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Review

# Reconstruction of upper limb soft-tissue defects after sarcoma resection with free flaps: A systematic review

**Elena Lucattelli[a,*], Irene Laura Lusetti[b], Federico Cipriani[a], Alessandro Innocenti[a], Giorgio De Santis[b], Marco Innocenti[a]**

[a] *Plastic and Reconstructive Microsurgery, Careggi University Hospital, Florence, Italy*
[b] *Plastic and Reconstructive Surgery, Policlinico di Modena, Modena, Italy*

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**Summary** *Background and Objectives:* Upper limb preservation after soft tissue sarcoma (STS) surgical excision is now the accepted gold standard and it often requires reconstruction with free flaps. The purpose of this review is to summarize current literature on upper limb reconstruction with free flaps after STS resection.
*Methods:* A systematic review was performed in July 2019 in PubMed and MedLine Ovid databases according to the PRISMA guidelines.
*Results:* A total of 17 studies were included in the final analysis, with 132 patients. The most common diagnosis was Malignant Fibrous Histiocytoma. The most frequent timing of flap coverage was immediate. The success rate was almost always 100%. The length of follow-up was reported in 11 studies with a range of 2-187 months. The most commonly reported patient-centered outcome was the MSTS Score. Based on the evidence of the literature collected, we divided the upper limb into four parts (shoulder, elbow and arm, forearm and wrist, and hand) and described the most common and functional free flaps used for reconstruction after STS resection.
*Conclusions:* Free flaps in the treatment of STS of the upper extremity have a good overall outcome, with a low postoperative complication rate. A wide array of free flaps is available for reconstruction, and the choice of flap is based on defect size, types of tissue required, postoperative functional goal, and surgeon preference. A greater degree of standardization is needed in the reporting of patient-centered outcomes to facilitate future comparative studies.

* Corresponding author.
*E-mail address:* elena.lucattelli@gmail.com (E. Lucattelli).

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## Contents



## Introduction

In 2018, the American Cancer Society estimated that 13,040 new soft tissue sarcomas (STS) would be diagnosed in the United States with an associated mortality of 5,150 patients. Approximately 50% of STS occurs in the extremities, and 30% of these are located in the upper limbs.[1]

Overall survival following treatment for extremity STS has improved over the past decades, with 5-year survival rate approaching 80%.[2] Limb preservation surgery is now the accepted gold standard treatment for patients with STS with less than 5% necessitating amputation. A multidisciplinary approach that integrates surgery with neoadjuvant or adjuvant chemo and/or radiotherapy provides local control in more than 90% of cases and has had a significant impact on disease-free survival.[3,4]

A successful multidisciplinary management of STS must take into account the quality of the oncological resection, the soft-tissue coverage and the functional outcome. Hence, the surgical pathway in the treatment of patients affected by STS of the extremities includes tumor resection with adequate margins, functionally and aesthetically acceptable reconstruction, and application of adjuvant therapy protocols.[5]

Resection of STS in the extremity frequently results in large complex soft-tissue defects which are not suitable for primary intention or skin graft closure. In these cases, pedicled or free flap reconstruction is mandatory to achieve the limb salvage, providing a stable and long-lasting soft-tissue coverage.

In the upper limb, efforts must be made to preserve hand function as much as possible. Therefore, nerve reconstruction and tendon transfers are procedures often associated with microsurgical soft-tissue reconstruction. The choice of the ideal flap must be customized in each single case including, when needed, chimera flaps incorporating tendons which may restore the function lost after oncological excision.

The purpose of this review is to summarize current literature on upper limb reconstruction after STS resection. This may help sarcoma teams to improve selection of the most appropriate flap for such reconstructions before initial treatment.

## Methods

A systematic search was performed in both PubMed and MedLine Ovid databases according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines. The search terms included " free flap", "microsurgical", "reconstruction", "sarcoma", and "upper limb". The inclusion criteria were the use of free flap transfer in reconstruction of the hand, wrist, forearm, elbow, arm, and shoulder and the possibility of gathering separated data for free flap transfer of the upper extremity if the study described multiple procedures. The references of the articles that met inclusion criteria after screening were reviewed to identify potential studies not captured by the initial database queries. We excluded non-English language studies. The initial review was conducted by two independent authors (E.L. and I.L.L.). Disagreements were solved through discussion, in which one additional author was involved (M.I.).

The patient characteristics recorded from each study included number of patients who met inclusion criteria, sex (male/female), age (mean), presenting status (primary, local recurrence), type of neoplasm, anatomical region, tumor stage, size of defect, time of flap coverage (immediate or delayed), and type of free flap. We also recorded the use of pre- and/or post-operative chemotherapy and/or radiotherapy. The postoperative results gathered included success rate, complications (minor or major), number of reoperations, length of follow-up, and outcome measure (TESS score, MSTS or other scales).

Patients with bone sarcomas or non-upper limb site were excluded from qualitative synthesis, as well as patients with post-traumatic reconstruction or reconstruction with techniques different than free flaps (pedicled flaps, direct closure, or split-thickness skin graft). Case reports described particular cases of reconstruction with chimeric flaps which included a bony component, so were excluded. On the

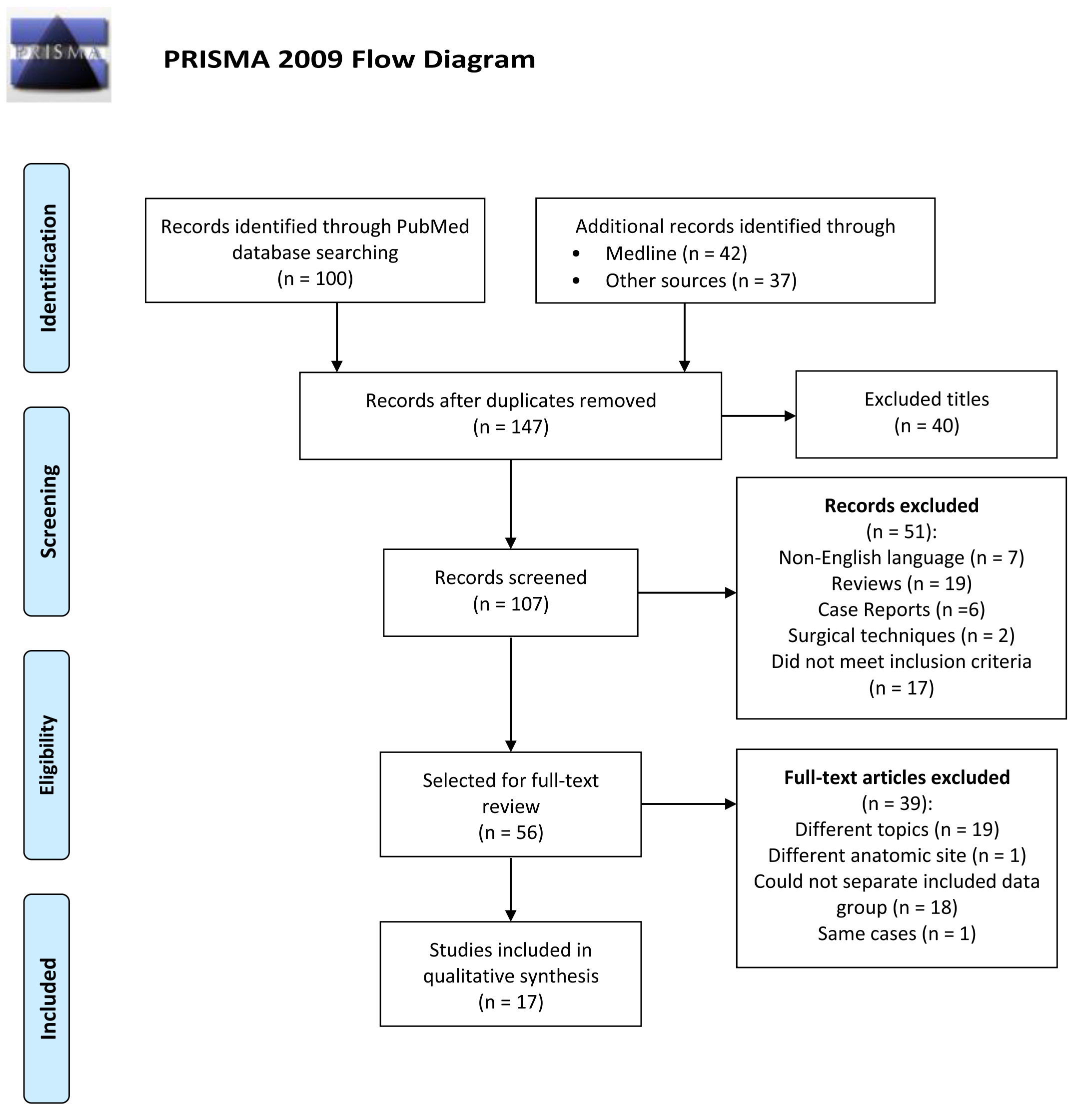


**Fig. 1** Flowchart of the selection process for inclusion of articles in the systematic review.

other hand, the articles with 1-3 cases we included in the review, contained longer case series which were reduced after the application of the aforementioned selection criteria.

## Results

After removal of duplicates, a total of 147 citations were identified. Fifty-six potentially relevant articles were selected through title/abstract screening, of which 17 studies remained for qualitative synthesis after full-text screening (Fig. 1). During the full-text review we had to remove an article of the same author of one of the included article because the cases described were the same.[2]

The 17 included studies encompassed 132 patients who met inclusion criteria (Table 1). Studies data are summarized in Table 2. Patients age was reported in 15 studies, and the average age was 49.25 (Fig. 2). Thirteen studies reported the sex of patients, among which 53% were male. Ninety-three types of neoplasm were specified of the 132 patients, and the most common diagnosis was Malignant Fibrous Histiocytoma (MFH) with the 30% of diagnosis followed by leiomyosarcoma in 10 cases. The time of flap coverage was immediate in all cases, as it was specified in 10 articles. Thirteen studies reported the use of pre- and/or post-operative radiotherapy, while only seven studies reported the use of pre- and/or post-operative chemotherapy. In those studies that reported radiotherapy use, 57% of patients received neoadjuvant radiotherapy whereas 31% of patients received adjuvant radiotherapy. In comparison, 20% of patients received neoadjuvant chemotherapy, and 14% of patients received adjuvant chemotherapy.

Success rate was reported in 16 articles and was 100% in all except three. Of all the 132 patients that received a free flap, only in three cases a flap loss was reported. Follow-up length was reported in 11 studies, ranging 2-187 months. Outcome results are summarized in Table 3. The most commonly reported patient-centered outcome was the MSTS Score, which was calculated in 6 studies.

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**Table 1** Results of literature analysis for free flap reconstruction of upper extremity after STS excision.

| N° | Author (year) | N° | Sex male/female | Age (years) (mean + SD) | Presenting status (primary/local recurrence) | Type of neoplasm | Anatomical region | Tumor stage | Size of defect | Time of flap coverage (immediate, ≤ 72h, >72h) | Type of free flap | RT (neo o adjuvant) | CT (neo o adjuvant) | Success rate | Major complications | Minor complications | N° of reoperations | FU | Outcome measures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Slump (2018) | 26 | 15/11 | 53.5 ± 15.2 | 24 / 2 | NA | 14 proximal, 12 distal | I: 5 (19.2%), II: 11 (42.3%), III: 8 (30.8%), IV: 2 (7.7%) | 9 $cm^3$ | 26 Immediate | LD, radial, RAM, ALT, gracilis, parascapular | 21 neo, 2 adjuvant | 0 neo | NA | 12 (14.1%) * | 10 (11,8%) * | NA | NA | Difference between the mean preoperative and postoperative functional score: TESS: 5.5 MSTS 87: -1.5 MSTS93: -3.3 |
| 2 | Stranix (2017) | 1 | F | 53 | NA | 1 Spindle cell sarcoma | 1 Distal dorsal forearm | NA | 12 × 10 | 1 Immediate | 1 ALT + VL + motor nerve + LFCN + IL band + TFL | RT adjuvant | 0 | 100,00% | 0 | 0 | 0 | 22 months | MSTS: 24/30 |
| 3 | Weichman (2015) | 3 | 2/1 | 22,29,46 | NA | 2 Epithelioid sarcomas, 1 leiomyosarcoma | 1 Dorsal thumb, 1 thumb, 1 dorsal thenar eminence | NA | 24,27,40 $cm^2$ | 3 Immediate | 3 aALT | 1 RT neo, 1 RT adjuvant | NA | 100,00% | 0 | 1 Wound dehiscence | 1 | 6,94,99 months | NA |
| 4 | Grinsell (2014) | 2 | 1/1 | 58, 74 | 1 / 1 | 1 Synovial sarcoma, 1 fibrosarcoma (recurrence) | 1 Deltoid, 1 biceps brachii | NA | NA | 2 Immediate | Myocutaneous medial gastrocnemius + motor nerve (from sciatic) + sensory nerve (from sural) | NA | NA | 100,00% | 0 | 0 | 0 | 12,24 months | MRC: 5/5 abduction and flexion of shoulder joint; 5/5 arm flexion (elbow range 30-120 degrees) |
| 5 | Mundinger (2014) | 2 | 1/1 | 26, 33 | 2 local recurrences | 1 Epithelioid sarcoma, 1 dedifferentiated osteosarcoma | 1 Forearm extensor compartment, 1 biceps | 3 | NA | 2 Immediate | 1 Non-innervated LD, 1 innervated gracilis | 1 RT neo e adjuvant | NA | 100,00% | 0 | 1 Inferior flap epidermolysis | 1 Wide local excision of local recurrence (ulnar reconstruction with fibula free flap); 1 flap debulking | 43.3 months (7-85) * | TESS: NA; 35.3 |
| 6 | Payne (2013) | 36 | 18/18 | 56.9 (17-78) | NA | 12 MFH, 3 liposarcomas, 6 fibrosarcomas, 5 MPNST, 3 DFSP, 5 leiomyosarcomas, 2 others | 14 Shoulder, 13 elbow, 9 wrist/hand | I: 7 (19%), II: 5 (14%), 3: 24 (67%) | 7 × 5 × 4 | NA | ALT, LD, RAM, gracilis | NA | NA | 97,00% | 1 Flap loss (partial), 1 DVT | 5 Wound infections, 2 delayed healing | 1 Surgical excision | NA | TESS: 87.68% MSTS 87: 28.78/35 MSTS 93: 81.38% |
| 7 | Grinsell (2012) | 3 | NA | NA | NA | 2 Pleiomorphic sarcomas, 1 liposarcoma | 2 Biceps + brachialis, 1 rhomboid + trapezius | NA | NA | 3 Immediate | 2 Innervated gracilis, 1 innervated LD | 3 RT neo | NA | 66,00% | 1 Flap loss (complete) | 0 | 1 Surgical excision and substitution with pedicled LD | 14,15,15 months | MSTS: 25,30,13 MRC: 4/5, 4/5, 5/5 DASH: 31, 0, 14 |

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**Table 1** *(Continued)*

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | Chao (2012) | 15 | NA | NA | NA | 2 MFH | 2 arm, 3 elbow, 9 forearm, 1 hand | NA | NA | NA | NA | 12 RT neo, 3 RT adjuvant | NA | 93,00% | 1 Flap loss (complete, due to venous thrombosis) | NA | 1 shoulder disarticulation due to local recurrence 3 months after reconstruction | NA | NA |
| 9 | Marré (2012) | 1 | NA | 52 | NA | 1 Angiosarcoma | 1 Arm | NA | NA | NA | 1 ALT | 1 RT neo | NA | 100,00% | 0 | 0 | 0 | NA | NA |
| 10 | Momeni (2011) | 6 | 3 / 3 | 36-84 (mean 63.5) | NA | 1 Myxofibrosarcoma, 2 Pleomorphic sarcomas, 1 rhabdomyosarcoma,1 synovial sarcoma, 1 myxoinflammatory sarcoma | 1 Elbow, 4 forearm, 1 hand | NA | 36,9-96 $cm^2$ (mean 65) | 6 Immediate | 6 ALT | 6 RT adjuvant | NA | 100,00% | 0 | 0 | 1 re-excision for R1 resection | 6-47 months (36) * | NA |
| 11 | Barner-Rasmussen (2010) | 12 | NA | 61* | NA | 7 MFH, 2 fibrosarcomas, 1 synovial sarcomas, 1 epithelioid sarcoma, 1 MPNST | NA | II: 1 (8,3 %), III: 5 (41.7 %), IV: 6 (49,8 %) | NA | NA | 5 LD, 1 ALT, 3 radial forearm, 2 TFL, 1 antebrachial replantation | 10 RT adjuvant, 1 RT neoadjuvant * | 1 CT adjuvant + neoadjuvant * | 100,00% | 1 Vein reanastomose, 1 hematoma | 2 Minor wound complications | NA | 2-187 months (5 DOD, 2 DUC, 5 NED) | NA |
| 12 | Muramatsu (2009) | 4 | 1 / 3 | 17-65 (mean 45.25) | 3 Primary / 1 local recurrence | 1 MFH, 1 angiosarcoma, 2 synovial sarcomas | 2 Dorsal arm, 1 dorsal hand, 1 thenar eminence | IIA: 3 (75%), IV: 1 (25%) | NA | 4 Immediate | 2 Gracilis, 1 Groin, 1 Peroneal | 2 RT adjuvant | 2 CT neo | 100,00% | 0 | 0 | 0 | 38-173 months (108.5), 3 NED, 1 DOD | Enneking scoring system: 30, 30, 23, 20 |
| 13 | Lee (2007) | 1 | M | 32 | NA | 1 Myxofibroma | Forearm | NA | 12 × 7 cm | NA | 1 TDAP (transverse) | NA | NA | 100,00% | 1 Subflap haematoma | 0 | 0 | | NA |
| 14 | Mehrara (2008) | 2 | 1/1 | 28-46 | NA | 1 Epithelioid sarcoma, 1 leiomyosarcoma | 2 Thumbs | NA | 5 × 6 cm | NA | ALT | None | None | 100,00% | 1 Stich abscess with exposition of bone graft, needed a first dorsal metacarpal artery flap | 0 | 0 | 22 months free from disease | MSTS: 28, 29 |
| 15 | Dabernig (2007) | 1 | M | 60 | 1 Local recurrence | 1 Sarcoma | 1 Upper arm | NA | 16 × 6 cm | 1 Immediate | 1 CSAP | NA | NA | 100,00% | 0 | 0 | NA | NA | NA |
| 16 | Kim JY (2004) | 15 | 8 / 7 | 56.8 (12-75) | 3 Primary, 12 recurrence | 6 MFH, 3 leiomyosarcomas, 2 synovial sarcomas, 2 liposarcomas, 1 epithelioid sarcoma, 1 unclassified sarcoma | 1 Arm and elbow, 1 elbow and forearm, 1 elbow, 10 forearm, 2 arm | I: 1(6.7%), II: 5 (33.3%), III: 7 (46.7%), IV: 2 (13.3%) | >5 cm in 8 patients, <5 cm in 9 patients | NA | 7 RAM, 3 LD, 2 gracilis, 1 scapular, 1 lateral arm, 1 radial forearm | 12 RT neo, 2 RT adjuvant, 4 adjuvant brachytherapy | 9 CT neo, 8 CT adjuvant | 100,00% | 2 Vessel thrombosis | 1 hematoma | 1 Resection and gracilis flap for local recurrence | 2-119 months, 4 DOD, 3 NED, 6 AWD, 2 DOC | Enneking score: range 14-30 |
| 17 | Ihara (2003) | 2 | 2 M | 65 (60-70) | 2 recurrences | 1 Liposarcoma, 1 DFSP | 2 Shoulder | IA: 2 (100%) | NA | 4 Immediate | 2 TFL | 0 | 1 CT | 100,00% | 0 | 0 | 0 | 62-67 months | MSTS: 97%, 100% |

aALT: adipofascial anterolateral thigh; ALT: anterolateral thigh; AWD: alive with disease; CSAP: circumflex scapular artery perforator; CT: chemotherapy; DASH: Disability of the Arm, Shoulder, and Hand; DFSP: dermatofibrosarcoma protuberans; DOD: dead of disease; DUC: death from unrelated cause; DVT: deep venous thrombosis; IL: ileotibial; LD: latissimus dorsi; LFCN: lateral femoral cutaneous nerve; MFH: malignant fibrous histiocytoma; MPNST: malignant peripheral nerve sheath tumor; MRC: Medical Research Council; MSTS: Musculoskeletal Tumor Society; NA: not applicable; NED: no evidence of disease; RAM: rectus abdominis muscle; RT: radiotherapy; TDAP: thoracodorsal artery perforator; TESS: Toronto Extremity Salvage Score; TFL: tensor fascia lata; VL: vastus lateralis. * data not divided for the group of patients of our interest among the other results described in the study

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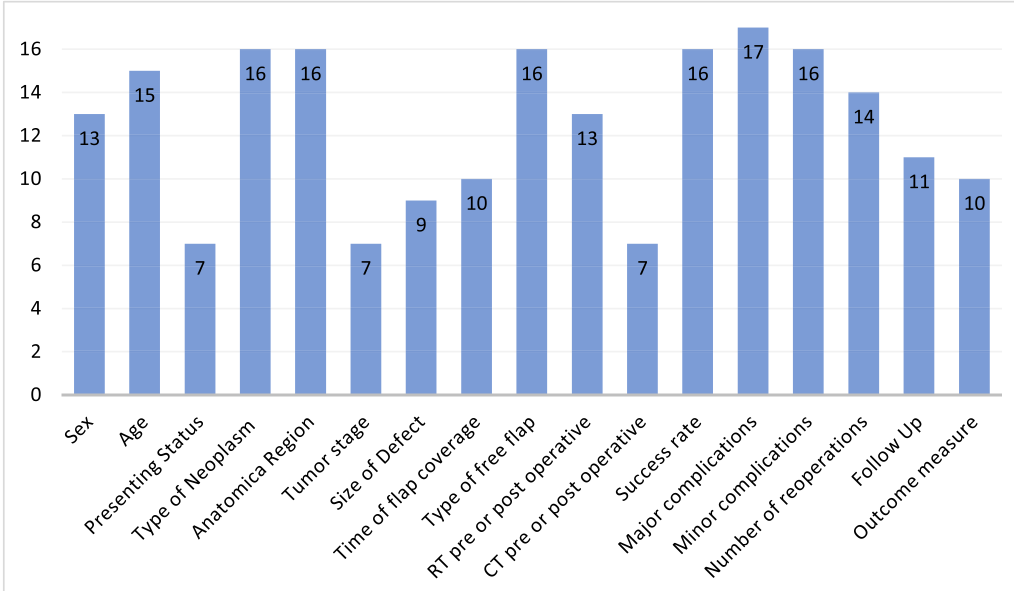


**Fig. 2** Bar graph showing the number of total articles (n = 17) reporting each variable. Numbers in black within the bars represent the number of articles describing each variable.

**Table 2** Overall study characteristics of free flap reconstruction in upper extremity STS treatment.

| | |
|---|---|
| Included papers | 17 |
| Number of patients | 132 |
| Average age (years) | 49.25 |
| Percent male | 53% |
| Length of follow-up (range in months) | 2-187 |

## Shoulder

Extirpation of sarcomas of the shoulder and its girdle with adequate margins often results in extensive defects of the overlying skin and functionally important muscles such as the deltoid and the trapezius.[6] Accordingly, not only wound coverage but also cosmetic and functional problems must be solved to obtain satisfactory results of limb salvage in this region. Soft-tissue reconstruction is usually accomplished using cutaneous, muscular, and musculocutaneous pedicled flaps around the shoulder as a donor source (Table 4). The latissimus dorsi (LD) pedicled flap is the procedure of choice for extensive defects after oncological resection as it is usually available, easy to harvest, and can provide a large amount of tissue coverage. Moreover, this flap can be a reliable source for functional reconstruction.[7,8] In some cases, such as previous thoracic surgery or axillary lymph node dissection, LD elevation may carry a risk of failure: in these cases, a tensor fascia lata or a medial gastrocnemius free flap can be harvested.

The tensor fascia lata muscle includes a strong fascia lata that provides an appropriate suspending structure for the shoulder.[9] Simultaneous harvest of the flap is feasible in either the supine or lateral positions during shoulder surgery. In addition, the flap can also be used as a functioning muscle with neurorrhaphy of the motor nerve.[10] The anatomic uniformity and the large diameter of the vascular pedicle minimize the drawbacks of this free flap. The flap could be a donor of first choice for shoulder reconstruction, especially for deltoid replacement, because its muscle belly is more compact and is nearly equivalent to that of the deltoid, whereas the LD can be too large. Functional use may also be feasible in the case of an entire defect of the trapezius by accomplishing a neurorrhaphy of the motor nerve with the spinal accessory nerve.

The functional medial gastrocnemius free flap has been described for deltoid reconstruction as good option in view of its strength, muscle bulk, length, and limited donor-site morbidity.[11]

## Elbow and arm

ALT flap is the flap of choice in case of STS involving this region for its long and sizeable pedicle, predictable anatomy, minimal donor-site morbidity, and its provision of the opportunity to implement a two-team approach.[12,13] Valuable alternatives are the thin circumflex scapular artery perforator flap (CSAP) and a rectus abdominis muscle (RAM) or myocutaneous (RAMC) free flap (Table 5).

The thin CSAP has been described as a valid alternative possessing easily defined surface markings, good pedicle length, and large-diameter vessels. Moreover, this flap avoids intramuscular dissection while retaining all the potential for thinning. The character of the dermis can be adjusted by varying the orientation of the skin paddle, and multiple chimeric options are possible.[14] However, this flap requires larger anatomical, radiological, and clinical studies to clearly define its potential dimensions, safety, and use.

Selection of a RAM or RAMC free flap can be associated with large defect sizes.[15] While the bulky nature of the flap

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**Table 3** Outcome results for anatomical region after free flap reconstruction of upper extremity after STS excision.

| Anatomical region | Study | Flap | Major complications | Minor complications | FU (months) | Reoperations |
|---|---|---|---|---|---|---|
| Shoulder | Grinsell et al. (2014) | 1 Myocutaneous medial gastrocnemius + motor nerve (from sciatic) + sensory nerve (from sural) | / | / | 12 | / |
| | Payne et al. (2013) | 11 ALT, 3 LD, 1 rectus abdominis | * | * | NA | * |
| | Grinsell et al. (2012) | 1 innervated LD | / | / | 14 | / |
| | Ihara et al. (2003) | 1 innervated TFL, 1 TFL. | / | / | 62, 78 | / |
| Arm | Grinsell et al. (2014) | 1 Myocutaneous medial gastrocnemius + motor nerve (from sciatic) + sensory nerve (from sural) | / | / | 24 | / |
| | Mundinger et al. (2014) | 1 innervated myocutaneous gracilis | / | 1 inferior flap epidermolysis | * | 1 flap debulking |
| | Grinsell et al. (2012) | 2 innervated gracilis | 1 failed | / | 15 | 1 Substituted with LD |
| | Chao et al. (2012) | 2 | * | * | NA | * |
| | Marrè et al. (2012) | 1 ALT | / | / | NA | / |
| | Dabering et al. (2007) | 1 CSAP | / | / | NA | / |
| | Kim JY et al. (2004) | 1 scapular muscle, 1 RAM, 1 RAMC | * | * | * | * |
| Elbow | Payne et al. (2013) | 9 ALT, 4 LD | * | * | NA | * |
| | Chao et al. (2012) | 3 | * | * | NA | * |
| | Momeni et al. (2011) | 1 ALT | / | / | * | * |
| | Kim JY et al. (2004) | 1 RAMC, 1 LDM + STSG | * | * | * | * |
| Forearm | Stranix et al. (2017) | 1 ALT + VL + motor nerve + LFCN + IL band + TFL | / | / | 22 | / |
| | Mundinger et al. (2014) | 1 LD | / | / | * | Local recurrence (ulnar reconstruction with free fibula flap) |
| | Chao et al. (2012) | 9 | * | * | NA | * |
| | Momeni et al. (2011) | 4 ALT | / | / | * | * |
| | Lee et al. (2007) | 1 TDAP | 1 sub-flap hematoma | / | NA | |
| | Kim JY et al. (2004) | 1 gracilis + STSG, 4 RAM + STSG, 1 LDMC, 1 LDM + STSG, 1 lateral arm muscle, 1 myocutaneous gracilis, 1 radial forearm | * | * | * | * |

(*continued on next page*)

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**Table 3** (*continued*)

| Anatomical region | Study | Flap | Major complications | Minor complications | FU (months) | Reoperations |
|---|---|---|---|---|---|---|
| Hand/wrist | Weichman et al. (2015) | 3 ALT | 1 wound dehiscence | / | 94, 99, 6 | 1 |
| | Payne et al. (2013) | 6 ALT, 2 rectus abdominis, 1 gracilis | * | * | NA | * |
| | Chao et al. (2012) | 1 | * | * | NA | * |
| | Momeni et al. (2011) | 1 ALT | / | / | * | * |
| | Muramatsu et al. (2009) | 2 innervated gracilis, 1 groin, 1 peroneal | / | / | 173, 86, 38, 137 | / |
| | Mehrara et al. (2008) | 2 ALT | 1 Stich abscess with exposition of bone graft | / | 22 | 1 first dorsal metacarpal artery flap |

aALT: adipofascial anterolateral thigh; ALT: anterolateral thigh; CSAP: circumflex scapular artery perforator; FU: follow-up; IL: ileotibial; LD: latissimus dorsi; LDM: latissimus dorsi muscle; LDMC: latissimus dorsi myocutaneous; LFCN: lateral femoral cutaneous nerve; NA: not applicable, RAM: rectus abdominis muscle; RAMC: rectus abdominis myocutaneous; STSG: split-thickness skin graft; TFL: tensor fascia lata; TDAP: thoracodorsal artery perforator; VL: vastus lateralis. *: data not divided for anatomical region

**Table 4** Surgical options for shoulder reconstruction.

| Flap | Advantages | Indications | Functional outcome | Limitations |
|---|---|---|---|---|
| LD pedicled flap | Easy to harvest, low donor-site morbidity, large amount of tissue, low operative time | First choice for deltoid reconstruction; allows functional reconstruction | Good functional recovery | Previous thoracic surgery or axillary lymph node dissection |
| (Innervated) tensor fascia lata free flap | Simultaneous harvest both in supine or lateral position, large diameter of vascular pedicle, limited donor-site morbidity, useful for deltoid replacement for its compact muscle belly | Second choice for deltoid reconstruction or complete trapezius replacement; allows functional reconstruction accomplishing a neurorrhaphy of the motor nerve with respectively axillary or spinal accessory nerve | MSTS: 97% for functional reconstruction | Previous thigh surgery involving tensor fascia lata muscle |
| (Innervated) medial gastrocnemius free flap | Easy to harvest, limited donor-site morbidity, allows two-team approach | Third choice for deltoid reconstruction;allows functional reconstruction accomplishing a neurorrhaphy of the motor nerve with axillary nerve | Complete abduction and flexion of the shoulder joint for functional reconstruction | Previous leg upper third surgery involving medial gastrocnemius muscle, short pedicle |

LD: Latissimus Dorsi; MSTS: Musculoskeletal Tumor Society

**Table 5** Surgical options for arm and elbow reconstruction.

| Flap | Advantages | Indications | Functional outcome | Limitations |
|---|---|---|---|---|
| (Thin) ALT free flap | Long and sizeable pedicle, predictable anatomy, minimal donor-site morbidity, allows two-teams approach; the lateral femoral cutaneous nerve can be included for possible sensory reinnervation. | First choice for soft-tissue reconstruction, especially for large defects; iliotibial band can be harvested along with VL muscle to anchor the resected tendon remnants and establish static musculoskeletal stabilization of joints | N/A | Previous thigh surgery, rarely small cutaneous perforator vessels |
| CSAP free flap | Thin, easy defined surface marking, good pedicle length, large diameter vessels, avoids intramuscular dissection | Second choice for soft-tissue reconstruction; ideal for the elbow joint | N/A | Requires lager anatomical, radiological, and clinical studies to clearly define its potential dimensions, safety, and use |
| RAM or RAMC free flap | Easy to harvest, predictable anatomy, allows two-team approach | Third choice for soft-tissue reconstruction, especially for large defects | N/A | Bulky, possible abdominal hernia and bulges |
| (Innervated) myocutaneous gracilis free flap | Limited donor-site morbidity, allows two-team approach | First choice for biceps reconstruction; allows functional reconstruction accomplishing a neurorrhaphy of the motor nerve with musculocutaneous nerve for elbow flexion | Good functional recovery | Short pedicle and small-diameter vessels |
| (Innervated) medial gastrocnemius free flap | Easy to harvest, limited donor-site morbidity, allows two-team approach | Second choice for biceps reconstruction; allows functional reconstruction accomplishing a neurorrhaphy of the motor nerve with musculocutaneous nerve for elbow flexion | Grade 5/5 arm flexion and abduction; elbow range 30-120 degrees | Previous leg upper third surgery involving medial gastrocnemius muscle, short pedicle |

ALT: Anterolateral Thigh; CSAP: Circumflex Scapular Artery Perforator; RAM: Rectus Abdominis Muscle; RAMC: Rectus Abdominis Myocutaneous; VL: Vastus Lateralis

at initial inset may be worrisome, over a time period of months, the flap atrophies, becoming more flush with the surrounding tissue. Disadvantages of its use relate mostly to donor site morbidity, with abdominal hernia and bulge formation being seen infrequently.

In case of massive resection of the biceps muscle, a myocutaneous gracilis free flap with a neurorrhaphy with musculocutaneous nerve can be successfully used in order to restore the elbow flexion.[8,16,17] Functional medial gastrocnemius free flap can be another option after biceps muscle resection.[11]

## Forearm and wrist

For small defects, propeller flaps based either on perforators raising from the vascular network of the elbow or from radial and ulnar arteries are the first choice.[18] In case of larger defects, thin ALT flap is routinely used (Table 6).[13,19]

The thoracodorsal artery perforator flap (TDAP) can be used for its minimal donor-site morbidity and relatively hidden scar that can be cosmetically improved by harvesting the flap in a transverse fashion.[20] RAM, RAMC, and gracilis muscle flaps are also described as other alternatives.[15]

**Table 6** Surgical options for forearm and wrist reconstruction.

| Flap | Advantages | Indications | Functional outcome | Limitations |
|---|---|---|---|---|
| Propeller flaps | Limited donor-site morbidity, low operative time, reconstruction "like with like" | First choice for soft-tissue reconstruction, especially for small defects | N/A | Not suitable for very large defects |
| Thin ALT free flap | Long and sizeable pedicle, predictable anatomy, minimal donor-site morbidity, allows two-teams approach; the lateral femoral cutaneous nerve can be included for possible sensory reinnervation | Second choice for soft-tissue reconstruction, especially for large defects; iliotibial band can be harvested along with VL muscle to anchor the resected tendon remnants and establish static musculoskeletal stabilization of joints | MSTS: 24/30. Near normal finger extension, active wrist extension achievable to neutral | Previous thigh surgery, rarely small cutaneous perforator vessels |
| TDAP free flap | Minimal donor-site morbidity with relatively hidden scar | Third choice for soft-tissue reconstruction, especially for small-medium defects | N/A | Does not allow two-team approach |
| (Innervated) gracilis free flap | Limited donor-site morbidity, allows two-team approach | First choice for extensor or flexor forearm muscles reconstruction | Enneking scoring system: 30/30 | Short pedicle and small-diameter vessels |
| (Innervated) LD free flap. | Easy to harvest, low donor-site morbidity, large amount of tissue | Second choice for extensor or flexor forearm muscles reconstruction | Good functional recovery | Bulky |
| (Innervated) RAM or RAMC free flap | Easy to harvest, predictable anatomy, allows two-team approach | Third choice for extensor or flexor forearm muscles reconstruction | Good functional recovery | Bulky, possible abdominal hernia and bulges |

ALT: Anterolateral Thigh; LD: Latissimus Dorsi; RAM: Rectus Abdominis Muscle; RAMC: Rectus Abdominis Myocutaneous; TDAP: Thoracodorsal Artery Perforator; MSTS: Musculoskeletal Tumor Society; VL: Vastus Lateralis

The myocutaneous ALT flap can be used in case of composite soft-tissue and muscular defects, while the iliotibial (IT) band can be harvested along with the vastus lateralis (VL) muscle to anchor the resected tendon remnants and establish static musculoskeletal stabilization of joints. The lateral femoral cutaneous nerve can be included for possible sensory reinnervation.[21] LD muscle or myocutaneous free flap is a valuable option for functional reconstruction after extensor or flexor compartments resection.[16,40]

## Hand

The hand presents specific challenges because of its unique anatomic structure. There is little soft tissue, and each compartment is narrow so that important structures exist in close proximity. Anatomic constraints make it difficult to achieve wide surgical margins.[17]

For hand palm reconstruction, the medial plantar flap is the only available option in order to reconstruct the defect with a specialized skin.[22] If not suitable, thin ALT, lateral arm, or SCIP free flaps may be used, although the quality of the skin is not comparable to that harvested from the foot sole (Table 7).[16,23,24]

In case of hand dorsum reconstruction, thin and pliable skin is required: ultrathin ALT or SCIP free flaps are the first choices (Table 8).[23,24] Peroneal free flap has been described as a valuable alternative.[17] Indeed, it can provide sufficient, healthy tissue without compromising the function of the leg, as the anatomy of the peroneal perforator is relatively constant and there is no need to sacrifice any main arteries in the lower leg. Moreover, the flap is thin and matches well with the upper limb skin in texture and contour, and it can be harvested as sensory flap if sural nerve is included.

The thumb poses a particular dilemma in that loss of the thumb seriously impairs the use of the hand and the entire

**Table 7** Surgical options for hand palm reconstruction.

| Flap | Advantages | Indications | Limitations |
|---|---|---|---|
| Medial plantar free flap | Low donor-site morbidity, reconstruction "like with like", allows two-team approach | First choice for soft-tissue reconstruction, especially for small defects | Previous foot surgery, short pedicle, and small-diameter vessels |
| Thin ALT free flap | Long and sizeable pedicle, predictable anatomy, minimal donor-site morbidity, allows two-teams approach; the lateral femoral cutaneous nerve can be included for possible sensory reinnervation | Second choice for soft-tissue reconstruction, especially for large defects | Previous thigh surgery, rarely small cutaneous perforator vessels |
| Lateral arm free flap | Allows two-team approach | Third choice for soft-tissue reconstruction, especially for small-medium defects | Previous arm surgery, important donor-site morbidity, bulky |
| SCIP free flap | Minimal donor-site morbidity, allows two-team approach | Fourth choice for soft-tissue reconstruction, especially for small-medium defects | Previous inguinal surgery, unreliable anatomy, short pedicle, and small-diameter vessels |

ALT: Anterolateral Thigh; SCIP: Superficial Circumflex Iliac Perforator

**Table 8** Surgical options for hand dorsum reconstruction.

| | Advantages | Indications | Limitations |
|---|---|---|---|
| Ultrathin ALT free flap | Long and sizeable pedicle, predictable anatomy, minimal donor-site morbidity, allows two-teams approach; the lateral femoral cutaneous nerve can be included for possible sensory reinnervation | First choice for soft-tissue reconstruction, especially for large defects | Previous thigh surgery, rarely small cutaneous perforator vessels |
| SCIP free flap | Minimal donor-site morbidity, allows two-team approach | Second choice for soft-tissue reconstruction, especially for small-medium defects | Previous inguinal surgery, not reliable anatomy, short pedicle, and small-diameter vessels |
| Peroneal free flap | Relatively constant anatomy, long and sizeable pedicle, minimal donor-site morbidity, allows two-team approach; the sural nerve can be included for possible sensory reinnervation | Third choice for soft-tissue reconstruction, especially for small-medium defects | Previous leg surgery, presence of peronea magna artery |

ALT: Anterolateral Thigh; SCIP: Superficial Circumflex Iliac Perforator

upper limb. The temporoparietal fascial and ALT fascial free flaps have been described for thin pliable flap coverage with a gliding surface.[25]

## Discussion

STS are rare malignant mesenchyme-derived tumors that commonly involve the extremities. Historically, these cases were treated by amputation, but improvements in surgical techniques, radiological imaging, and adjuvant therapies have now made limb preservation possible in the majority of cases.[3,26] Multidisciplinary management of patients with extremity STS frequently involves both wide resection to achieve clear margins and (neo)adjuvant radiation to minimize local recurrence. In many cases, this results in extensive soft-tissue defects that cannot be managed using simple wound closure or skin grafting techniques. Reconstruction using pedicled or free flaps is therefore often necessary to provide coverage of vital structures or prostheses and facilitate limb preservation.[27] Particularly, free flap reconstruction is needed in 11–18% of patients undergoing limb-sparing surgery for upper extremity STS.[15,28,29]

As free flaps require microvascular anastomosis, they may be perceived to be more complicated and therefore associated with higher complication risk.[30] On the other hand, pedicled flaps often involve extensive surgical dissection adjacent to the zone of tumor ablation, which might adversely affect functional outcome. Free flaps, indeed, may be preferable when adjacent pedicled flaps are located within the field of preoperative radiation.[31,32] Slump et al. demonstrated that the type of flap used was not an independent predictor of complications in patients with upper extremity reconstruction, and free and pedicled flaps were associated with similar postoperative functional outcomes in upper limb reconstruction.[33] Patients who experienced complications exhibited lower postoperative functional scores. However, the functional scores used in the study only consider the site of tumor ablation while flap reconstructions may also result in some degree of impairment at the donor site, which was not evaluated.

The need for coverage with a well-vascularized tissue responds not only to the nature of the lesion itself, but also to the impaired healing of irradiated and sometimes scarred tissue frequently encountered after STS resection. Patients with multiple interventions due to affected margins and in whom radiotherapy has been repeatedly applied for local recurrence are much more prone to develop complications following reconstruction, with subsequent worsening of functional outcomes and poor quality of life. As irradiated and scarred tissue with impaired blood supply will often fail to heal even with microsurgical transfers, as demonstrated by Marré et al., the reconstructive surgeon should be involved in the management of STS patients from day 1.[34] Some studies suggest that acute irradiation may predispose to microvascular thrombosis, yet free flaps, if successful, may potentially protect against complications related to damage caused by neoadjuvant radiation therapy by replacing irradiated tissue with well-vascularized nonirradiated tissue from distant sites.[35-37] The findings of Chao et al. suggest that the timing of irradiation has no significant bearing on the development of perioperative recipient-site complications, but long-term recipient site complications occurred significantly more often with adjuvant than with neoadjuvant radiotherapy, with "probably because of smaller radiation doses and field sizes with the second option. Moreover, in case of neoadjuvant radiotherapy, irradiated tissues are replaced by well-vascularized, non-irradiated free flap tissues, and postoperative complications are less frequent to occur.[32]

The main goal of reconstructive surgery has traditionally been soft-tissue coverage because in the majority of the cases, the remaining muscles are able to hypertrophy and partially replace the function of the resected muscles. The indication for a functional reconstruction has been limited therefore to the forearm and the posterior leg,[38] but in some cases this has been extended to the thigh, the anterior lower leg, the shoulder, and the buttock, with overall satisfactory results.[39] In their study, Grinsell et al. found that the use of innervated free flaps did not increase the severity of postoperative complications compared to noninnervated flaps, while providing a much better functional outcome. Despite the complexity of including multiple vessel and nerve repairs and the tensioning of muscle and tendon units making it a more complex task, they suggest that the excellent functional outcome for these patients justifies the potentially higher flap loss rate. Several studies reported the use of reinnervated free flaps for reconstruction of shoulder, biceps brachii, and forearm extensor compartment,[11,16,33] with an overall satisfactory functional outcome. However, as the studies used different functional scores (MSTS, MRC, and TESS), it was difficult to compare functional outcomes between them.

Our study demonstrated a lack of homogeneous reporting of outcomes following upper limb reconstruction after STS excision. Several studies combined results for patients undergoing different procedures or for indications other than malignancy, such as infection or trauma. This led to several papers being excluded from this study and also made data extraction more difficult in some papers that did not meet inclusion criteria. Additionally, some studies combined results for upper and lower extremity reconstruction. Stratifying data based on specific diagnosis, graft site, and patient demographics would facilitate the ability of investigators to apply evidence-based conclusions to patient care.

This study was subject to several limitations. The studies comprising our review were primarily retrospective, nonrandomized, and uncontrolled and thus prone to selection and observer bias. Additionally, some studies reported outcomes for their entire cohort, making it difficult to control for confounding factors. It was not possible to perform a true meta-analysis to calculate outcomes and standard deviations because estimates of variability within each study were not available. Studies employed different surgical techniques, postoperative management, and physical therapy regimens, further confounding the outcomes. Despite these limitations, this review provides an initial outlook on the generally successful use of free flaps for upper extremity STS.

## Conclusion

Limb salvage does not adversely affect oncological outcome, and the functional benefits of limb salvage with soft-tissue reconstruction in sarcoma surgery have been established. Free flaps provide well-vascularized tissue facilitating wound healing and also tolerate radiotherapy well. In addition, no further morbidity is caused to the extremity. A wide array of free flaps is available for reconstruction following upper extremity tumor resection, and the choice of flap is based on defect size, types of tissue required, postoperative functional goal, and surgeon preference. Future studies should attempt to correlate patient demographics, specific oncologic diagnosis, flap type, and the use of chemotherapy/radiotherapy with postoperative functional outcome, rate of reoperations and complications.

## Declaration of Competing Interest

None declared.

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