Coverage of Amputation Stumps Using a Latissimus Dorsi Flap With a Serratus Anterior Muscle Flap

A Comparative Study

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Abstract: Amputation of the extremities is a definitive reconstructive option, and surgeons should aim to preserve maximum overall function. If the exposed bone cannot be adequately covered using local tissues, the stump can be reconstructed using a number of well-described free flap transfer techniques.

Between January 2002 and December 2011, 31 patients with severe injuries to the lower extremities underwent above-the-knee, below-the-knee, and Chopart and Ray amputations. Bony stumps were covered using latissimus dorsi myocutaneous flaps alone (group 1), or together with serratus anterior muscle flaps (group 2). The groups were compared with respect to age, flap survival, skin flap size, immediate complications, wound sloughing, deep ulceration, need for bone amputation, limb visual analog scale score, time to prosthesis, and follow-up duration.

The mean area of the latissimus dorsi skin flap was 255.9 cm^2, and immediate complications occurred in 8 (25.8%) patients. In the double-padding group, there were fewer cases of deep ulceration than in the single-flap group, and prostheses could be worn sooner. There were no statistically significant differences in other parameters.

Successful reconstruction of amputation stumps requires an adequate, durable, weight-bearing, and well-contoured soft tissue cover. A latissimus dorsi musculocutaneous flap together with a serratus anterior muscle flap provides well-vascularized muscle tissue and a durable skin paddle, leading to less ulceration than conventional flap techniques.

Key Words: amputation, free flaps, latissimus dorsi flaps, serratus anterior flaps, reconstruction

(*Ann Plast Surg* 2016;76: 88–93)

Amputation is a necessary, although definitive, reconstructive option in certain circumstances, such as high-energy trauma or a crushing injury. Shortening of the bone may facilitate wound closure using local tissues; however, the level of amputation should maximize overall function. Every effort should be made to preserve a functional joint and adequate bone length, to facilitate the patient's functional recovery and rehabilitation.[1–3]

Several techniques, such as stump skin traction or tissue expansion, enable adequate coverage of the exposed bone, when local tissue is insufficient. However, these techniques may result in further shortening of the proximal bone. One of the main techniques known to overcome insufficient skin coverage while maintaining bone length involves free flap transfer.[3–7]

Reconstruction of amputation stumps with free flaps has been described extensively in the literature. A large number of studies have investigated different types of flaps (eg, muscle with skin graft, musculocutaneous, or fasciocutaneous flaps), different donor sites (scapular, latissimus dorsi, anterolateral thigh, groin, rectus abdominis, or fillet), and have compared their outcomes.[2–7]

However, the reconstructed area is frequently affected by skin erosion and sloughing with ulceration, especially if the stump is weight-bearing or in direct contact with a prosthesis. To prevent chronic ulceration, we investigated a double-padding technique, involving the use of combined latissimus dorsi and serratus anterior muscle flaps, which could decrease the shear force generated by movement.

We present 14 cases of amputation reconstructed by double padding with a latissimus dorsi musculocutaneous flap and a serratus anterior muscle flap, and we compare their outcomes with 17 previous cases where a latissimus dorsi musculocutaneous free flap was used on its own.

PATIENTS AND METHODS

We reviewed the medical records of all patients who underwent bony stump reconstruction in the lower extremities from January 2002 to December 2011. A total of 31 patients with severe traumatic injuries, diabetic infections, and acute embolic syndrome due to aortic dissection were included. Patient characteristics assessed, consisted of sex, age, etiology, amputation level, flap size (myocutaneous flap with or without serratus anterior muscle flap), immediate complications, wound sloughing, deep ulceration, need for proximal bone amputation, limb visual analog scale (VAS) score (a subjective patient score after beginning to walk or wear a prosthesis; range, 0–10), time to prosthesis or walking, and duration of follow-up (Tables 1 and 2).

To reconstruct the bony stump in group 1 (single flap), a latissimus dorsi myocutaneous flap was used on its own. Between January 2002 and December 2008, we relied entirely on the latissimus dorsi myocutaneous flap, which resulted in a number of postoperative complications. Subsequently, we changed our approach, and between January 2009 and December 2011 we used the latissimus dorsi myocutaneous flap together with the serratus anterior muscle flap, which we refer to as double padding (group 2).

Statistical Analysis

The χ^2 test and Fisher exact test were used to compare flap survival rates, immediate complications, mild wound sloughing (no need for surgery), deep ulceration (surgery required), and need for proximal bone amputation. Student *t* test was used to compare age, latissimus dorsi myocutaneous flap size (in square centimeters), limb VAS score [median (1Q, 3Q)], and time to prosthesis (in weeks). The Wilcoxon rank sum test

Received August 11, 2013, and accepted for publication, after revision, March 13, 2014.
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Conflicts of interest and sources of funding: none declared.
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Sang Wha Kim, as the first author, assisted in all surgical procedures and was responsible for writing the article. Kyu Tae Hwang and Seung Bae Jeon assisted in writing the article, collected data, and took part in the operations. Youn Hwan Kim, as corresponding author, performed all the operations, collected the data, and cowrote the article with the first author.
All authors followed the principles outlined in the Declaration of Helsinki, and this investigation was approved by the Institutional Review Board of the College of Medicine, Hanyang University (2013-04-014-001).

ISSN: 0148-7043/16/7601–0088
DOI: 10.1097/SAP.0000000000000220

TABLE 1. Summary of Conventional Latissimus Dorsi Myocutaneous Flap Alone Group

Number	Sex	Age, y	Etiology	Amputation Level	Flap Size (Latissimus Dorsi Flap), cm^2	Immediate Complications	Wound Sloughing	Deep Ulceration	Required Proximal Bony Amputation	Limb VAS Score	Time Until Prosthesis or Shoes After Flap Surgery, wk	Follow-ups, mo
1	M	48	Severe crushing trauma	Below the knee	22 × 14	Chronic seroma (donor site)	None	None	None	2	10	12
2	M	52	Diabetic foot infection	Chopart	18 × 10	None	(+)	None	None	3	10	12
3	F	61	Severe crushing trauma with infection (MRSA)	Below the knee	19 × 14	Partial flap loss (secondary healing)	(+)	(+)	(+)	4	12	14
4	M	60	Diabetic foot infection	Chopart	16 × 10	None	None	None	None	2	12	16
5	M	68	Severe crushing trauma with infection (MRSA)	Below the knee	23 × 15	None	(+)	(+)	None	3	12	8
6	M	53	Diabetic foot infection	Chopart	19 × 10	None	None	None	None	3	10	18
7	M	62	Severe crushing trauma with infection (MRSA)	Below the knee	22 × 12	Total flap loss (venous thrombosis)	(+)	(+)	(+)	4	16	6
8	M	50	Aortic dissection, embolization	Chopart	20 × 13	None	(+)	(+)	(+)	3	12	12
9	F	65	Diabetic foot infection	Second, third, fourth, fifth ray amputation	16 × 8	Wound disruption (donor site)	None	None	None	3	8	12
10	F	70	Severe crushing trauma	Below the knee	18 × 13	None	None	None	None	4	14	24
11	F	65	Diabetic foot infection	fourth and fifth ray amputation	18 × 9	None	None	None	None	2	4	12
12	M	34	Severe crushing trauma with infection (*Pseudomonas*)	Chopart	20 × 11	Wound disruption (flap site)	None	None	None	1	8	18
13	M	32	Severe crushing trauma	Below the knee	24 × 13	None	None	None	None	1	12	26
14	F	67	Severe necrotizing fasciitis	Above the knee	26 × 16	None	(+)	(+)	None	2	16	20
15	M	33	Severe crushing trauma with infection (MRSA)	Below the knee	24 × 15	None	None	None	None	3	14	12
16	M	51	Severe crushing trauma	First, second, third ray amputation	17 × 13	None	None	None	None	3	8	12
17	M	44	Severe crushing trauma	Below the knee	20 × 15	None	None	None	None	2	14	8

MRAS indicates Methicillin-resistant Staphylococcus aureus.

TABLE 2. Summary of Latissimus Dorsi Myocutaneous Flap Combined With Serratus Anterior Muscle Flap Group

Number	Sex	Age, y	Etiology	Amputation Level	Flap Size (Latissimus Dorsi Flap, Serratus Anterior Muscle Flap), cm^2	Immediate Complications	Wound Sloughing	Deep Ulceration	Required Proximal Bony Amputation	Limb VAS Score	Time Until Prosthesis or Shoes After Flap Surgery, wk	Follow-ups, mo
1	M	60	Severe crushing trauma with infection (*Aeromonas hydrophila*)	Below the knee	22 × 12 7 × 6	None	(+)	None	None	2	8	36
2	M	38	Severe crushing trauma with infection (MRSA)	Below the knee	18 × 11 10 × 8	Wound disruption (donor site)	None	None	None	2	8	16
3	M	44	Severe crushing trauma with infection (MRSA)	Below the knee	19 × 11 11 × 10	None	None	None	None	2	8	30
4	F	66	Severe crushing trauma	Chopart	22 × 12 7 × 5	None	None	None	None	3	10	22
5	M	62	Severe crushing trauma	Above the knee	20 × 12 10 × 9	Arterial thrombosis (emergent thrombectomy with vein graft)	(+)	None	None	3	10	28
6	M	45	Diabetic foot infection	Fifth ray amputation	14 × 8 7 × 4	None	None	None	None	3	6	12
7	F	54	Diabetic foot infection	Chopart	20 × 10 10 × 7	None	None	None	None	1	8	20
8	M	52	Diabetic foot infection	Second, third, fourth, fifth ray amputation	20 × 10 12 × 8	None	None	None	None	1	8	12
9*	F	75	Postoperative sequela of severe crushing trauma with infection (unstable wound)	Below the knee	Three component: 20 × 13 (skin flap), 10 × 8 (muscle flap), and 9 × 7 (SA flap)	None	None	None	None	2	8	12
10	M	52	Severe crushing trauma with infection (MRSA)	Below the knee	26 × 18 14 × 12	None	(+)	None	None	2	8	12
11	M	48	Severe crushing trauma	Chopart	17 × 12 10 × 8	None	None	None	None	2	10	8
12	F	64	Severe crushing trauma (MRSA)	Below the knee	24 × 16 12 × 10	None	None	None	None	3	12	12
13	M	26	Severe crushing trauma	Below the knee	26 × 17 16 × 11	None	None	None	None	2	12	18
14	M	52	Diabetic foot infection	Fourth, fifth ray amputation	18 × 9 8 × 7	Wound disruption (flap site)	None	None	None	1	8	12

*Patient number 9 had difficulty in flap insetting; hence, we harvested 3 components separately including latissimus dorsi perforator skin flap, muscle flap, and serratus anterior muscle flap, which were described in the text.

was used to compare follow-up duration (in months). *P* values less than 0.05 were considered statistically significant.

Operative Technique

The amputations were performed by a team of orthopedic surgeons. The focus was on preserving the main vessels, which were to be used as recipient vessels in the reconstructive operations. Debridement was achieved by massive irrigation, often in combination with negative pressure dressings applied for 2 weeks to achieve wound stability. The final reconstructive procedures were performed once the wounds were quiescent.

Reconstructive operations were performed by a 2-team approach. One team prepared the bony stump and dissected the recipient vessels. The bony stump was precisely burred and carved until no sharp margins remained. The second team harvested the flap, with the patient in a supine position with arms slightly elevated and abducted. The incision landmark was between the posterior border of the pectoralis major muscle and the anterior border of the latissimus dorsi muscle. A key step was identification of the anterior border of the latissimus dorsi muscle. Once the border was found, dissection was performed between the latissimus dorsi and the chest wall. Once the latissimus dorsi and serratus anterior muscles had been detached, the thoracodorsal vessels were dissected and drained into the subscapular vessels. For maximum pedicle length, dissection was always performed along the subscapular vessel proximal to the axillary vessels. The remaining steps were essentially the same as those performed in conventional procedures. Instead of harvesting the whole latissimus dorsi muscle, only the exact amount needed to cover the bony stump was included in the myocutaneous flap.

To enable double-adding of the bony stump in group 2, the serratus anterior muscle (including fascia) was harvested in an anterograde fashion from the subscapular artery branch point to its distal portion at the rib cage. We used the freestyle approach, which involved locating the pedicles first, and then designing the flap according to the defect.

The serratus anterior muscle was fixed to the bony stump together with the surrounding fascia and periosteum using 2-0 absorbable suture materials. The latissimus dorsi muscle was then fixed to the serratus anterior muscle or subcutaneous tissues, as a second layer over the entire bony stump.

Vessel anastomosis was completed with either 9-0 or 10-0 sutures (Ethicon; Johnson & Johnson, USA). Postoperatively, prostaglandin analogs were administered intravenously for 2 weeks (Eglandin; Mitsubishi Tanabe Pharma Korea, Seoul, Korea) in all cases, and heparin was administered to patients with a history of deep vein thrombosis due to a previous open fracture.

RESULTS

We reconstructed bony stumps using latissimus dorsi myocutaneous flaps with or without serratus anterior muscle flaps in 31 patients. Twenty-two patients were men, and the mean age was 53.3 years (range, 32–75 years).

Twenty patients had severe crushing injuries, 10 had diabetic foot infections, and 1 had acute embolic syndrome due to aortic dissection. Amputation was performed below the knee in 15 patients, above the knee in 2 patients, Chopart amputation was performed in 8 patients, and Ray amputation in the remaining 6. The mean size of the latissimus dorsi flap was 255.9 cm^2, and the mean size of the serratus anterior muscle flap was 87.71 cm^2. The overall immediate complication rate was 25.8% (8 patients).

Seventeen patients received only latissimus dorsi myocutaneous flaps (group 1), whereas 14 received additional serratus anterior muscle flaps (group 2). Detailed patient characteristics are summarized in Tables 1 and 2.

Comparison of Outcomes

The outcomes in both groups are summarized in Table 3. There were no significant differences between the groups with respect to age, anatomical location of amputation, flap survival rate, size of skin flap, immediate complications, wound sloughing, need for proximal bone amputation, limb VAS score, or duration of follow-up.

TABLE 3. Summary of Outcomes Between Myocutaneous Alone Group and Double Padding Group

	Myocutaneous Flap Group (n = 17)	Double Padding Group (n = 14)	*P*
Age, y	53.8	52.7	0.8075
Anatomic locations of amputation			
Above the knee	1	1	0.887
Below the knee	8	7	0.870
Chopart	5	3	0.613
Ray amputation	3	3	0.791
Flap survival rate	16/17	14/14	0.356
Latissimus dorsi skin flap size, cm^2	254.47	257.64	0.9237
Immediate complication	5/17	3/14	0.613
Mild wound sloughing (no need for surgery)	6/17	3/14	0.397
Deep ulceration (need for surgery)	5/17	0/14	0.027
Required proximal bony amputation	3/17	0/14	0.098
Limb VAS score [median (1Q, 3Q)]	3 (2, 3)	2 (1.75, 3)	0.0698
Time until prosthesis wearing, wk	11.29	8.86	0.0149
Follow-ups	14.24	17.86	0.2650

Deep ulceration was more frequent in group 1 than in group 2, affecting 5/17 (29.4%) patients in group 1 versus 0/14 patients in group 2 ($P = 0.027$). Moreover, the mean time to prosthesis was significantly longer in group 1 (11.3 vs 8.9 weeks; $P = 0.0149$).

Although there was no significant difference in the limb VAS score ($P = 0.07$), patients in group 2 felt more comfortable and experienced less pain while wearing shoes or prostheses, which shortened the time from surgery to prosthesis.

CASE ILLUSTRATION

Case 9 (Double-Padding Technique)

A 75-year-old female patient underwent an unstable, below-the-knee amputation with insufficient soft tissue padding on the bony stump, and consequently, could not wear a prosthesis for a year after the surgery (Fig. 1). As there were no suitable vessels for anastomosis, we planned to use the medial genicular artery and the great saphenous vein on the medial thigh. The orthopedic surgeon shaved the sharp bony margin, and the following flaps were harvested: a 20 × 13-cm latissimus dorsi skin flap with a 10 × 8-cm latissimus dorsi muscle flap, and a 9 × 8-cm serratus anterior muscle flap. To facilitate flap inset and accurate positioning of the muscle, we separated the muscle and skin components of the latissimus dorsi flap. The bony stump area was then double padded with the 2 muscle flaps. The thoracodorsal artery was anastomosed end-to-end to the medial genicular artery, and the thoracodorsal vein was anastomosed end-to-end to the great saphenous vein. The donor site was covered with artificial dermis and a split-thickness skin graft. Eight weeks after the operation, the patient was fitted with a prosthesis. A follow-up assessment at 12 months revealed a healthy stump without ulceration.

DISCUSSION

Severe damage to bony structures, especially when accompanied by soft tissue deficiencies, is often associated with more proximal

FIGURE 1. A, A 75-year-old male patient who underwent an unstable, below-the-knee amputation of the left leg. B, A harvested 20 × 13-cm latissimus dorsi skin flap with a 10 × 8-cm latissimus dorsi muscle flap, and a 9 × 8-cm serratus anterior muscle flap. C, Latissimus dorsi and serratus anterior muscle flaps cover the bony stump. D, A 6-month postoperative view reveals no ulceration in the stump area.

amputation. In all cases, preservation of bone length and a functional joint is not only important for the patient's functional recovery but also superior to wearing prostheses.[1,3,5]

When attempting a reconstruction, it is crucial that the soft tissue coverage of the stump be durable, sufficiently mobile to absorb shear and direct forces, and have a reasonable contour and appropriate thickness for fitting a prosthesis or footwear.[4–7] Insufficient padding of the bony stump can result in chronic pain and ulceration, eventually leading to a more proximal amputation. As a result, many reconstructive surgeons have described free-tissue transfer procedures that attempt to overcome the problem of insufficient coverage associated with fillet flaps, conventional myocutaneous flaps, and fasciocutaneous flaps.[3–7]

Using the amputated extremity as a source of undamaged "spare parts" suitable for fillet flaps circumvents the issue of donor-site morbidity.[5,6] However, spare-part harvesting must always be followed by immediate reconstruction.[6] In our patients, a wide zone of injury due to high-energy trauma often made it difficult to determine the extent of devitalized tissue and necessary debridement. In most cases, serial debridement and vacuum-assisted closure were necessary, which delayed reconstruction. Unlike the fillet flap, other free tissue transfers can be harvested later, and final reconstruction can be delayed.[3,6]

With the development of microsurgical techniques and instruments, the popularity of free perforator flaps has increased in every reconstructive field. Free perforator flaps can be harvested from the same or contralateral extremity with minimal functional disturbance and loss of muscle. In most cases, the available pedicle is long enough to reach past the zone of injury,[4] and sensory recovery is faster due to the flap's thinness. However, despite their many advantages, free perforator flaps are generally too thin to be used in stump reconstruction, especially if the stump is weight-bearing or in direct contact with a prosthesis. In such cases, only a thick musculocutaneous flap can provide the required stability, durability, and weight-bearing tolerance.[8] The ample amount of soft tissue (including muscle) in this type of flap can provide sufficient padding for the bony stump, whereas the abundant blood supply helps to control infection. Furthermore, the flap's durable skin paddle provides resistance to shear forces while walking.

The latissimus dorsi musculocutaneous flap is particularly useful for covering large defects, because it includes a large portion of muscle, and a skin paddle that can be shaped to match the defect. The flap is sufficiently large to cover the stump, whereas the donor site remains well covered. Its thin layer of subcutaneous fat and the tight adherence of skin and muscle provide sufficient durability to resist shear.[1,8] Moreover, the flap has a constant anatomy, long pedicle length, and is associated with minimal donor-site morbidity.

However, our experience of soft tissue reconstruction during the past decade suggests that, despite the sufficient padding and meticulous surgical technique, chronic deep ulceration in the distal stump area remains a serious concern (Fig. 2). Of the 17 patients in group 1, 5 (29.4%) developed deep ulcerations that mostly lead to further surgery such as local flap coverage and proximal bone amputation. Ulceration is typically caused by contact pressure and shear forces generated at the stump-socket interface due to joint movement.[1] This pressure invariably leads to some degree of muscle atrophy, whereas shear forces may disrupt flap adherence to the bony stump, resulting in severe pain and recurrent ulceration.[4,5]

Because of surgical experience and growing anatomical knowledge of the subscapular system, we have been able to harvest the latissimus dorsi and the serratus anterior muscle flaps at the same time, to form what is known as the latissimus dorsi chimeric flap.[9,10] We have gone on to apply this flap successfully to the reconstruction of the head and neck, complex wounds, and extensive limb defects, and finally to the reconstruction of bony stumps in amputees. In fact, what prompted this approach was the idea behind the layer of cloths used by mountain hikers, where multiple layers of light clothing are considered better than 1 thick layer. Subsequently, used the following 3 layers: the skin, the latissimus dorsi muscle, and the serratus anterior muscle to pad bony stumps, and this proved to be more effective than the single-flap approach.

To harvest the 2 flaps together, surgeons must be intimately familiar with the subscapular system. The subscapular artery branches into 2 main arteries as follows: the circumflex scapular artery and the thoracodorsal artery. The latter runs distally and gives rise to the serratus anterior branch before entering the latissimus dorsi muscle. Because of its

FIGURE 2. Chronic ulceration of a conventional latissimus dorsi myocutaneous flap.

vascular anatomy, the subscapular system offers a variety of individual flaps, capable of including muscle, skin, fascia, and bone, all attached to a common pedicle.[11,12] Since its introduction by Buncke et al and Takayanagi and Tsukie,[13] the serratus anterior muscle flap has been recommended for use in upper- and lower-limb reconstruction, and in craniofacial reconstruction. As a muscle flap, it provides thin, pliable muscle that fills soft tissue defects, and as a fascial flap, it provides a gliding surface. Moreover, when correctly harvested, there is little or no functional morbidity.[14–17] Although it can be used alone, it is usually harvested together with the latissimus dorsi flap. When they are used in combination, each component flap has independent mobility, so that each can be inset with precision.[8] In most cases, they were use as separate component to expand the coverage of the extensive defect. Franceschi et al[10] reported 11 consecutive combined latissimus dorsi and serratus anterior free muscle transfer for coverage of extensive wounds such as lower extremity soft tissue loss and mutilating hand injuries requiring coverage in both dorsal and volar aspect of the hand. Nowadays, chimeric pattern flap is used for lower extremity resurfacing, especially for extreme defects that include almost the entire lower leg.[9]

To achieve double padding, the skin paddle of the latissimus dorsi musculocutaneous flap should be sufficiently large to cover the entire stump area without the need for a skin graft. On the other hand, the muscle should only just cover the bony stump, to minimize donor-site morbidity. Like the transverse rectus abdominis musculocutaneous flap used in breast reconstruction, this type of flap is muscle sparing.[18,19] The serratus anterior flap should be harvested from the branch point of the serratus anterior vessels to its distal end. Both flaps are drained by a common pedicle, the subscapular artery, which is dissected proximally to the axillary artery to achieve greater length. For precision, the serratus anterior muscle is first fixed to the bony stump after the vessel anastomosis, and the latissimus dorsi muscle is inset above it. The musculocutaneous flap is then positioned to cover the whole stump area. The serratus anterior muscle and the latissimus dorsi muscle cover the bony stump completely, with the serratus anterior fascia separating the 2 muscles. The serratus anterior muscle is attached to the bony stump, whereas the latissimus dorsi muscle adheres tightly to the skin paddle. Therefore, although some muscle atrophy can be expected, the double padding should ensure adequate coverage of the stump. Moreover, the serratus anterior fascia between the muscles functions as a barrier that bears the pressure and reduces the shear forces between the bony stump and the flap, and this fascia does not atrophy and is not resorbed. We demonstrate here that the double-padding technique can prevent chronic and deep ulceration, and may shorten the time to prosthesis, which can lead to a faster return to social life for our patients.

This study was retrospective in nature and, therefore, lacks the advantage of a randomized, controlled, prospective design. In addition, by the time we started to operate on the more recent group of patients, our surgical experience had increased and surgical techniques had advanced (including radical debridement, perforator dissection, flap harvest, flap design, flap inset, and microsurgical anastomosis); this effect cannot be evaluated using statistical methods and could affect the results presented here. Most importantly, our sample size was small, which limits our ability to compare the effectiveness of the 2 procedures. Although several differences were statistically significant, we expect they will be more pronounced as the numbers of treated patients increase.

CONCLUSIONS

Successful reconstruction of amputation stumps requires an adequate, durable, weight-bearing, and well-contoured soft tissue cover. A latissimus dorsi musculocutaneous flap combined with a serratus anterior muscle flap offers a long, anatomically constant pedicle, well-vascularized and stable muscle tissue, a durable skin paddle that tolerates shear forces, and is associated with minimal donor-site morbidity. Although our 2 series were small, double padding with a combined latissimus dorsi musculocutaneous flap and a serratus anterior muscle flap seems to be a more effective reconstructive option for amputation stumps than the conventional myocutaneous flap, especially when the bony stump is prominent.

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