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ARTICLE

Immediate tendon transfer for functional reconstruction of a dorsal forearm defect after sarcoma resection

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ABSTRACT

In the treatment of sarcoma, the reconstructive surgeon must consider not only limb salvage but also functional reconstruction. The aim of this study was to evaluate a functional reconstruction of a dorsal forearm defect after sarcoma resection using immediate tendon transfer. Patients who underwent reconstruction of a dorsal forearm defect after sarcoma resection with an immediate tendon transfer between 1997 and 2019 at our hospital were included in this retrospective study. Patient demographics, tumor characteristics, surgical characteristics and functional outcomes were examined. Nine patients were included in this study. Tendon transfer of the flexor carpi radialis (FCR) or the flexor carpi ulnaris (FCU) to the extensor digitorum communis (EDC), the brachioradialis (BR) to the EDC, and the palmaris longus (PL) tendon to the extensor pollicis longus (EPL) was performed in seven, two and five patients, respectively. Seven patients underwent reconstruction using a free flap. Neither anastomosis complications nor infections were encountered. Partial flap necrosis and donor site dehiscence were seen in one case each. The mean distal interphalangeal (DIP), proximal interphalangeal (PIP) and metacarpophalangeal (MP) joint active extension were 4.4°, 6.1° and 11.1° postoperatively. The mean Musculoskeletal Tumor Society (MSTS) score was 26. Immediate tendon transfers of the FCR or the FCU to the EDC and the PL tendon to the EPL can be considered an optimal functional reconstruction of a dorsal forearm defect after sarcoma resection.

Abbreviations: Anterolateral Thigh (ALT) flap; Superficial Circumflex Iliac artery perforator (SCIP) flap

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Introduction

Soft tissue sarcomas (STS) are rare neoplasms that can occur on any part of the body. Approximately, 50% of STS occurs in the extremities, and 30% of these are located in the upper extremities [1]. In the last few decades, five-year survival following the treatment for extremity STS has approached 80% [2]. Limb preservation surgery is now the gold standard treatment for patients with STS [3]. A recent high-powered study using the National Cancer Database showed that the ratio of amputation was 8% and that of limb salvage was 92% [4]. In the upper limb reconstruction, the reconstructive surgeon must consider not only limb salvage but also functional reconstruction to achieve a better quality of life for the patient.

Especially in the setting of wide resection of sarcoma at the dorsal aspect of the forearm, not only the extensor compartment muscles but also the posterior interosseous nerve or radial nerve may be resected. In that case, tendon transfer is one option for the reconstruction of finger extension. However, there are a few reports on tendon transfer for patients with sarcoma on the upper extremities [5,6].

In this article, we report on functional reconstruction of a dorsal forearm defect after sarcoma resection using immediate tendon transfer with or without free tissue transfer. Its feasibility and effectiveness are validated by examining clinical cases and evaluating the functional outcomes. We also describe the surgical technique of immediate tendon transfer using the flexor carpi radialis (FCR) and the palmaris longus (PL) tendon for restoring finger extension.

Patients and methods

Institutional Review Board approval was obtained. Nine patients who had undergone reconstruction of a dorsal forearm defect after sarcoma resection with immediate tendon transfer between 1997 and 2019 at our hospital were included in this study. This retrospective analysis included a systematic review of all operation reports and clinical follow-up data. Patients' demographic data obtained from the medical records included gender, age, STS stage and follow-up periods. Data on defect size, flap size, reconstruction method and operative time were obtained from operative notes. Histologic tumor type, tumor size and surgical margin were obtained from pathology reports. Functional results such as Musculoskeletal Tumor Society (MSTS) upper extremity scoring and range of motion (ROM) of fingers were obtained from medical records. Categories within this system include pain, function, emotional acceptance, hand positioning, manual dexterity and lifting ability. Each category is rated on a scale of 0–5, with 5 representing normalcy or full function [7]. The MSTS score was determined at least one year after the surgery.

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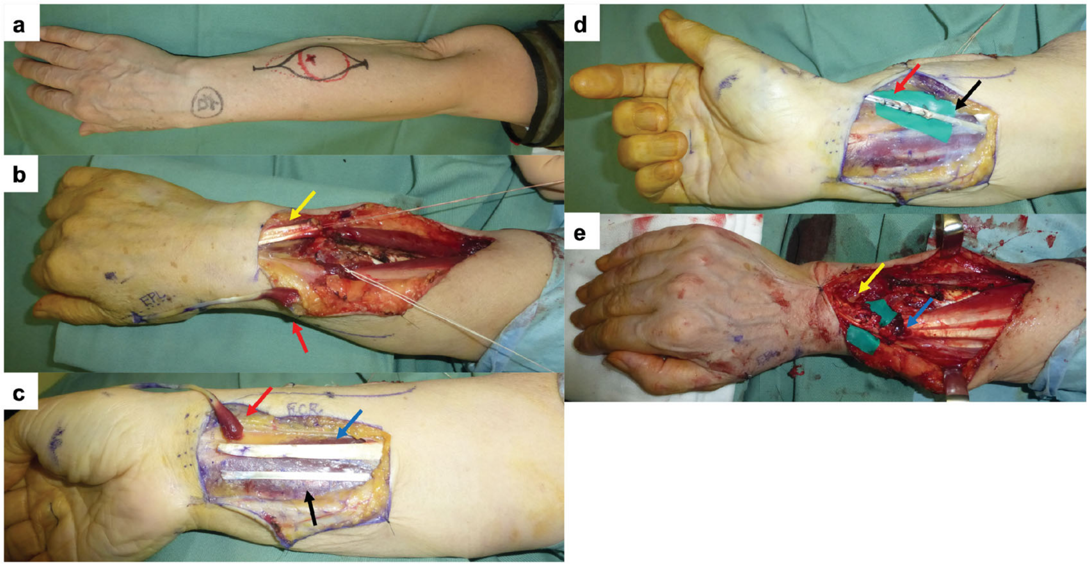

Figure 1. (a) A 75-year-old female suffered from soft tissue sarcoma on the dorsal aspect of the right forearm. (b) The defect after tumor ablation. Yellow arrow: extensor digitorum communis (EDC), red arrow: extensor pollicis longus (EPL). (c) The palmaris longus (PL) tendon and the flexor carpi radialis (FCR) were identified from longitudinal incision of the volar aspect of the forearm. Red arrow: EPL, blue arrow: FCR, black arrow: PL. (d) The transfer of the PL to the EPL was performed in the volar wound. Red arrow: EPL, black arrow: PL. (e) The transfer of the FCR to the EDC and the extensor digitorum minimi (EDM) was performed in the dorsal defect. Yellow arrow: EDC, blue arrow: FCR.

Surgical technique

The FCR, the flexor carpi ulnaris (FCU) and the brachioradialis (BR) were used for restoration of finger extension. The PL tendon was used for restoration of thumb extension. Herein, we describe the typical tendon transfers used in this case series. Surgical wide resection followed by immediate tendon transfer was planned. After the tumor ablation, the extensor digitorum communis (EDC), extensor digitorum minimi (EDM) and the extensor pollicis longus (EPL) were identified from the defect of the dorsal aspect (Figure 1(b)). The PL tendon and the FCR were identified from a longitudinal incision of the volar aspect of the forearm (Figure 1(c)). The volar incision should be designed not to compromise the flap perfusion (Figures 1(c) and 3(c)). Both tendons were transected and freed up to the middle of the forearm to allow redirection of the tendons to their new insertions. The EPL was rerouted toward the volar aspect of the wrist. The transfer of the PL to the EPL was performed in the volar wound (Figure 1(d)). Our preferred tension is with the wrist in neutral and with maximum tension on the EPL and PL tendons. The FCR was passed around the radial border of the forearm thorough a subcutaneous tunnel. The transfer of the FCR to the EDC and EDM was performed in the dorsal defect (Figure 1(e)). When using the BR or the FCU for restoration of finger extension, the identification and transfer were the same as when using FCR. However, the FCU was passed around the ulnar border of the forearm. Our preferred tension is with the wrist in approximately 30° of extension and the metacarpophalangeal (MP) joints in slight (10° to 15°) flexion. After the tendon transfers, the defect was closed with or without a free flap transfer. As adequate skin coverage is essential for successful tendon transfer, if the vascularity of the tissue covering the suture of the tendon is at all suspicious, a flap transfer should be considered without hesitation. We strongly recommend the use of indocyanine green angiography to confirm the skin perfusion after tumor ablation. When using a free flap transfer, recipient vessels should be chosen so that the anastomosis site is located away from the transferred tendon. The arm was immobilized with the wrist extension of 30°, the MP joints in slight flexion, and the thumb in maximum extension and abduction in a volar splint. Active flexion and passive extension exercises were started two weeks postoperatively. Active extension was allowed from three weeks after surgery. Removable short arm splints to hold the wrist, fingers and thumb in extension were used for an additional three weeks.

Results

Nine patients who underwent reconstruction of a dorsal forearm defect after sarcoma resection with immediate tendon transfer were included in this study. The mean age was 56 years (range 24–75 years). There were four male (44.4%) and five females (55.5%). The histological diagnoses were undifferentiated pleomorphic sarcoma (UPS) in five patients, myxoid liposarcoma in two patients, myxofibrosarcoma in one patient, and periosteal osteosarcoma in one patient. None of the patients in this study received postoperative radiation therapy. The mean operative time was 480 min (range 250–690). The mean size of the defect was 7.2×9.5 cm (range $2–13 \times 3–14$ cm). Seven patients underwent reconstruction using a free flap. In the nine patients in our case series, the posterior interosseous nerve was resected in four cases and the radial nerve was resected in one case. In these cases with neurectomies, tendon transfer was performed without nerve reconstruction because the palmar sensation was intact. Tendon transfer of the FCR to the EDC was performed in six patients. Tendon transfer of the BR to the EDC was performed in two patients. Tendon transfer of the FCU to the EDC was performed in one patient. Tendon transfer of the PL tendon to the EPL was performed in five patients. Neither anastomosis complications nor infections were encountered. Partial flap necrosis was seen in one case, which was treated using skin grafting. Donor site wound dehiscence was seen in one case, which was treated conservatively. The mean follow-up period was 101.3 months (range 21–201). The mean distal interphalangeal (DIP), proximal interphalangeal (PIP) and MP joint active extension of the middle finger after the rehabilitation was 4.4° (range 30/0), 6.1° (range 30/0) and 11.1° (range 60/–10H(hyperextension)). No abnormality of finger flexion was detected. The mean MSTS score was 26 (range 22–30). The oncological outcomes were as follows: seven patients achieved a continuous disease-free status, one was alive with disease, and one died of another disease. Patient demographics and a summary of the reconstruction performed are given in Table 1. Table 2 shows the surgical outcomes. In our case series, the FCR or FCU was transferred in seven cases and the BR was transferred in two cases for the finger extension. Table 3 shows the functional results and subjective evaluation of the patients who underwent tendon transfer using the FCR or FCU.

Case reports

Case 1

A 75-year-old female suffered from soft tissue sarcoma on the dorsal aspect of the right forearm (Figure 1(a)). Surgical wide resection followed by immediate tendon transfer was planned. Surgical wide resection with a 1–2 cm margin, including the extensor compartment muscles (EDM, EDC, extensor indicis proprius (EIP), extensor carpi ulnaris (ECU), EPL, APL) and posterior interosseous nerve, was performed. The extensor carpi radialis longus (ECRL) and the extensor carpi radialis brevis (ECRB) were preserved (Figure 1(b)). Then, the planned tendon transfers were performed. The transfers of the FCR to the EDC and the EDM, and the PL tendon to the EPL were performed (Figure 1(d,e)). The skin defect was closed primarily. The resected mass was confirmed to be a UPS. The postoperative course was uneventful. The arm was immobilized with a wrist extension of 30° in a volar splint, and active flexion and passive extension exercises were started two weeks postoperatively. Active extension was allowed from three weeks after surgery. Within 32 months, the patient returned to normal activity with full fist motion, pinch of the thumb and little finger, DIP joint extension of 0°, PIP joint extension of 0°, MP joint extension of –10H°, thumb interphalangeal (IP) joint extension of 0°, and thumb MP joint extension of 10°. The MSTS score and the quick disabilities of the arm, shoulder and hand (DASH) score were 30 and 2.27, respectively (Figure 2, Supplementary Video 1).

Case 2

A 74-year-old male suffered from soft tissue sarcoma on the dorsal aspect of the left forearm (Figure 3(a)). Additional surgical wide resection followed by immediate tendon transfer was planned. Surgical wide resection, including the extensor compartment muscles (EDC, EDM, ECRL, ECRB, EPL) and posterior interosseous nerve, was performed (Figure 3(b)). A preoperatively planned tendon transfer was performed. Transfers of the FCR to the EDC and the EDM, and the PL tendon to the EPL were performed (Figure 3(c–e)). The size of the defect after tumor ablation was 11.5 × 12.5 cm. The skin defect was covered using an 11 × 18 cm superficial circumflex iliac artery perforator (SCIP) free flap (Figure 3(f)). The posterior interosseous artery and vein were used as recipient vessels. The resected mass was confirmed to be a UPS. The same rehabilitation as with case 1 was performed. Within 21 months, the patient returned to normal activity with full fist motion, pinch of the thumb and little finger, DIP joint extension of 0°, PIP joint extension of 5°, MP joint extension of 5° and thumb IP joint extension of 0°. The MSTS score was 27 (Figure 4).

Discussion

Herein, we report our institution's experience with immediate tendon transfer for reconstruction of a dorsal forearm defect after

Table 1. Patient demographics and reconstructive summary.

No.	Age (years)	Gender	Defect size (cm)	Resection	Tendon transfer	Flap	Size of skin paddle (cm)	Recipient vessels	Histology	Stage	Surgical margin (cm)
1	24	Male	4.3 × 7.5	Radius, ECU, EDC	PL → EPL, BR → EDC, EDM	Fibula	4 × 7	Radial a and v	Periosteal OS	IIIA	3
2	37	Male	2 × 3	Posterior interosseous nerve	PT → ECRL PL → EPL, FCR → EDC, EDM	N/A	N/A	N/A	Myxoid LS	IIIA	3
3	47	Male	8 × 12	EDC, posterior interosseous nerve	FCR → EDC	ALT	8 × 12	Radial a and v	UPS	IIIA	3
4	69	Female	9.5 × 10	BR, EDC, ECRL, ECRB, FCR	FCR → EDC	ALT	9 × 10	Radial a and v	MFS	IA	3
5	74	Female	7.5 × 8	FCU, ECU, EDC	FCU → EDC	ALT	7.5 × 8	Radial a and v	UPS	II	3
6	26	Female	7 × 14	BR, EDC, ECRL, ECRB, APL, EPL, ECU, radial nerve	PL → EPL, FCR → EDC, EDM	ALT	7 × 14	Radial a and v	UPS	II	3
7	65	Female	13 × 13.5	ECU, EDM, EDC, ECRB	BR → EDC, EDM	ALT	14.5 × 13.5	Ulnar a and v	UPS	IIIB	2
8	75	Female	2.5 × 5	EDC, EDM, ECU, EIP, EPL, posterior interosseous nerve	PL → EPL, FCR → EDC, EDM	N/A	N/A	N/A	Myxoid LS	IIIA	3
9	74	Male	11.5 × 12.5	EDC, EDM, ECRB, ECRL, EPL, posterior interosseous nerve	PL → EPL, FCR → EDC, EDM	SCIP	11 × 18	Posterior interosseous a and v	UPS	IIIA	2
Average	56		7.2 × 9.5								

ECU: extensor carpi ulnaris; EDC: extensor digitorum communis; BR: brachioradialis; ECRL: extensor carpi radialis longus; ECRB: extensor carpi radialis brevis; FCR: flexor carpi radialis; FCU: flexor carpi ulnaris; APL: abductor pollicis longus; EPL: extensor pollicis longus; EDM: extensor digitorum minimi; EIP: extensor indicis proprius; PL: palmaris longus; PT: pronator teres; ALT: anterolateral thigh; SCIP: superficial circumflex iliac artery perforator; OS: osteosarcoma; LS: liposarcoma; MFS: myxofibrosarcoma; UPS: undifferentiated pleomorphic sarcoma.

Table 2. Postoperative outcomes.

No.	Operation time (min)	Follow up period (months)	Complications	MSTS score	DIP extension (°)	PIP extension (°)	MP extension (°)
1	445	201	N/A	24	30	30	60
2	425	118	N/A	22	0	0	10
3	512	132	N/A	27	0	0	0
4	470	113	Partial necrosis	28	0	0	0
5	502	90	N/A	25	0	0	20
6	690	128	N/A	23	0	0	−10H
7	553	77	Donor-site dehiscence	28	10	20	25
8	250	32	N/A	30	0	0	−10H
9	477	21	N/A	27	0	5	5
Average	480	101.3		26/30	4.4	6.1	11.1

MSTS: Musculoskeletal Tumor Society score; DIP: distal interphalangeal; PIP: proximal interphalangeal; MP: metacarpophalangeal; H: hyperextension.

Table 3. Functional results and subjective evaluation of the patients using FCR or FCU for tendon transfer ($n = 7$).

Functional results	Value	Range
Mean MSTS score	26	22–30
Mean DIP extension	0	0/0
Mean PIP extension	0.7	5/0
Mean MP extension	2.1	20/−10H

FCR: flexor carpi radialis; FCU: flexor carpi ulnaris; MSTS: Musculoskeletal Tumor Society score; DIP: distal interphalangeal; PIP: proximal interphalangeal; MP: metacarpophalangeal; H: hyperextension.

sarcoma resection. Our results showed a good functional result and a high success rate of reconstruction.

For the reconstruction of a complex upper extremity defect, whether to choose staged functional reconstruction or immediate functional reconstruction is an important issue. A previous study, in which immediate reconstruction and staged reconstruction were compared in patients with complex severe dorsal hand defects after trauma, showed that immediate functional reconstruction and soft tissue coverage required fewer operations, with greater recovered ROM and faster return to work [8]. In our study, we obtained good functional results with immediate functional reconstruction; the mean MSTS score was 26, and the mean finger DIP, PIP and MP joint extension were 4.4°, 6.1° and 11.1°. No abnormality of finger flexion was detected. This suggested that immediate tendon transfer may be effective. This may be biologically plausible because immediate functional restoration minimizes undesired changes of anatomical structures. When the resected tendons and muscles are atrophied or adhere to the surrounding tissues because of the first surgery, it may not be possible to achieve sufficient functional improvement even if secondary functional reconstruction is performed. Secondary functional reconstruction is accompanied by fibrotic changes and delayed wound healing [5].

We must make a clear distinction between defects due to the trauma and defects due to the resection of STS. In the treatment of STS, additional excision or postoperative radiation therapy may be necessary if the pathological findings of resected specimens do not show sufficient resection. In our case series, we performed immediate tendon transfer only in cases that were judged to be resectable with a sufficient margin on preoperative radiographic and pathologic findings. Moreover, in all of our cases, the pathological findings showed a negative margin, and no additional resection or postoperative radiation was performed. An immediate tendon transfer may not be suitable for patients with an extensive tumor on which it is difficult to perform adequate resection. Therefore, elaborate preoperative planning is extremely important for determining the indication for immediate tendon transfer.

The functional disability associated with sarcoma resection consists of dysfunction due to neurectomy and due to muscle resection. Tendon transfer techniques for paralysis can be applied to patients with the sarcoma on the forearm. The choice of tendons to transfer for radial nerve palsy is the main problem for reconstructive surgeons. The FCU and the FCR are widely used for restoration of finger extension. However, the choice between these two tendons remains controversial [9–12]. The FCU is the stronger flexor of the wrist, having twice as much power compared to the FCR [10]. This property of the FCU entails the following two drawbacks when used for tendon transfer; radial deviation and loss of wrist strength. Therefore, the FCR is our preferred option for the restoration of finger extension due to the drawbacks of the FCU. Its excursion is equal to that of the EDC, with slightly inferior power [11]. In our case series, the FCU was transferred in one case. In this case, the FCR had to be preserved to maintain the wrist flexion because the wide resection included the FCU. The BR transfer was performed in two patients. In these two cases, the surgery was complex, requiring reconstruction of extensive defects and bone reconstruction, respectively. Therefore, the BR tendon transfer, which is a much simpler method, was chosen to avoid a prolonged operation time. The FCR could be transferred in six out of nine patients in our series and good finger extension was obtained. This suggested that this method may be feasible even with sarcoma patients. This may be biologically plausible because tumors rarely extend beyond the interosseous membrane and the muscles and tendons of the ventral aspect are intact. This is because dense regular connective tissue is assumed to provide a more robust anatomical barrier to tumor cell infiltration [13,14]. Tables 2 and 3 showed better postoperative ROM of finger extension in the patients who underwent tendon transfer using the FCR or FCU than in the patients who underwent tendon transfer using the BR. This suggests that using FCR or FCU may be an effective way of restoring the finger extension.

Plastic and reconstructive surgical techniques such as local flap and free flap transfers are essential for improving patients' quality of life. Several recent studies have shown that a free tissue transfer is as safe as reconstruction with a local flap [15–18]. Free tissue transfer allows radical oncosurgical resections and enables adequate defect coverage, along with preservation of the function [19]. Several articles have concluded that the use of a vascularized flap for reconstruction after tumor resection is a reliable, safe and necessary technique [15]. On the other hand, adequate skin coverage is essential for successful tendon transfer. Therefore, if the vascularity of the tissue covering the suture of the tendon is at all suspicious, a flap transfer should be considered without hesitation. In our study, an immediate tendon transfer with a free tissue transfer was performed in six cases and the flaps survived completely in five cases. Partial flap necrosis, which was not on the

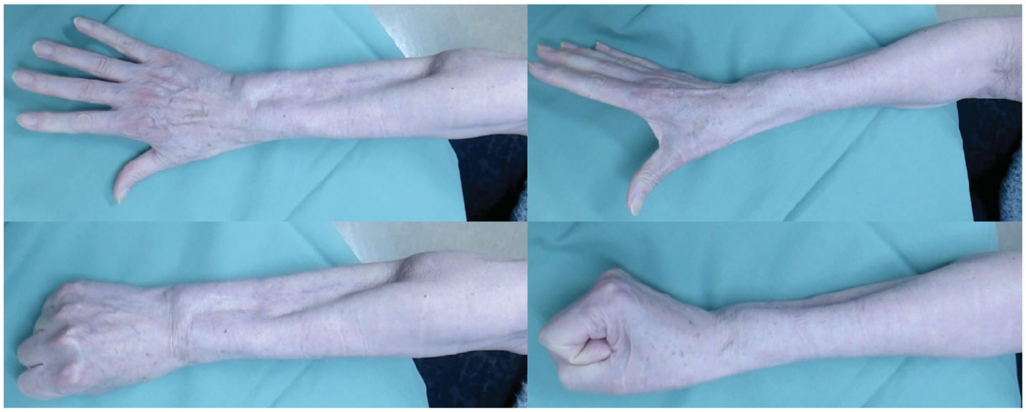

Figure 2. Postoperative view at 16 months after the surgery.

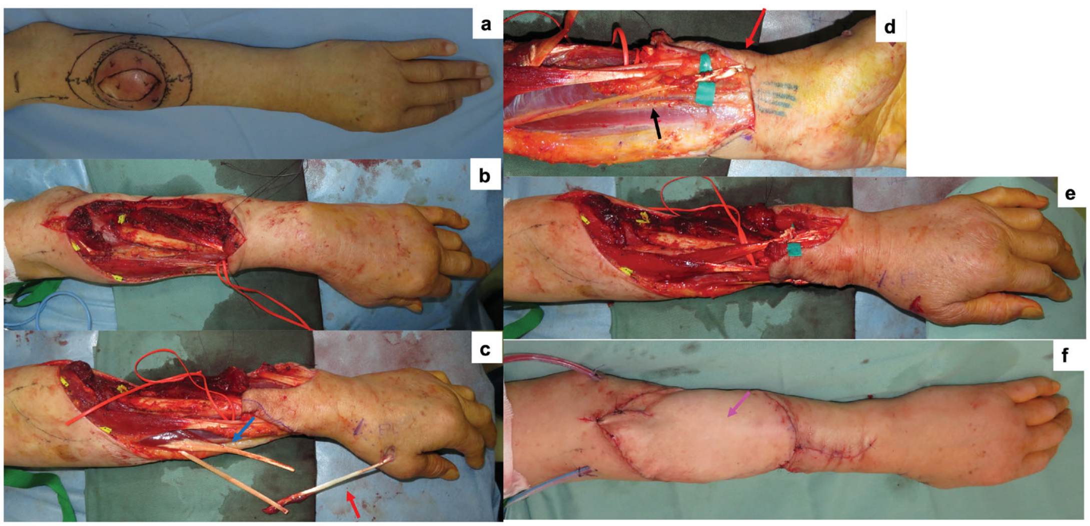

Figure 3. (a) A 74-year-old male suffered from soft tissue sarcoma on the dorsal aspect of the left forearm. (b) The defect after tumor ablation. (c) The palmaris longus (PL) tendon and the flexor carpi radialis (FCR) were identified from the defect on the forearm. Red arrow: EPL, blue arrow: FCR, black arrow: PL. (d) The transfer of the PL to the EPL was performed in the volar wound. Red arrow: EPL, black arrow: PL. (e) The transfer of the FCR to the EDC and the extensor digitorum minimi (EDM) was performed in the dorsal defect. Yellow arrow: EDC, blue arrow: FCR. (f) The superficial circumflex iliac artery perforator (SCIP) flap was transferred. Pink arrow: SCIP flap.

Figure 4. Postoperative view at 21 months after the surgery.

transferred tendon, was seen in one case, but there was no functional problem. These results suggest the safety of this operative method. Previously, an anterolateral thigh (ALT) flap was used as an option for reconstruction after sarcoma resection on the forearm [5]. Recently, however, the SCIP flap has been our preferred option due to the following merits. First, the SCIP flap harvest leaves an inconspicuous scar in a concealed region with minimal functional morbidity. Second, unlike other perforator flaps, such as the ALT flap, the donor site of the SCIP flap can still be directly closed after harvesting a flap with a width exceeding 12 cm [20].

In our case series, seven patients achieved a continuous disease-free status, one was alive with disease, and one died of another disease after 105 months of disease-free status after the surgery. Seven patients survived for more than five years and four patients remained in disease-free status for more than 10 years after the surgery. There was no limb amputation during their survival. These results strongly support the concept that reconstructive surgery should be performed not only for survival but also for function.

The greatest limitation of this study is the paucity of cases. No firm conclusions can be drawn from a series of only nine patients. However, the good functional results indicated that the immediate tendon transfer using FCR or FCU may be a good option for functional reconstruction (Table 3). For more rigorous statistical analysis, a study with a large number of patients is warranted.

Conclusions

In conclusion, immediate tendon transfer is one of the options for functional reconstruction of a dorsal forearm defect after sarcoma resection. Good finger extensions were obtained using transfers of the FCR or FCU to the EDC and EDM, and the PL tendon to the EPL.

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Ethics: This report was published with the consent and permission of the patients involved.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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