Invited review article

Hand therapy of the repaired flexor digitorum profundus tendon

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Abstract

There are several postsurgical protocols for the hand therapy of flexor tendon injury. The modifications in splints and hand therapy protocols, along with advancement in surgical materials and technique for flexor tendon repair, have allowed the therapy of sutured flexor tendon to continue to evolve toward early mobilization. Yoshizu introduced a new six-strand suture technique, called the Yoshizu #1 technique, so that the early active flexion exercises have been performed. Recently, the hand therapy protocols using early active motion, such as the Kleinert method, the Duran method, and active place-and-hold exercise are popular. Many surgeons and therapists are modifying these techniques or using combined techniques to improve outcomes. However, optimal model of hand therapy protocol of flexor tendon injury has not been identified. We have adopted early active flexion exercise for hand therapy protocol of flexor tendon injury since the Yoshizu #1 technique was developed and have improved our protocol little by little to acquire a good outcome of the treatment. In this paper, we describe about the overview of the operative techniques, the postoperative treatment and the evaluation for flexor tendon injury that our group performs actually.

Introduction

There are several postsurgical protocols for the hand therapy of flexor tendon injury. Harmer introduced a tendon suture with a recommendation for early active mobilization in 1917 [1], although this approach did not become widespread, so that before the 1970s, most flexor tendon therapy protocols focused on immobilization during the first 3 weeks following repair, which was based on extrinsic healing process. However, in the mid-1970s, the controlled passive motion was reported by Duran and Houser. They stated that 3 to 5 mm of tendon excursion was sufficient to prevent restrictive adhesions following tendon repair [2]. In addition, Lister and Kleinert reported excellent results with immediate passive motion using an extension block splint that allowed active finger extension and an attached rubber band on the nail of the injured finger which keeps on passive flexion position [3, 4]. These protocols protect an adhesion at the repair site of the tendon and provide the tensile strength needed for optimal active motion. Since that time, modifications in splints and hand therapy protocols, along with advancement in surgical materials and technique,

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have allowed the therapy of sutured flexor tendon to continue to evolve toward early mobilization [5]. Various core suture techniques designed to tolerate tension during early active mobilization have been described [6]. Tang stated that nine factors that affect the strength of a surgical repair, namely the number of suture strands, the tension of the repair, the core suture purchase, the type of tendon–suture junction, the diameter of the suture locks in the tendons, the suture calibre, and the peripheral suture [6]. Yoshizu (1996) introduced a new six-strand suture technique, called the Yoshizu #1 technique, intended to maximize early active mobilization. The Yoshizu #1 technique simplifies the six-strand suture technique because it comprises the Kessler and Tsuge techniques, and its average maximum load at a 3-mm gap formation was reported to be 42 N [7]. Additionally, the Yoshizu #1 technique maintains its original strength 1 week after surgery, and the maximum load up to a 3-mm gap at 3 weeks after repair significantly exceed the loads measured at the time of repair [7]. This method satisfies almost all of Tang's nine factors. As describing above, core suture techniques have been designed to evolve toward early mobilization, however, optimal model of hand therapy protocol of flexor tendon injury has not been identified.

Most would agree that the ideal protocol would allow enough excursions [8, 9] (Figure 1) to prevent adhesion formation without creating stress that would compromise the tendon repair. Within the last decade, there have been many articles published regarding tendon excursion and safe tendon loading immediately after surgery. These articles laud the benefits of early active mobilization for increased tendon strength and improved active range. Silfverskiöld and May reported that tendon excursion positively correlates with clinical results and carefully controlled active flexion should produce greater tendon excursion than passive flexion [10, 11]. On the other hand, other groups have attempted systematic literature reviews of hand therapy

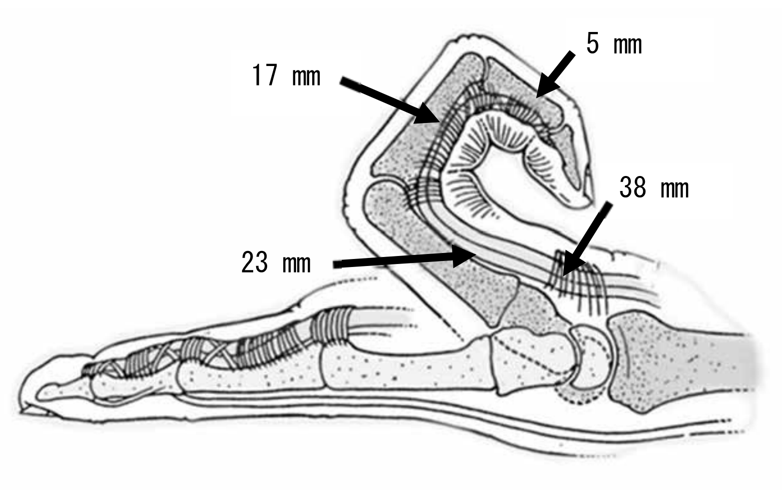


Figure 1. Tendon excursion of flexor digitorum profundus [9]

protocols following flexor tendon repair. Chesney et al reviewed hand therapy protocols of flexor tendon injuries in zone Ⅱ. They determined that early motion protocols were superior to static splinting and that no significant difference existed between early active and early passive protocols [12]. Additionally, the dynamic tenodesis motion at the wrist and fingers also are also gaining favor. However, the range of flexor tendon excursion to the proximal direction cannot be gained by these early passive techniques, so that early active flexion is thought to be important to overcome this fault.

Recently, hand therapy protocols using early active motion, such as the Kleinert method, the Duran method, and active place-and-hold exercise which places active loading or tension on the tendon in conjunction with an extension block splint are popular. Many surgeons and therapists are modifying these techniques or using combined techniques to improve outcomes [13]. Regarding a dorsal plaster splint, the wrist commonly is placed in slight flexion (10–30°). Lieber measured tendon force during electric stimulation of the proximal flexor muscle mass using a clinically relevant canine model and showed that the FDP (flexor digitorum profundus) tendon force with the wrist extended was two to three times greater than that measured with the wrist flexed [14] (Figure 2). In addition, the study using electrical stimulation to the FDP of human showed that the grip force during electrical stimulation to the FDP significantly increased with the increase of the wrist dorsiflexion angle and that at the wrist neutral position was significantly higher as compared with that at palmar flexion 30 degrees [15] (Figure 3). However, there have been many articles published regarding immobilized wrist position. Actually, the immobilized position of the wrist is chosen according to surgeons and therapists preferences

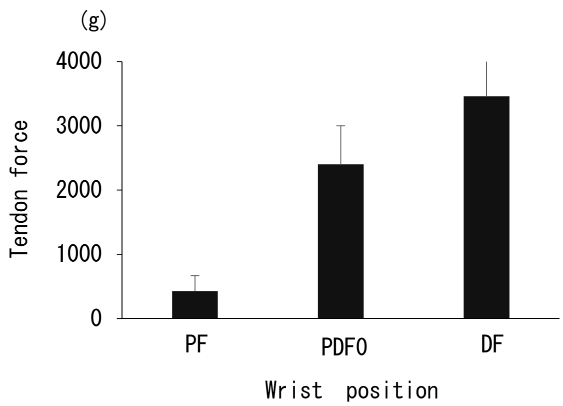


Figure 2. Tendon force during electric stimulation of proximal flexor muscle mass using a canine model
PF: wrist palmar flexion, PDF0: wrist neutral position, DF: wrist dorsiflexion

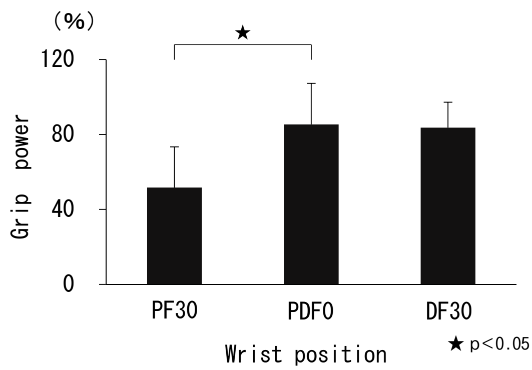


Figure 3. Grip force during electrical stimulation to flexor digitorum profundus
PF30: wrist palmar flexion in 30 degree, PDF0: wrist neutral position, DF30: wrist dorsiflexion in 30 degree

(Table 1).

We have adopted early active flexion exercise for the hand therapy protocol of flexor tendon injury from 1993, and added improvement to security little by little to acquire a good outcome of the treatment [16]. In this paper, we describe about the overview of the operative techniques, the postoperative treatment and the evaluation for flexor tendon injury that our group performs actually.

Overview of operative techniques

We use Yoshizu #1 technique for tendon repair because gliding resistance is 1kg or less for normal tendon excursion, and even if gliding resistance of sutured tendon increase, Yoshizu #1 of which the tensile strength is about 4Kg is enough for tendon gliding.

First, the FDS (flexor digitorum sublimis) tendon is repaired with 4-0 or 5-0 monofilament nylon using figure-of-eight or Tsuge sutures, plus peripheral epitenous sutures using 6-0 monofilament nylon. Next, the FDP tendon is repaired using the Yoshizu #1 technique [7, 17]. The Yoshizu #1 technique is a combination of the Tsuge suture with a looped thread and the modified Kessler suture, using double threads with two needles (Bear Medic Corp., Ichikawa, Japan) attached to 4-0 monofilament nylon. Locking sites on the modified Kessler suture are at least 7 mm apart from the tendon ends, whereas the locking sites on the Tsuge suture are at least 9 mm from the tendon ends. A simple running peripheral epitenous suture is added using 6-0 monofilament nylon. The tendon sheath opening is excised where sutured areas of the repaired tendons caught on the edges of their sheath windows and obstructed free movement. In addition, partially excising or venting of the A2 pulley (about one-half to two-thirds the length of the A2 pulley) is performed when both the FDS and FDP tendons is repaired in the area of the A2 pulley (Zone 2C) [6, 18].

Table 1. Wrist position with early mobilization program combining passive and active flexion

study	year	repair method	No. strand	wrist position	rupture ratio
Brunelli G, et al	1983	Slip-knots suture	2-strand	25°flexion	3%
Savage R, et al	1989	Three grasping stitch suture	6-strand	0°flexion	4%
Cullen KW, et al	1989	Modified Kessler suture	2-strand	30°flexion	4%
Small JO, et al	1989	Kessler-Mason-Allen suture	2-strand	mid (45°) flexion	8%
Bainbridge LC, et al	1994	Modified Kessler suture	2-strand	30°flexion	7%
Elliot D, et al	1994	Tajima suture	2-strand	30°flexion	6%
Silfverskiold K, et al	1994	Modified Kessler suture	2-strand	0°flexion	4%
Baktir A, et al	1996	Modified Kessler suture	2-strand	0°flexion	2%
Yoshizu T, et al	1996	Yoshizu-1	6-strand	0°flexion	6%
Hatanaka H, et al	2002	Hatanaka suture	2-strand	20°flexion	1%
Klein L, et al	2003	Tajima, Modified Kessler suture	4-strand	0°flexion	3%
Hung LK, et al	2005	Modified Kessler suture	2-strand	40°flexion	7%
Yen CH, et al	2008		4-strand	30°flexion	1/20 pt
Saini N, et al	2010	Modified Kessler suture	2-strand	0-5°flexion	3%

Postoperative treatment

If the hospitalization of at least four weeks after surgery is possible, we choose the early active mobilization for postoperative treatment but choose an immobilization method for three weeks if impossible. When the early active mobilization for postoperative treatment is chosen, a selected therapist enters the operating room and during operation, confirms the situation and site of the sutured tendon, and the remained ligamentous sheath. Generally hand therapy techniques using the modified Kleinert method, Duran method and active flexion exercises are carried out the first 3 weeks postoperatively [16].

Postoperatively the hand is immobilized in a dorsal plaster splint by the therapist. We chose a neutral position as the wrist immobilization position. The MP (metacarpophalangeal) joints are held at 30-60° of flexion and the proximal and distal interphalangeal joints are allowed to full extension. Rubber band traction is used a monofilament nylon or a string attached to a fingernail of injured finger. It is pulled proximally under a pulley placed in the palm of the hand and is knotted with a rubber band attached to a splint on the proximal forearm. The rubber band traction is applied to all four fingernails to prevent extension contracture and to gain the tendon excursion proximally (Figure 4).

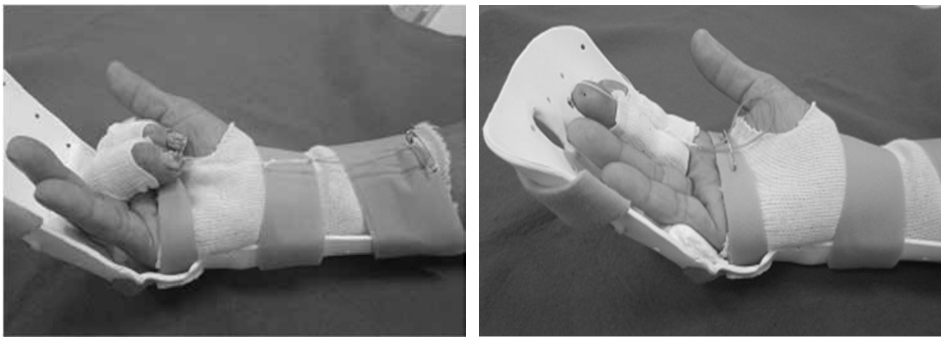
Mobilization is begun on the first postoperative day, regardless of digital nerve repairs. The patients performed ten active PIP (proximal interphalangeal) and DIP (distal interphalangeal) joint extension exercises each hour. During extension exercises, a pad is placed on the dorsum of the proximal phalanx to act as a fulcrum for full extension and the tension of the rubber band is unloaded by drawing it distally by the therapist. In addition, the controlled passive extension is preformed to prevent the development of flexion contracture of the PIP and DIP joints according to Duran's method [2]. The passive flexion produced by the rubber band traction is increased by pushing down on the tips of the digits as much as possible. While flexing the PIP and DIP joints passively, the patients are instructed to hold the digits gently and actively for 2-3 sec. This active flexion exercise is performed about five sets (ten times per set) per day under the supervision of the therapist. Active flexion exercises without passive help are not encouraged because the finger and tendons would be swollen and have more friction at this time. At 1 week after beginning the mobilization, unassisted active flexion exercises, such as simple fisting within the restraints of the dorsal plaster splint, are allowed up to five sets. In addition, an independent tendon gliding exercise of the FDS is performed under the supervision of the therapist. At night, the rubber band is released from their attachment on the forearm and the digits are placed in an extended position comfortably.

At 4 weeks after surgery, dorsal block splint is permitted to remove for gentle active flexion-extension exercises, however, the splint is worn at all times except during hand therapy. The patients are instructed to extend the wrist actively with active digit flexion and to relax the wrist into flexion with simultaneous digit extension.

At 6 weeks after surgery, Bunnell blocking exercises are initiated, if necessary, to improve the range of active flexion of digits. The dorsal block splint is removed except at night. The splint is fully removed at 8 weeks after surgery, and the simultaneous extension of the wrist and digits is permitted. The power gripping is allowed at 12 weeks after surgery.

Outcome measurement

Clinical results are evaluated using TAM (total active motion) and Strickland and Glogovac's criteria [19]. TAM is the sum of maximal active motion ranges at the MP, PIP and DIP joints in the fist position, minus the total extension deficit at these joints [20, 21]. In addition, FDP muscle power testing is also needed. Generally, Jamar hand held dynamometer is used for the grip



(a) modified Kleinert method

(b) Duran method

(c) active flexion exercises (place and hold)

Figure 4. Hand therapy techniques using the modified Kleinert method, Duran method and active flexion exercises

strength measurement, however, FDP strength cannot be assessed using this dynamometer. The hand dynamometer (CFS003, Reptrino, Nagano, Japan) which authors developed comprises an independent tension sensor for each finger (Figure 5). The patients place a ring connected to the sensor on the distal phalanx. The flexion force of each finger can be measured by grasping (Figure 6). Figure 7 showed that the flexion force of the ring finger during electrical stimulation with

Figure 5. Developed hand dynamometer

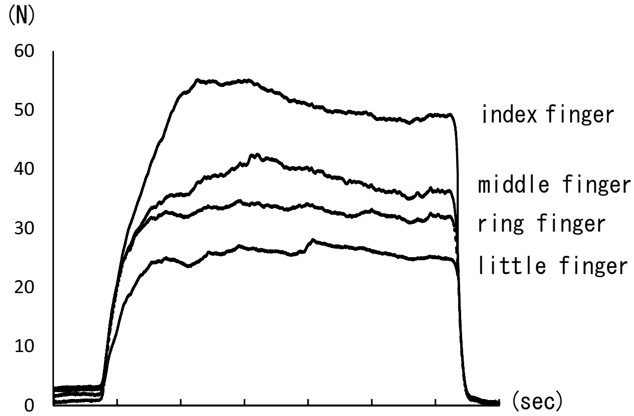


Figure 6. Flexion force of each finger using hand dynamometer during grasping

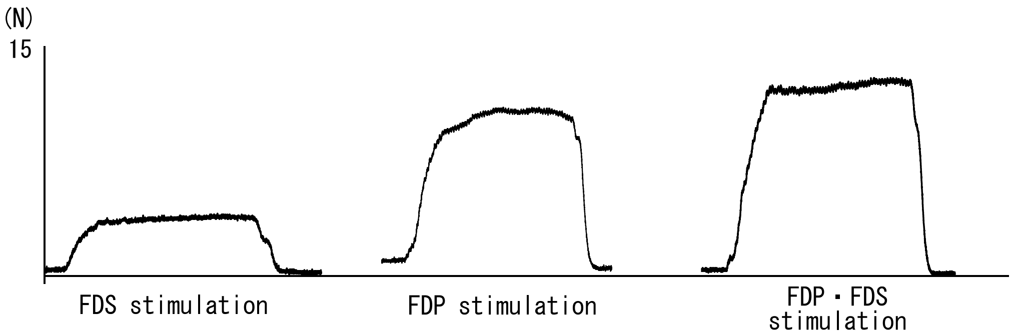


Figure 7. Flexion force of the ring finger during electrical stimulation with the constant intensity to the ulnar side of FDP and FDS

the constant intensity to the ulnar side of FDP and FDS of the ring finger, and it is found that the contractive force of the FDP is reflected more in the flexion force as compared with that of FDS. With Jamar hand held dynamometer, muscle activity of FDS is always superior to that of FDP, which is around 80% of maximum voluntary contraction even at maximal grip and in contrast, with the development hand dynamometer, the FDP activity increases accompanied with the increase of the grip strength and reached to 100% activity. Thus, we recommend use of the hand dynamometer which we developed. In addition, the Quick Disability of the Arm, Shoulder, Hand-Japanese version ('Quick DASH-JSSH') score is recorded for patient-rated outcomes only in the long-term follow-up evaluation [22].

Conclusion

It is important to get certain tendon suture techniques and choice of the correct protocol for the flexor tendon injury to obtain a stable treatment outcome in accord with the fact of the practice. It is not necessary to challenge early active mobilization taking a risk. The immobilization method takes time until it is cured, but the final outcome is not poor if a tenolysis is performed. If the early active mobilization for postoperative treatment is chosen, it is necessary that hand surgeon has a right technique of tendon suture with the correct way for the early active mobilization for flexor tendon repair. For hand therapists, the skills for diagnosis of tendon adhesion and contracture, and control abilities for exercises based on the diagnostic results are necessary. The nurse must check that the hospitalized patients are performing the exercise safely in the ward. Furthermore, the patients must have the high motivation and ability for understanding the postoperative treatment schedule and meaning of the exercises.

References

1. Elliot D, Giesen T. Avoidance of unfavourable results following primary flexor tendon surgery. Indian J Plast Surg. 2013; 46: 312-324.
2. D Duran RJ, Houser RG. Controlled passive motion following flexor tendon repair in zones 2 and 3. In: American Academy of Orthopaedic Surgeons Symposium on tendon surgery in the hand. St. Louis: CV Mosby; 1975; 105-114.
3. Lister GD, Kleinert HE, Kutz JE, Atasoy E. Primary flexor tendon repair followed by immediate controlled mobilization. J Hand Surg Am. 1977; 2: 441-451.
4. Werntz JR, Chesher SP, Breidenbach WC, Kleinert HE, Bissonnette MA. A new dynamic splint for postoperative treatment of flexor tendon injury. J Hand Surg Am. 1989; 14: 559-566.
5. Edinburg M, Widgerow AD, Buddulph SL. Early postoperative mobilization of flexor tendon injuries using a modification of the Kleinert technique. J Hand Surg Am. 1987; 12: 34-38.
6. Tang JB. Flexor tendon injury and reconstruction. In: Chang J, editor. Plastic surgery. 3rd ed. London: Elsevier Saunders; 2013; 178-209.
7. Kusano N, Yoshizu T, Maki Y. Experimental study of two new flexor tendon suture techniques for postoperativeearly active flexion exercises. J Hand Surg Br. 1999; 24: 152-156.
8. Verdan CE, Primary repair of flexor tendons. J Bone Joint Surg Am. 1960; 42A: 647-57.
9. Strickland JW. Biologic rationale, clinical application, and results of early motion following flexor tendon repair. J Hand Ther. 1989; 2: 71-83.
10. Silfverskiöld KL, May EJ. Flexor tendon repair in zone II with a new suture technique and an early mobilization program combining passive and active flexion. J Hand Surg Am. 1994; 19: 53-60.
11. Silfverskiöld KL, May EJ, Törnvall AH. Flexor digitorum profundus tendon excursions during controlled motion after flexor tendon repair in zone II: a prospective clinical study. J Hand Surg Am. 1992; 17: 122-131.
12. Chesney A, Chauhan A, Kattan A, Farrokhyar F, Thoma A. Systematic review of flexor tendon rehabilitation protocols in zone II of the hand. Plast Reconstr Surg. 2011; 127: 1583-1592.
13. Chow JA, Thomes LJ, Dovelle S, Milnor WH, Seyfer AE, Smith AC. A combined regimen of controlled motion following flexor tendon repair in “no man’s land.” Plast Reconstr Surg. 1987; 79: 447- 455.
14. Lieber RL, Amiel D, Kaufman KR, Whitney J, Gelberman RH. Relationship between joint motion and flexor tendon force in the canine forelimb. J Hand Surg Am. 1996; 21: 957-962.
15. Oyama M, Odagiri M, Matsuzawa S,

Nakamura Y, Houei T, Yoshizu T. Relationship between wrist position and muscle force and activities in the flexor digitorum profundus (in Japanese). J Hand Surg Jpn. 2015; 31: 1025-1029.
16. 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. 2015; 40: 250-258.
17. Yoshizu T. Immediate mobilization following flexor tendon repair (in Japanese). J Musculoskelet Syst. 1996; 9: 881-890.
18. Tang JB. Clinical outcomes associated with flexor tendon repair. Hand Clin. 2005; 21: 199-210.
19. 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: 537-543.
20. Elliot D, Harris SB. The assessment of flexor tendon function after primary tendon repair. Hand Clin. 2003; 19: 495-503.
21. Tang JB. Clinical outcomes associated with flexor tendon repair. Hand Clin. 2005; 21: 199-210.
22. Imaeda T, Toh S, Wada T, Uchiyama S, Okinaga S, Kusunose K, et al. Validation of the Japanese Society for Surgery of the Hand Version of the Quick Disability of the Arm, Shoulder, and Hand (Quick DASH JSSH) questionnaire. J Orthop Sci. 2006; 11: 248-253.