Two-Stage Flexor Tendon Reconstruction in Zone II Using a Silicone Rod and a Pedicled Intrasynovial Graft

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Purpose: To evaluate the results of a modified Paneva–Holevich technique for flexor tendon reconstruction in zone II.

Methods: Twenty patients (22 digits) with poor prognosis injuries (Boyes grade 2–5) were reconstructed. The technique included placing a silicone rod and creating a loop between the flexor digitorum profundus (FDP) and the flexor digitorum superficialis (FDS) in the first stage and reflecting the latter as a pedicled graft through the pseudosheath created around the silicone rod in the second stage.

Results: After a follow-up period of at least 1 year (mean, 50 mo) the rate of good and excellent results was 82% according to the Buck-Gramco scale and 73% using the modified Strickland scale.

Conclusions: These results compare favorably with those using the classic (Hunter) 2-stage reconstructions with a silicone rod and a free tendon graft. Apart from technical versatility, additional advantages of the technique include using a local intrasynovial graft, the absence of donor site morbidity, and a low rate of postreconstruction tendon ruptures and tenolysis. (J Hand Surg 2003;28A:652–660. Copyright © 2003 by the American Society for Surgery of the Hand.)

Key words: Flexor tendons, staged reconstruction, Paneva–Holevich, intrasynovial graft.

The reconstruction of a scarred flexor tendon system in zone II of the hand remains a challenge for the hand surgeon. The rationale of tendon grafting is to create tenorrhaphy sites outside zone II where adhesions do not interfere with function. Two-stage flexor tendon reconstruction using a silicone rod in the first stage and a free tendon graft through the pseudosheath formed around the silicone in the second stage, as described by Hunter[1] in 1971, is the most widely accepted treatment for poor prognosis patients (Boyes grade 2–5).[2–8] Nevertheless this method presents some problems. An intrasynovial tendon is replaced by an extrasynovial graft (palmaris longus [PL], plantaris, toe extensors) of varying (usually smaller) size. Because the graft is harvested in the second stage it is difficult to determine the size of the silicone rod that should be used and

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Table 1. Etiology

Etiology	n (Digits)	Mean Time Elapsed (mo)
Failed primary repair	8	4.9
Amputation	6	10
Neglected tendon lacerations	3	3
Failure of previous hand surgery	4	23
Electric burn	1	12

the width of the pulleys to be reconstructed during the first stage. In addition the proximal stump of the profundus tendon is usually difficult to retrieve in the second stage. The proximal and distal tenorrhaphies to the graft (proximal and distal) must heal simultaneously and be able to withstand the loads of the rehabilitation program.

In 1965 Paneva-Holevich[9] described a method for reconstructing flexor tendons both in acute and in neglected injuries that involved creating a loop between the flexor digitorum profundus (FDP) and the flexor digitorum superficialis (FDS) proximal stumps and reflecting the latter after 2 or 3 months as a pedicled graft. A combination of the Hunter[1] and Paneva-Holevich[9] techniques was first published by Kessler[10] in 1972.

By combining the 2 techniques some of the aforementioned problems are solved. The scarred or destroyed FDP is replaced by an intrasynovial donor tendon (FDS) of similar size. Moreover accurate matching of the spacer (silicone rod) and the reconstructed pulleys to the graft can be made because the graft is identified during the first stage. The bulky FDS-FDP loop is easier to retrieve in the second stage and by that time the proximal tenorrhaphy has healed.

Several studies of this combined method under different eponyms have been reported during the past 30 years.[10–20] The number of patients in these reports is relatively small and the evaluation methods vary, thus not permitting direct comparison.

Recently the interest in the modified Paneva–Holevich[16] technique has been renewed after reports (both experimental and clinical)[21–23] of potentially improved performance of intrasynovial tendon grafts compared with the traditional extrasynovial ones. Although the term *pedicled tendon graft* is used for the FDS in this technique, the tendon essentially is used as a free intrasynovial graft but with the proximal tenorrhaphy having healed by the time the second stage is performed.

The purpose of this study is to present our results with a modified Paneva–Holevich technique using evaluation methods compatible with those used in other studies as well as to review the surgical technique and results presented to date in the literature.

Material and Methods

Between 1992 and 2000 31 patients underwent a modified Paneva–Holevich reconstruction in the Department of Orthopaedic Surgery of the University of Ioannina, Greece. Twenty patients, 22 digits with zone II injuries and a follow-up period of at least 1 year, are presented. Excluded from the study were 3 patients lost to follow-up evaluation, 7 patients with a follow-up period of less than 1 year or injury in another zone of the hand, and 1 thumb reconstruction with a modification of the technique. The mean age of the 20 patients being presented was 24 years (range, 3–54 y). All patients had suffered injuries of both flexor tendons to the affected digit with considerable scarring and had a nonfunctional flexor apparatus. Six index fingers, 7 middle, 3 ring, and 6 small fingers were reconstructed. The etiology and modified Boyes and Stark grading[1] of the initial injuries are described in Tables 1 and 2.

Surgical Technique

The surgical technique includes 2 stages. It is important that an aggressive physiotherapy program precedes the first stage to overcome stiffness and achieve maximum passive motion both in flexion and in extension.

Stage I. In stage I the injured digit is explored through a Bruner incision. Once the indication for a staged technique is confirmed the injured tendons and scar tissue are removed. Intact annular pulleys are opened only if absolutely necessary. A 1-cm distal flexor digitorum profundus stump is spared and if an intact flexor digitorum superficialis insertion is present it is preserved for pulley reconstruction. Any necessary soft-tissue release is performed.

A second inverted L incision is made in the palm (Fig. 1) and is extended proximally or distally as

Table 2. Modified Boyes and Stark Grading

Grade		n (Digits)
2	Scar	4
3	Joint	5
4	Nerve or artery	4
5	Multiple	9

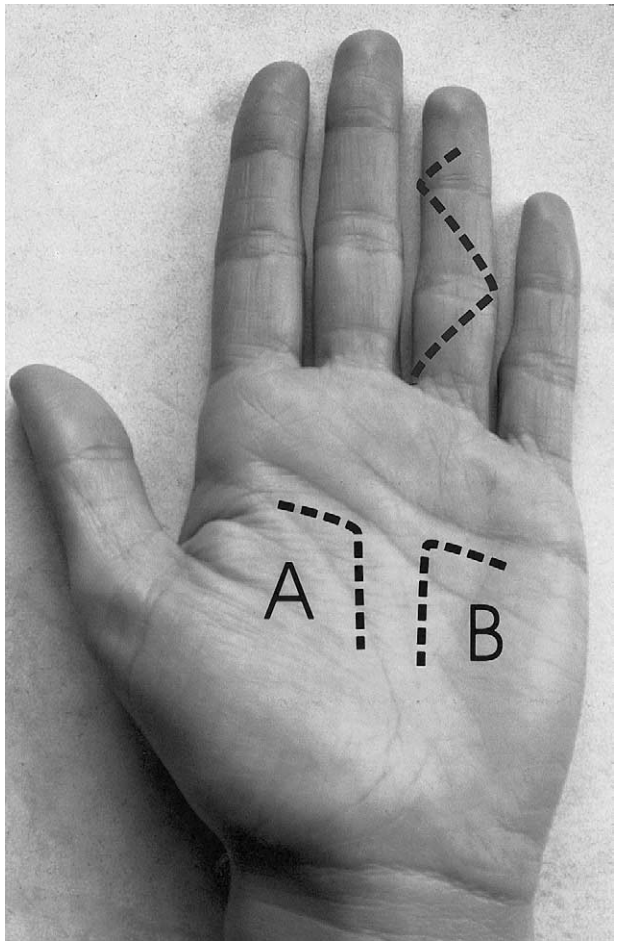

Figure 1. In stage I the hand is explored through a Bruner incision in the affected finger and an inverted L incision in the palm. The flap in the palm is based to the (A) thenar crease for the index and middle fingers and to the (B) hypothenar crease for the ring and small fingers.

necessary. The proximal stumps of the FDS and FDP of the injured finger are retrieved, freed of adhesions, and sutured together at the lumbrical level with an end-to-end coaptation loop using 3 or 4 absorbable sutures. An oval-shaped silicone or reinforced silicone implant with a width corresponding to the FDS diameter is chosen. Injured and opened pulleys are repaired by using nonabsorbable sutures, whereas missing ones are reconstructed by using the excised tendon material and possibly one tail of the flexor digitorum superficialis (Fig. 2). The direct suturing to the remnants of the pulleys or the pulley rim technique is preferred. As many pulleys as feasible are reconstructed, especially A_1, A_2, and A_4 (in this series a mean of 2.7 pulleys per digit were repaired or reconstructed).

The final implant is inserted proximal to distal, is cut proximal to the lumbrical level, and its uninhibited movement is checked. The distal insertion of the implant is achieved by a pull-out suture with a button placed proximal to the nail and direct sutures to the profundus stump (Fig. 3A). Any necessary secondary procedures are completed and the wound is closed. Secondary procedures during stage I in this series included nerve repair in 7 digits, proximal interphalangeal joint arthrolysis in 3 digits, and web space plasty in 2 digits.

A dorsal splint with the wrist in 30° flexion, the metacarpophalangeal (MCP) joint in 70° flexion, and the interphalangeal joints in a slightly flexed position is applied. After stage I, passive motion is started 3 days after surgery. The goal is to achieve full passive flexion after the first stage and to preserve it until the second stage is performed.

Stage II. Stage II is performed after a minimum of 3 months. A midpalmar incision is used to retrieve the loop, which because of its volume usually is identified easily (Fig. 4). All the loops in this series

Figure 2. During stage I surgery the scarred tendon is removed, a silicone rod is inserted, the pulleys are reconstructed over it, and the proximal stumps of the FDS and the FDP are sutured together in an end-to-end coaptation loop (scissors).

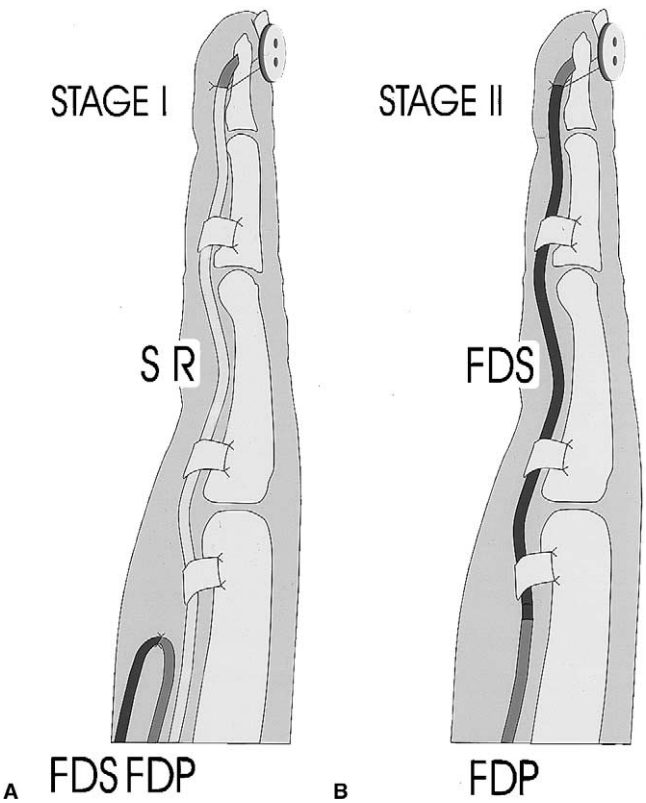

Figure 3. Schematic overview of the modified Paneva–Holevich procedure. (A) Stage I. Silicone rod (SR) insertion, pulley reconstruction, loop between proximal stumps of the FDS and the FDP created in the palm. (B) Stage II. The FDS is cut proximally and reflected distally through the pseudosheath created around the silicone rod as a pedicled graft.

were found to be well healed and strong. Trimming of a bulky loop was necessary in 2 patients.

A longitudinal incision at the palmar aspect of the distal third of the forearm is used to identify the corresponding FDS, cut it at the musculotendinous level, bring it through the proximal incision, and suture it to the proximal end of the silicone rod (Fig. 5). The FDP muscle is used as the motor muscle for the finger.

Finally an angular incision is made over the distal interphalangeal (DIP) joint and the silicone rod with the graft sutured to it is retracted through this incision. After the silicone rod is discarded the tension of the graft is estimated with temporary stabilization with a hypodermic needle through the skin of the distal phalanx. The desired tension is adjusted so that the injured finger is kept in slightly more flexion compared with adjacent fingers through the range of motion of the wrist. Anchoring of the graft to the distal phalanx is done with a pull-out suture and button and direct suturing to the profundus stump (Fig. 3B). A splint similar to that used in stage I is applied.

An early controlled motion program is used (passive flexion, active extension).[24] The splint and button are removed by 5 weeks and active motion and blocking exercises are initiated together with night splinting to avoid flexion contractures.

Pull-out sutures were associated with nail deformities early in this series. As a result the technique was modified regarding the pull-out suture so that it now exits proximal to the nail matrix on the dorsum of the distal phalanx instead of next to the base of the nail and is tied over a well-padded button.

Follow-Up Evaluation

Assessment of the patients included measurement of active and passive motion and pulp to distal flexion crease distance in the clenched fist position (Fig. 6). The pulp-to-pulp pinch strength, the key pinch strength between the affected finger and the thumb, and the grip strength of the hand were also measured using a pinch gauge (Baseline; FEInk, Irvington,

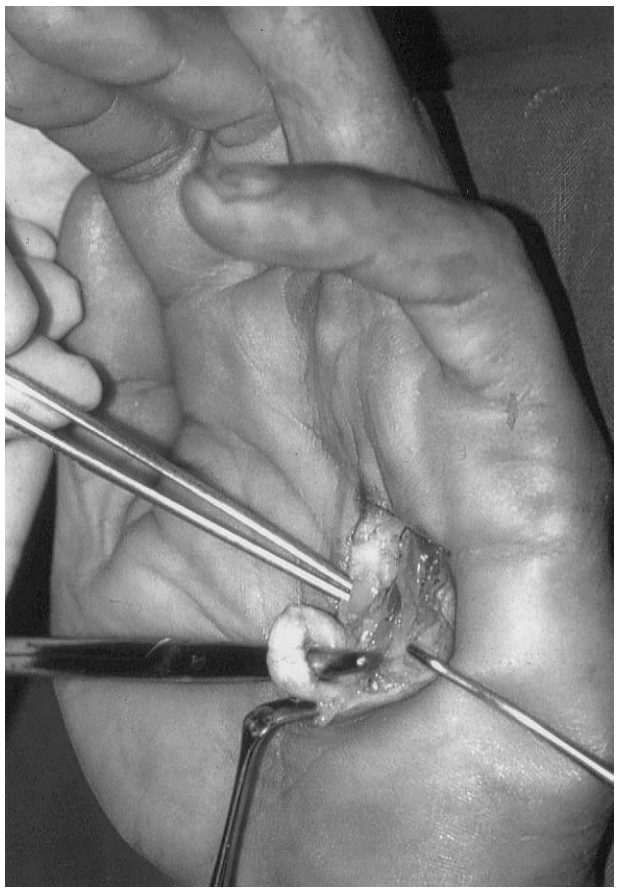

Figure 4. During stage II the FDS-FDP loop and the proximal end of the silicone rod are retrieved through a small midpalmar incision.

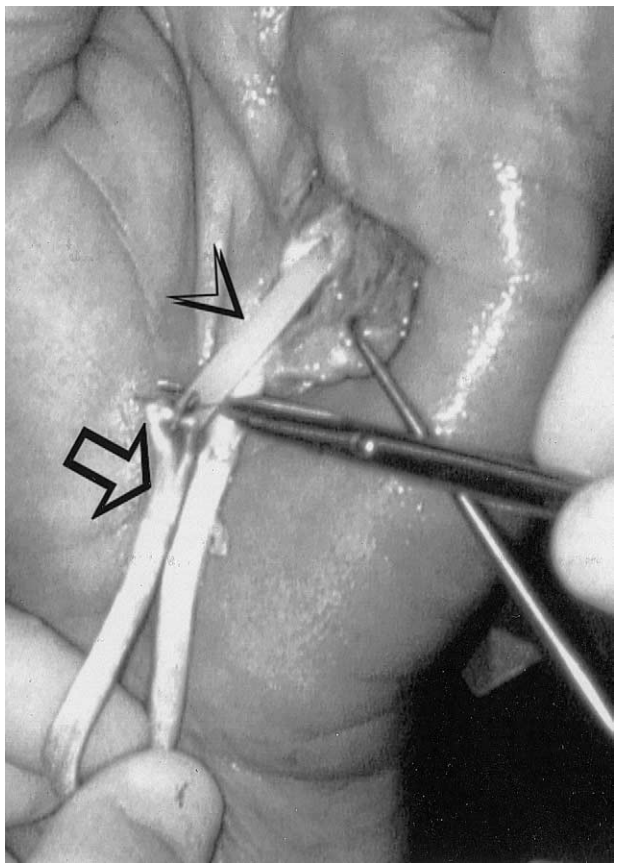

Figure 5. Stage II. The FDS tendon is cut proximally at the musculotendinous level and brought through to the midpalmar incision (arrow). It is sutured temporarily to the proximal end of the silicone rod (arrowhead) to be retracted through the pseudosheath to the distal phalanx.

NY) and a hydraulic dynamometer (Jamar; Sammons Preston, Bolingbrook, IL), respectively. Three measurements of all of the parameters were obtained and averaged. The measurements were repeated and compared with the corresponding finger of the uninjured extremity. In accordance with the recent literature[25] extremity dominance was not taken into consideration for strength comparisons. The results were classified according to the Buck-Gramco rating[26] and to the revised classification system of Strickland.[23] The latter classification does not take MCP motion into account. The indices used in the largest series of Hunter technique reconstruction published so far[6] were calculated from the measured digital motion values in this series for comparison. Finally the Littler-Bunnell intrinsic tightness test was performed and bowstringing of the tendon, painful scars, and nail deformities were recorded. Although data on grip and pinch strength and 2-point discrimination were collected from children under the age of 10 years at the final follow-up evaluation these were excluded because of high intermeasurement variability.

The medical files and surgical records of all patients were reviewed and intraoperative problems and postoperative complications were recorded.

Results

All our patients had a follow-up time of at least 1 year (mean, 50 mo; range, 12–101 mo). The mean total active motion achieved was 189° (71% that of the contralateral respective finger) out of 219° of total passive motion. The mean total active extension deficit was 40° and mostly occurred in the DIP joint; a mean DIP extension deficit of 26° was observed in 16 of 23 fingers.

The pulp to distal flexion crease distance was 0 cm in 10 fingers, 0.5 cm in 3 fingers, 1 to 2 cm in 4 fingers, and more than 2 cm in 5 fingers. The mean grip, pinch, and key pinch strengths were 73%, 65%, and 80%, respectively, compared with the contralateral unaffected extremity. Overall a good and excellent Buck-Gramco score was achieved in 82% of the digits (Table 3). According to the Strickland scale the rate of good and excellent results was 73% (Table 4).

Intrinsic tightness testing was negative for all patients and bowstringing caused by pulley rupture was observed in 4 patients (2 in the MCP and 2 in the proximal interphalangeal joint). Eight patients had

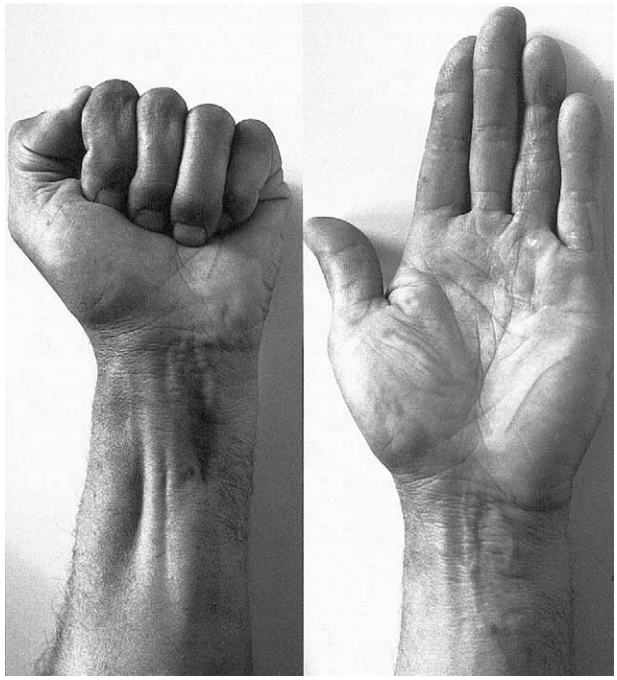

Figure 6. The ring finger (of the same patient in Figures 2, 4, and 5) at 3.5-years follow-up evaluation in flexion and extension.

Table 3. Buck-Gramco Rating

Result	Score	n (Digits)
Excellent	14–15	11
Good	11–13	7
Satisfactory	7–10	2
Poor	0–6	2

some form of nail deformity but only one considered it to be cosmetically unacceptable. One patient had a sensitive scar and one patient presented with triggering at the MCP without functional impairment.

During the second stage problems with the small size of the FDS were encountered in 2 patients with small finger reconstructions. In one patient the slim FDS graft was reinforced with a PL graft and in the other patient a conversion to a free PL graft technique at that stage was necessary.

Deep infection was observed in 2 patients in stage I. In both patients *Staphylococcus aureus* was cultured. In one patient the silicone rod was removed and reinserted after 6 months. In the other patient the infection responded well to intravenous antibiotic administration and closed irrigation drainage of the pseudosheath. No skin necrosis, rod buckling, rod migration, silicone synovitis, or proximal tenorrhaphy rupture (complications that have been reported with the Hunter method[6,27]) were encountered in this series.

Additional (after stage II) surgery was needed in 3 patients. In one patient the distal attachment of the graft ruptured and regrafting with PL was performed. In another patient a slack graft was retensioned by shortening it proximal to the wrist and in a third patient with a marked DIP flexion contracture the DIP was arthrodesed. DIP arthrodesis was indicated in 2 other patients because of a DIP flexion deformity but they are content with the functional result and refuse additional surgery. No tenolysis was performed in this series.

One of the 2 patients with poor results according to the Buck-Gramco scale was a 50-year-old woman with 5 previous surgeries in the small finger and the palm. She presented with a stiff pre–stage I finger that improved very little after soft-tissue release at that stage. At the last follow-up evaluation the patient had a strong and functioning graft with most of the motion at the MCP joint and little interphalangeal motion. The other poor result was that of a 5-year-old boy who sustained an electric burn on his hand. His middle finger was salvaged in an abdominal flap without primary tendon treatment. The proximal interphalangeal joint palmar plate and cartilage suffered damage from the original injury resulting in proximal interphalangeal joint subluxation. Although the joint was arthrolysed and reduced in stage I and the final result was a strong and functioning graft the proximal interphalangeal joint remained stiff in extension. The final result in both these patients is considered poor compared with normal but they were able to convert their limited passive motion (which did not improve before stage II) into active motion.

Discussion

The role of staged flexor tendon reconstruction using the modified Paneva–Holevich technique has long been recognized by the Committee on Tendon Injuries[26] but the wide acceptance of the Hunter technique by hand surgeons has limited its use.

Indications are essentially the same as in the Hunter technique and include flexor tendon reconstruction in Boyes 2 to 5 injuries in zone II with considerable scarring of the tendon bed. Other indications include replantation with damage to the fibrosseous canal and failed previous reconstruction. The indications have to be confirmed with the intraoperative findings during the stage I surgery. The procedure should not be performed if the FDS is intact. Scarring in the palm should be considered a relative contraindication.

Although the surgical technique is essentially the same in all previous reports of the method small modifications in the technique or the rehabilitation program have been described. During stage I the loop between the FDS and the FDP also can be accomplished either with a Kessler suture[18] or by using a fish-mouth technique.[20] Some surgeons fold the lumbrical muscle belly over this tenorrhaphy[14,15,20] but this may increase the risk for a lumbrical plus finger. In pulley reconstruction, except for the excised tendon material, the PL[15] and extensor retinaculum[17] also have been used. The encircling technique of pulley reconstruction also has been reported[20] but it requires abundant tendon material and is not suitable for children. Distal stabilization of the silicone rod

Table 4. Revised Strickland Rating

Result	Active Flexion (PIP + DIP) − Extensor Lag	n (Digits)
Excellent	132+	8
Good	88–131	8
Fair	44–87	2
Poor	<44	4

Table 5. The Modified Paneva–Holevich Technique in the Literature

Study	n (Digits) in Zone II	Evaluation	Good and Excellent Results (%)
Kessler[10]	6	Strickland*	83
Winspur et al[13]	10	Buck-Gramco*	80
Brug et al[14]	27	Buck-Gramco	52
Chuinard et al[15] (superficialis finger)	16	Boyes (modified)	62.5
Paneva-Holevich[16]	39	Boyes (modified)	56*
Alnot[17]	19	Total active motion–total active extension deficit	73*
Naam[18]	21	Strickland and Glogovac	52.4
Brug et al[19]	76	Buck-Gramco	55
This study	22	Buck-Gramco	82
		Modified Strickland	73

*Calculated based on data provided in the original articles.

only to the profundus stump (with no pull-out suture) has been reported to be sufficient.[10,13,14,18,20] A longer post–stage I immobilization period of up to 2 weeks[14,15,20] also has been proposed but this could potentially increase stiffness while posing no obvious advantages in this stage. Performing stage II as early as 8 to 10 weeks has been described.[14,15] The distal anchoring of the graft during stage II should withstand sufficient stress. In this regard attachment to the profundus stump and a pull-out suture has been invariably advised by all investigators. Although contraindicated in children additional strength can be achieved by passing the graft through an osseous tunnel in the distal phalanx.[10] After stage II mobilization with dynamic flexion traction similar to that reported here also has been used by other investigators.[13–15,18] In some of these reports the splint was removed earlier (3 instead of 5 wk) although forceful active flexion is not recommended before the fifth week. Controlled active flexion also was used by some investigators,[17,18] whereas a more aggressive protocol with only 5 days of dorsal splinting and immediate active flexion was described by Paneva-Holevich.[16]

More radical modifications of the technique include creating a loop between the FDS and the PL in the distal forearm as described by Foucher et al,[28] but it has no obvious advantages for zone II injuries in fingers other than the thumb, which can be reconstructed by creating a loop between the flexor pollicis longus and PL in the first stage.[9] The Paneva–Holevich technique has been used for staged superficialis finger reconstruction (anchoring of the graft in the middle phalanx) either as a primary[15] or as a salvage procedure after rupture of the distal insertion of the graft.[17] The injured FDS tendon of an adjacent finger (sutured in a loop with the profundus of the reconstructed finger in stage I) also can be used as a graft.[14] In cases in which the FDP muscle function is absent or questionable the technique can be modified to use the FDS of the same or an adjacent finger as motors.[6]

Results with the modified Paneva–Holevich technique are equally good or better than those achieved by the Hunter method. This is supported by the comparison of the range of motion in this report and in the Wehbe et al[6] report of Hunter reconstructions. The mean total active motion in that study was 176° versus 189° of total active motion observed in the patients presented here. Comparison with 2 of the largest series[7,8] using the Hunter technique further supports this conclusion. The rate of good and excellent results in zone II in these reports are 40% and 42%, respectively, according to the La Salle-Strickland scale, compared with the 72% achieved in the present series (revised Strickland scale). The results of previous reports of the modified Paneva–Holevich technique are listed in Table 5. It should be noted that the diversity of the patients included in these reports limits the value of direct comparison. It also should be noted that the evaluation scales used in this report do not take into consideration the preoperative condition of the digit and thus express the functional outcome compared with normal rather than reflecting the improvement of a mangled digit.

The modified Paneva–Holevich technique has further advantages. It uses an intrasynovial graft (FDS), which has better morphologic and functional characteristics[21–23] than extrasynovial grafts. The FDS graft has a more appropriate size with a mean cross-sectional area of 10.6 mm^2 compared with the 3.1 mm^2, 1.6 mm^2, and 3.2 mm^2 of PL, plantaris, and toe extensors, respectively.[29] It is a stable anatomic structure compared with plantaris and PL, which are

reported to be absent in 20% and 25% of healthy individuals, respectively.[30] Donor site morbidity also is minimized with this procedure. The proximal tenorrhaphy has healed by the time the second stage is performed; this nullifies the incidence of proximal rupture, which is reported in 7% of Hunter reconstructions.[6] No tenolysis was performed in this series whereas in Hunter reconstructions it has been reported with a rate of 12% to 47%.[6–8]

Technically with the modified Paneva–Holevich technique the size of the silicone rod and as a consequence, the size of the reconstructed pulleys, can be assessed precisely according to the FDS size during stage I. In addition the bulky loop at the lumbrical level is easier to identify during stage II than FDP alone with the Hunter method. Should abandoning the technique during stage II or regrafting be needed conversion to the classic free grafting technique of Hunter can be done. A potential technical disadvantage is that tensioning of the graft must be performed at the distal anchoring point.

Problems can be encountered in the small finger if the FDS is small. This can be overcome by reinforcement of the tendon with a PL graft, by conversion to a free graft technique, or by using the injured FDS of an adjacent finger.[14]

The DIP flexion contracture often observed in this and other[18] series can be attributed to the dynamic flexion traction that was used. If a patient can attend a hand therapy program with early controlled active flexion protocols this problem potentially could be minimized. Prolonged night splinting or late dynamic splinting also could be helpful. A closely supervised hand therapy program also would reduce the incidence of bowstringing owing to pulley rupture. The extraperiosteal wraparound technique for pulley reconstruction should be considered for crucial pulley reconstruction.

Six patients in this series were children less than 14 years of age at the time of surgery (one child was operated on at 3 years of age). The results of these young patients were rewarding (3 excellent, 2 good, 1 poor result according to the Buck-Gramco scale). Both with Hunter and with the modified Paneva–Holevich method better results were achieved in young adults.[6,14,18] Comparison of the 2 techniques in children showed better results following the modified Paneva–Holevich technique in one study.[31]

Finally in some patients it is clear that the extent of the initial injury rather than the technique that is applied is a better determinant of the final result. In general maximum passive motion before stage II is the goal of the hand therapy program. In addition the patient should be well motivated and the possibility of a prolonged rehabilitation period and a less than perfect result should be explained carefully.

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