OPEN

PRS GLOBAL OPEN

ORIGINAL ARTICLE

Hand

# Vascularized Toe Proximal Interphalangeal Joint Transfer in Posttraumatic Fingers: Analysis of Prognostic Factors for Suboptimal Outcomes

Chi-Wei Huang, MD*
Ming-Huei Lin, MD*
Che-Hsiung Lee, MD*†
Shih-Heng Chen, MD*†
Chung-Cheng Hsu, MD*†
Cheng-Hung Lin, MD*†
Ren-Wen Huang, MD*†
Yu-Te Lin, MD, MSc, FACS*†‡

**Background:** Posttraumatic finger osteoarthritis of the proximal interphalangeal joint (PIPJ) is a difficult problem. Over the past decade, we have reported several methods for improving the outcomes of vascularized toe joint transfer (VJT). In this study, we focused on determining poor prognostic factors which lead to a suboptimal outcome.

**Methods:** A consecutive series of patients with posttraumatic osteoarthritis of the PIPJ who received VJT between January 2008 and January 2021 were enrolled in this study. The senior surgeon (Y.-T.L.) performed the surgery in all cases. In this retrospective study, we reexamine the initial trauma-related soft tissue and bony structure injuries of the recipient finger, to assess the baseline tissue quality before VJT. The injuries were classified into five major categories according to their anatomic region. The functional outcome parameters (including range of motion, percentage of use, and extensor lag of the transferred PIPJ) were collected. Univariate and multivariate linear regression analyses were performed using the generalized estimated equation model to identify the correlation between the injury category involved and functional outcome.

**Results:** A total of 59 digits were enrolled. Our results revealed that the fingers with previous vascular injury that received revascularization procedures had relatively suboptimal functional outcomes. These fingers had a significantly lower percentage of use both before ($\beta = -0.222$, $P = 0.006$) and after ($\beta = -0.177$, $P = 0.006$) receiving secondary procedures to improve functional outcome.

**Conclusions:** Patients with prior revascularization surgery were associated with a poor functional outcome after VJT. *(Plast Reconstr Surg Glob Open 2023; 11:e5314; doi: 10.1097/GOX.0000000000005314; Published online 4 October 2023.)*

## INTRODUCTION

Posttraumatic osteoarthritis of the proximal interphalangeal joint (PIPJ) is a difficult problem. Symptoms (including pain, stiffness, and poor motion) are common after severe trauma to the PIPJ. Vascularized toe joint transfer (VJT) is one of the options to solve these symptoms.

The history of VJT can be traced back to the 1960s when Harry J. Buncke first described an autogenous whole joint transplantation in a monkey model.[1] G. Foucher reported the very first free VJT in the 1970s.[2–9] However, despite years of development, the outcome of VJT remains unsatisfactory. A systematic review in 2008 reported that the mean active range of motion (ROM) after VJT was 37 degrees, which is less than for a prosthetic arthroplasty.[10] Many authors revealed that the main problem for motion is an average extensor lag of 30 degrees after VJT.[4,11,12]

In the past decade, our research team has reported several methods for improving the outcome of VJT.[4,13–19] In a recent report published in 2019, we improved the active ROM of the PIPJ after VJT from 37 to 58 degrees, with an

*From the *Department of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital, Linkou Medical Center, Taoyuan, Taiwan; †College of Medicine, Chang Gung University, Taoyuan, Taiwan; and ‡International Master Science Program in Reconstructive Microsurgery, Chang Gung University, College of Medicine, Taoyuan, Taiwan.*

*Received for publication June 30, 2023; accepted August 21, 2023.*

*Drs. Huang and Lin contributed equally to this work.*



DOI: 10.1097/GOX.0000000000005314

Disclosure statements are at the end of this article, following the correspondence information.

Related Digital Media are available in the full-text version of the article on www.PRSGlobalOpen.com.

average reduction in extensor lag from 30 to 18 degrees.[13] However, there were still a certain number of patients who encountered a suboptimal outcome after VJT in this group.

In this study, we focused on finding the prognostic factors associated with a suboptimal outcome after VJT. We hypothesized that the preoperative quality of the recipient finger had a significant correlation with the functional outcome after VJT. In this retrospective study, we reexamined the initial trauma-related soft tissue and bony structure injuries of the recipient finger to assess the quality of the baseline tissue before VJT. We classified the injuries into five major categories according to their anatomy. Linear regression analysis was used to assess the correlation between injury category involvement and functional outcome after VJT.

## PATIENTS AND METHODS

A consecutive series of patients with trauma-related PIPJ stiffness who received VJT between January 2008 and January 2021 were enrolled in this study. The senior surgeon (Y.T.L.) performed the surgery in all cases. Single and double joint transfers were included in this study. Exclusion criteria included thumb reconstruction, follow-up time less than 6 months, and immediate reconstruction failure.

We conducted a retrospective chart review for analysis. The demographic data collected included sex, age, and trauma mechanism. We designed a classification system to analyze initial trauma-related injuries of the recipient fingers. There are five categories in the system, including flexor and extensor tendon injuries that required repair, PIPJ intraarticular fracture, vascular injuries that required revascularization, and extensive

### Takeaways

**Question:** What would be the potential prognostic factor of vascularized toe joint transfer (VJT) in posttraumatic fingers?

**Findings:** Fifty-nine posttraumatic fingers that received VJT were analyzed in this study. The retrospective analysis of the preoperative condition of the fingers that received VJT showed that fingers with previous revascularization surgery had suboptimal outcomes compare to the others.

**Meaning:** Posttraumatic fingers that had received revascularization surgery is a poor prognostic factor for VJT.

soft tissue injuries. We did functional outcome measurements in two aspects. The first was the passive ROM of the toe joint. The baseline ROM of the transferred toe joint had variations among patients. Therefore, the final active ROM of the transferred joint was divided by the passive ROM of the toe joint before the transfer to overcome this baseline variable, which then generated a value we named percentage of use (POU). The second functional outcome we measured was the extensor deficit of the PIPJ after transfers.

In this series, 18 patients obtained above-average results 6 months after the VJT and did not require secondary procedures. Of the patients, 69.5% required secondary procedures, including tenolysis, joint contracture release, or corrective osteotomy, excluding cases of scar revision for aesthetic reasons. We used the ROM of the finger after it was stabilized for 6 months as the first post-VJT ROM value. The final outcome was then assessed at least 1 year after the operation. So, we collected the data after the initial VJT and then we also assessed the improvement gained by the revision. These time points were important because they

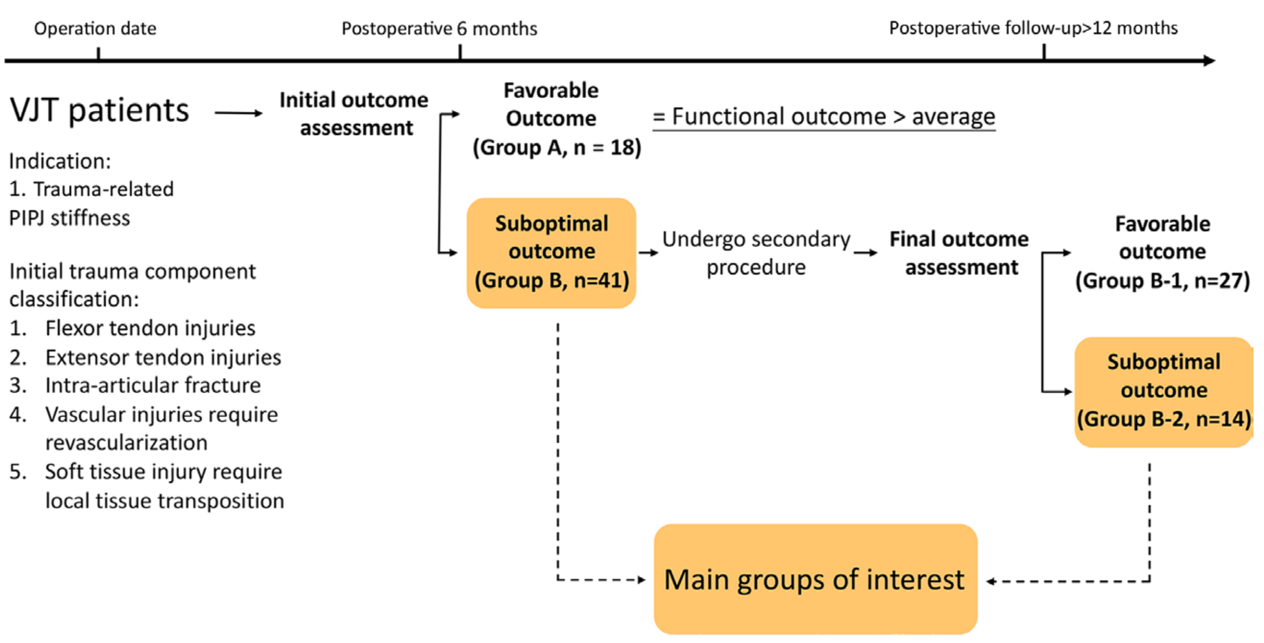


**Fig. 1.** Schematic diagram for the VJT patient treatment algorithm.

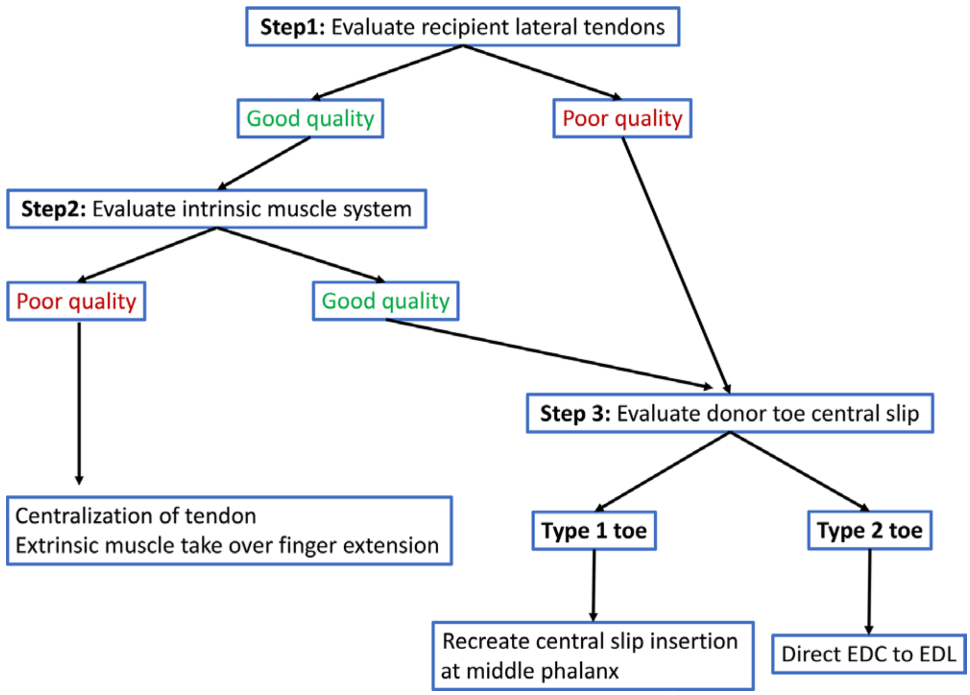


**Fig. 2.** The extensor mechanism reconstruction algorithm.

allowed us to assess the initial outcome before secondary procedures, the final outcome after secondary procedures, and the outcome improvement after secondary procedures (Fig. 1). The suboptimal outcome (Fig. 1, group B and B-2) in this study was defined as a POU less than average for our series or an extensor deficit greater than average for our series. We compared the POU and extensor deficit separately as an above-average POU or ROM does not directly relate to an above-average extensor deficit, and vice versa.

This case-control series study was approved by the institutional review board of our hospital (IRB No. 202002065B0).

### Extensor Mechanism Reconstruction Algorithm

Conducting a proper reconstruction of the extensor mechanism according to the patient's condition is crucial to obtaining a successful outcome. In this series, we applied the reconstruction algorithm we published previously.[14,16,20,21] In brief, in cases where the intrinsic muscle was dysfunctional, but the lateral bands of the recipient finger were in continuity, centralization of the finger lateral bands can be done, to allow the extrinsic muscle to take over extension of the metacarpophalangeal joint, PIPJ, and distal interphalangeal joint extension. When the intrinsic muscle remains functioning, the extensor reconstruction is then dependent on the donor toe. The extensor mechanism can be further classified into two subsets, which have been described in the previous publication by our research team.[9,10] According to cadaver and clinical case studies, there are two types of insertion for the central slip from the toe. Reconstruction of the extensor mechanism was therefore adjusted according to its anatomical variance. For a type 1 toe, which lacks central slip insertion in the middle phalange, recreating this tendon insertion site at the middle phalange is important. This can be done using either the modified Stack technique[14,16] or the Te technique.[7] For a type 2 toe, the central slip insertion site is present at the middle phalange. In such conditions, a Pulvertaft weave tenorrhaphy between the finger and the toe extensor can be performed (Fig. 2).

### Statistical Analysis

Statistical analysis was conducted using IBM SPSS, version 26. Our data were repeated recorded data through the follow-up timeline. Therefore, we chose the generalized estimating equation method with an exchangeable structure to identify contributors to the inferior outcome after VJT. With this model, a univariate linear regression was first performed to identify potential contributors. Groups with a $P$ value less than 0.1 in univariate linear regression were defined as potential contributors and proceeded to the multivariate linear regression model. Finally, a multivariate linear regression was applied to avoid interaction between contributors. A paired sample $t$ test was used to assess outcome improvement after secondary procedures. All $P$ values were two-sided, and the significance level was set at a $P$ value less than 0.05.

## RESULTS

A total of 64 patients with 68 digits were included in the current study. Two digits were abandoned from the study due to loss of data records in the outpatient charts. Seven digits were abandoned due to a follow-up of less than 6 months. Of the patients, 74.6% were men, and the average age was 31.9 years. Preoperative conditions were assessed, and the central tendon insertion of the toe was classified according to the classification criteria described in our previous article.[9,10] Type 1 toes accounted for 88.1% of the toes harvested for VJT. Initial trauma-related conditions were collected. Crushing injuries accounted for 52.5% of the total injuries, cutting injuries for 16.9%, amputation for 27.1%, and bite wounds for 3.4% of the injuries. Fingers with previous repair of vascular injury accounted for 27.3%, flexor tendon injury with repair accounted for 44.1%, extensor tendon injury with repair accounted for 57.6%, previous PIPJ intraarticular fracture accounted for 50.8%, and previous soft tissue defect accounted for 16.9% of cases. (**See table 1, Supplemental Digital Content 1**, which displays patient demographics and preoperative parameters. **http://links.lww.com/PRSGO/C795**.)

In patients with an initial favorable outcome (Fig. 1, group A, n = 18), the average ROM and POU of the transferred PIPJ were 62.8 degrees and 88.9%, respectively, and the average extensor lag was 21.8 degrees. In patients with an initial suboptimal outcome (Fig. 1, group B, n = 41), the mean ROM and POU of the transferred PIPJ were 40.2 degrees and 56.7%, respectively, and the mean extensor lag was 22.6 degrees. The average final ROM and POU of the transferred PIPJ were 54.0 degrees and 76.1% respectively, and the average final extensor lag of the transferred PIPJ was 22.0 degrees (Fig. 1, group A + B-2 + B-2). The average postoperative follow-up was 33.3 months, and 69.5% of the fingers received secondary procedures to improve functional outcomes. (**See table 2, Supplemental Digital Content 2,** which displays operation and outcome-related parameters. **http://links.lww.com/PRSGO/C796**.)

### Using an Algorithm to Select the Reconstruction Method Results in Equal Functional Outcomes

The method used to reconstruct the extensor mechanism during VJT was selected using an algorithm that we previously published.[8] In this series, four types of reconstruction method were used. Centralization of the lateral bands was used in 18.6% of the transferred joints. Stack and Te procedures were used to reconstruct central slip insertion of the toe middle phalange, which accounted for 11.9% and 52.5% of all transferred toe joints, respectively. Finally, 16.9% of the fingers allowed for direct repair of the EDL and EDB tendons for extensor mechanism reconstruction (**Supplemental Digital Content 2**, **http://links.lww.com/PRSGO/C796**).

We performed multivariate linear regression using a generalized estimated equation model to identify the correlation between the reconstruction method and functional outcomes. The results showed that the four reconstruction methods had no significant differences from each other regarding functional outcomes before secondary procedures. Similar results were seen in the final functional outcome data. This result indicates that the final functional outcome will be similar if we carefully apply our extensor reconstruction algorithm by deeply evaluating the condition of the recipient finger extensor mechanism (Tables 1 and 2).

### Initial Affected Components Serve as Outcome Indicators for VJT Surgery and after Revision Surgery

We classified the injury condition into five categories, according to its affected anatomic region, including vascular injury, flexor tendon injury, extensor tendon injury, intraarticular fracture, and soft tissue injuries with defect. We were curious about whether the trauma-related recipient condition would affect the initial and final functional outcomes of the transferred joints. Univariate linear regression, using the generalized estimated equation model, was conducted to identify the correlation between component involvement and functional outcomes. Groups that reached a $P$ value less than 0.1 were identified as potential contributors and were then included within a multivariate linear regression analysis.

During the initial evaluation of the outcomes (group A + B), flexor tendon injuries with repair (β = -0.158, $P$ = 0.006), extensor tendon injuries with repair (β = -0.105, $P$ = 0.061), intraarticular fracture (β = 0.135, $P$ = 0.02), and vascular revascularization injuries with revascularization (β = -0.27, $P$ < 0.001) were potential contributors to POU;

**Table 1. Multivariate Linear Regression by Generalized Estimating Equation Model Identify Correlations between Reconstruction Method and Functional Outcome before Revision (Group A + B)**

| | POU | | | | Extensor Lag | | | |
|---|---|---|---|---|---|---|---|---|
| | Centralization | Stack | Te | EDC-EDL | Centralization | Stack | Te | EDC-EDL |
| Centralization | | −0.061 ($P$ = 0.575) | 0.051 ($P$ = 0.463) | 0.089 ($P$ = 0.518) | | −20.054 ($P$ = 0.666) | −00.284 ($P$ = 0.936) | −60.914 ($P$ = 0.126) |
| Stack | | 0 | −0.009 ($P$ = 0.922) | −0.028 ($P$ = 0.852) | | 0 | 20.338 ($P$ = 0.585) | −40.86 ($P$ = 0.338) |
| Te | | | 0 | 0.038 ($P$ = 0.770) | | | 0 | −70.198 ($P$ = 0.065) |
| EDC-EDL | | | | | | | | |

**Table 2. Multivariate Linear Regression by Generalized Estimating Equation Model Identify Correlations between Reconstruction Method and Final Functional Outcome (Group A + B-1 + B-2)**

| | POU | | | | Extensor Lag | | | |
|---|---|---|---|---|---|---|---|---|
| | Centralization | Stack | Te | EDC-EDL | Centralization | Stack | Te | EDC-EDL |
| Centralization | | 0.009 (p = 0.934) | 0.094 ($P$ = 0.473) | 0.083 ($P$ = 0.306) | 0 | 0.565 ($P$ = 0.898) | −10.03 ($P$ = 0.756) | −40.465 ($P$ = 0.286) |
| Stack | | | −0.045($P$ = 615) | −0.074 ($P$ = 0.432) | | 0 | −10.595 ($P$ = 0.677) | −50.029 ($P$ = 0.27) |
| Te | | | | −0.029 ($P$ = 0.593) | | | | −30.428 ($P$ = 0.332) |
| EDC-EDL | | | | | | | | |

**Table 3. Multivariate/Univariate Linear Regression by Generalized Estimating Equation Model to Identify Correlations between Components Involved and POU before Revision (Group A + B)**

| | Univariate | | | | Multivariate | | | |
|---|---|---|---|---|---|---|---|---|
| | | 95% Wald CI | | | | 95% Wald CI | | |
| Components | β | Lower | Upper | *P* | β | Lower | Upper | *P* |
| Flexor tendon | −0.158 | −0.27 | −0.046 | 0.006 | 0.05 | −0.178 | 0.078 | 0.445 |
| Extensor tendon | −0.105 | −0.214 | 0.005 | 0.061 | 0.009 | −0.123 | 0.140 | 0.898 |
| Intraarticular fx | 0.135 | 0.021 | 0.249 | 0.02 | 0.08 | −0.016 | 0.176 | 0.1 |
| Soft tissue defect | −0.035 | −0.140 | 0.069 | 0.506 | | | | |
| Revascularization | −0.27 | −0.38 | −0.16 | <0.001 | −0.222 | −0.381 | −0.062 | 0.006 |
| No. components | −0.051 | −0.087 | −0.015 | 0.006 | | | | |
| Components > 2 | −0.113 | −0.225 | −0.002 | 0.047 | | | | |
| Components > 3 | −0.160 | −0.273 | −0.048 | 0.005 | | | | |

extensor tendon injuries with repair (β = 4.953, $P = 0.067$) and vascular revascularization injuries with revascularization (β = 7.602, $P = 0.016$) were potential contributors to extensor lag, as determined by univariate linear regression analysis. These factors were then included within multivariate linear regression. The multivariate analysis results showed that fingers with previous vascular injuries that received a revascularization procedure had a significantly reduced POU compared with the other groups (β = -0.222, $P = 0.006$). Fingers with previous repair of extensor tendon injuries and revascularization after vascular-related injuries tended to have a larger extensor lag, but this difference was not statistically significant (Tables 3 and 4).

During the final outcome evaluation (group A + B-1 + B-2), flexor tendon injuries with repair (β = -0.144, $P = 0.004$), extender tendon injuries with repair (β = -0.087, $P = 0.071$), and vascular injuries with revascularization (β = -0.211, $P < 0.001$) were correlated with POU; soft tissue defect with reconstruction (β = 4.318, $P = 0.079$) and revascularized vascular injuries (β = 4.965, $P = 0.065$) were correlated with extensor lag, by univariate linear regression analysis. Multivariate linear regression analysis revealed that vascular injuries with revascularization (β = -0.177, $P = 0.006$) were significantly correlated with POU. Skin loss with soft tissue reconstruction (β = 4.606, $P = 0.073$) and vascular injuries with revascularization (β = 5.157, $P = 0.059$) tended to have a larger extensor lag, but this difference was not statistically significant (Tables 5 and 6).

We also analyzed the correlation between the categories involved and the improvement in functional

**Table 4. Multivariate/Univariate Linear Regression by Generalized Estimating Equation Model to Identify Correlations between Components Involved and Extensor Lag before Revision (Group A + B)**

| | Univariate | | | | Multivariate | | | |
|---|---|---|---|---|---|---|---|---|
| | | 95% Wald CI | | | | 95% Wald CI | | |
| Components | β | Lower | Upper | *P* | B | Lower | Upper | *P* |
| Flexor tendon | 4.606 | −1.216 | 10.429 | 0.121 | | | | |
| Extensor tendon | 4.953 | −0.353 | 10.26 | 0.067 | 2.439 | −3.908 | 8.785 | 0.451 |
| Intraarticular fx | −4.266 | −10.004 | 1.471 | 0.145 | | | | |
| Soft tissue defect | 3.005 | −3.684 | 9.694 | 0.379 | | | | |
| Revascularization | 7.602 | 1.392 | 13.813 | 0.016 | 6.365 | −1.366 | 14.095 | 0.107 |
| No. of components | 1.776 | 0.185 | 3.368 | 0.029 | | | | |
| Components > 2 | 3.688 | −1.804 | 9.181 | 0.188 | | | | |
| Components > 3 | 5.59 | −0.284 | 11.465 | 0.062 | | | | |

**Table 5. Multivariate/Univariate Linear Regression by Generalized Estimating Equation Model to Identify Correlations between Components Involved and POU after Revision (Group A + B–1 + B–2)**

| | Univariate | | | | Multivariate | | | |
|---|---|---|---|---|---|---|---|---|
| | | 95% Wald CI | | | | 95% Wald CI | | |
| Components | β | Lower | Upper | *P* | β | Lower | Upper | *P* |
| Flexor tendon | −0.144 | −0.243 | −0.045 | 0.004 | −0.060 | −0.154 | 0.034 | 0.213 |
| Extensor tendon | −0.087 | −0.181 | 0.008 | 0.071 | 0.010 | −0.100 | 0.120 | 0.865 |
| Intraarticular fx | 0.08 | −0.042 | 0.153 | 0.266 | | | | |
| Soft tissue defect | −0.037 | −0.128 | 0.054 | 0.424 | | | | |
| Revascularization | −0.211 | −0.319 | −0.103 | 0.000 | −0.177 | −0.304 | −0.050 | 0.006 |
| No. components | −0.054 | −0.089 | −0.019 | 0.002 | | | | |
| Components > 2 | −0.121 | −0.216 | 0.027 | 0.012 | | | | |
| Components > 3 | −0.153 | −0.257 | −0.050 | 0.004 | | | | |

**Table 6. Multivariate/Univariate Linear Regression by Generalized Estimating Equation Model to Identify Correlations between Components Involved and Extensor Lag after Revision (Group A + B–1 + B–2)**

| | Univariate | | | | Multivariate | | | |
|---|---|---|---|---|---|---|---|---|
| | 95% Wald CI | | | | 95% Wald CI | | | |
| Components | β | Lower | Upper | *P* | β | Lower | Upper | *P* |
| Flexor tendon | 0.207 | −40.732 | 50.145 | 0.935 | | | | |
| Extensor tendon | 30.39 | −10.282 | 80.061 | 0.155 | | | | |
| Intraarticular fx | −10.457 | −60.327 | 30.413 | 0.558 | | | | |
| Soft tissue defect | 40.318 | −0.499 | 90.136 | 0.079 | 4.606 | −0.422 | 90.635 | 0.073 |
| Revascularization | 40.965 | −0.316 | 100.245 | 0.065 | 5.157 | −0.199 | 100.513 | 0.059 |
| No. of components | 10.219 | −0.385 | 20.824 | 0.136 | | | | |
| Components > 2 | 20.807 | −20.026 | 70.641 | 0.255 | | | | |
| Components > 3 | 20.797 | −20.366 | 70.96 | 0.288 | | | | |

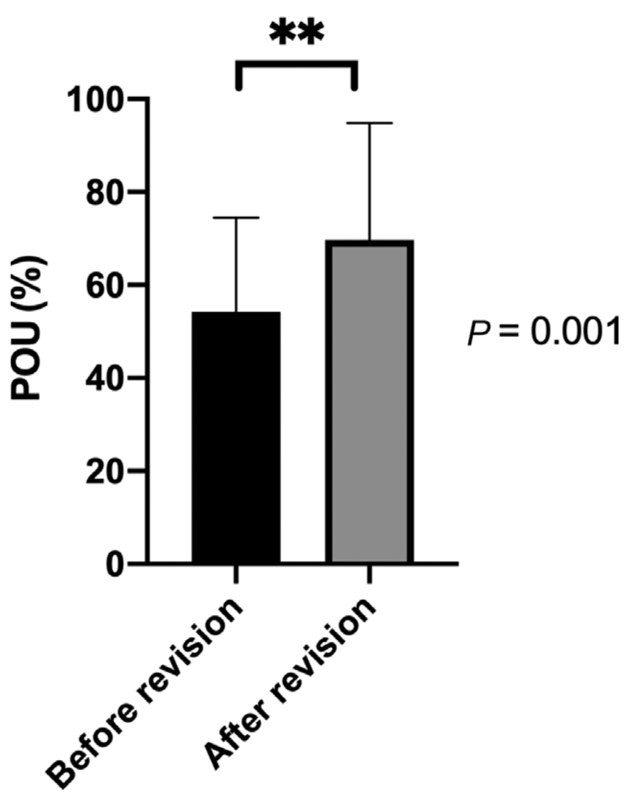


**Fig. 3.** Significant improvement in POU after secondary procedures for patients with initial suboptimal outcomes.

outcomes gained by secondary procedures. Univariate linear regression analysis was initially conducted to identify the correlation between the category involved and improvement in functional outcomes after secondary procedures. The secondary procedures provided a significant improvement in the POU in patients with an initial suboptimal outcome (mean POU increase: 15.48%, *P* = 0.001 by a paired sample *t* test; Fig. 3). The results showed that only groups with previous intraarticular fracture had a significantly reduced benefit in POU improvement compared with other groups (β = -0.599, *P* = 0.001). There were no specific components that showed a significant correlation with extensor lag improvement (Tables 7 and 8).

## DISCUSSION

The goal of VJT is to establish a stable and viable joint with sufficient functional ROM. By deeply evaluating the condition of the recipient extensor tendon, and making use of our previously reported extensor mechanism reconstruction algorithm, we improved the functional outcome of VJT.[5] The average functional ROM in our series of VJT successfully achieved the functional ROM of 60 degrees for the proximal interphalangeal joint, as reported by Hume et al.[22] However, this accomplishment was only achieved by the performance of some secondary procedures. In fact, 60% of our patients needed secondary procedures for correction of tendon adhesion and malunion to achieve a better functional ROM.

**Table 7. Multivariate/Univariate Linear Regression by Generalized Estimating Equation Model to Identify Correlations between Components Involved and Revision POU Improvement**

| | Univariate | | | | Multivariate | | | |
|---|---|---|---|---|---|---|---|---|
| | 95% Wald CI | | | | 95% Wald CI | | | |
| Components | β | Lower | Upper | *P* | β | Lower | Upper | *P* |
| Flexor tendon | −0.090 | −0.210 | 0.134 | 0.654 | | | | |
| Extensor tendon | −0.007 | 0.176 | 0.170 | 0.971 | | | | |
| Intraarticular fx | −0.599 | −0.403 | −0.117 | 0.001 | | | | |
| Skin loss | −0.082 | −0.165 | 0.248 | 0.683 | | | | |
| Revascularization | −0.056 | −0.158 | 0.208 | 0.782 | | | | |
| No. components | −0.231 | −0.110 | 0.030 | 0.247 | | | | |
| Components > 2 | −0.184 | −0.247 | 0.092 | 0.357 | | | | |
| Components > 3 | −0.161 | −0.242 | 0.105 | 0.422 | | | | |

**Table 8. Multivariate/Univariate Linear Regression by Generalized Estimating Equation Model to Identify Correlations between Components Involved and Revision Extensor Lag Improvement**

| | Univariate | | | | Multivariate | | | |
|---|---|---|---|---|---|---|---|---|
| | 95% Wald CI | | | | 95% Wald CI | | | |
| Components | β | Lower | Upper | *P* | β | Lower | Upper | *P* |
| Flexor tendon | −0.056 | −11.553 | 8.465 | 0.755 | | | | |
| Extensor tendon | 0.032 | −9.119 | 10.847 | 0.861 | | | | |
| Intraarticular fx | 0.156 | −5.684 | 14.27 | 0.387 | | | | |
| Skin loss | 0.03 | −12.787 | 15.044 | 0.87 | | | | |
| Revascularization | −0.007 | −11.066 | 10.657 | 0.97 | | | | |
| No. components | 0.095 | −7.368 | 12.59 | 0.597 | | | | |
| Components > 2 | 0 | −10.365 | 10.389 | 0.998 | | | | |
| Components > 3 | 0.076 | −3.985 | 6.086 | 0.673 | | | | |

To the best of our knowledge, this is the first study to focus on finding possible risk factors associated with suboptimal outcomes after VJT. Regardless of the surgical technique used, we hypothesized that the functional outcome may be correlated with initial trauma-related soft tissue injuries and joint destruction. The evaluation of the functional outcome of our patients was based on two aspects. First, we measured the POU of the transferred toe, which was calculated by dividing the active ROM after transfer by the passive ROM of the origin toe before surgery. This study mainly focused on the operative outcome of VJT so POU, which represents the ROM we preserved from the donor toe, was considered a more precise measurement than the ROM. Second, we measured the extensor lag after VJT. Our data were collected from the outpatient department follow-up data of a single surgeon, and included the repetitive collection of data across different time points for each patient. Therefore, we used the generalized estimated equation model as our main statistical method, which had the main advantage of fully interpreting the collected repetitive data.

Our results did not reveal significant differences in functional outcomes across the different reconstruction methods used. This further implies that by following our reconstruction algorithm, we can achieve a similar functional outcome despite the different extensor mechanism injuries being encountered. We then proceeded to search for possible risk factors associated with suboptimal outcomes by re-considering the initial trauma-related injuries.

To ensure that we systematically analyzed the initial trauma-related injuries, we classified them into five major categories. We chose these five categories based on our prior clinical experience, as we believed that these five categories would be most associated with the final result. Our results suggest that a recipient finger with a history of revascularization surgery is an indicator of a suboptimal outcome. This group of patients had significantly less POU and a notably larger extensor lag after VJT. In addition, these patients continued to have poorer outcomes despite receiving secondary procedures to improve the outcome. In addition, previous revascularization cases were more likely to undergone touch-up procedures but did not reach statistical significance. (**See table 3, Supplemental Digital Content 3,** which whows that previous revascularization cases were more likely to undergo touch up procedures but did not reach statistical significance. **http://links.lww.com/PRSGO/C797**.)

Our results showed that neither previous extensor nor flexor tendon injury were poor outcome indicators, which was a surprise, as tendon injury often leads to severe adhesion. Perhaps the significance was masked by the limited number of patients in this study. In addition, due to the use of retrospective chart reviews to collect data for this research, we were unable to further classify the injured condition of the extensor mechanism. A simple yes or no may not fully represent the severity of the injury. Further stratification of the severity of extensor injury should be performed in future studies, and the number of included patients must also be increased to ensure there can be a meaningful analysis.

Fingers with prior skin and soft tissue loss tended to have a large final extensor lag in our study. The cases of skin loss were caused by mechanisms such as avulsion, crushing, and degloving, which are vulnerable to contracture and limit the extension of the joint. Significant extensor lag in the PIPJ results in unsatisfactory aesthetics and also affects grasping function.

The reason why patients who had received previous revascularization surgery were likely to have an inferior outcome may be explained by two reasons. First, fingers with previous vascular injuries in our series tended to have a more extensive and complex initial trauma. Most of these patients sustained crushing injuries or a crushing amputation, which suggests that these patients had a wider and more complicated trauma zone. This may further influence tissue quality and the outcome after another extensive surgery with more scar tissue. The second factor is the quality of tissue perfusion. In the authors' personal experience, although these fingers were salvaged by previous revascularization surgery, the occurrence of vascular injury implies that the recipient finger had a certain degree of tissue perfusion compromise. These two factors further influence tissue quality, and tendon adhesion and malunion can occur.

In addition, our results showed that overall, secondary procedures provide benefits to patients who receive VJT (Fig. 3). These findings may provide to surgeons evidence that demonstrates the benefits of secondary procedures for improved functional outcomes after initial VJT. We also compared our early result (ie, surgery done before 2015) with our latter result. The result showed improvement over time, but did not show statistical significance. (**See figure, Supplemental Digital Content 4,** which shows that refined technique over time showed improvement of functional outcome regarding POU but did not reach statistical significance. **http://links.lww.com/PRSGO/C798**.)

Limitations of the current study included the limited number of included cases. Our ultimate goal was to establish a prognostic prediction model for VJT. More cases are needed to set up the risk score and external validation of our data. The other important missing data in our series were patient compliance with rehabilitation. Some patients did not strictly follow our rehabilitation protocol, either due to stable condition or acceptable function. Some patients dropped out of our institute's rehabilitation program and went to another local department, which was closer or more convenient for them. We believe that an effective rehabilitation program will strongly affect the postoperative functional outcome, and this will be our next area of research. Furthermore, the indications that we chose for patients to receive VJT may have affected the functional outcomes. More detailed indications were not available in the patient records.

## CONCLUSIONS

This is the first study to identify possible risk factors for suboptimal outcomes after VJT. Patients with prior revascularization surgery were associated with a poor functional outcome.

***Yu-Te Lin, MD, MSc, FACS***
Department of Plastic and Reconstructive Surgery
Chang Gung Memorial Hospital
Chang Gung University, College of Medicine; and
International Master Science Program in Reconstructive Microsurgery
Chang Gung University, College of Medicine
5, Fu-Shing St., Kweishan
Taoyuan, Taiwan
E-mail: linutcgmh@gmail.com

### DISCLOSURES

*The authors have no financial interest to declare in relation to the content of this article. This study was supported by Chang Gung Memorial Hospital, Linkou, Taiwan [grant no. CMRPG3K1851].*

### ACKNOWLEDGMENTS

*The authors would like to thank the personnel at the Maintenance Project of the Center for Big Data Analytics and Statistics (grant no. CLRPG3D0049) for their statistical assistance, and thank Chang Gung Memorial Hospital for their support with study design and monitoring, data analysis, and interpretation.*

### REFERENCES

1. Buncke HJ, Jr, Daniller AI, Schulz WP, et al. The fate of autogenous whole joints transplanted by microvascular anastomoses. *Plast Reconstr Surg.* 1967;39:333–341.
2. Chen SH, Wei FC, Chen HC, et al. Vascularized toe joint transfer to the hand. *Plast Reconstr Surg.* 1996;98:1275–1284.
3. Foucher G, Lenoble E, Smith D. Free and island vascularized joint transfer for proximal interphalangeal reconstruction: a series of 27 cases. *J Hand Surg Am.* 1994;19:8–16.
4. Foucher G, Hoang P, Citron N, et al. Joint reconstruction following trauma: comparison of microsurgical transfer and conventional methods: a report of 61 cases. *J Hand Surg Br.* 1986;11:388–393.
5. Foucher G, Sammut D, Citron N. Free vascularized toe-joint transfer in hand reconstruction: a series of 25 patients. *J Reconstr Microsurg.* 1990;6:201–207.
6. Ellis PR, Hanna D, Tsai TM. Vascularized single toe joint transfer to the hand. *J Hand Surg Am.* 1991;16:160–168.
7. Mohan R, Wong VW, Higgins JP, et al. Proximalization of the vascularized toe joint in finger proximal interphalangeal joint reconstruction: a technique to derive optimal flexion from a joint with expected limited motion. *J Hand Surg Am.* 2017;42:e125–e132.
8. Kuzu İ M, et al. Functional improvement with free vascularized toe-to-hand proximal interphalangeal (PIP) joint transfer. *Plast Reconstr Surg Glob Open.* 2018;6:1775.
9. Tsai TM, Singer R. Elective free vascularized double transfer of toe joint from second toe to proximal interphalangeal joint of index finger: a case report. *J Hand Surg Am.* 1984;9:816–820.
10. Squitieri L, Chung KC. A systematic review of outcomes and complications of vascularized toe joint transfer, silicone arthroplasty, and PyroCarbon arthroplasty for posttraumatic joint reconstruction of the finger. *Plast Reconstr Surg.* 2008;121:1697–1707.
11. Hierner R, Berger AK. Long-term results after vascularised joint transfer for finger joint reconstruction. *J Plast Reconstr Aesthet Surg.* 2008;61:1338–1346.
12. Tsubokawa N, Yoshizu T, Maki Y. Long-term results of free vascularized second toe joint transfers to finger proximal interphalangeal joints. *J Hand Surg Am.* 2003;28:443–447.
13. Lin YT. Technical keys in maximizing finger proximal interphalangeal joint motion after vascularized toe joint transfers. *J Hand Surg Eur Vol.* 2019;44:667–675.
14. Lin YT, Kao DS, Wan DC, et al. Simultaneous reconstruction of extensor mechanism in the free transfer of vascularized proximal interphalangeal joint. *Tech Hand Up Extrem Surg.* 2013;17:20–24.
15. Lin YT, Loh CY. A novel technique for correcting extensor lag in vascularized toe PIP joint transfers. *Tech Hand Up Extrem Surg.* 2016;20:104–107.
16. Loh CYY, Hsu C-C, Lin C-H, et al. Customizing extensor reconstruction in vascularized toe joint transfers to finger proximal interphalangeal joints: a strategic approach for correcting extensor lag. *Plast Reconstr Surg.* 2017;139:915–922.
17. Chen HY, Lin Y-T, Lo S, et al. Vascularised toe proximal interphalangeal joint transfer in posttraumatic finger joint reconstruction: the effect of skin paddle design on extensor lag. *J Plast Reconstr Aesthet Surg.* 2014;67:56–62.
18. Hsu CC, et al. The impact of transferred vascularized toe joint length on motion arc of reconstructed finger proximal interphalangeal joints: a cadaveric study. *J Hand Surg Eur Vol.* 2017;42:789–793.
19. Lin YT, Chen S-H, Loh CYY, et al. Rationalizing the vascular anatomy for oblique osteotomy of the metatarsal head during toe/joint transfers of the metatarsophalangeal joint. *Plast Reconstr Surg Glob Open.* 2018;6:e1805.
20. Lam WL, Waughlock N, Hsu C-C, et al. Improving the extensor lag and range of motion following free vascularized joint transfer to the proximal interphalangeal joint: part 2. A clinical series. *Plast Reconstr Surg.* 2013;132:271e–280e.
21. Waughlock N, Hsu C-C, Lam W-L, et al. Improving the extensor lag and range of motion following free vascularized joint transfer to the proximal interphalangeal joint: part 1. An observational and cadaveric study. *Plast Reconstr Surg.* 2013;132:263e–270e.
22. Hume MC, Gellman H, McKellop H, et al. Functional range of motion of the joints of the hand. *J Hand Surg Am.* 1990;15:240–243.