SCIENTIFIC ARTICLE

Treatment of Complete Brachial Plexus Injuries Using Double Free Muscle Transfer

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Purpose The purpose of this study was to examine the surgical outcomes of double free muscle transfer (DFMT) performed in patients with complete brachial plexus injury (BPI).

Methods We retrospectively analyzed the outcomes of DFMT for 12 patients with complete BPI who were followed up for more than 2 years after the final muscle transplantation. Their mean age was 29 years (range, 18−41). Three patients underwent contralateral C7 nerve root transfer before the DFMT. The range of motion (ROM) of the shoulder, elbow, and fingers was measured. Patient-reported outcome measures, including Disability of the Shoulder, Arm, and Hand (DASH) scores and visual analog scale (VAS) scores for pain, were also examined.

Results The mean shoulder ROM against gravity was $22° \pm 8°$ in abduction and $33° \pm 5°$ in flexion. Seven patients underwent phrenic nerve (PhN) transfer to the suprascapular nerves, and five exhibited asymptomatic lung impairment on spirography more than 2 years after PhN transfer. The mean elbow ROM against gravity was $111° \pm 9°$ in flexion and $-32° \pm 7°$ in extension. All patients obtained elbow flexion $>90°$ against a 0.5-kg weight. All patients obtained touch sensation and two recognized warm and cold sensations in the affected palm. The mean total active motion of the affected fingers was $44° \pm 11°$. All patients exhibited hook function of the hands. The mean preoperative and postoperative DASH scores were 70.3 ± 13.4 and 51.8 ± 15.9, respectively. The mean pain VAS score was 28 ± 31 at the final follow-up.

Conclusions Double free muscle transfer provided patients with complete brachial plexus palsy with good elbow flexion and hand hook functions. *(J Hand Surg Am. 2025;50(3):382.e1-e10. Copyright © 2025 by the American Society for Surgery of the Hand. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).)*

Type of study/level of evidence Therapeutic IV.

Key words Brachial plexus injury, double free muscle transfer, muscle transplantation, nerve transfer.

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Patients with complete brachial plexus injury (BPI) lose all motor and sensory functions of the affected upper extremities except for limited motion of the scapula. Because BPI often happens in young active people during their productive years, a BPI can cause substantial disability, impairment, and great socioeconomic loss.[1,2]

Reconstruction of finger function after total BPI is very challenging, and only shoulder elevation and elbow flexion reconstruction have been prioritized for these patients. [3–9] At the end of the last century, new surgical approaches were described to create function in the paralyzed fingers affected by total BPI. One approach was double free muscle transfer (DFMT), and the other was contralateral cervical seventh nerve root (CC7) transfer.[2,10–18]

Double free muscle transfer was described by Doi et al[2,10–13] and is used to reconstruct finger extension and flexion using two free vascularized muscles. DMFT is a well-known procedure, however, most papers reporting the outcomes of DFMT operations were authored by Doi et al.[2,10–13] The purpose of this study was to report our outcomes of DFMTs performed on 12 BPI patients followed up at least 2 years at two tertiary medical centers.

MATERIALS AND METHODS

We performed DFMT on 14 patients with traumatic brachial plexus palsy who had been followed up for more than 2 years after the second muscle transplantation. Two patients were excluded from the present study. In one patient, venous congestion occurred in a transplanted muscle, which was later removed. The other patient showed spontaneous recovery of multiple muscles in the affected upper limb after the second muscle transplantation. All DFMT operations were performed essentially as described by Doi et al.[2,10–13] This study was approved by the committee for medical ethics of our university hospital.

The mean age of the patients (11 men and 1 woman) at the time of the first muscle transplantation was 29 years (range, 18–41). Nine patients exhibited complete brachial plexus palsy. Two showed partial recovery of the cervical fifth (C5) nerve root (patients 5 and 7), and one showed partial recovery of the thoracic first nerve root (T1) (patient 2) during the follow-up. The mean intervals from the injury to the first muscle transplantation and to the second muscle transplantation were 105 (range, 71–139) and 186 (range, 154–249) days, respectively. The mean follow-up period after the second muscle transplantation was 72 months (range, 24–182) (Table 1).

Surgery

Intraoperative somatosensory evoked potentials (SEPs) were examined at C5–C7 in seven patients, C5–C8 in three, and C5–Th1 in two. Two patients (patients 5 and 7) demonstrated positive SEPs at the C5 nerve root and slight shoulder motion. The other 10 patients showed no response to the SEPs in the nerve roots examined. In all patients, except for patients 2, 5, and 7, using the intraoperative findings of the brachial plexus exploration and electrophysiological studies, we found no cervical roots available as a motor source for the brachial plexus reconstruction. However, not all nerve roots were explored or examined during surgery.

Three patients underwent CC7 transfer 3 to 5 weeks before the first muscle transplantation (patients 1–3) (Table 1).[19–21] A pedicled vascularized ulnar nerve segment harvested from the affected arm was transplanted subcutaneously between the superoposterior part of CC7 and the affected median nerve.[22–24] In one patient (patient 2), a part of the nerve was taken from the transplanted ulnar nerve segment and approximated to the obturator nerve of the transplanted muscle. In another patient (patient 3), a partial ulnar nerve segment was transferred to the affected suprascapular nerve (SsN) in an attempt to gain scapulohumeral function (Table 2).[24]

Elbow flexion and digit motion reconstruction using DFMT: Twenty-three free vascularized gracilis muscles and one latissimus dorsi muscle were used for muscle transplantation. The muscles for digit extension were transplanted between the clavicle and the digit extensors, and those for flexion were transplanted between the second and third ribs and the long digit flexors.[2,10–13] The donor nerves of the transplanted muscles for digit extension and flexion reconstruction are shown in Table 2.

We performed shoulder elevation surgery combined with the first muscle transplantation to the finger extensors (Fig. 1) and elbow extension, scapula stabilization and palmar sensitization surgery with the second muscle transplantation to the finger flexors (Fig. 2) in all but two patients, who exhibited ipsilateral accessory nerve (AccN) palsy, which recovered spontaneously by the time of the second muscle transplantation (patient 3 and 5) (Table 2).[2,10–13]

Shoulder reconstruction: Nine patients underwent neurotization of the SsN.[3–6] One patient (patient 1) had shoulder arthrodesis, and the other two (patients 5

TABLE 1. Types of Injury and Interval Between Injury and Muscle Transplantation

Pt	Age (years)	Types of Injury	Injury to the 1st MT (days)	Injury to the 2nd MT (days)	Follow-up Period After the 2nd MT (Months)
1	19	l-C5-T1	93	154	182
2	33	l-C5-T1 (T1; partially spared)	139	170	123
3	31	r-C5-T1	132	190	126
4	41	l-C5-T1	82	155	28
5	33	r-C5-T1 (C5; partially spared)	110	184	89
6	38	r-C5-T1	121	181	41
7	20	r-C5-T1 (C5; partially spared)	71	169	24
8	20	r-C5-T1	94	192	79
9	39	l-C5-T1	130	249	36
10	32	r-C5-T1	83	183	44
11	18	l-C5-T1	86	203	47
12	20	l-C5-T1	115	199	39

MT, muscle transfer.

TABLE 2. Donor Nerves of the Transplanted Muscles and Peripheral Nerves

Pt	1st M	2nd M	SsN	LTN	Radial N	Median N
1	AccN	ICN	(Arthrodesis)	None	CC7	CC7
2	CC7	ICN	AccN	None	CC7	CC7
3	ICN	AccN	CC7	None	CC7	CC7
4	AccN	ICN	PhN	ICN	ICN	ICN
5	ICN	AccN	None	None	ICN	ICN
6	AccN	ICN	PhN	ICN	ICN	ICN
7	AccN	ICN	None	None	ICN	ICN
8	AccN	ICN	PhN + SuN	ICN	ICN	ICN
9	AccN	ICN	PhN	ICN	ICN	ICN
10	AccN	ICN	PhN	ICN	ICN	ICN
11	AccN	ICN	PhN	ICN	ICN	ICN
12	AccN	ICN	PhN	ICN	ICN	ICN

1st M, the first transplanted muscle; 2nd M, the second transplanted muscle; AccN, accessory nerve; CC7, contralateral 7th cervical nerve root transfer; ICN, intercostal nerve; LTN, long thoracic nerve; PhN, phrenic nerve; SsN, suprascapular nerve; SuN, sural nerve graft.

and 7) did not undergo shoulder reconstruction because of the positive SEPs and deltoid muscle contraction when the C5 nerve roots were stimulated electrically. The donor nerves of the SsN reconstruction were the phrenic nerve (PhN) in seven patients, AccN in one (patient 2), and a part of the ulnar nerve segment connected to CC7 in one (patient 3)[24]. All PhNs were sectioned 1 cm caudal to the clavicle and transferred to the SsN. In one patient (patient 8), a sural graft was added to the PhN transfer (Table 2).

Palmar sensation reconstruction: The source of palmar sensation reconstruction was CC7 transfer in three patients (patients 1–3) and the lateral branches of three or four intercostal nerves (ICNs), which were transferred to the median nerve branch of the lateral cord in nine patients (Table 2).

Elbow extension reconstruction: Elbow extension reconstruction was performed by coaptation of the triceps muscle branch of the radial nerve to the side of the transplanted ulnar nerve segment (side-to-end anastomosis) in three patients who received CC7 transfer (patients 1–3) and by transfer of two ICNs to the triceps muscle branches in nine patients (Table 2).[13,24,25]

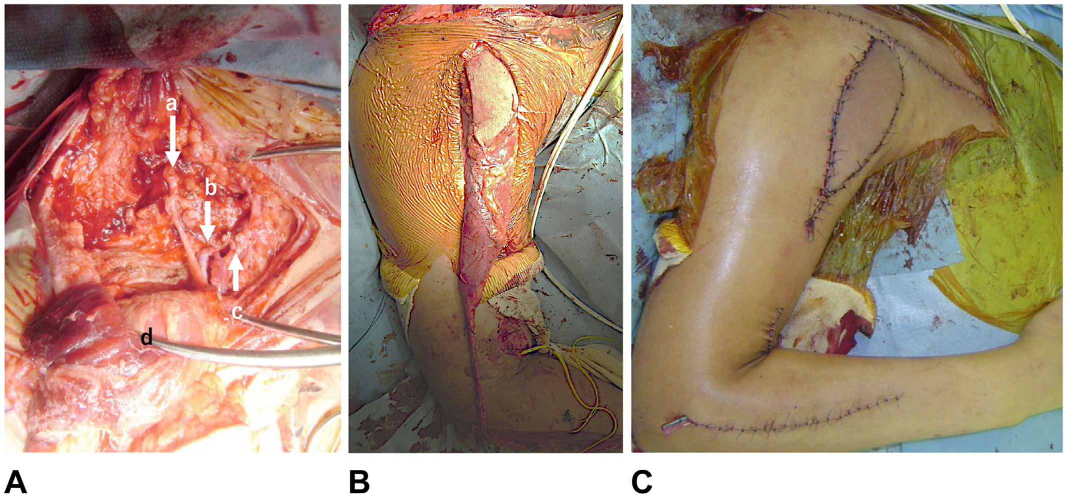

FIGURE 1: Intraoperative photograph of the gracilis muscle transfer for finger extension reconstruction. **A** Neurovascular anastomoses. **B** After finishing the neurovascular anastomosis, the gracilis muscle was passed through the subcutaneous tunnel and sutured to the digital extensor tendons. **C** After muscle transplantation. **a** Stump of the obturator nerve of the gracilis muscle, which was later sutured to the accessory nerve. **b** Arterial anastomosis of the nutrient artery of the gracilis muscle. **c** Venous anastomosis of the nutrient vessels of the gracilis muscle. **d** The transplanted gracilis muscle.

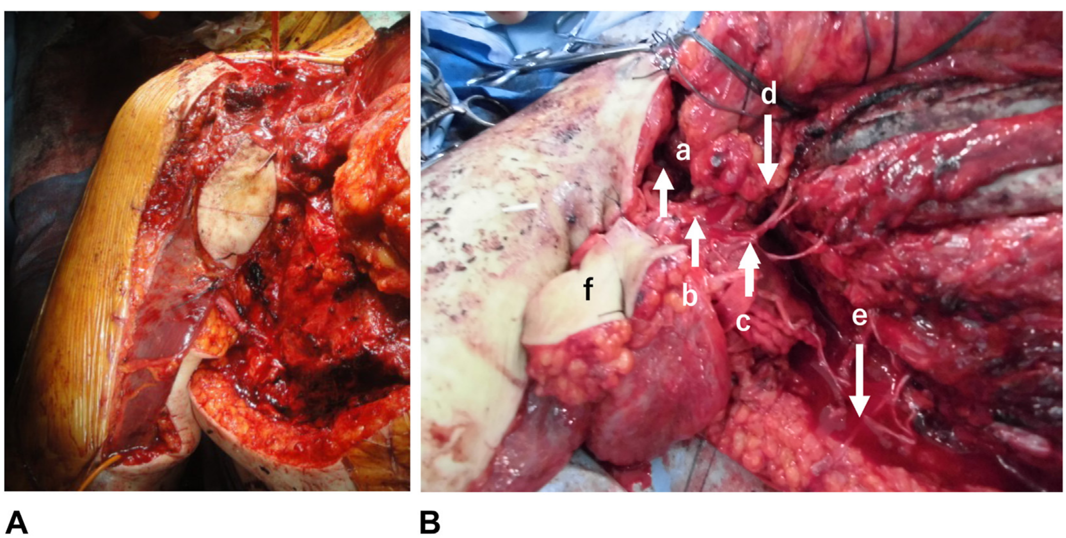

FIGURE 2: Intraoperative photograph of the gracilis muscle transfer for finger flexion reconstruction. **A** The gracilis muscle was fixed to the second and third ribs. **B** Neurovascular anastomosis. **a** Anastomosis of the third and fourth intercostal nerves to a triceps brachii muscle branch of the radial nerve. **b** Anastomosis of the nutrient vessels of the transplanted gracilis muscle to the thoracodorsal vessels. **c** Anastomosis of the fifth and sixth intercostal nerves to the obturator nerve of the gracilis. **d** Anastomosis of the lateral branches of the fourth to sixth intercostal nerves to the median nerve branch of the lateral cord. **e** Anastomosis of the seventh intercostal nerve to the long thoracic nerve. **f** The transplanted gracilis muscle.

Long thoracic nerve (LTN) reconstruction (scapula stabilization) and additional surgery: LTN reconstruction was performed in seven patients (patients 4, 6, and 8–12) using a single ICN transfer (Table 2).[24,26] Additionally, wrist arthrodesis was performed in two patients. Five patients underwent arthrodesis of the proximal interphalangeal joints of all fingers. One underwent a Zancolli capsulodesis of the metacarpophalangeal joints (Table 3).[27]

Complications: One patient (patient 2) exhibited partial necrosis in the first transplanted muscle. After removal of the necrotic part, the muscle was augmented by the transfer of the sternal part of the affected pectoralis major muscle, which had reinnervated spontaneously.[28] Six patients underwent tenolysis of the transplanted muscles in the forearms (once in four patients, twice in two patients) after the second muscle transplantation (Table 3). Five patients

TABLE 3. Finger Joint Fixation and Times of Tenolysis

Pt	PIP Joint Arthrodesis	MP Joint Capsulodesis	Wrist Joint Arthrodesis	Tenolysis
1	+	−	+	1
2	−	−	−	1
3	−	−	−	0
4	−	−	−	0
5	+	−	−	2
6	−	+	−	2
7	−	−	−	0
8	+	−	−	0
9	−	−	+	1
10	−	−	−	0
11	+	−	−	0
12	+	−	+	1

(patient 6, 9, 10, 11 and 12) who underwent spirography more than 2 years after PhN transfer exhibited asymptomatic lung impairment (a percentage of vital capacity $< 80\%$).

Postoperative rehabilitation

A standard rehabilitation protocol to prevent joint contracture was started 2 to 3 days after surgery with tension-free positioning of the transplanted muscles. Passive extension of the transplanted muscle started 5 weeks after surgery. All patients were instructed to apply force to the transplanted muscles in coordination with respiration. At 8 weeks, the range of motion (ROM) was extended gradually, but the elbow joint was prohibited from extending to more than $-30°$.

Measurements

Physical measurements were obtained at the final follow-up more than 2 years after the second muscle transplantation. Joint angles were measured using a goniometer.

Active shoulder range of motion

The maximum active shoulder abduction and flexion angles, including scapula motion against gravity, were measured. Shoulder abduction was defined as the angle formed between the line parallel to the line connecting the first to the sixth thoracic spines and the central line of the upper arm in the coronal plane. Shoulder flexion was the angle between the central line of the trunk and affected upper arm in the sagittal plane. Shoulder external rotation was the angle formed between the central line of the forearm with the elbow in the 90° flexed position and the line parallel to the coronal plain of the trunk in the axial plane.

Active flexion and extension arcs and strength of the elbows

The maximum angles for elbow flexion and extension against gravity with or without a load of a 0.5-kg or 2-kg weight were measured. Categories of elbow flexion and extension strength were shown in Tables 4 and 5, respectively.

Total active motion of fingers

Total active motion (TAM) of the index, middle, ring, and little fingers of each affected hand was measured with the affected wrist joint grasped firmly by the contralateral healthy hand to stabilize the affected limb. The mean of the TAMs of the four fingers of each hand was used to represent the TAM of the hand.

Finger hook and prehension function

Finger hook function is defined as the ability to lift a paper bag containing a 2-kg weight using the affected index to little fingers. Finger prehension function was defined as the ability to grasp a ping–pong ball from a table using the digits and palm of the affected hand without assistance of the healthy hand.

Palmar sensation

For the sensory evaluation of the affected palms, touch, warm, and cold sensations were examined. Touch sensation was evaluated by touching the affected palms with a paint brush. Warm or cold sensations were evaluated by immersing the patients' affected hands in warm (42–45 °C) or cold (4–6 °C) water, respectively.

TABLE 4. Category of Elbow Flexion Force

Grade	Definition
Not Flexible	Unable to flex the elbow joint against gravity
Flexible	Able to flex the elbow joint <90° against gravity
Strongly Flexible	Able to flex the elbow joint ≥90° against gravity
Resistively Flexible	Able to flex the elbow joint ≥90° against a 0.5-kg weight attached to the affected wrists
Powerfully Flexible	Able to flex the elbow joint ≥90° against a 2-kg weight attached to the affected wrists

TABLE 5. Category of Elbow Extension Force

Grade	Definition
Not Extendable	Unable to extend against gravity
Extendable	Able to extend against gravity, but unable to reach the maximally extended position
Fully Extendable	Able to extend to the maximally extended position against gravity
Resistively Extendable	Able to extend to the maximally extended position against a 0.5-kg weight attached to the affected wrists
Powerfully Extendable	Able to extend to the maximally extended position against a 2-kg weight attached to the affected wrists

Patient-reported outcome measures

Disability of the Arm, Shoulder, and Hand (DASH) scores were recorded preoperatively and at the final follow-up for each patient. The score on the visual analog scale (VAS) for pain in the affected upper extremity (0 [no pain] to 100 [unendurable pain]) was recorded at the final follow-up.

Ventilatory function and body mass index (BMI) in patients receiving PhN transfer

Six of the seven patients who received PhN transfer underwent respiratory function tests using a spirography and an anteroposterior plain chest X-ray examination before and more than 2 years after the PhN transfer (range, 26–47 months; median, 36). BMI was calculated at the time of the final spirography tests.

TABLE 6. Results of Shoulder Function

Pt*	Shoulder Flexion (°)†	Shoulder Abduction (°)†	Shoulder External Rotation (°)
1	10	30	-70
2	25	30	-45
3	30	40	0
4	10	30	-60
5	25	30	-15
6	35	45	10
7	20	25	-45
8	30	35	-35
9	20	35	-70
10	15	35	-50
11	20	30	-70
12	25	30	30
Mean ± SD	22 ± 8	33 ± 5	-35 ± 34
95% CI	17.1 to 27.1	29.5 to 36.4	-56.5 to -13.5

CI, confidence interval; SD, standard deviation.
*Patients 4, 6, and 8-12 underwent long thoracic nerve reconstruction.
†The shoulder flexion and abduction angles were measured under gravity.

RESULTS

Shoulder function

The outcomes of shoulder abduction, flexion, and external rotation are shown in Table 6. All patients showed gradual improvement in shoulder motion with time after the operation. Before surgery, all patients exhibited inferior dislocation or severe subluxation of the affected shoulders, which had recovered to almost normal or slight subluxation positions at the final follow-up.

The mean arcs of shoulder flexion, abduction, and external rotation for the seven patients who received LTN reconstruction were 22° ± 9° (95% confidence interval [CI], 14.2 to 30.1), 34° ± 5° (95% CI, 29.3 to 39.3), and −35° ± 40° (95% CI, −71.9 to 1.9), respectively. The mean arcs for the five patients without LTN reconstruction were 22° ± 8° (95% CI, 12.6 to 31.4), 31° ± 6° (95% CI, 29.3 to 39.2), and −35° ± 28° (95% CI, −69.3 to −0.8), respectively. There were no apparent differences in the shoulder flexion and abduction ranges between patients with and without LTN reconstruction.

Elbow flexion and extension

All patients were able to flex the elbow joints more than 90° while carrying a 0.5-kg weight. Five patients

TABLE 7. Results of Elbow Function

Pt	Elbow Extension/Flexion Angles (°)	Elbow Flexion Force*	Elbow Extension Force†
1	−30/120	Powerfully	Extendable
2	−30/100	Resistively	Not Extendable
3	−45/110	Resistively	Not Extendable
4	−20/105	Powerfully	Fully Extendable
5	−35/110	Powerfully	Extendable
6	−30/100	Resistively	Extendable
7	−25/110	Resistively	Extendable
8	−35/125	Powerfully	Extendable
9	−40/115	Resistively	Extendable
10	−35/115	Resistively	Extendable
11	−30/110	Resistively	Extendable
12	−25/125	Powerfully	Extendable
Mean ± SD	32 ± 7/111 ± 9	–	–
95% CI	27.3−36.0/105.1−116.6	–	–

CI, confidence interval; SD, standard deviation.

*Elbow flexion force: resistively, able to flex the elbow joint ≥90° against a 0.5-kg weight attached to the affected wrists; powerfully, able to flex the elbow joint ≥90° against a 2-kg weight attached to the affected wrists.

†Elbow extension force: fully extendable, able to extend the elbow joint to the maximally extended position against gravity; extendable, able to extend the elbow joint against gravity but unable to reach the maximally extended position; not extendable, unable to extend the elbow joint against gravity.

could flex the elbow joints >90° with a 2-kg weight. These elbow flexion angles were similar to those reported in previous papers.[2,12] Ten patients were able to extend the elbow joints against gravity, but only one patient was able to reach the maximally extended position (Table 7).

Palmar sensation

At the final follow-up, all patients obtained touch sensation, and two patients recognized warm and cold sensations in the affected palm (Table 8). All three patients who received median nerve reconstruction in the affected hand using CC7 transfer still complained of paresthesia in the middle and ring fingers of their healthy hand when the affected palm was touched with a paint brush.

Finger function

All patients obtained hook function, and five gained prehension function in the affected hands (Table 8) (Video S1 and 2).

Patient-reported outcome measures

The DASH scores improved after surgery in all patients except one, who complained of complex regional pain syndrome-like symptoms in the affected upper limb. The mean postoperative VAS score was 28 (varied from 0 to 100) (Table 9).

Respiratory function after PhN transfer

The %vital capacity (VC) decreased in all six patients who underwent respiratory testing, and the average decrease was 14%. At the final follow-up, all patients except one remained within the category of restrictive respiration impairment (%VC < 80%); however, they were asymptomatic. No patients showed obstructive impairment (a forced expiratory volume within 1 sec of <70%), and this value did not change markedly after the operation. The patients with a lower %VC were likely to demonstrate greater diaphragm elevation. No obvious association was found between the postoperative %VC and BMI (Table 10).

DISCUSSION

As noted in previous reports, recovery of elbow flexion function was satisfactory in all patients in this study.[2,12] This recovery may be related to the distal suture sites of the transplanted muscles in the forearms, as reported, the transplantation of two muscles, both of which worked for elbow flexion, and the

TABLE 8. Results of Hand and Finger Function

			Sensation of the Palm		
Pt	Finger Function	Mean TAM (°)	Touch	Warm	Cold
1	Hook & prehension	35	+	–	–
2	Hook	48	+	–	–
3	Hook & prehension	53	+	–	–
4	Hook	33	+	–	–
5	Hook & prehension	44	+	–	–
6	Hook	23	+	–	–
7	Hook	48	+	–	–
8	Hook & prehension	48	+	–	–
9	Hook & prehension	55	+	+	+
10	Hook	58	+	+	+
11	Hook	33	+	–	–
12	Hook	45	+	–	–
Mean ± SD	–	44 ± 11	–	–	–
95% CI	–	36.9–50.2	–	–	–

CI, confidence interval; SD, standard deviation; TAM, total active motion of fingers.

TABLE 9. Results of Patient-Reported Outcomes

Pt	Pre-DASH	Post-DASH	Pain VAS
1	40.9	38.3	25
2	85	30.8	0
3	85	60.8	49
4	83.3	60	32
5	67	43	13
6	67.2	39.2	34
7	62.5	45	0
8	75.8	59.2	5
9	85.8	64.7	66
10	68.1	89.3	100
11	62.5	45	0
12	60.9	45.8	10
Mean ± SD	70.3 ± 13.4	51.8 ± 15.9	28 ± 31
95% CI	61.8–78.8	41.7–61.8	8.1–47.5

CI, confidence interval; DASH, Disability of the Arm, Shoulder and Hand scores; Pre-DASH, preoperative DASH scores; Post-DASH; postoperative DASH scores; SD, standard deviation; VAS; visual analog scale (0-100).

physical characteristics of our patients who were skeletally smaller than standard western people.[29]

The goal for elbow extension was set at about -30° because the flexion torque of the elbow joint is smaller than the flexion from the fully extended position. Most patients obtained weak elbow extension strength. Similar outcomes have been previously reported.[2,10–12,30,31] Because the triceps brachii muscle is a pinnate muscle, its muscle sliding length is shorter and contraction speed is slower than those in fusiform muscles, such as the biceps brachii muscle. Therefore, functional recovery might have been poorer in the triceps brachii muscles in this study than the biceps brachii muscles with two ICN transfers reported previously.[8,9,32]

The patients' shoulder arcs remained severely restricted at the final follow-up. SsN and AccN are often injured in shoulder trauma with or without BPI injury.[33,34] When the patients received the BPI, the SsN may have been injured at both the brachial plexus and the periphery, including the suprascapular and spinoglenoid notches. Scapula stabilization is important for obtaining good shoulder function.[35] In this study, we found no apparent difference in shoulder ROM between patients who did and did not receive LTN reconstruction, although this study had a small sample size and did not evaluate serratus anterior muscle function. It is possible that a single ICN transfer may have provided the muscle with too few nerve fibers to work effectively. In addition, both transplanted muscles act as shoulder adductors. The patients may have unconsciously applied force to the transplanted muscles when they tried to elevate the shoulders. These factors may have contributed to the restricted shoulder motion even after SsN neurotization.

TABLE 10. Results of Spirography of Patients with Phrenic Nerve Transfer and Body Mass Index

Pt	Pre-%VC	Pre-%FEV1.0	Post-%VC	Post-%FEV1.0	BMI	Interval (M)
1	–	–	–	–	–	–
2	–	–	–	–	–	–
3	–	–	–	–	–	–
4	–	–	–	–	–	–
5	–	–	–	–	–	–
6	88	92	67	88.9	24.3	35
7	–	–	–	–	–	–
8	87.9	93.8	80.8	85.4	20.2	30
9	86	82.3	66.4	82.2	25.1	31
10	81.1	99.46	60.6	88.89	23.8	26
11	80.3	94.7	66	91	19.1	37
12	71	87.02	55.1	90	27.3	39
Mean ± SD	81.3 ± 6.6	91.5 ± 6.8	67.3 ± 8.2	87.5 ± 2.7	23.3 ± 3.0	Median; 36
95% CI	73.1 − 89.4	83.0 − 99.9	57.2 − 77.5	84.1 − 90.9	20.1 − 26.5	–

BMI, body mass index; CI; confidence interval; %FEV1.0, percent predicted forced expiratory volume in one second; interval, interval between spirography and phrenic nerve transfer; M, months; SD, standard deviation; %VC, percent predicted vital capacity.

The mean TAM in the affected fingers was 44°, which is similar to that reported previously.[2,10−12,30,36] All patients moved the affected fingers by stabilizing the affected elbow joint using gravity because of weakness in the triceps brachii muscle. The reconstructed upper limb functions may have been influenced by the outcomes of DFMT and other factors, including recovery of shoulder function and elbow extension, tenolysis of the transplanted muscles, wrist fusion, and the procedures to restrict the motion of digital joints.

The palmar sensation reconstructed by ICN transfer was similar to that reconstructed by CC7 transfer. In the current study, the hemi-CC7 was transferred.[19−21,23,24] The axons regenerated from the CC7 transfer may have been wasted by the side-to-end anastomosis with the radial nerve and partial nerve transfer from the transplanted ulnar nerve segments.[23−25] This may have resulted in poorer sensory outcomes of the affected palms compared with the original CC7 operations reported previously.[14,15]

Five of the six patients having respiratory testing more than 2 years after PhN transfer showed asymptomatic lung impairment. Use of the PhN for BPI reconstruction remains controversial.[37−40] To avoid using PhN, which is a vital nerve, we tried to use CC7 transfer combined with DFMT but stopped because the strong sensory and motor link between the affected and contralateral limbs remained in the patients at the final follow-up.[22,23]

The limitations of this study include a small cohort size and the possible inclusion of patients with preganglionic BPI injury, which might have shown some spontaneous recovery.

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