001**	
Michigan score			
Preoperative	34.7 ± 7	35.7 ± 6.2	0.662
Postoperative	65 ± 6.9	61.8 ± 6.1	0.151
p Value[b]	**0.0001**	**0.0001**	
Visual Analog Scale for pain			
Preoperative	2.6 ± 1.5	2.3 ± 1.8	0.640
Postoperative	0.4 ± 0.6	0.5 ± 0.7	0.718
p Value[b]	**0.0001**	**0.0001**	
Grip strength (% of uninvolved hand)			
Preoperative	72.3 ± 12.3	75.3 ± 12.1	0.471
Postoperative	92.2 ± 9.9	95.3 ± 7.8	0.311
p Value[b]	**0.0001**	**0.0001**	
Pinch strength (% of uninvolved hand)			
Preoperative	84.8 ± 11	77.7 ± 23.3	0.258
Postoperative	90 ± 12.6	92.1 ± 11.6	0.610
p Value[b]	0.132	**0.034**	

DASH: Disabilities of the Arm, Shoulder and Hand (DASH) score.
Values in bold indicate that they are statistically significant.
[a]Unpaired t-test.
[b]Paired t-test.

[16]. In our study, we observed an increment in postoperative TAM of the involved finger in both groups. We obtained good to excellent results according to Strickland's score in 83% of patients in group I, and in 82% of patients in group II.

Another controversial issue is whether reconstruction of the isolated FDP tendon injury is a requisite. There are series suggesting that good outcome can be obtained with isolated FDP tendon reconstructions [17]. On the other hand, FDP tendon reconstruction in the occasion of an intact FDS tendon and preserved PIP joint movements put the existing finger function and even adjacent finger functions at risk. Therefore, some authors stated that it should be reserved for selected patients who demand high manual dexterity, such as elite musicians and skilled technicians [11]. We inform these patients in detail preoperatively about the outcomes and potential risks and patients willing to undergo surgery were operated. No further surgery was indicated for patients who have a stable DIP joint and are not willing to undergo FDP tendon reconstruction. On the other hand, in patients who had an instability at DIP joint, in order to improve grip strength, we suggested DIP arthrodesis or tenodesis.

When the technique was first described, the tendon prosthesis and later the tendon graft were placed between the fingertip and the distal forearm. Afterwards, the proximal palmar attachment option was applied for patients with scarring on the wrist and good results were obtained. Rowland applied the proximal attachment in zone III for the first time in six patients [5]. Subsequently, Winston applied the proximal attachment in zone III in 11 patients with isolated FDP avulsion and observed an average improvement of 75° in TAM [18]. Valenti and Gilbert performed two-stage tendon reconstruction in 23 pediatric patients using the Paneva-Holevich technique. Thirteen patients who had fingertip-to-palm tendon grafting had better results when compared to 10 patients who had fingertip-to-forearm tendon grafting [6]. Coyle et al. performed fingertip-to-palm reconstruction for 35 digits of 34 patients and achieved good and excellent results at a rate of 69%. Coyle et al. stated the advantages of this technique as: using the injured digit's own FDP as a motor, preserving lumbrical functions and requirement of a shorter tendon graft [16]. Samora and Klinefelter stated that performing the fixation in zone V provides more gliding space for the tendon juncture. In addition, it was stated that the scarring of the palm in general also necessitates the attachment in zone V [13]. As far as we know, this is the first study aiming to compare the results of fingertip-to-palm and fingertip-to-forearm tendon reconstruction for isolated FDP tendon injuries. In our study, we compared the two techniques in patients with similar age groups and Boyes' classification. We observed no difference between the postoperative mean TAM, Michigan and DASH scores. Similarly, there was no significant difference between pinch and grip strengths. Our findings contrasted with the statement of Samora and Klinefelter and comparable results were obtained with fingertip-to-palm tendon reconstruction. Furthermore, we observed that the length of the used tendon grafts was significantly reduced in zone III tenorrhaphy.

Retrospective design and formation of the cohort groups may be stated as the limitations of this study. Although held in a single center, surgical treatment preferences of two surgical teams would arise a question about the reliability of the results. The level of expertise of the surgeons in both surgical teams was evaluated according to criteria defined by Tang [19]. First surgical team consisting of three surgeons had experience level of IV, III and III. Second surgical team consisted of the same number of surgeons who had level III surgical expertise each. We believe that distribution of the patients according to preference of the surgical teams has negligible effect on end-point outcomes.

In conclusion, this study demonstrates that comparable results can be obtained with fingertip-to-palm and fingertip-to-forearm staged tendon reconstructions. Fingertip-to-palm tendon

reconstruction seems to be more advantageous when multiple flexor tendon injuries aimed to be reconstructed, in which requirement of tendon graft can be fulfilled with less donor site morbidity.

Disclosure statement

The authors have no conflicts of interest to declare.

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