A Randomized Clinical Trial Comparing Immediate Active Motion With Immobilization After Tendon Transfer for Claw Deformity

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Purpose Immobilization after tendon transfers has been the conventional postoperative management. A recent study indicated beneficial effects of an immediate active motion protocol (IAMP) after tendon transfer for claw deformity correction compared with effects in a historical cohort. In this study, we further tested this hypothesis in a randomized clinical trial comparing the effectiveness of the IAMP with that of conventional immobilization.

Methods Fifty supple claw hand deformities were randomized postoperatively into 2 equal groups for IAMP and immobilization. Therapy began on the second postoperative day for the IAMP group and on the twenty-second postoperative day for the immobilization group. The primary outcome measures were deformity correction, active range of motion of digits, tendon transfer insertion pullout, and time until discharge from rehabilitation. Secondary outcome measures were swelling, pain, hand strength, and dexterity. Both groups were compared at discharge from rehabilitation and at the last clinical follow-up (at least 1 year postoperatively).

Results Assessments were available for all 50 patients at discharge and for 23 patients in each group at follow-up. The average follow-up was 18 months for the IAMP group and 17 months for the immobilization group. Deformity correction, range of motion, swelling, dexterity, and hand strength were similar for both groups at discharge and a follow-up. There was no evidence of tendon insertion pullout in any patient of either group. Relief of pain was achieved significantly earlier with IAMP. Morbidity was reduced by, on average, 22 days with IAMP.

Conclusions We found that the immediate active motion protocol is safe and has similar outcomes compared with those of immobilization, with the added advantage of earlier pain relief and quicker restoration of hand function. Immediate motion after tendon transfer can significantly reduce morbidity and speed up the rehabilitation of paralytic limbs, and it may save expense for the patients. *(J Hand Surg 2009;34A:488–494. Copyright © 2009 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Therapeutic I.

Key words Claw deformity correction, immediate active motion protocol, Zancolli's lasso procedure, postoperative morbidity, reeducation of tendon transfer.

Additional material is available online.

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Immobilization is the conventional postoperative management after tendon transfers in hands and feet. Restoration of function after tendon transfers usually requires a relatively long period of time because of immobilization and the re-education process. Studies showing improvement in tendon repair outcome after early active motion[1] provided a basis to investigate the feasibility of early mobilization after tendon transfers.

A claw hand due to ulnar nerve neuritis is the most common deformity in the upper limb in Hansen's disease.[2] Whereas the success rate of tendon transfers for claw hand correction in the supple hand is high,[2,3] acceptance of corrective surgery is low because of morbidity throughout the long rehabilitation time and loss of earnings during treatment. Early active mobilization after tendon transfers would accelerate the period of rehabilitation for paralytic limbs and may therefore resolve a major hurdle of reconstructive surgery. Recent studies by Rath demonstrated the safety of early active mobilization of claw deformity correction[3] and opposition transfers[4] in small-cohort studies that were compared with a historical cohort of patients that had received immobilization. These studies indicated that early active mobilization might lead to similar outcomes with reduced rehabilitation time compared with immobilization. However, these cohorts were not controlled in a randomized clinical design, and information on secondary outcome measures such as pain, swelling, grip, pinch, and hand function was limited. To establish the effectiveness of the concept of early active mobilization protocol more rigorously, we designed a randomized clinical trial to compare early active mobilization with immobilization of tendon transfers for claw deformity correction in the hands of patients with Hansen's disease.

MATERIALS AND METHODS

Patients

Patients with claw deformity who had been referred to a large regional leprosy reconstructive surgery hospital were asked to participate in a single-center trial from May 2005 to June 2006. During this period, 69 patients had surgery for claw deformity correction performed by the first author, of whom 50 met the criteria for inclusion in the randomized clinical trial. Therapists in the outpatient department selected the participants for the trial. Data of all 50 patients obtained during postoperative therapy were analyzed for early results. Forty-six patients were available for follow-up beyond 1 year for late analysis (Fig. 1).

Patients were included when they had the following:

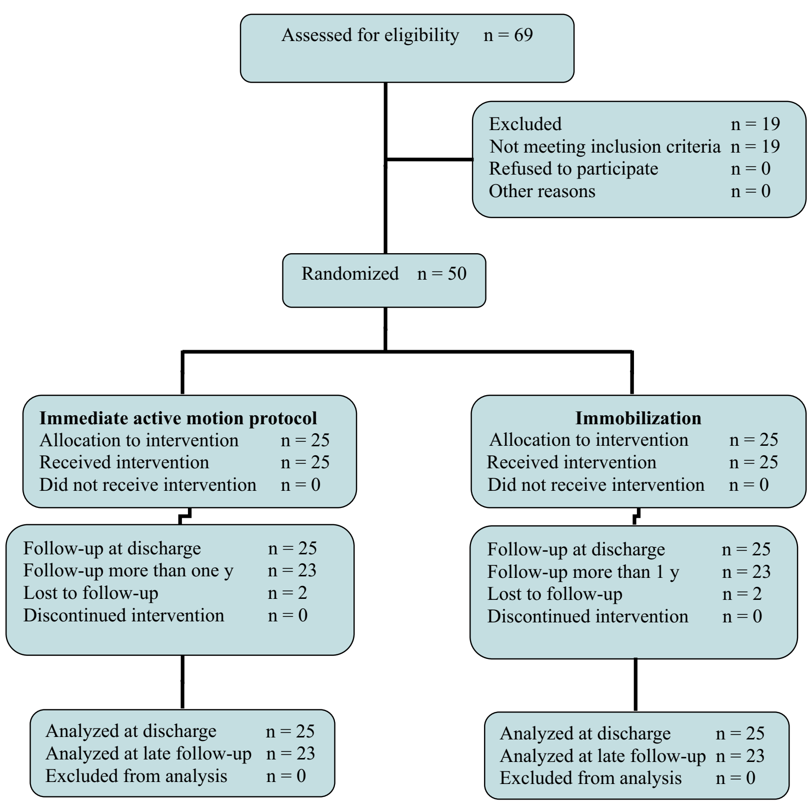

FIGURE 1: Flowchart of patients in the randomized clinical trial.

(1) Ulnar nerve paralysis of more than 1 year's duration and completion of multidrug therapy for treatment of Hansen's disease. Hands with combined ulnar and low median nerve paralysis were also included, provided the ulnar nerve paralysis had been present for at least 1 year. (2) A supple claw hand without contractures at the time of surgery.[5] (3) A latent claw deformity in which digits can voluntarily achieve the intrinsic plus position (metacarpophalangeal [MCP] joint flexion with proximal interphalangeal [PIP] joint in full extension) but develops clawing with an extension force applied by the therapist over the MCP joint. Latent claw digits received tendon transfer simultaneously to avoid the possibility of future clawing.[6] (4) Good preoperative isolation of the flexor digitorum superficialis (FDS) of the middle finger indicated by voluntary contraction of the donor FDS.

Patients were excluded when they had the following: (1) complicated claw hands,[7] defined as the inability to extend the PIP joint with the MCP joint blocked in flexion (negative Bouvier test[5]) or MCP joint contracture in extension, and (2) an FDS middle finger unsuitable as a donor because of weakness of the flexor digitorum profundus.

Approval was obtained from the institutional review board and informed consent forms were signed by all patients.

Group allocation

The patients were divided equally into a group receiving an immediate active motion protocol (IAMP) and a group receiving an immobilization protocol for 3 weeks after surgery (immobilization group). Randomization into 2 groups was performed using unmarked, sealed opaque envelopes that were mixed thoroughly in a box. A person not involved in the trial did the group assignment by opening an envelope picked at random from the box after completion of surgery and wound closure. A therapist not involved in the care of the patient and blinded to group assignment performed the last follow-up assessment at home or at a regional follow-up clinic.

The groups were similar for age, gender, and site, type, and duration of paralysis (Table 1). Seven hands in the IAMP group and 5 hands in the immobilization group had combined ulnar and median nerve paralysis. Four digits in the IAMP group and 3 digits in the immobilization group had latent clawing. All 50 hands had 4 digit claw corrections.

TABLE 1. Descriptive Data for the IAMP Group and the Immobilization Group at Baseline

Parameter	IAMP Group	Immobilization Group	p Value*
Age, y (mean ± SD)	31 ± 10	28 ± 10	.54
Male, n	20	19	
Female, n	5	6	
Duration of paralysis, y (mean ± SD)	4 ± 4	3 ± 2	.79
Type of paralysis			
Ulnar, n	18	20	
Median and ulnar, n	7	5	
Site, n	R = 15	R = 12	
	L = 10	L = 13	

*Values indicate the significance level of the *t*-test comparing both groups.

Surgical techniques

The surgical procedure was similar to that described by Rath.[3] The FDS of the middle finger was sectioned between the C1 and A2 pulleys using an oblique volar incision in the finger, retrieved though a small incision distal to the carpal tunnel, and split lengthwise into 4 equal parts. The tendon slips were routed along the lumbrical canal to each finger and inserted into the A1 and proximal A2 pulleys. With the wrist in neutral position, the tendon slips were tensioned to produce MCP joint flexion of 50° to 70° with more flexion in the ulnar digits. The tendon slip was folded back, attached to itself with a Pulvertaft weave, and sutured using a 3-0 nonabsorbable suture as described by Rath[3] (Fig. 2). The hands for the IAMP group were supported for pain relief with a plaster of Paris dorsal splint extending to the PIP joint with the wrist in neutral position and the MCP joint in 70° of flexion. A circular plaster of Paris cast was applied in the same position in the immobilization group for 3 weeks.

Therapy protocols

The postoperative rehabilitation was institution-based (inpatient) and under supervision of a therapist trained specifically for care of paralyzed hands and feet (Appendix 1; this appendix may be viewed at the *Journal's* Web site, www.jhandsurg.org). The postoperative protocols were similar in both groups except that the transfer was actively mobilized on the 2nd postoperative day in the IAMP group and at the beginning of the 4th postoperative week in the immobilization group. As a result, the treatment protocol in the 1st, 2nd, 3rd, and 4th postoperative weeks in the IAMP group corresponded with the protocol in the 4th, 5th, 6th, and 7th postoperative weeks in the immobilization group. In

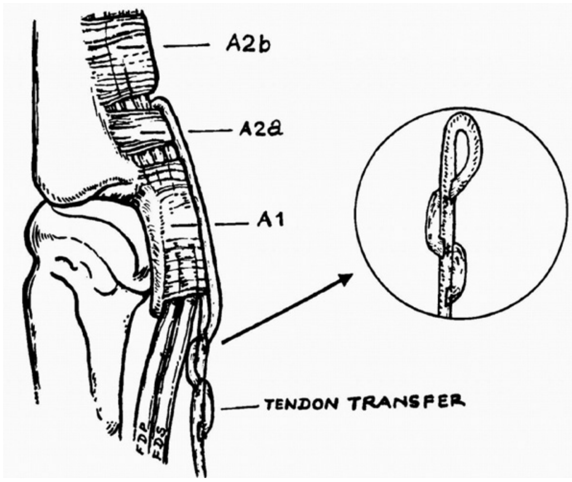

FIGURE 2: Diagram to illustrate the insertion of FDS slip to A1 and A2a flexor pulley and the Pulvertaft weave for tendon attachment. (Reprinted with permission from Rath, S. Immediate postoperative active mobilization versus immobilization following tendon transfer for claw deformity correction in the hand. J Hand Surg 33A:232–240.)

addition, in the immobilization group, digital casts in full extension were applied during the first 2 weeks as the standard postimmobilization therapy protocol to assist concentrate transfer action on the MCP joint.

In the first 2 weeks of therapy, patients were trained to perform active flexion of the MCP joint while attempting to keep the PIP joint in full extension and to perform fist closure by active PIP joint flexion. For opening the fist, the PIP joints are actively extended at first by keeping the MCP joints flexed and then extending the MCP joint to achieve an open hand position. The therapist blocked the MCP joint at 30° with a dorsal splint to avoid overstretching of the transfer. From the position of maximum MCP joint extension in the open hand position, the flexion sequence was repeated to fist closure.

During the first 2 weeks of therapy in the immobilization group, we used PIP joint digital casts in full extension to concentrate transfer action during MCP joint flexion and relaxation of transfer during MCP joint extension. The cast was removed each day during therapy, and the sequence to achieve open hand position and fist closure was followed similar to that in the IAMP group. Digital casts were discontinued by the end of the 2nd week as the transfer action (of MCP joint flexion) is usually integrated with that of the extensor digitorum communis action producing PIP joint extension. Ability to maintain actively the MCP joint in flexion and the PIP joint in the range 0 to 30° indicates good integration of the transferred tendon with the action of the extensor digitorum communis. When necessary, digital casts were continued longer until this integration was established.

We started transfer strengthening exercises and light functional activities after good integration of the transfer. At the end of the 3rd week of therapy, patients in both groups received occupational therapy for daily living activities restricted to a weight limit of 0.5 kg. Hands in both groups were supported after therapy with a dorsal blocking splint that kept the MCP joint in 70° of flexion in the 1st week and 50° in the 2nd week. Thereafter, the dorsal blocking splint was reduced to 30° and used only at night for 3 months. Patients were usually discharged from rehabilitation at the end of the 4th week of therapy. All patients were discharged with good integration of transfer and deformity correction. For patients with only ulnar nerve paralysis, a prerequisite for discharge was the ability to perform activities of daily living (ADL) like dressing, grooming, and eating. Activities of daily living assessments in hands with combined ulnar-median nerve paralysis were not done after claw correction, as these hands required an opposition transfer to achieve ADL. Hands with swelling and poor integration of transfer continued with therapy until good deformity correction and ADL were achieved. The discharge was decided independently by the treating therapist, and the physician conducting the trial remained blinded to the timing of discharge.

We advised patients to return for clinical follow-up monthly for 3 consecutive months after discharge, then at 3-month intervals for 1 year and subsequently once a year. Patients with good transfer integration and strength were allowed to return to sedentary occupation at 8 weeks and unrestricted activities at 12 weeks after discharge from rehabilitation.

Outcome assessment

The primary goal of the immediate mobilization was to obtain earlier discharge from rehabilitation with successful claw deformity correction and without an increase of tendon transfer insertion pullout. Therefore, primary outcome measures were deformity correction, active range of motion (AROM) of digits, tendon transfer pullout incidence, and time until discharge. As secondary outcome measures, we measured swelling, hand strength, pain, and dexterity.

To assess hand function, we asked patients to move the hand actively to an open hand position (MCP and interphalangeal joints fully extended), intrinsic plus position (MCP joints flexed and interphalangeal joints extended), and fist position. The MCP joint and PIP joint angles in open hand and intrinsic plus position indicate the level of deformity correction.[3] The intrinsic plus position, in addition, provides an objective assessment of transfer integration after claw digit correction.[3] Active range of motion of each digit was calculated by subtracting angles at open hand position from fist closure angles. All angles in the individual patients were recorded in steps of 5°.

Tendon transfer insertion pullout was objectively assessed by inspection of the MCP joint angles recorded daily for the first 2 weeks of therapy and then at the end of each week. As described earlier,[3] rapid extension of MCP joint in open hand position with loss of MCP joint flexion in intrinsic plus position and decrease in AROM of MCP joint indicates transfer insertion pullout.

Swelling was determined by measuring the volume of the operated hand using a water displacement method.[8] The percentage increase of postoperative over preoperative volume was compared for both groups at discharge from rehabilitation.

Grip strength was measured using a Jamar dynamometer, and key pinch strength was measured using a pinch dynamometer (North Coast Medical Inc., Morgan Hill, CA). To compare groups, the percentage change over the preoperative strength was determined.

Pain was measured using a visual analog scale with scores from 0 (no pain) to 10 (most severe pain). Assessments were done at the end of each week of therapy. Postoperative time in weeks when a zero-score was achieved was compared for both groups.

Dexterity was measured using the timed pick-up test. The percentage change in time (seconds) compared with the preoperative score was determined for comparison of the groups.

Deformity correction, AROM, timed pick-up test, and pinch and grip strengths were assessed during follow-up. Return to work was assessed at 3-month follow-up after discharge from rehabilitation. Outcome assessments of both groups were compared at (1) discharge from rehabilitation (discharge analysis) and (2) last follow-up more than 1 year after the surgery (follow-up analysis).

Statistical analysis

Parametric data analysis with independent sample *t*-test for equality of means was used to determine the mean, standard deviation, standard error of mean, and 95% confidence interval. A p value $<$.05 was taken as significant. All data were analyzed with statistical software (SPSS version 12.0.1; SPSS Inc., Chicago, IL).

RESULTS

Data were collected between June 2005 and December 2007. Data were available for all 50 patients at discharge from rehabilitation. The last follow-up data beyond 1 year were available from 46 patients (Fig. 1). The average follow-up at last clinical review was 18 months ± 5 for the IAMP group and 17 months ± 4 for the immobilization group.

There was no difference between the groups in the MCP joint angles at discharge and at follow-up in both the intrinsic plus position (p = .146) (Appendix 2; this appendix may be viewed at the *Journal's* Web site, www.jhandsurg.org) and the open hand position (p = .143) (Appendix 3; this appendix may be viewed at the *Journal's* Web site, www.jhandsurg.org). In the open hand position at discharge, there was significantly less extension lag in the donor digit PIP joint angles (p = .021) (Appendix 4; this appendix may be viewed at the *Journal's* Web site, www.jhandsurg.org) in the IAMP group compared with that in the immobilization group. In the intrinsic plus position at discharge, the PIP joint of the index and the donor digit had significantly less extension lag in the IAMP group (p = .018 and p = .003, respectively) (Appendix 5; this appendix may be viewed at the *Journal's* Web site, www.jhandsurg.org) compared with that in the immobilization group. However, both groups were similar at follow-up (p = .784). The total active digit flexion did not differ between both groups at discharge (p = .105) and at follow-up (p = .479) (Appendix 6; this appendix may be viewed at the *Journal's* Web site, www.jhandsurg.org).

There was no incidence of transfer insertion pullout in any of the patients in both groups. Patients were discharged from rehabilitation significantly earlier (p $<$ .001) in the IAMP group (36 days ± 7; range, 30–64 days) compared with those in the immobilization group (54 days ± 4; range, 40–58 days). Morbidity was significantly reduced by a mean of 22 days by immediate postoperative active mobilization of tendon transfer (p $<$ .001).

In the IAMP group, complete relief of pain was achieved significantly earlier, at, on average, 3 weeks compared with 6 weeks in the immobilization group (p $<$ .001). Pain persisted until 4 weeks after surgery in 1 IAMP group patient compared with pain persisting in 19 patients in the immobilization group. There was no difference between the groups in postoperative swelling of the hand at discharge from rehabilitation (p = .07). There was no swelling of the hand at final assessment. Similarly, there was no difference in the timed pick-up test between the groups at discharge from rehabilitation (p = .8) and at final assessment (p = .5) (Appendix 7;

this appendix may be viewed at the *Journal's* Web site, www.jhandsurg.org). There was no difference in the pinch or grip strength in both groups at discharge and at follow-up (Appendix 8; this appendix may be viewed at the *Journal's* Web site, www.jhandsurg.org).

DISCUSSION

The purpose of this study was to compare a postoperative tendon transfer management protocol of immediate active motion with treatment by immobilization. Using a randomized controlled trial design in which patients were operated on by a single surgeon enabled bias-free comparison of tendon transfers for claw deformity correction. We found that immediate postoperative active motion for tendon transfer for claw corrections is safe and without an increased risk of insertion pullout. In addition, there is quicker resolution of pain, earlier restoration of hand function, and significant reduction of morbidity compared with those of immobilization. Donor digits in the IAMP group had less extension lag at discharge, but at follow-up the results were similar to the immobilization group. Similarly, improvements in intrinsic plus positions with IAMP observed at discharge did not persist at follow-up. Patients were discharged from rehabilitation 22 days earlier with full independent ADL with IAMP.

The concept of immediate active motion of tendon transfer follows the principle of early active motion protocols for tendon repairs,[1] which has greatly improved the results of flexor and extensor tendon injuries. Our previous studies demonstrated the feasibility and safety of immediate active mobilization of opposition tendon transfers[4] and claw deformity correction by pulley insertion.[3] The major limitations of these studies were that we compared the prospective trial with a retrospective cohort that lacked reliable historical information on pain, swelling, hand function, and strength. The current study demonstrates that pain was relieved significantly earlier with immediate active motion, and this might explain the quicker restoration of hand function.

Our previous reports[3,4] demonstrated earlier restoration of hand function and morbidity reduction with IAMP, but long-term outcomes of tendon transfer were similar compared with those of immobilization. This randomized clinical trial reaffirms the results of the previous studies[3,4] and suggests that early motion protocol affects the initial phase of rehabilitation, and the long-term results are as good as those of immobilization.

The earlier use of the hand in daily life may considerably affect the cost of tendon transfer surgery. This is consistent with other reports in the literature. For example, Rath[3] demonstrated earlier restoration of hand function by an average of 21 days after claw correction with immediate active mobilization and predicted the economic impact with the change in postoperative protocol. Germann et al.[9] concluded in patients receiving extensor indicis proprius transfer for thumb extension that hand function recovered more quickly after early dynamic motion than after immobilization, shortening total rehabilitation time and making dynamic motion treatment highly cost-effective. Megerle et al.[10] concluded that early active motion has comparable outcome with that of dynamic motion after transfer of the extensor indicis tendon without resulting in more complications.

There are a number of limitations in the current study. A first limitation is that there are no objective data on return to productive activities. All patients in both groups with isolated ulnar nerve paralysis returned to their previous activities by 3 months after discharge from rehabilitation. As patients in the IAMP group were discharged on average 22 days earlier, it is therefore presumed that return to work is quicker in the IAMP group, although this was not objectively quantified in the current study. It should be noted that hands with median nerve paralysis needed a further opposition transfer and thus prolonged rehabilitation time. A second limitation is that the outcomes of pick-up test and pinch power in the 12 ulnar and median nerve paralyzed hands were excluded from the analysis. The third limitation is that we did not assess cost savings associated with the earlier discharge in the IAMP group. A fourth limitation is that there are no data on patient satisfaction outcomes.

There are surgical technique aspects that should be considered before further application of IAMP to other tendon transfers. The prerequisite of a strong insertion may limit the choice of donors and sites of insertion. For example, Stiles-Bunnell's transfer for claw correction may not be suitable for early motion, as the lateral bands are too thin for a Pulvertaft weave. Similarly, donors requiring lengthening by fascial grafts are unsuitable for Pulvertaft weave, and this will limit the choice of donors.

This study was performed on claw hands with complete sensory loss in Hansen's disease. In these hands, there is a possible danger of patients creating too much force on the transfer because of lack of pain sensation. In other patient groups, such as those who have sustained nerve injury, this danger may be less apparent, as there is usually some sensation restored at the time of tendon transfer. Additionally, the professions of the patients in this study are probably such that they are doing work that is more demanding, putting the sutured tendons at a higher risk. Taken together, this suggests that the application of IAMP after claw correction in other patient groups with intrinsic paralysis may also be safe, although this should be further investigated in clinical trials. These principles of early active immobilization have been applied safely to tibialis posterior tendon transfer for foot drop correction by Roth et al.[11]

We did not compare therapy time per session between both groups. However, we did record time per therapy session for the last 22 patients in the trial. In the first 2 weeks of therapy, the mean time per session for the early mobilization group ($n = 10$) was 25 min $\pm$ 5 compared with 43 min $\pm$ 6 for the immobilization group ($n = 12$). In the 3rd and 4th weeks of therapy, time per session was similar in both groups.

The current study demonstrates that an early motion protocol results in quicker restoration of function. This may be owing to the combination of more rapid transfer integration and earlier pain relief. The reduced morbidity and speedy recovery of disability allows the individual to return to work and social activities. Future trials should investigate the economic and social impact of this new postoperative protocol and should indicate whether the same technique can be applied to other patient groups.

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APPENDIX 1
Therapy protocol

The goal of therapy for dynamic claw deformity correction is to achieve metacarpophalangeal (MCP) joint stability and integration of the transfer with the extrinsic muscles. Integration of transfer is possible only with a stable MCP joint (ie, a successful transfer contraction). An integrated transfer produces proximal interphalangeal (PIP) joint extension, which is an essential step for successful deformity correction.

The aim of therapy is to initiate the following:

Preoperatively:

1. Isolation exercise for the donor tendon: Contraction on command of the donor flexor digitorum superficialis (FDS) while keeping the PIP joint and other digits in extension. This exercise initiates relaxation of the FDS of the adjoining digits and this facilitates PIP joint extension of these digits after tendon transfer.

Postoperatively:

2. Prevention rupture, edema, adhesions, and contractures.
3. Contraction of the donor tendon to produce MCP joint flexion; followed by
4. Ability to achieve complete PIP joint extension in any MCP joint position (neutral to any flexed position) indicates *integration* of the transfer activity.
5. Restoration of the normal sequence of digital motion (ie, MCP joint flexion followed by PIP joint flexion for fist closure and PIP joint extension followed by MCP joint extension for fist opening).

	Therapy	
	Immediate Active Mobilization Protocol Group	Immobilization Group
First and second week postoperatively	Dorsal blocking splint is removed at 48 hours and the patient is encouraged to perform active flexion of the MCP joint while attempting to keep the PIP joint in full extension and then fist closure by active PIP joint flexion. For opening the fist, the PIP joints are actively extended, keeping the MCP joints flexed and then extending MCP joint to achieve an open hand position. A 30° dorsal MCP joint block splint is used by the therapist to avoid overstretching of the transfer. From the position of maximum MCP joint extension in open hand position, the flexion sequence is repeated. The hand is supported after therapy with a 70° dorsal blocking splint in the 1st week and 50° dorsal blocking splint in the 2nd week.	Plaster of Paris cast.
Third week postoperatively	Transfer strengthening exercises and light functional activities. At the beginning of the 3rd week, the patients are sent to occupational therapy for daily living activities restricted to a weight limit of <500 g or 1 lb. The dorsal blocking splint is reduced to 30° and used at night only for 3 months to protect from inadvertent stretching of the transfer during sleep. Patients are discharged from rehabilitation after achieving independent ability to perform daily living activities such as dressing, grooming, and eating.	Plaster of Paris cast.
Fourth week postoperatively	Discharge.	A digital cast with PIP joint in full extension is applied to assist transfer integration exercises. The hand is supported after therapy with a 70° dorsal blocking splint.
Fifth and sixth weeks postoperatively		Transfer strengthening exercises and light functional activities. At the end of the 6th week, the patients are sent to occupational therapy for daily living activities restricted to a weight limit of <500 g or 1 lb. The dorsal blocking splint is reduced to 30° and used at night only for 3 months to protect from inadvertent stretching of the transfer during sleep. Patients are discharged from rehabilitation after achieving independent ability to perform daily living activities such as dressing, grooming, and eating.
Seventh and eighth weeks postoperatively		Discharge.

APPENDIX 2. Analysis of MCP Joint Flexion Angles in the Intrinsic Plus Position

Finger	Intervention Group	Discharge			Follow-Up		
		Mean (°)	SD (°)	p Value	Mean (°)	SD (°)	p Value
Index	IAMP	71	6	.595	75	8	.359
	Immob.	70	7		73	6	
Middle	IAMP	71	6	.229	76	8	.312
	Immob.	69	8		73	6	
Ring	IAMP	70	6	.327	75	9	.125
	Immob.	68	6		72	6	
Little	IAMP	67	7	.832	75	8	.703
	Immob.	67	6		74	7	
Total digits	IAMP (n = 100)	70	6	.146	(n = 92) 75	8	.051
	Immob. (n = 100)	69	7		(n = 92) 73	6	

IAMP, immediate active motion protocol; Immob., immobilization.

APPENDIX 3. Analysis of MCP Joint Angles in the Open Hand Position

Finger	Intervention Group	Discharge			Follow-Up		
		Mean (°)	SD (°)	p Value	Mean (°)	SD (°)	p Value
Index	IAMP	32	10	.505	8	16	.484
	Immob.	34	9		11	11	
Middle	IAMP	35	8	.582	10	16	.311
	Immob.	36	9		13	9	
Ring	IAMP	34	9	.378	11	19	.635
	Immob.	36	8		13	15	
Little	IAMP	31	12	.418	14	21	.744
	Immob.	34	10		16	19	
Total digits	IAMP (n = 100)	33	10	.143	(n = 92) 11	18	.243
	Immob.(n = 100)	35	9		(n = 92) 13	14	

IAMP, immediate active motion protocol; Immob., immobilization.

APPENDIX 4. Analysis of PIP Joint Angles in the Open Hand Position

Finger	Intervention Group	Discharge			Follow-Up		
		Mean (°)	SD (°)	p Value	Mean (°)	SD (°)	p Value
Index	IAMP	1	8	.646	7	13	.532
	Immob.	2	7		10	13	
Middle	IAMP	0	9	.021	14	24	.418
	Immob.	6	10		20	25	
Ring	IAMP	–1	10	.065	8	23	.973
	Immob.	4	9		9	19	
Little	IAMP	5	8	.434	11	18	.719
	Immob.	7	9		9	14	
Total digits	IAMP (n = 100)	1	9	.005	(n = 92) 10	20	.553
	Immob. (n = 100)	5	9		(n = 92) 12	18	

IAMP, immediate active motion protocol; Immob., immobilization.

APPENDIX 5. Analysis of PIP Joint Angles in the Intrinsic Plus Position

Finger	Intervention Group	Discharge			Follow-Up		
		Mean (°)	SD (°)	p Value	Mean (°)	SD (°)	p Value
Index	IAMP	8	10	.018	18	16	.551
	Immob.	16	11		21	21	
Middle	IAMP	7	9	.003	19	21	.627
	Immob.	16	10		22	27	
Ring	IAMP	11	11	.053	16	20	.972
	Immob.	17	11		16	22	
Little	IAMP	12	11	.219	13	17	.433
	Immob.	16	11		9	15	
Total digits	IAMP (n = 100)	10	10	.000	(n = 92) 16	18	.784
	Immob. (n = 100)	16	10		(n = 92) 17	22	

IAMP, immediate active motion protocol; Immob., immobilization.

APPENDIX 6. Total Active Motion of Digit Flexion

Finger	Intervention Group	Discharge Mean (°)	Discharge SD (°)	Discharge p Value	Follow-Up Mean (°)	Follow-Up SD (°)	Follow-Up p Value
Index	IAMP	197	23	.638	229	26	.606
	Immob.	193	27		225	22	
Middle	IAMP	201	28	.215	224	32	.470
	Immob.	191	29		216	39	
Ring	IAMP	195	28	.350	219	34	.845
	Immob.	188	24		217	35	
Little	IAMP	187	29	.588	210	31	.980
	Immob.	183	25		210	28	
Total digits	IAMP (n = 100)	195	27	.105	(n = 92) 220	31	.479
	Immob. (n = 100)	189	26		(n = 92) 217	31	

IAMP, immediate active motion protocol; Immob., immobilization.

APPENDIX 7. Outcomes of IAMP and Immobilization Group for Pain and Swelling and Timed Pick-Up Test

	IAMP	Immobilization	p Value*
Zero pain level (VAS score) achieved, wk (mean ± SD)	3 ± 1	6 ± 1	<.001
Swelling expressed as percentage increase of preoperative volume, % (mean ± SD)	16 ± 12	14 ± 14	.07
Timed pick-up test expressed as percentage of preoperative pick-up time in ulnar nerve paralyzed hands, % (mean ± SD)			
Discharge	96 ± 31	100 ± 41	.8
Follow-up	88 ± 41	102 ± 86	.5

IAMP, immediate active motion protocol; Immob., immobilization; VAS, visual analog scale.
*Values indicate the significance level of the *t*-test comparing both groups.

APPENDIX 8. Grip and Pinch Strength Data

Parameter	Intervention Group	Preoperative Mean (kg)	Preoperative SD (kg)	Preoperative Range (kg)	Discharge Mean (kg)	Discharge SD (kg)	Discharge Range (kg)	Discharge Percent of Preoperative Strength (%)	Follow-Up Mean (kg)	Follow-Up SD (kg)	Follow-Up Range (kg)	Follow-Up Percent of Preoperative Strength
Grip strength	IAMP	18	±6	12–29	6	±3	1–12	31	19	±6	10–33	101
	Immob.	16	±8	1–38	7	±4	2–12	41	17	±5	8–26	103
Pinch strength	IAMP	4	±1	1–6.5	3	±2	1–9	75	3	±1	1.5–6	94
	Immob.	4	±2	1–9.2	2	±1	0–4	63	3	±1	1–6	84

IAMP, immediate active motion protocol; Immob., immobilization.