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Original Research

Flexor Tendon Grafting Using Extrasynovial Tendons Followed by Early Active Mobilization

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A R T I C L E I N F O

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Purpose: This study evaluated the outcomes of early active mobilization after flexor tendon grafts using extrasynovial tendons with a novel distal fixation technique.
Methods: This study was a retrospective case series. The flexor digitorum profundus (FDP) tendons of 7 digits in 7 patients were reconstructed with extrasynovial tendons, which included the palmaris longs, plantaris, and extensor digitorum longus, in a single- or 2-stage procedure between 2008 and 2017. Of the 7 patients, 6 were male and the average patient age was 48 years. The injuries involved 2 middle, 2 ring, and 3 little fingers. The tendons were sutured into the appropriate FDP tendon proximally using end-weave anastomosis; the distal end of the graft was fixed to the distal stump of the FDP using an interlacing suture or a small bone anchor combined with the pull-through technique. The digits were mobilized with a combination of active extension and passive and active flexion in a protective orthosis during the first 6 weeks after surgery. Average follow-up was 18 months. We measured active and passive digit motion both before tendon grafting and at the final evaluation. Outcomes were graded by the LaSalle formula to assess staged flexor tendon reconstruction.
Results: Average passive range of motion (ROM) of the proximal and distal interphalangeal joints before flexor tendon grafting was 146° (SD, 22°). Mean active ROM of these joints at the final evaluation was 123° (SD, 34°). Using the LaSalle formula, mean recovery of active motion was 83%. We encountered no grafted tendon rupture and no finger required tenolysis.
Conclusions: Our proximal and distal fixation techniques allowed the autologous extrasynovial tendon grafts to withstand the stress encountered during early active mobilization with good postoperative ROM and minimal complications.
Type of study/level of evidence: Therapeutic I.

Direct primary repair immediately after flexor tendon injury of the hand is standard clinical practice.[1] Over the past 2 decades, strong core tendon repair techniques associated with adequate pulley release, followed by early active mobilization, have improved outcomes.[2,3] However, flexor tendon reconstruction is required if primary repair fails.[4,5] Unlike primary repairs, early active mobilization is rarely scheduled after tendon grafting because of the uncertain survival of the grafted tendon and potential weakness of the distal tendon at the base of the distal phalanx. We evaluated the outcomes of early active mobilization after flexor tendon grafting using extrasynovial tendons and hypothesized that our distal fixation technique would lead to similar outcomes as seen in primary repairs with early mobilization.

Materials and Methods

This study was a retrospective case series. Potential patients were identified by searching our institutional billing records from 2008 to 2017 for International Classification of Diseases, 10th Revision, code S561. Inclusion criteria were: (1) complete hand flexor digitorum profundus (FDP) tendon laceration with or without a concomitant flexor digitorum superficialis (FDS) tendon laceration; (2) 1- or 2-stage tendon grafting using an extrasynovial tendon; (3) rehabilitation that included early active mobilization;

Declaration of interests: No benefits in any form have been received or will be received by the authors related directly or indirectly to the subject of this article.

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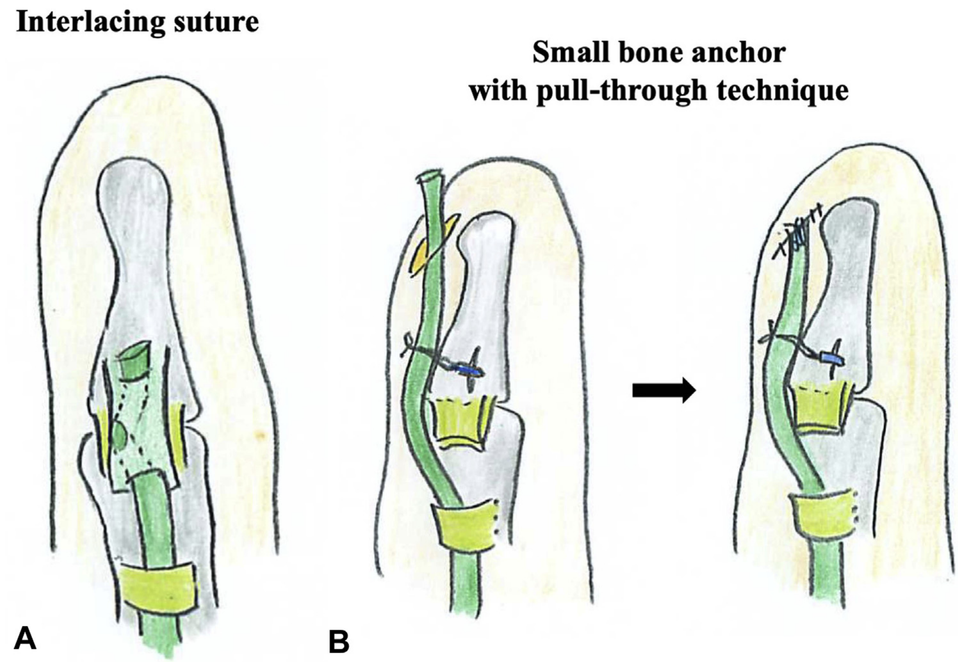

Figure 1. Fixation method for the distal end of the tendon graft. **A** The distal portion of the graft was woven through the distal stump of the FDP tendon. **B** When the distal stump of the FDP tendon was unavailable, the distal end of the graft was fixed using a small bone anchor combined with the pull-through technique. The graft was passed through the pulp space and the skin over the tip of the finger, and then fixed with a small bone suture anchor. The skin was closed after the protruding end was removed and allowed to fall back into the pulp.

Table 1
Injury-Related Patient Data

Patient	Age at Time of Tendon Grafting, y	Sex	Involved Finger	Injury Mechanism	Classification of Boyes and Stark[11]	Interval Between Injury and Extrasynovial Tendon Graft, wk	Reconstruction Method	Level of Surgical Expertise
1	61	M	Little	Neglected FDP avulsion injury	Good	5	1-stage	4*
2	66	M	Middle	Subcutaneous zone 2 FDP rupture caused by infection	Scar	31	1-stage	4
3	36	M	Middle	Neglected zone 1 FDP laceration	Good	12	1-stage	4
4	39	M	Ring	Flexion contracture after flexor tenolysis	Salvage	82	2-stage	4
5	55	M	Ring	Flexor tendon rupture after primary repair	Scar	25	2-stage	2†
6	30	M	Little	Flexor tendon rupture after primary repair	Salvage	48	2-stage	4
7	48	F	Little	Flexion contracture after tendon grafting	Salvage	68	2-stage	4

* Very experienced specialist.
† Less-experienced specialist.

Table 2
Intraoperative Findings and Complications

Patient	FDS Tendon Treatment	Excised Pulley	Reconstructed Pulley	Grafted Tendon	Proximal Fixation Site	Distal Fixation Method	Complications
1	None	A5 + C3 + A4 + C2	None	Palmaris longus	Palm	Interlaced suturing to distal stump of FDP	None
2	Excision	C2 + A3 + C1 + A2	None	Palmaris longus	Palm	Interlaced suturing to distal stump of FDP	Tendon bowstringing
3	None	C3 + A4 + C2	None	Palmaris longus	Palm	Interlaced suturing to distal stump of FDP	None
4	Excision	C2 + A3 + C1 + A2	A2	Palmaris longus	Palm	Small bone anchor combined with pull-through technique	None
5	Excision	C2 + A3 + C1 + A2	A2	Plantaris	Distal forearm	Interlaced suturing to distal stump of FDP	None
6	Excision	A4 + C2 + A3 + C1	None	Palmaris longus	Distal forearm	Small bone anchor combined with pull-through technique	None
7	Excision	C2 + A3 + C1 + A2	A2	Extensor digitorum longus	Palm	Interlaced suturing to distal stump of FDP	None

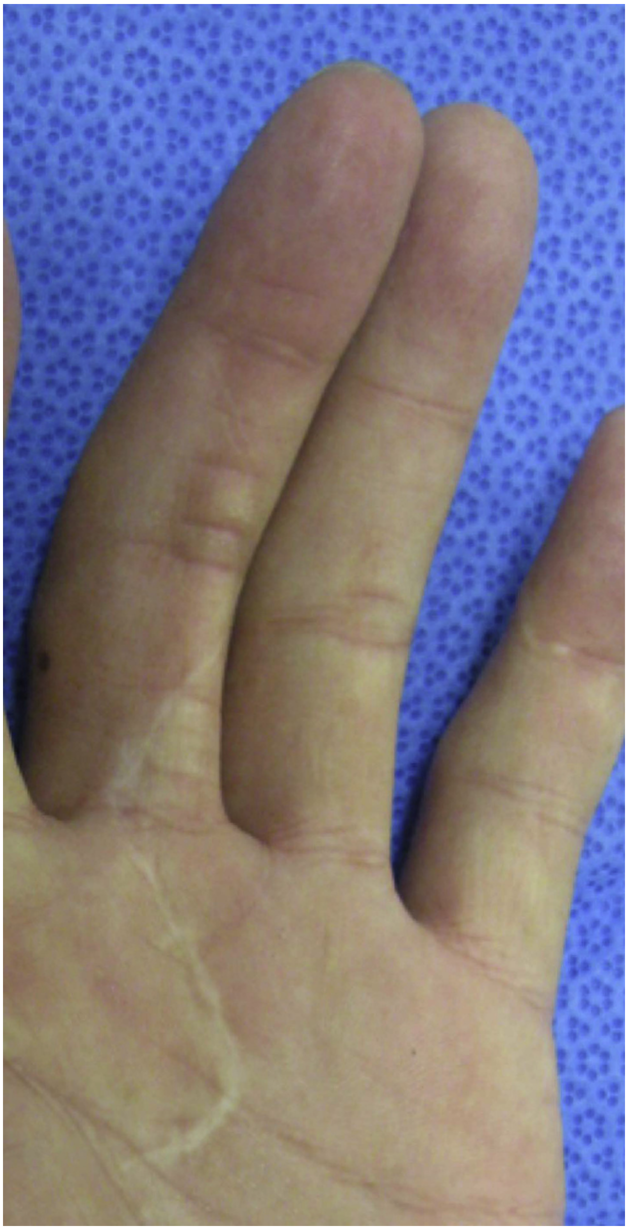

Figure 2. Bowstringing of the middle finger was evident at the final visit.

and (4) follow-up greater than 6 months. Exclusion criteria were: (1) replantation or finger revascularization; (2) extensor tendon injuries; (3) joint injuries; and (4) skin defects. Patient demographics and injury details were retrieved from hospital records. All of our operative records include simple sketches of the surgical procedures, which enabled us to note retrospectively the treatment details for the FDS tendon and pulleys (eg, excision and reconstruction), the level of division of the FDP tendon, and the fixation methods used at the distal and proximal ends. This study was approved by the local ethics committee, and all patients provided written informed consent for their data to be used in this study.

Surgical methods

All operations were performed under loupe magnification with patients under either axillary block or general anesthesia. A favorable intraoperative recipient bed (no excessive scarring and a neurovascularly intact digit) indicated that 1-stage flexor tendon grafting was appropriate; an unfavorable recipient bed (excessive scarring and/or considerable obstruction of the ligamentous pulleys) required placement of a silicone rod before flexor tendon grafting. The entire scar was excised; when both tendons were lacerated, the FDS tendon was resected from a point 1 or 2 cm proximal to its insertion back to the level of the musculotendinous junction. Pulleys were retained if possible; however, when the A2 pulley had to be excised, a silicone rod was inserted in conjunction with reconstruction of the A2 pulley using the resected FDS tendon. The palmaris longus tendon, plantaris tendon, or extensor digitorum longus tendon was harvested for use as the extrasynovial tendon graft based on the proximal tenorrhaphy site and the presence or absence of a palmaris longus tendon. The distal end of the graft was fixed using an interlacing suture connecting it to the distal stump of the FDP, or by employing a small bone anchor combined with the pull-through technique (Fig. 1).[6] Which technique was used depended on the distal FDP tendon stump length. When it was 7 mm or more, the interlacing suture technique was carried out. Extrasynovial tendon grafts such as the palmaris longus tendon or extensor digitorum longus tendon usually ran from the fingertip to the palm. When moderate to severe scar tissue was found during placement of a silicone rod, the proximal suture of the graft was shifted proximally to the carpal tunnel in the wrist region during the second operation. In these cases, the plantaris tendon was harvested. The second operation was performed at least 3 months after the placement of a silicone rod. The finger was held in slightly greater flexion than in the resting position and the grafted tendon was proximally sutured into the appropriate FDP tendon via an end-weave anastomosis.

Postoperative treatment

After tendon grafting, all patients were hospitalized for at least 3 weeks. Hospitalization costs were covered by either industrial injury or personal health insurance. Digit rehabilitation commenced with a primary repair active mobilization regime previously described[2,7] and was performed by our hand therapy unit on the first postoperative day. The hand was immobilized in a dorsal plaster orthosis with the wrist at approximately 0° to 30° of palmar flexion, the metacarpophalangeal joints at 30° to 60° of flexion, and the interphalangeal (IP) joints fully extended. Initially, for the first 2 postoperative weeks, rubber band traction with a palmar pulley was applied to all 4 fingers to prevent extension contracture of the finger and minimize the power required to mobilize the tendon actively at daytime. The orthosis was removed during hand therapy. In 2014, rubber band traction was replaced by passive flexion, as performed by the patient using the unaffected hand. At night, the rubber bands were released and the digits were placed in an orthosis in a comfortable extended position. Active IP joint extension exercises without rubber band traction were initiated on the first postoperative day. As an early active flexion exercise, patients were instructed to hold the digits gently and actively while flexing the IP joints passively as much as possible. We also performed controlled passive extension to prevent flexion contractures of the IP joints. Isolated FDS gliding exercises were added when the superficialis tendon was intact. Unassisted active flexion exercises within the restraints of the dorsal plaster orthosis were allowed 1 week after mobilization exercises began, and synergistic wrist motion exercises (the wrist was extended when the digits were flexed, and the wrist was flexed when the digits were extended) commenced 4 weeks after surgery. At 6 weeks, the dorsal plaster orthosis was removed, except at night. The orthosis was removed completely 8 weeks after surgery and patients were permitted to extend the wrist and digits simultaneously. Power gripping was allowed at 12 weeks.

Table 3
Recovery and Range of Active Digital Motion

Patient	Follow-Up, mo	Passive Range of PIP and DIP Joints Before Flexor Tendon Grafting (degrees)	Active Range of PIP and DIP Joints at Final Evaluation (degrees)	Active Motion Recovery (%)*
1	16	155	125	81
2	45	146	110	75
3	14	170	170	100
4	19	115	105	91
5	13	172	155	90
6	7	130	65	50
7	13	131	128	92

* Using the formula of LaSalle and Strickland.[8]

Outcome measurements

The surgeon or therapist who had been part of the treatment team measured active and passive digit motion with a goniometer at the 2 finger joints (ie, the proximal interphalangeal [PIP] and distal interphalangeal [DIP] joints), both before tendon grafting and at the final evaluation. Maximum passive flexion was determined by gently pressing the finger while recording the flexion angles of each joint. Active motion recovery after tendon grafting was evaluated using the formula of LaSalle and Strickland[8]: the sum of active PIP and DIP joint flexion minus the summed extension deficits of the same joints at final evaluation divided by the sum of passive PIP and DIP joint flexion minus the summed extension deficits of the same joints before extrasynovial tendon grafting, multiplied by 100. Results were classified as excellent (75% to 100%), good (50% to 74%), fair (25% to 49%), or poor (less than 24% of normal). Active range of motion (AROM) of the PIP and DIP joints at the final visit was evaluated using the criteria of Strickland and Glogovac[9] and Tang.[10] The sum of active flexion at the PIP and DIP joints minus the summed extension deficits at the same joints was divided by 175° and multiplied by 100: (PIP flexion + DIP flexion) − (PIP extension lag + DIP extension lag) / 175° × 100 = percentage of normal active PIP and DIP motion. Results were classified as excellent (85% to 100% of normal IP motion), good (70% to 84% of normal), fair (50% to 69% of normal), or poor (less than 50% of normal) using the criteria of Strickland and Glogovac. The Tang criteria also require a separate evaluation of any finger in which the PIP and DIP joints fail to attain 30% of maximal range of motion (ROM). The outcome was classified as excellent (90% to 100% of normal motion of the PIP and DIP joints), good (70% to 89% of normal), fair (50% to 69% of normal), poor (30% to 49% of normal), or failed (less than 30% of normal). Intraoperative findings and complications, such as rupture of the grafted tendon, phlegmon, or wound dehiscence after tendon grafting, were noted at each visit.

Results

Number of patients and injured fingers

A total of 10 fingers in 10 consecutive patients treated from 2008 to 2017 met the selection criteria; 3 fingers in 3 patients were excluded because their records did not include good surgical notes and/or lacked objective data before tendon grafting and/or on final evaluation. A total of 7 fingers in 7 consecutive patients were included in the final analysis. Six of the patients were male, average age 48 years (range, 30–66 years) at the time of grafting. Table 1 shows the timing of extrasynovial tendon grafting and other injury-related data, including the preoperative conditions of the fingers according to the classification of Boyes and Stark,[11] and the level of surgical expertise, which was divided into 5 groups by Tang[10]: 1 = nonspecialist; 2 = less experienced specialist; 3 = experienced specialist; 4 = highly experienced specialist; and 5 = expert. In patients undergoing 2-stage reconstruction, average time from silicone rod insertion to tendon grafting was 17 weeks (range, 16–18 weeks).

Intraoperative findings and complications

Of the 3 fingers that underwent 1-stage tendon grafting, one finger with a zone 2 injury underwent complete excision of the pulleys (from C2 to A2) and the FDS tendon. Because this patient sustained a subcutaneous zone 2 FDP rupture caused by infection, no silicone rod was inserted and the A2 pulley was not reconstructed. Of the 4 fingers that underwent 2-stage tendon grafting, the A4 pulley was preserved in 3; these fingers (all with zone 2 injuries) underwent A2 pulley reconstruction using the resected FDS tendon. Other relevant intraoperative findings are shown in Table 2.

No wound complications or infections were noted. We encountered no rupture of a grafted tendon and no finger required tenolysis. The patient in whom the extensor digitorum longus tendon was used as the extrasynovial tendon graft had slightly limited extension of the donor toe; however, gait was apparently normal. At the final visit, one patient who had undergone 1-stage tendon grafting to treat a subcutaneous zone 2 FDP rupture caused by infection exhibited subjective and objective tendon bowstringing (Table 2, Fig. 2). No patients reported suture or anchor-related complications at final follow-up.

Recovery and range of active digital motion

Average passive ROM of the PIP and DIP joints before flexor tendon grafting was 146° (range, 115° to 172°). Mean AROM of these joints at the final evaluation was 123° (range, 65° to 170°). Using the LaSalle and Strickland[8] formula, mean active motion recovery was 83% (range, 50% to 100%); we noted 6 excellent and 1 good result. Using the criteria of Strickland and Glogovac,[9] the grafts were excellent for 2 digits, good for 2, fair for 2, and poor for 1. Using the Tang criteria,[10] the graft was excellent for 1 digit, good for 3, fair for 2, and poor for 1 (Table 3, Fig. 3). The 3 fingers in the fair or poor category had poor preoperative conditions with either scar (n = 1, fair) or salvage situations (n = 2, fair and poor).

Discussion

Tendon grafts have traditionally been immobilized for 2 to 3 weeks, but outcomes have often been unsatisfactory because of adhesions requiring tenolysis.[8,11,12] LaSalle et al[8] noted that fair and poor results, based on the same rating scale used in our study, was seen in 61% of digits managed by immobilization after the 2-stage flexor tendon grafts. Tenolysis rates in patients managed after surgery by immobilization vary from 12% to 47%, and the tendon rupture rate is 3% to 14%.[8,11–13] Tonkin et al[13] were the first to report that flexor tendon grafting can be managed after surgery by immediate controlled mobilization (Kleinert technique), which reduces the rates of rupture and graft tenolysis compared with those in an immobilized group; however, the postoperative management techniques have not been proven to affect range of active digital motion of the PIP and DIP joints at the final evaluation. In recent years, early active mobilization has been recommended after tendon grafting.[14–18] Our results are consistent with prior series with rupture rates of 0% to 27%, recovery rates of 59% to 84%, and

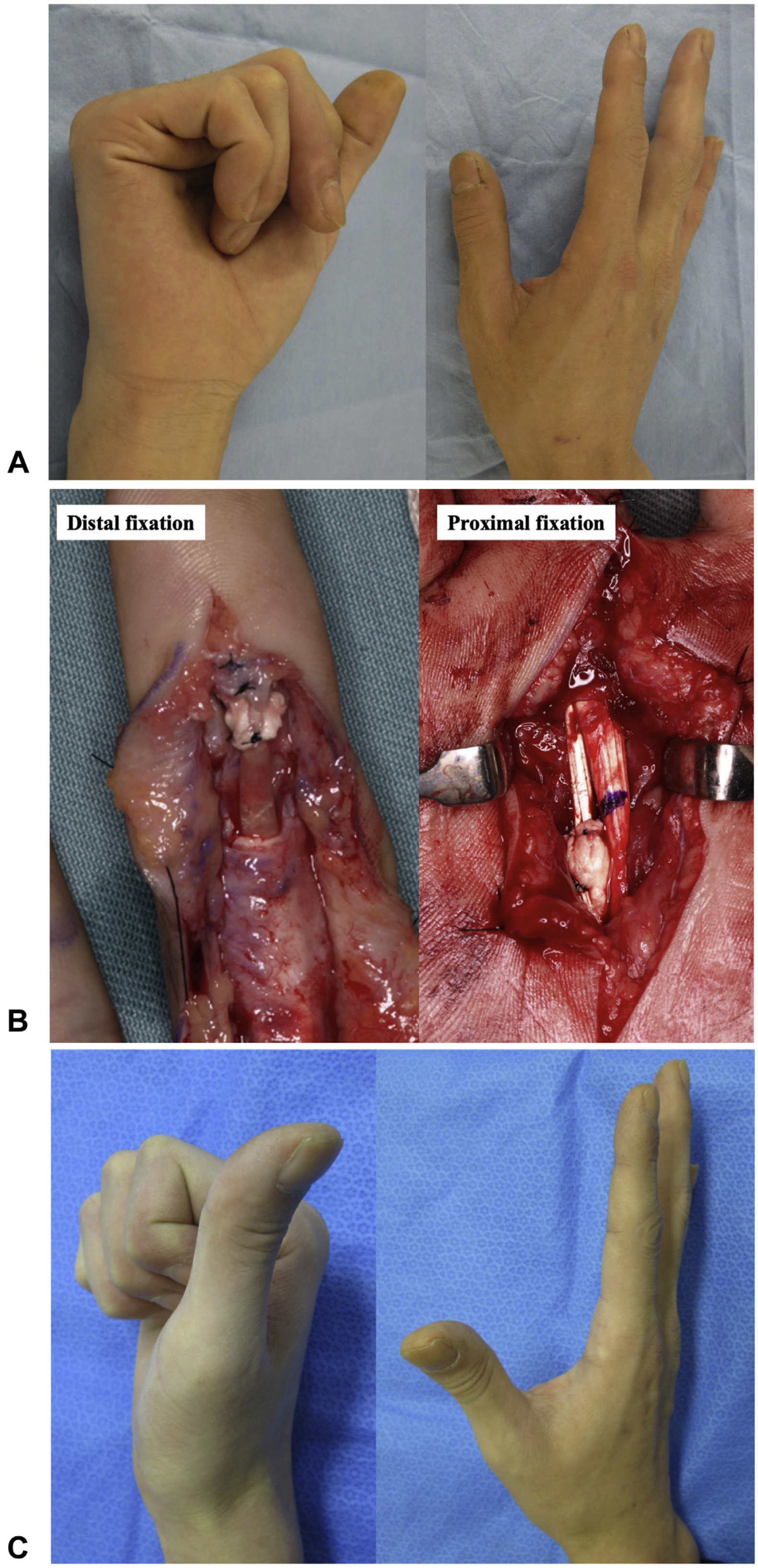

Figure 3. Clinical photographs of a 36-year-old man who underwent 1-stage reconstruction of the middle finger of the right hand using a palmaris longus tendon graft. A Preoperative active flexion and extension. B The distal end of the graft was anchored to the distal stump of the FDP using an interlacing suture. The grafted tendon was sutured into the proximal stump of the FDP tendon via an end-weave anastomosis. C Postoperative active flexion and extension at 14 months after surgery.

Table 4
Reports Employing Early Active Mobilization After Flexor Tendon Grafting

Year	Authors	Fingers, n	Reconstruction Method	Source of Tendon Graft	% Rupture	Mean Active Range of PIP and DIP Joints at Final Evaluation (degrees)	Active Motion Recovery (%)
1995	Silfverskiöld and May	11	2-stage	Extrasynovial	27	136	76[*]
1997	Khan et al	9	2-stage	Extrasynovial	0	NR	NR
2000	Leversedge et al	10	2-stage	Intrasynovial	10	96	59[b]
2007	Bertelli et al	14	1-stage	Extrasynovial	0	122	NR
2017	Ohi et al	9	1- or 2-stage	Intrasynovial	11	143	84[†]
Current study		7	1- or 2-stage	Extrasynovial	0	123	83[*]

NR, no record.
[*] Using the formula of LaSalle and Strickland.[8]
[†] Compared with the corresponding finger of the opposite (healthy) hand.

AROM at the final visit of 96° to 136° (Table 4). Theoretically, early active mobilization after flexor tendon grafts could decrease adhesion formation and improve patient outcomes compared with immobilization or the Kleinert technique. However, this remains speculative because our results were not compared with those of other postoperative motion programs.

Early active mobilization after flexor tendon grafting requires much stronger fixation of the graft than immobilization or the Kleinert technique. The weave technique of tendon interlacing, such as the Pulvertaft technique or the end-weave anastomosis used in this study, is widely applied at the graft's proximal juncture. Methods of distal graft attachment, however, remain controversial.[19] With a single interlacing suture placed through both tendons at their free ends, a repair can withstand a load of 38 N to 80 N before breaking.[20−22] Silva et al[23] reported that the average failure force was 44 N when a single bone anchor was used to reattach the tendon to the distal phalanx. Urbaniak et al[22] recorded forces of up to 35 N in the long flexors during unresisted active flexion in patients undergoing carpal tunnel surgery. Thus, we believe that our distal juncture technique (ie, application of an interlacing suture to the distal stump of the FDP or use of a small bone anchor combined with the pull-through technique) allows the graft to withstand stresses encountered during early active mobilization. The technique used depends on not only the distal FDP tendon stump length but also on the bone quality and size of the distal phalanx. For cases with poor bone quality of the distal phalanx owing to disuse after the flexor tendon injury, the interlacing suture is recommended to prevent problems related with the placement of bone anchor (ie, decrease in the strength of anchor fixation, anchor migration, and penetration of nail matrix). We prefer to carry out the pull-through technique for additional strength to an anchor repair in cases with a small distal phalanx, which can accommodate only a single micro bone anchor. The pull-out button technique has been considered the standard method for reattaching the graft to the distal phalanx. Kang et al[24] reported that the postoperative complication rate of this technique is high (65%) and included nail deformities, infection, and prolonged hypersensitivity. In addition, a biomechanical study suggested that pull-out repairs have equivalent strength to bone anchors, but the stiffness was notably lower than that observed with the bone anchor technique.[25] This finding indicates that the repair site using the pull-out button technique is at risk for excessive elongation during active digital flexion.

In the current study, the preoperative to postoperative average passive ROM to AROM ratio of the PIP and DIP joints was 83%. This recovery rate was considerably higher than that of patients managed after surgery by immobilization.[8] Average AROM at the final evaluation was only 123°, and clinical outcomes using the criteria of Strickland and Glogovac[9] and Tang[10] were suboptimal. However, these results were similar to other studies that used early active mobilization as postoperative therapy (Table 4). We believe that although the choice of postoperative treatment is obviously important, the preoperative condition of the finger (eg, the extent of scarring, presence or absence of a fibrous tendon sheath, and extent of nerve injury) is more important in terms of the probability of a good outcome after tendon grafting.

An autologous extrasynovial tendon, as used in the current study, is commonly employed to replace the injured flexor tendon. Several studies have sought to improve tendon glide and reduce adhesion by using intrasynovial tendon grafts; these grafts differ from extrasynovial tendons in terms of anatomical and biomechanical features.[26−28] Gelberman et al[29] suggested that the unique angiogenic response of intrasynovial flexor tendon grafts may allow healing with only minimal ingrowth of vascular adhesions. Recently, free-tendon grafting using intrasynovial donor tendons was performed in an effort to reduce adhesion formation[16,17]; however, the clinical results seem to be similar to those obtained after extrasynovial tendon grafting (Table 4). Compared with intrasynovial tendons, the weak point when using extrasynovial tendons as free grafts is likely to be the grip of the sutures at the distal tendon−bone junctions. Silfverskiöld et al[18] proposed that the mesh-reinforced suture technique was useful to increase the holding power of 2-stage extrasynovial tendon grafts; however, our method for the distal junction can be performed even in the case of 1-stage grafting.

Limitations of this study included the small sample size, long hospital stay, length of follow-up, and potential reviewer bias, because this study was retrospective. The small number of cases requiring flexor tendon grafting makes it virtually impossible to obtain a series sufficiently large to attain statistical significance. Unfortunately, 3 patients were excluded from the current study owing to missing data. In addition, heterogeneity, such as the zone of injury, reconstruction method, and preoperative conditions, prevents us from drawing causal conclusions from this study. Other bias domains, such as participant selection and measurement of outcomes, were low because factors associated with these domains were relatively uniform.

Our results indicate that autologous extrasynovial tendon grafts survive and heal during early active mobilization, accompanied by some adhesions. Strong graft fixation at the distal and proximal junctions, as described here, is required for safe early active mobilization after grafting. Our described technique yielded results similar in terms of active motion to previously published series without cases of graft failure.

References

1. Tang JB, Chang J, Elliot D, Lalonde DH, Sandow M, Vögelin E. IFSSH flexor tendon committee report 2014: from the IFSSH flexor tendon committee (chairman: Jin Bo Tang). *J Hand Surg Eur Vol.* 2014;39(1):107−115.
2. Moriya K, Yoshizu T, Maki Y, Tsubokawa N, Narisawa H, Endo N. Clinical outcomes of early active mobilization following flexor tendon repair using the

six-strand technique: short- and long-term evaluations. *J Hand Surg Eur Vol*. 2015;40(3):250–258.
3. Tang JB, Zhou X, Pan ZJ, Qing J, Gong KT, Chen J. Strong digital flexor tendon repair, extension-flexion test, and early active flexion: experience in 300 tendons. *Hand Clin*. 2017;33(3):455–463.
4. Fletcher DR, McClinton MA. Single-stage flexor tendon grafting: refining the steps. *J Hand Surg Am*. 2015;40(7):1452–1460.
5. Freilich AM, Chhabra AB. Secondary flexor tendon reconstruction, a review. *J Hand Surg Am*. 2007;32(9):1436–1442.
6. Pulvertaft RG, Chir M. Flexor tendon grafting. In: Flynn JE, ed. *Hand Surgery*. 3rd ed. Baltimore, MD: Williams and Wilkins; 1982:265–276.
7. Moriya K, Yoshizu T, Tsubokawa N, Narisawa H, Matsuzawa S, Maki Y. Outcomes of flexor tendon repairs in zone 2 subzones with early active mobilization. *J Hand Surg Eur Vol*. 2017;42(9):896–902.
8. LaSalle WB, Strickland JW. An evaluation of the two-stage flexor tendon reconstruction technique. *J Hand Surg Am*. 1983;8(3):263–267.
9. Strickland JW, Glogovac SV. Digital function following flexor tendon repair in Zone II: a comparison of immobilization and controlled passive motion techniques. *J Hand Surg Am*. 1980;5(6):537–543.
10. Tang JB. Outcomes and evaluation of flexor tendon repair. *Hand Clin*. 2013;29(2):251–259.
11. Boyes JH, Stark HH. Flexor-tendon grafts in the fingers and thumb: a study of factors influencing results in 1000 cases. *J Bone Joint Surg Am*. 1971;53(7):1332–1342.
12. Whebé MA, Mawr B, Hunter JM, Schneider LH, Goodwyn BL. Two-stage flexor-tendon reconstruction: ten-year experience. *J Bone Joint Surg Am*. 1986;68(5):752–763.
13. Tonkin M, Hagberg L, Lister G, Kutz J. Post-operative management of flexor tendon grafting. *J Hand Surg Br*. 1988;13(3):277–281.
14. Bertelli JA, Santos MA, Kechele PR, Rost JR, Tacca CP. Flexor tendon grafting using a plantaris tendon with a fragment of attached bone for fixation to the distal phalanx: a preliminary cohort study. *J Hand Surg Am*. 2007;32(10):1543–1548.
15. Khan K, Riaz M, Murison MS, Brennen MD. Early active mobilization after second stage flexor tendon grafts. *J Hand Surg Br*. 1997;22(3):372–374.
16. Leversedge FJ, Zelouf D, Williams C, Gelberman RH, Seiler JG III. Flexor tendon grafting to the hand: an assessment of the intrasynovial donor tendon—A preliminary single-cohort study. *J Hand Surg Am*. 2000;25(4):721–730.
17. Ohi H, Uchiyama S, Kanda T, Mukoda M, Hayashi M, Kato H. Outcomes of grafting intrasynovial tendons of the toes to the hands in 10 patients: a preliminary report. *J Hand Surg Eur Vol*. 2017;42(5):469–472.
18. Silfverskiöld KL, May EJ. Early active mobilization of tendon grafts using mesh reinforced suture techniques. *J Hand Surg Br*. 1995;20(3):301–307.
19. Wei Z, Thoreson AR, Amadio PC, An KN, Zhao C. Distal attachment of flexor tendon allograft: a biomechanical study of different reconstruction techniques in human cadaver hands. *J Orthop Res*. 2013;31(11):1720–1724.
20. Gabuzda GM, Lovallo JL, Nowak MD. Tensile strength of the end-weave flexor tendon repair: an in vitro biomechanical study. *J Hand Surg Br*. 1994;19(3):397–400.
21. Tanaka T, Zhao C, Ettema AM, Zobitz ME, An KN, Amadio PC. Tensile strength of a new suture for fixation of tendon grafts when using a weave technique. *J Hand Surg Am*. 2006;31(6):982–986.
22. Urbaniak JR, Cahill JD Jr, Mortenson RA. Tendon suturing methods: analysis of tensile strengths. In: *American Academy of Orthopaedic Surgeons Symposium on Tendon Surgery in the Hand*. St. Louis, MO: CV Mosby; 1975:70–80.
23. Silva MJ, Hollstien SB, Fayazi AH, Adler P, Gelberman RH, Boyer MI. The effects of multiple-strand suture techniques on the tensile properties of repair of the flexor digitorum profundus tendon to bone. *J Bone Joint Surg Am*. 1998;80(10):1507–1514.
24. Kang N, Marsh D, Dewar D. The morbidity of the button-over-nail technique for zone 1 flexor tendon repairs: should we still be using this technique? *J Hand Surg Eur Vol*. 2008;33(5):566–570.
25. Matsuzaki H, Zaegel MA, Gelberman RH, Silva MJ. Effect of suture material and bone quality on the mechanical properties of zone I flexor tendon-bone reattachment with bone anchors. *J Hand Surg Am*. 2008;33(5):709–717.
26. Hasslund S, Jacobson JA, Dadali T, et al. Adhesions in a murine flexor tendon graft model: autograft versus allograft reconstruction. *J Orthop Res*. 2008;26(6):824–833.
27. Momose T, Amadio PC, Zobitz ME, Zhao C, An KN. Effect of paratenon and repetitive motion on the gliding resistance of tendon of extrasynovial origin. *Clin Anat*. 2002;15(3):199–205.
28. Uchiyama S, Amadio PC, Coert JH, Berglund LJ, An KN. Gliding resistance of extrasynovial and intrasynovial tendons through the A2 pulley. *J Bone Joint Surg Am*. 1997;79(2):219–224.
29. Gelberman RH, Chu CR, Williams CS, Seiler JG III, Amiel D. Angiogenesis in healing autogenous flexor-tendon grafts. *J Bone Joint Surg Am*. 1992;74(8):1207–1216.