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ORIGINAL ARTICLE

Two-stage Flexor Tendon Reconstruction in Zone 2 of the Hand in Children

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Abstract: Two-stage flexor tendon reconstruction (Hunter) is indicated in children with extensive adhesions in zone 2 of the hand, with some reservations concerning the patient's age and cooperation. Nine children (mean age 6.9 years) were treated with the modified Paneva-Holevich technique, which has advantages over the classic Hunter reconstructions. It involves an intrasynovial graft (FDS of the injured finger) that is anatomically stable and morphologically more appropriate compared with free grafts. The size of the silicone rod is precisely assessed in the first stage, the proximal tenorrhaphy has healed by the time the second stage is performed, and donor site morbidity is minimized. After a mean follow-up of 40.1 months, the mean total active motion was 196 degrees, and eight patients achieved a good or excellent result according to the Buck-Gramcko and the revised Strickland scale. Staged flexor tendon reconstruction is technically feasible even in very young children. Results in children are comparable to those achieved in adults.

Key Words: children, flexor tendons, staged reconstruction, Paneva-Holevich, intrasynovial graft

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In the past three decades primary or delayed primary repair of flexor tendons, even in zone 2 of the hand (formerly known as "no man's land"), has become the established treatment of flexor tendon lacerations. Results after such repairs in children have been reported to be analogous to those achieved in adults, with a satisfactory result in over 70% in children,[4,9,11,12,15,22,29] but there are still an important number of young patients with a poor initial result. A number of factors contribute to this. In some patients the diagnosis is delayed: as many as 25% of flexor tendon lacerations in children are reported to be missed at the initial examination.[23] Children often use the adjacent uninjured finger to move the injured one (the "trapping" phenomenon, Fig. 1), thus further delaying the diagnosis. Flexor tendon repair is technically demanding because of the small size of the tendons. Young children cannot cooperate in a rehabilitation program efficiently. Delays in diagnosis, suboptimal surgical technique, and prolonged immobilization can lead to adhesion formation and impaired function.

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When faced with a scarred flexor tendon system (especially in zone 2 of the hand), the surgeon has few options. Tenolysis can be attempted, but results in children under 11 years of age have been poor.[5] One-stage tendon grafting is known to be successful only if a number of prerequisites are met: nearly full preoperative passive motion, minimal scarring, and intact annular pulleys. Tenodesis and arthrodesis are unattractive options because they cause considerable growth retardation of the finger, and amputation can only rarely be accepted in a severely mangled digit in a child.

In the adult population two-stage flexor tendon grafting has produced consistently good results in flexor tendon reconstruction.[2,3,14,18,26–28,31] The scarred tendons are removed and a silicone rod is implanted in the first stage. In the 3-month interval between the two stages a "pseudosheath" is formed around the silicone rod, which will provide nutrition and a smooth gliding surface for the tendon graft. In the second stage either a free tendon graft (palmaris longus [PL], plantaris, toe extensors with the Hunter technique)[14] or the flexor digitorum superficialis (FDS) of the injured finger as a "pedicled" tendon graft (with the modified Paneva-Holevich technique[3,24]) is inserted through the "pseudosheath." Reports on the application of staged flexor tendon reconstruction in children are scarce.[1,13,30]

The purpose of this study was to present our experience and results of staged flexor tendon reconstruction in children with zone 2 injuries using the modified Paneva-Holevich technique.

MATERIALS AND METHODS

Between 1992 and 2002, nine children underwent a modified Paneva-Holevich reconstruction in the Department of Orthopaedic Surgery of the University of Ioannina, Greece. The mean age of the patients at the time of the procedure was 6.9 years (range 2.3–15). All patients had suffered injuries of both flexor tendons to the affected digit in zone 2 of the hand with significant scarring and had a nonfunctional flexor apparatus. Two index fingers, three long fingers, two ring fingers, and two little fingers were reconstructed. The etiology included delayed diagnosis of at least 3 months in three patients, failed primary repair in three patients, failed previous

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AU1 **FIGURE 1.** The ''trapping'' phenomenon. The child uses a healthy finger to flex the adjacent injured finger with a nonfunctional flexor apparatus. Here the patient is using the healthy little finger to flex the ring finger, which had its scarred flexor tendons removed and a silicone rod inserted during the first stage of the reconstruction and thus does not have individual motion.

hand surgery in two patients, and an electric burn to the hand in one patient. All injuries were grade 2 or above in the T1 modified Boyes and Stark grading[14] (Table 1).

The surgical technique includes two stages.[3] It is important that an aggressive physiotherapy program precedes the first stage to overcome stiffness and achieve maximum passive range of motion. The use of magnifying loupes during the operation is imperative. In stage 1 the injured digit is explored through a Bruner incision. Once the indication for a staged technique is confirmed, the injured tendons and scar F2 tissue are removed (Fig. 2A). Intact annular pulleys are opened only if necessary. A 1-cm distal profundus stump is spared. Any soft tissue release necessary is performed. A second incision is made in the palm and is extended proximally or distally as 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 in an end-to-end coaptation loop using three or four absorbable sutures (Fig. 2B). An oval silicone or Dacron-reinforced silicone implant (Wright, Arlington, TN) with a size corresponding to the FDS diameter is chosen. Opened pulleys are repaired using nonabsorbable sutures, while damaged ones are reconstructed using the excised tendon material (Fig. 2C). The direct suturing to the remnants of the pulleys or to the pulley rim technique is preferred.

The final implant is inserted proximal to distal and is cut proximal to the lumbrical level, and its unprohibited movement is checked. The distal anchoring of the silicone rod is achieved by direct sutures to the profundus stump and a pullout suture with a button placed proximal to the nail matrix. Any necessary secondary procedures are completed and the wound is closed. Secondary procedures during stage 1 in this series included nerve repair (Fig. 2C) in two digits and proximal interphalangeal (PIP) joint arthrolysis in two patients.

A dorsal splint with the wrist in 30 degrees of flexion, the metacarpophalangeal (MP) joint in 70 degrees of flexion, and the interphalangeal joints in a slightly flexed position is applied. After stage 1, passive motion is started 3 to 5 days after surgery. In children too young to cooperate, passive mobilization of all the fingers simultaneously is performed by their parents five times daily.

Stage 2 is performed after a minimum of 3 months. A midpalmar incision is used to retrieve the loop, which due to its volume is usually easily identified. A longitudinal incision at the palmar aspect of the distal third of the forearm is used to identify the corresponding FDS, and it is cut at the musculotendinous level after the correct length of the graft is verified. The FDS is then delivered into the incision in the palm by pulling it through the carpal tunnel, and it is sutured temporarily to the proximal end of the silicone rod. The flexor digitorum profundus muscle is used as the motor muscle for the finger. Finally an angular incision is made over the distal interphalangeal (DIP) joint, the distal end of the silicone rod is identified, and the rod with the graft sutured to it is retracted through this incision. The graft is thus inserted in the newly rebuilt digital canal. After the silicone rod is discarded, the tension of the graft is estimated. The desired tension is adjusted so that the injured finger is kept in slightly

TABLE 1. Patient Data

Pt. No.	Gender	Age	Finger	B&S	F-Up (mo)	TAM	TAM%	TAED	TPM	Grip%
1	M	3.3	long	2	12	180	69	45	270	
2	M	4.5	little	2	12	230	85	20	260	
3	M	12	index	3	101	195	72	60	255	95
4	F	4	index	3	84	195	75	0	245	84
5	F	12	long	3	53	260	96	0	275	85
6	M	5	long	5	53	115	44	60	160	70
7	M	15	little	5	20	195	75	65	195	85
8	M	4	ring	4	14	190	79	0	220	
9	M	2.3	ring	2	12	200	81	10	250	

B&S, Boyes and Stark grading 2 = scar, 3 = joint, 4 = artery or nerve, 5 = multiple; TAM, total active motion; TAM%, TAM compared to the corresponding uninjured digit; TAED, total active extension deficit; TPM, total passive motion; Grip%, grip strength compared to the contralateral uninjured hand (in patients >10 at final follow-up).

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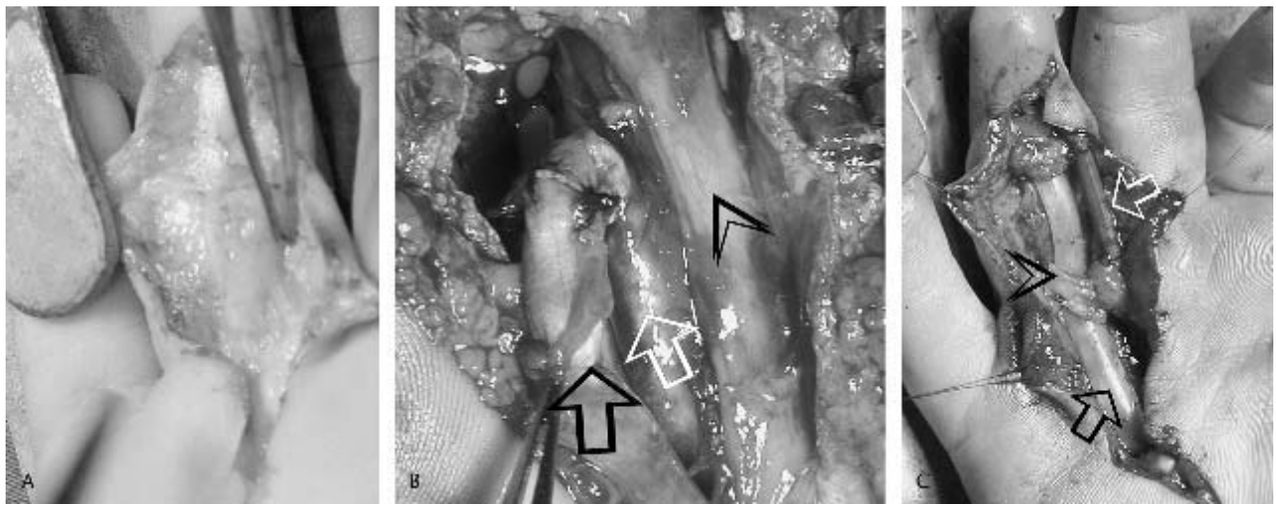

FIGURE 2. A, During the first stage the finger is surgically explored and the scarred flexor tendons are identified and removed. B, The proximal stumps of the FDP (light arrow) and FDS (dark arrow) are sutured in an end-to-end coaptation loop. The median nerve (arrowhead) is protected. C, Finally, a silicone rod (dark arrow) is inserted and damaged pulleys are reconstructed over it (arrowhead) from excised tendon material. Possible digital nerve injuries are also addressed in the first stage, here using a silicone tube (light arrow) as a nerve conduit.

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 pullout suture and button and direct suturing to the profundus stump. A splint similar to that used in stage 1 is applied.

For children old enough to cooperate, an early controlled motion program is used (passive flexion, active extension dynamic[16]). 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. In younger children the fingers are passively mobilized in the splint by the parents as described earlier for 4 weeks, and active mobilization with toys and activities follows.

Assessment of the patients included measurement of active and passive motion and pulp-to-distal flexion crease distance in the clenched fist position. In patients older than 10 years of age at final follow-up, 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 Baseline pinch gauge (FEInk, Irvington, NY) and a Jamar hydraulic dynamometer (Sammons Preston, Bolingbrook, IL), respectively. The length of the affected digit was recorded. Three measurements of all of the parameters were obtained and the average was calculated. The measurements were repeated and compared with the corresponding finger of the uninjured hand. The results were classified according to the Buck-Gramcko rating[17] and to the revised classification system of Strickland.[19] The latter classification does not take MP motion into account.

RESULTS

The mean follow-up of the patients from the stage 2 procedure was 40.1 months (range 12–101 months). The mean total active motion (TAM) achieved was 196 degrees (75% that of the contralateral finger) out of 237 degrees of total passive motion (TPM). The mean total active extension deficit (TAED) was 29 degrees and mostly occurred in the DIP joint; a mean DIP extension deficit of 30 degrees was observed in five of nine fingers.

In the five patients older than 10 years of age at the final follow-up, the mean grip, pinch, and key pinch strengths were 83%, 59%, and 77% respectively compared with the contralateral unaffected extremity. Overall a good or excellent result was achieved in all but one patient both with the Buck-Gramcko[17] and the revised Strickland[19] ratings (Table 2, Fig. 3). The mean TAM achieved in children over the age of 10 at the time of the original operation (216 degrees) was higher compared with the TAM in children under 10 (185 degrees), but the cohorts were too small for statistical analysis.

Bowstringing was observed at the MP joint of one patient. Five patients had some form of nail deformity, but no patient or parent considered it to be cosmetically unacceptable. One patient presented with triggering at the MP without functional impairment. Shortening of the digit (0.5 cm) combined with a mild rotational deformity was observed in one patient.

During the second stage, problems with the small size of the FDS were encountered in the two patients with little finger

TABLE 2. Results After Zone 2 Flexor Tendon Reconstructions

	Buck-Gramcko[17] Rating		Revised Strickland[19] Rating	
Result	Score	n (digits)	Active flexion (PIP + DIP)-extensor lag	n (digits)
Excellent	14–15	5	132+	2
Good	11–13	3	88–131	6
Satisfactory/fair	7–10		44–87	
Poor	0–6	1	<44	1

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FIGURE 3. The reconstructed long finger in a 3-year-old at 12 months of follow-up in flexion and extension.

reconstructions. In one patient the slim FDS graft was reinforced with a PL graft, and in the other patient conversion to a free PL graft technique at that stage was necessary.

Deep infection was observed in one patient in stage 1, and *Staphylococcus aureus* was cultured. The patient was initially treated conservatively with antibiotics, but finally the silicone rod had to be removed and reinserted after 3 months. No skin necrosis, rod bulking, rod migration, silicone synovitis, or proximal tenorrhaphy rupture (complications that have been reported with the Hunter method[28,31]) were encountered in these patients. No tenolysis was performed. In one patient a slack graft was retensioned by shortening it proximal to the wrist.

The only patient with a poor result was a 5-year-old boy who sustained an electrical burn on his hand. His middle finger was salvaged in an abdominal flap without primary tendon treatment. The PIP palmar plate and cartilage suffered damage from the original injury, resulting in PIP subluxation. Although the joint was arthrolysed and reduced in stage 1 and the final result was a strong and functioning graft, the PIP joint remained stiff in extension. The result was recorded as poor with the evaluation scales used in this study, but the patient transformed all preoperative passive motion into postoperative active motion.

DISCUSSION

The first report on staged flexor tendon reconstruction in children[13] was by James Hunter, the pioneer of such reconstructions in adults. In that paper 17 fingers were reconstructed. Although contemporary assessment methods were not used, nine (53%) fingers were reported to have transformed their full range of preoperative passive motion into postoperative active motion (which is considered an excellent result in the LaSalle and Strickland[18] scale), but in only one finger the pulp-to-distal palmar crease distance was 0. One failure was reported due to "synovitis." The author considered the results to be "cause for optimism" but believed that the method was not suitable for "infants or children too young to cooperate."

The optimism expressed by Hunter was challenged by Amadio et al,[2] who reported an 80% failure rate in 10 reconstructions in patients younger than 10 years. That report was included in an article on adult reconstructions. When Amadio reported his experience in 13 children alone,[1] the poor result rate dropped to 54%. Four of seven patients with a poor result in that report had suffered complications (infections and a graft rupture).

Although better results were achieved in young adults in some series,[6,20,31] it was not until recently that these were confirmed in children. Valenti and Gilbert[30] described 24 children with a 73% rate of good and excellent results on the LaSalle and Strickland[18] scale. Coyle et al[7] achieved more than 200 degrees of final TAM in 7 of 10 patients aged under 20 years in their series. Our series supports this, with eight of nine patients achieving a good or excellent result and a mean TAM of 196 degrees. In this report, only zone 2 injuries were included, and the evaluation scales used express the functional outcome compared with normal rather than comparing it with the preoperative condition of the finger. It seems that staged flexor tendon reconstruction can be as effective in children as in adults.

The surgical technique used in children is essentially the same as in adults, with only minor modifications. Aggressive dissection in the vicinity of joints should be avoided for fear of growth plate disturbance. Osseous tunnels and the extraperiosteal wrap around technique for pulley reconstruction can also affect digital growth. Skin closure with absorbable sutures should be considered, especially in younger children. Although both long (extending to the distal forearm) and short (extending to the palm) silicone rods have been used, it seems that the latter are advantageous in children.[7,30] The modified Paneva-Holevich technique used in this series has been shown to be technically versatile, diminishes donor site morbidity, and is associated with a lower rate of postreconstruction tendon ruptures and tenolysis compared with the classic Hunter technique in adults.[3] The modified Paneva-Holevich reconstruction presents several technical advantages. It uses an intrasynovial donor tendon (FDS) with a size similar to that of the affected tendons. The silicone rod and the reconstructed pulleys can be accurately matched to the graft, since 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. Donor site morbidity is minimized, since no free grafts are harvested with this technique. Superior results were achieved with the Paneva-Holevich technique in children in one study.[30] This technique may not be appropriate for little finger reconstructions in children because of the small size of the FDS in that finger.

In children too young to cooperate in the rehabilitation program, it is preferable to protect the finger for 4 weeks, with passive mobilization by the parents for that period. Since the proximal tenorrhaphy is healed by the time the second stage is performed with the modified Paneva-Holevich technique, the fear of proximal graft rupture in the early rehabilitation period is minimized. Immobilization of up to 4 weeks has not been shown to adversely affect the outcome of primary flexor tendon repair in young children.[4,9,15,22]

Children over the age of 10 achieved better results than younger ones, both in this and in another[30] report, although the number of patients was too small to reach statistical

significance. Improvement in flexion with the growth of the hand was observed over a period of years in both reports. Children should be followed until skeletal maturity.

No clinically significant digital length discrepancies were found in this study, although the osseous length was not assessed with radiographs. Growth retardation of the finger has been shown to occur after neglected flexor tendon lacerations,[8,10,29] and to a lesser extent after primary flexor tendon repair,[10,21] but its functional significance has not been studied. The effect of tendon injury, repair, or reconstruction on hand dominance in young children has also not been clarified.

For children too young to cooperate in the rehabilitation program, delaying the reconstruction until the age of 7 to 8 years has been supported.[13,25] Based on the data available, no definite conclusions can be drawn. The benefits of such a delay should be weighed against the possible consequences of the prolonged disuse of the affected finger and of an untreated concomitant nerve injury, which cannot be readily recognized in the very young. We believe that reconstruction should be attempted in young children too, provided that the surgeon is familiar with the procedure (preferably the modified Paneva-Holevich technique) and meticulous surgical technique is used. The family should also be able to understand its important role in the prolonged rehabilitation period and should have realistic expectations as to the outcome.

REFERENCES

1. Amadio PC. Staged flexor tendon reconstruction in children. *Ann Chir Main*. 1992;11:194–199.
2. Amadio PC, Wood MB, Cooney WP, et al. Staged flexor tendon reconstruction in the fingers and hand. *J Hand Surg [Am]*. 1983;8: 263–267.
3. Beris AE, Darlis NA, Korompilias AV, et al. Two-stage flexor tendon reconstruction in zone II using a silicone rod and a pedicled intrasynovial graft. *J Hand Surg [Am]*. 2003;28:652–660.
4. Berndtsson L, Ejeskar A. Zone II flexor tendon repair in children. *Scand J Plast Reconstr Surg Hand Surg*. 1995;29:59–64.
5. Birnie RH, Idler RS. Flexor tenolysis in children. *J Hand Surg [Am]*. 1995;20:254–257.
6. Brug E, Stedtfeld HW. Experience with a two-staged pedicled flexor tendon graft. *Hand*. 1979;11:198–205.
7. Coyle MP, Leddy TP, Leddy JP. Staged flexor tendon reconstruction fingertip to palm. *J Hand Surg [Am]*. 2002;27:581–585.
8. Cunningham MW, Yousif NJ, Matloub HS, et al. Retardation of tendon growth after injury to the flexor tendons. *J Hand Surg [Am]*. 1985; 10:115–117.
9. Fitussi F, Lebellec Y, Frajman JM, et al. Flexor tendon injuries in children: factors influencing prognosis. *J Pediatr Orthop*. 1999;19:818–821.
10. Gaisford JC, Fleegler EJ. Alterations in finger growth after flexor tendon injuries. *Plast Reconstr Surg*. 1973;51:164–168.
11. Grobbelaar AO, Hudson DA. Flexor tendon injuries in children. *J Hand Surg [Br]*. 1994;19:696–698.
12. Hollwarth M, Haberlik A. Flexor tendon injuries in childhood. *Z Kinderchir*. 1985;40:294–298.
13. Hunter JM, Salisbury RE. Use of gliding artificial implants to produce tendon sheaths. Techniques and results in children. *Plast Reconstr Surg*. 1970;45:564–572.
14. Hunter JM, Salisbury RE. Flexor-tendon reconstruction in severely damaged hands. A two-stage procedure using a silicon-Dacron reinforced gliding prosthesis prior to tendon grafting. *J Bone Joint Surg [Am]*. 1971;53:829–858.
15. Kato H, Minami A, Suenaga N, et al. Long-term results after primary repairs of zone 2 flexor tendon lacerations in children younger than age 6 years. *J Pediatr Orthop*. 2002;22:732–735.
16. Kleinert HE, Kutz JE, Atasoy E, et al. Primary repair of flexor tendons. *Orthop Clin North Am*. 1973;4:865–876.
17. Kleinert HE, Verdan C. Report of the committee on tendon injuries. *J Hand Surg [Am]*. 1983;5:794–798.
18. LaSalle WB, Strickland JW. An evaluation of the two-stage flexor tendon reconstruction technique. *J Hand Surg [Am]*. 1988;13:559–562.
19. Leversedge FJ, Zelouf D, Williams C, et al. Flexor tendon grafting to the hand: an assessment of the intrasynovial donor tendon—a preliminary single-cohort study. *J Hand Surg [Am]*. 2000;25:721–730.
20. Naam NH. Staged flexor tendon reconstruction using pedicled tendon graft from the flexor digitorum superficialis. *J Hand Surg [Am]*. 1997;22:323–327.
21. Nishijima N, Fujio K, Yamamuro T. Growth of severed flexor tendons in chickens. *J Orthop Res*. 1995;13:138–142.
22. O'Connell SJ, Moore MM, Strickland JW, et al. Results of zone I and zone II flexor tendon repairs in children. *J Hand Surg [Am]*. 1994;19:48–52.
23. Osterman LA, Paksima N. Flexor tendon injuries and repair in children. In: Hunter JM, Schneider LH, Mackin EJ, eds. *Tendon and Nerve Surgery in the Hand*, 1st ed. St. Louis: Mosby, 1997:593–598.
24. Paneva-Holevich E. Two-stage reconstruction of the flexor tendons. *Intern Orthop*. 1982;6:133–138.
25. Schneider LH. Flexor tendons: late reconstruction. In: Green DP, Hotchkiss RN, Pederson WC, eds. *Operative Hand Surgery,* 4th ed. New York: Churchill Livingstone, 1999:1898–1941.
26. Soucacos PN. Two-stage flexor tendon reconstruction using silicone rods. In: Vastamaki M, ed. *Current Trends in Hand Surgery.* Amsterdam: Elsevier, 1995:353–357.
27. Soucacos PN. Secondary flexor tendon repair. In: Duparc S, ed. *Textbook on Techniques in Orthopaedic Surgery and Traumatology.* Paris: Elsevier SAS, 2000.
28. Soucacos PN, Beris AE, Malizos KN, et al. Two-stage treatment of flexor tendon ruptures. Silicone rod complications analyzed in 109 digits. *Acta Orthop Scand*. 1997;68:48–51.
29. Vahvanen V, Gripenberg L, Nuutinen P. Flexor tendon injury of the hand in children, a long-term follow-up study of 84 patients. *Scand J Plast Reconstr Surg Hand Surg*. 1981;15:43–48.
30. Valenti P, Gilbert A. Two-stage tendon grafting in children. *Hand Clin*. 2000;16:573–578.
31. Wehbe MA, Mawr B, Hunter JM, et al. Two-stage flexor-tendon reconstruction. *J Bone Joint Surg [Am]*. 1986;68:752–763.

