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Original Article

Sequential Free Flaps in Lower Extremity Reconstruction

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Introduction: Sequential free flaps are often utilized for complex defects, particularly for recurrent head and neck tumors. However, their application in lower extremity (LE) reconstruction following trauma or oncology is less common. This study evaluated the indications, flap survival rates, and complications of sequential free flaps utilized in LE reconstruction.
Methods: Data from our multicenter database spanning from 2002 to 2020 were analyzed retrospectively through chart review. Adult patients who underwent sequential free flaps to the LE without complete initial flap loss were included. Outcome measures included ultimate flap viability and complications associated with sequential reconstructions.
Results: A total of 6 patients were identified: 2 patients (33%) required a second reconstruction following trauma, 1 patient (17%) following tumor recurrence, and 3 patients (50%) for chronic

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wounds related to infection. Most second free flaps survived (83%), with the exception of one in which the patient ultimately underwent a transfemoral amputation. Complications were observed in 3 patients (50%).

Conclusion: The main indication for second free flap reconstruction in the LE is the failure of durable wound closure with the first reconstruction, despite the absence of flap loss. In these complex scenarios, it is often prudent to utilize preoperative vascular imaging and to use distinct recipient vessels from those used in the first flap. Overall, sequential free flaps can be used in complex cases of limb salvage; however, they are associated with a substantial risk of complications.

Level of Evidence: Therapeutic-IV.

Introduction

Although free flaps usually enable single-stage reconstruction for most extremity defects, some patients may require sequential microvascular flap reconstruction due to factors such as partial primary flap loss, recurrent tumors, extensive or massive defects, or persistent wounds despite initial flap reconstruction.[1] In this study, we define "sequential free flap" as a second free flap performed after an initial free flap reconstruction for the same indication when the first free flap did not achieve its intended purpose.

Sequential free flaps are often utilized in head and neck reconstruction and are primarily indicated for regional recurrence, subsequent primary malignancies, or long-term complications despite comprehensive treatment.[2-4] Previous neck dissection or radiotherapy may cause fibrosis, limiting the availability of suitable recipient vessels. In addition, the presence of the first flap may render dissection more challenging,[5,6] potentially deterring plastic surgeons from undertaking second free flap procedures for the same defect.[5] Nevertheless, for appropriately selected patients, sequential free flaps remain a viable option for head and neck reconstruction.[3,5]

Outside of the head and neck region, sequential free flaps may be utilized in complex extremity reconstruction, particularly for addressing extensive degloving and avulsion injuries of the upper extremity and in restoring both bone as well as soft tissue in cases of acute trauma and chronic infections.[7] This includes restoring limbs or digits in patients with multiple amputations and enhancing function in congenital and posttraumatic hand deformities.[7]

This study aimed to describe our experience with sequential free flap use in lower extremity (LE) reconstruction, including indications, technical considerations, flap survival rates, complication rates, and potential risk factors for failure.

Methods

Study design and ethical approval

Following approval from the Institutional Review Board (IRB no. 2020P000174), patients who underwent their first LE free flap reconstruction at 1 of 2 urban hospitals in the Northeastern United States between January 2002 and December 2020 were identified using Current Procedural Terminology (CPT) codes for microvascular free tissue transfer (15756, 15757, 15758, 20969, 20970, 20972, and 20973) (see Supplemental Digital Content 1). Patients younger than 18 years old at the time of the procedure were excluded from the study. We identified 427 patients who underwent free flap

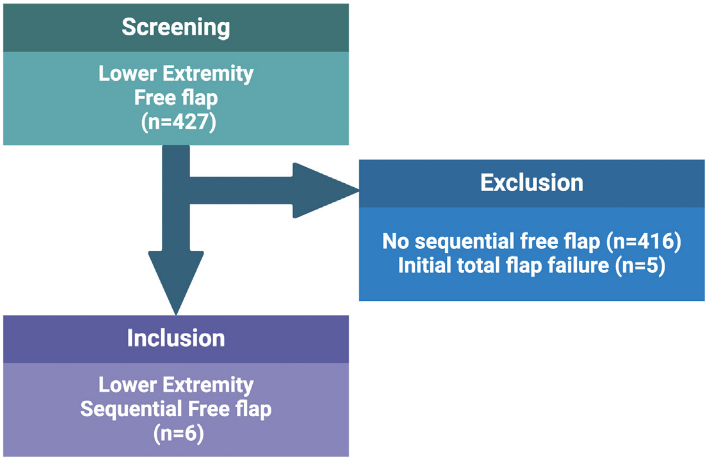

Figure 1. Flowchart of the patient inclusion and exclusion process. The figure was created with Biorender.com.

procedures for extremity coverage. Among them, 416 patients did not undergo a sequential free flap procedure. Patients who had vascular failure of the initial free flap were also excluded. A total of 6 patients who underwent sequential free flap procedures for LE coverage were identified and included in the final analysis. Figure 1 outlines the inclusion and exclusion criteria.

Data acquisition

Patient data were obtained through manual chart review of electronic health records and recorded using Research Electronic Data Capture (REDCap 12.4.27, Vanderbilt University), a digital data collection tool compliant with Health Insurance Portability and Accountability Act regulations. Patient demographics, including age, sex, body mass index, and comorbidities such as hypertension and depression, were collected. The characteristics of each flap reconstruction included preoperative imaging, indication for reconstruction, defect size and location, type of free flap utilized, recipient vessels, operative time, and the hospital length of stay. Flap viability was defined as a viable free flap that successfully covered the original defect without any partial or total flap failure. This definition aligns with the concept of total flap survival. Partial flap loss referred to a situation in which a portion of the flap developed necrosis, leading to delayed healing and requiring a secondary surgical intervention to achieve complete wound closure.

Statistical analysis

Due to the small sample size, adhering to rules of normality was not reliable. Therefore, all numerical data are reported as mean with standard deviation, and dichotomous and categorical data are reported as frequency (n) and percentage (%). Data analysis was conducted using R Software (RStudio version 2023.03.0, R Foundation for Statistical Computing, Vienna, Austria).

Results

Of the 6 patients included, 4 (66.7%) were female, with a mean body mass index of 28.7 $\pm$ 6.9 kg/m^2. The mean age at the time of the second free flap surgery was 43 $\pm$ 17 years. Table 1 summarizes the patient demographics.

The most common indication for second free flap reconstruction in the LE was chronic nonhealing wounds resulting from infection or trauma (n = 4, 66.7%). The interval between sequential free flaps ranged from 14 days to 9 years. The average defect sizes of first and second reconstructions were 342

Table 1
Patient demographics.

Patient	Sex	Age at sequential flap, y	BMI (kg/m^2)	Alcohol, smoking	Comorbidities	Diagnosis	Oncological treatment
1	F	21	20.2	None	Lymphocytic colitis	Explosive injury with right exposed tibia, Gustilo: IIIC	NA
2	F	28	26.2	None	None	High-energy injury with right exposed tibia and left exposed popliteal fossa, Gustilo: IIIB	NA
3	F	55	26.6	None	1. Hypertension 2. Early stage breast cancer (DCIS) 3. Benign neoplasm of large intestine 4. Stage IV appendiceal mucinous adenocarcinoma	Myxofibrosarcoma of RLE S/P resection with recurrence	Radio-chemotherapy
4	F	36	40	Alcohol use	1. Depressive disorder 2. Hyperinsulinism 3. Morbid obesity	Osteosarcoma of right femur S/P resection with chronic wounds	Radio-chemotherapy
5	M	55	33.4	None	Depression	Synovial sarcoma grade 2/3 of left knee S/P resection with chronic wounds	Radio-chemotherapy
6	M	63	25.6	None	Hypertension	Osteomyelitis of LLE with chronic wounds	NA

Abbreviations: BMI, body mass index; DCIS, ductal carcinoma in situ; F, female; LLE, left lower leg; M, male; NA, not applicable; RLE, right lower leg; S/P, status post.

cm^2 (range: 105-1100 cm^2) and 371 cm^2 (range: 108-800 cm^2), respectively. Free anterolateral thigh flaps (n = 2, 33.3%) and free latissimus dorsi (LD) myocutaneous flaps (n = 3, 50%) were the most utilized in the first and second reconstructions, respectively. The average surgical time of the first free flap was 472 min (range 414-599 min), and the second free flap was 712 minutes (range: 403-787 minute). Table 2 provides an overview of surgery characteristics. A description of the treatment trajectory of 2 cases is shown in Supplemental Digital Content 2.

The total flap survival rates, defined as complete flap viability without partial or total flap failure, were 50% for the first reconstruction and 83.3% for the second reconstruction. Three patients (50%) had partial flap loss after the first reconstruction. One patient had total failure of the second flap due to osteomyelitis, leading to a transfemoral amputation. After the second free flap surgery, 3 patients (50%) had complications: hematoma of the donor site (n = 1, 16.7%), venous congestion requiring flap salvage with revision of anastomosis (n = 1, 16.7%), and infection with delayed wound healing (n = 1, 16.7%). The mean length of stay was 18 days (range: 8-34) for the first reconstruction and 14 days (range: 8-34) for the second reconstruction. The mean intensive care unit stay was 3.2 days for both reconstructions. Tables 3 and 4 show the complication and flap survival rates and surgical comparison between the first flap and sequential free flap procedures, respectively.

Discussion

In this retrospective study involving 6 patients who underwent sequential free flap reconstruction in the LE, chronic nonhealing wounds were identified as the primary indication in this series (66.7%).

Table 2
Surgical characteristics.

Patient	Order	Etiology of wound defect	Surgical indication	Laterality	Defect size (cm^2)	Flap type	Recipient vessel/anastmosis	Surgical time (min)	Interval between flap surgeries	Preoperative imaging	ICU stay (days)	LOS (days)	Complication	Flap viability
1	1st	Traumatic	Explosive injury with exposed tibia	RLE	NA	Rectus abdominus free muscle flap + STSG	ATA/E-E	NA	3 years	Formal Angiography	4	14	None	Good
	2nd	Traumatic	Severe scar contractures		324	Prefabricated lower abdominal free flap	Superficial femoral artery/E-S	458		none	3	12	None	Good
2	1st	Traumatic	High-energy injury with exposed popliteal fossa	LLE	1100	Omental free flap	Descending geniculate artery/E-E	599	14 days	CTA, Formal Angiography	13	34	Partial flap loss	Partial flap loss
	2nd	Infectious	Persistent soft tissue defect		800	Left LD myocutaneous free flap	PTA/E-E	1787					Hematoma of donor site	Good
3	1st	Oncologic	Myxofibrosarcoma S/P resection with defect	RLE	225	Right ALT free flap	PTA/E-E	416	2.5 years	none	2	8	None	Good
	2nd	Oncologic	Tumor recurrence		108	Left ALT free flap	ATA/E-S	454		none	0	12	None	Good

(*continued on next page*)

Table 2 (*continued*)

Patient	Order	Etiology of wound defect	Surgical indication	Laterality	Defect size (cm^2)	Flap type	Recipient vessel/anastmosis	Surgical time (min)	Interval between flap surgeries	Preoperative imaging	ICU stay (days)	LOS (days)	Complication	Flap viability
4	1st	Oncologic	Osteosarcoma of right femur S/P resection	Right knee	200	Right ALT free flap	PTA/E-E	414	72 days	Formal Angiography	0	27	Partial flap loss	Partial flap loss
	2nd	Infectious	Persistent soft tissue defect		650	Right LD myocutaneous flap	Femoral artery/E-S	739			0	8	None	Good
5	1st	Oncologic	Oncologic	Left Knee	120	Right VRAM free flap	Descending branch of Lateral femoral circumflex artery/E-E	459	165 days	Formal Angiography	0	13	Partial flap loss	Partial flap loss
	2nd	Infectious	Persistent soft tissue defect		120	Right ALT free flap	PTA/E-E	403			0	11	Reopen for venous congestion	Good
6	1st	Infectious	Osteomyelitis of left lower leg	LLE	105	Right gracilis muscle free flap	PTA/E-E	NA	9 years	Formal Angiography	0	12	None	Good
	2nd	Infectious			224	Left LD myocutaneous free flap	Peroneal artery/E-E	431		CTA	3	9	Persistent osteomyelitis	Total flap loss

Abbreviations: ALT, anterior lateral thigh; ATA, anterior tibial artery; CTA, computed tomography angiography; E-E, end-to-end; E-S, end-to-side; LD, latissimus dorsi; LLE, left lower leg; NA, not applicable; RLE, right lower leg; S/P, status post; STSG, split thickness skin graft; PTA, posterior tibial artery; VRAM, vertical rectus abdominis myocutaneous.

Table 3
Complication and flap survival rates between the flap procedures.

	First reconstruction (n = 6)	Second reconstruction (n = 6)
Complications, n (%)		
None	3 (50.0)	3 (50.0)
Reopen for venous congestion	0 (0)	1 (16.7)
Partial flap loss	3 (50.0)	0 (0)
Hematoma of donor site	0 (0)	1 (16.7)
Persistent osteomyelitis	0 (0)	1 (16.7)
Total complication rate (%)	**50.0**	**50.0**
Flap viability, n (%)		
Good	3 (50.0)	5 (83.3)
Partial flap loss	3 (50.0)	0 (0)
Total flap loss	0 (0)	1 (16.7)
Total flap survival rate (%)	**50**	**83.3**

Table 4
Surgical comparison between the flap procedures.

	First reconstruction (n = 6)	Second reconstruction (n = 6)
Initial etiology of wound, n (%)		
Traumatic	2 (33.3)	2 (33.3)
Oncologic	3 (50.0)	1 (16.7)
Infection	1 (16.7)	3 (50.0)
Indication for sequential free flap reconstruction, n (%)		
Severe scar contractures		1 (16.7)
Tumor recurrence		1 (16.7)
Persistent soft tissue defect		4 (66.7)
Type of free flap, n (%)		
Anterolateral thigh flap	2 (33.3)	2 (33.3)
Latissimus dorsi myocutaneous flap	0 (0)	3 (50.0)
Rectus abdominus free muscle flap + STSG	1 (16.7)	0 (0)
Omental free flap	1 (16.7)	0 (0)
Vertical rectus abdominis myocutaneous flap	1 (16.7)	0 (0)
Gracilis muscle flap	1 (16.7)	0 (0)
Prefabricated flap from the lower abdomen	0 (0)	1 (16.7)
Defect size (mean (range)), cm^2	342 (105-1100)	371 (108-800)
Operative time (mean ± SD), minutes	472 ± 67	712 ± 540
Length of stay (mean ± SD), days	18 ±10	14 ± 9

Abbreviations: SD, standard deviation; STSG, split thickness skin graft.

Of the second free flap cases, complications occurred in 50%. While 83.3% of patients achieved successful flap survival, one case resulted in total flap loss, ultimately leading to a transfemoral amputation and failed limb salvage. Based on our experience, we propose several technical considerations to optimize outcomes.

The predominant indication for sequential free flap coverage is chronic nonhealing wounds due to trauma or infection. Severe LE trauma often results in extensive soft tissue defects that may require an additional free flap for soft tissue coverage. Persistent wound defects secondary to chronic osteomyelitis or infection following adjuvant therapy for malignant diseases have also been reported.[1-3] Despite undergoing primary free flap reconstruction, patients with ongoing infection may require additional debridement and second flap reconstruction for secondary wound closure.

Additional indications include significant deformities from severe scarring and tumor recurrence. Surgical release of soft tissue, tendons, and joints can resolve severe scarring from the first free flap reconstruction, but soft tissue defects with vital organ exposure often arise. Sequential free flaps may offer a solution by providing vascularized tissue for coverage.[8] When present, tumor recurrence commonly necessitates radical resection and soft tissue coverage through sequential free flap reconstruction.[1] It is also the most common indication in head and neck reconstruction.[1,3]

Excluding case 1, all cases underwent preoperative vascular imaging using angiography or computed tomographic angiography (CTA). Preoperative CTA and angiography have been established as valuable tools in free flap reconstruction.[9-12] Ahmet Duymaz et al. recommend CTA or LE angiography as a first routine step for potential free flap candidates, citing its ability to visualize LE vasculature, especially for evaluating recipient vessels following trauma.[13,14]

Based on our experience, preoperative vascular imaging is crucial for sequential free flap reconstruction. The normal vascular anatomy is often altered by the initial pathology and after the first reconstruction. Preoperative vascular imaging before the second reconstruction allows surgeons to assess the vascular anatomy and may provide information regarding the optimal recipient artery.[13,15] In addition, CTA can provide vascular details of the donor site if the ipsilateral or contralateral extremity is used for this purpose. We recommend routine preoperative angiography or CTA imaging for patients undergoing second free flap reconstruction.

In this series, the interval between sequential free flap reconstructions varied widely, ranging from 2 weeks to several years, similar to head and neck reconstruction for which a mean interval of 13.5 $\pm$ 35.5 months (range, 2 days to 16 years) has been reported.[1] This variability is influenced by the underlying etiology and specific need for a second free flap, such as cancer recurrence, second primary cancer, or correction of soft tissue contractures and volume deficits.[5]

Previous literature advises a minimum 3-month interval after primary free flap reconstruction to ensure adequate revascularization and circulation.[16-20] In our case series, most patients underwent second flap reconstruction more than 3 months after the first procedure. Case 1 underwent a second reconstruction 3 years later to address the contracture caused by the initial free muscle flap with a split-thickness skin graft. Although muscle-only flaps with split-thickness skin graft may reduce the need for secondary procedures in the long term,[20] the grafted skin may still undergo significant secondary contracture over time.[21] Case 3 involved recurrence of myxofibrosarcoma, a type of cancer reported to have a 31% local recurrence rate at 3 years,[22] and required further tumor excision and a second free flap reconstruction 2.5 years after the initial reconstruction. Cases 5 and 6 experienced chronic infection and subsequent incomplete wound healing. The intervals between their sequential procedures also exceeded 3 months: 165 days and 9 years, respectively.

However, certain exceptions may necessitate earlier intervention. For example, exposed hardware in the setting of large soft tissue defects poses a high risk of infection, as seen in cases 2 and 4 (for details, see Supplementary Digital Content 2). Debridement and soft tissue coverage for hardware salvage are generally recommended as early as possible and within 2 weeks after exposure.[23,24] In case 2, after the initial free flap surgery, there was coverage of all hardware. However, a second free flap became necessary within 2 weeks, indicating that a larger flap may have been necessary at the first stage.

In all our cases, second free flaps utilized recipient vessels distinct from those used in the first free flap. The availability of suitable recipient vessels is an important issue in sequential free flap reconstruction.[25] Although few studies specifically address recipient vessel selection in LE sequential reconstruction, our decision was driven by several factors. First, during a second flap reconstruction, the first flap remains viable, and there is a great effort to avoid injury to the primary pedicle. Second, vessels previously utilized for microsurgical anastomosis may be inherently more thrombogenic because of prior trauma. Determining the macroscopically visible area of prior trauma can be challenging, complicating the accurate determination of its true extent.[26] In addition, in most cases of secondary free flap reconstruction of LEs, failure of the second flap would most often result in amputation, thus allowing the reconstructive surgeon the latitude to use another vessel without substantial consequence.

Traditional approaches to selecting recipient vessels for primary free flaps typically involve end-to-end or end-to-side arterial or venous anastomosis.[27] However, these techniques may pose challenges in complex LE scenarios[28] due to the altered vascular anatomy and distal limb circulation affected by previous surgeries. Drawing from our clinical experience, we have developed an algorithm (Figure 2) to guide the selection of the anastomosis method for the second free flap in sequential reconstruction. This algorithm considers 2 factors: the level of the recipient vessel in the second reconstruction (using the knee as a reference point) and the recipient vessel used for the first free flap.

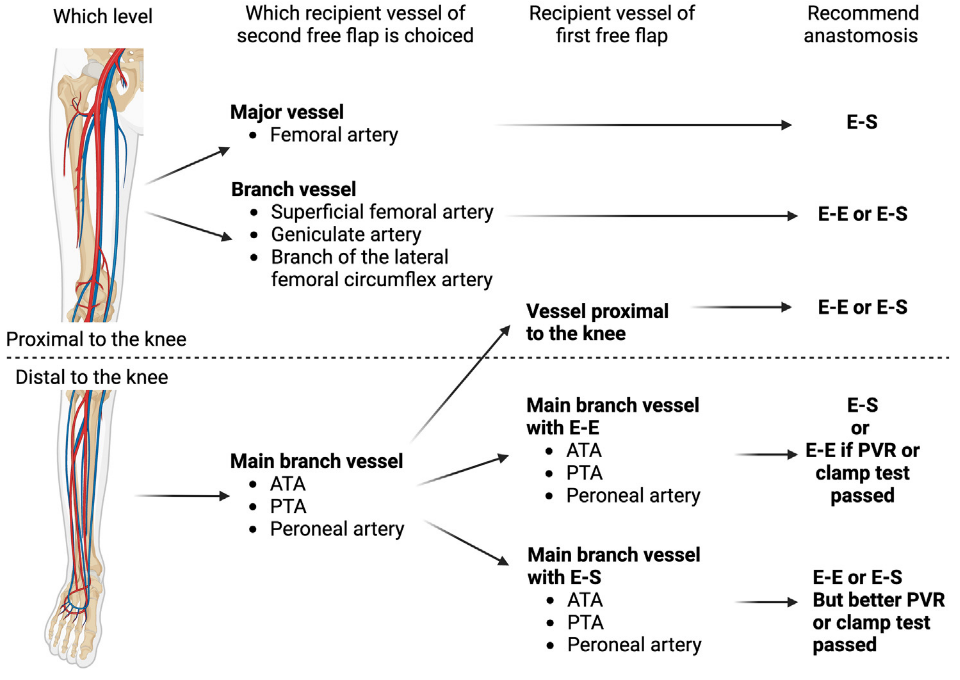

Figure 2. Decision tree for the selection of the anastomosis method for the second free flap in sequential reconstruction. Abbreviations: ATA, anterior tibial artery; clamp test, intraoperative clamp trial; E-E, end-to-end; E-S, end-to-side; PTA, posterior tibial artery; PVR, pulse volume recording.
The figure was created with Biorender.com.

Whenever possible, we prioritize selecting a recipient vessel from a different vascular system than was used for the first free flap. This approach, along with an end-to-side anastomosis, may help preserve optimal circulation in the distal limb. However, an end-to-end technique can also be considered if pulse volume recording or intraoperative clamp tests demonstrate sufficient perfusion or if amputation is already an alternative treatment option. When recipient vessels are limited or unsuitable, identification of proximal (or distal) vessels is important. If there is insufficient vessel length, vein grafts or arteriovenous loop grafts can be used.

In our cases, the LD myocutaneous flap was the most commonly utilized flap for sequential reconstructions (50%). The average soft tissue defect covered by the LD flap was 558 cm^2, exceeding the 324 cm^2 covered by the prefabricated lower abdominal free flap and the 120 cm^2 covered by the anterolateral thigh free flap. Furthermore, we observed that the 3 LD flaps cases had the largest defect sizes of all second reconstructions, and they were all indicated for chronic, infected wounds. Two cases had defect sizes that exceeded the initial wound dimensions, likely due to the need for extensive debridement to ensure complete debridement and clearance of infection before the second reconstruction. Given the ability of LD flaps to cover larger soft tissue defects, we consider it the most suitable workhorse option, aligning with the findings of Yu et al.[29]

Although our findings demonstrate that sequential free flaps can achieve successful soft tissue coverage, the complication rate is substantial (50%). Thorough preoperative planning, careful patient selection, and use of acceptable recipient vessels are essential to minimize the risks associated with these procedures. However, despite complications, the outcomes of a second reconstruction were overall favorable, except for one chronic osteomyelitis case involving persistent and ongoing infection.

Chronic osteomyelitis can have devastating consequences, including prolonged hospitalization, multiple surgeries, flap failure in sequential reconstruction, and even secondary amputation.[30-32] In our case, we exhausted nearly all available reconstructive options except free vascularized bone flap.

This highlights the significant challenge presented by LE osteomyelitis. Therefore, the potential need for amputation as a definitive treatment should be openly discussed with patients preoperatively as part of informed consent.

This study had several limitations. The retrospective nature of the study introduced the risk of missing data, as our findings rely on medical records. Not all parameters were clearly documented, particularly in complex cases. Furthermore, no long-term functional outcomes were available for these patients. Additionally, due to the small sample size, no comparative statistical analysis could be conducted, and we were limited to describing our findings.

Conclusion

In this case series, we demonstrated that sequential free flap reconstruction in the LE commonly achieves good results in limb coverage; however, it is associated with a relatively significant risk of complications, and informed consent for potential limb loss is essential. Utilizing distinct recipient vessels from the first flap and using angiography or CTA for preoperative vascular imaging are recommended

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Ethical approval, funding and conflict of interest

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jpra.2025.02.012.

References

1. Moratin J, Horn D, Heinemann M, et al. Multiple sequential free flap reconstructions of the head and neck: A single-center experience. *PlastReconstrSurg*. 2021;148(5):791e–799e.
2. Gupta AK, McKenna WG, Weber CN. Local recurrence in head and neck cancer: relationship to radiation resistance and signal transduction. *Clin Cancer Res*. 2002;8(3):885–892.
3. Hanasono MM, Corbitt CA, Yu P, Skoracki RJ. Success of sequential free flaps in head and neck reconstruction. *J PlastReconstrAesthetSurg*. 2014;67(9):1186–1193.
4. Cooper JS, Porter K, Mallin K, et al. National cancer database report on cancer of the head and neck: 10-year update. *Head Neck*. 2009;31(6):748–758.
5. Chiu WK, Chou CY, Chen SG, Chen C, Wang HJ, Yang TF. Is sequential free flap safe in oral cancer reconstruction in the same patient? an outcome and complication analysis. *Jpn J Clin Oncol*. 2020;50(2):152–158.
6. Mochizuki Y, Harada H, Shimamoto H, Tomioka H, Hirai H. Multiple free flap reconstructions of head and neck defects due to oral cancer. *PlastReconstrSurg Glob Open*. 2017;5(6):e1337.
7. Whitney TM, Buncke HJ, Lineaweaver WC, Alpert BS. Multiple microvascular transplants: a preliminary report of simultaneous versus sequential reconstruction. *Ann Plas Surg*. 1989;22(5):391–404.
8. Uygur F, Duman H, Çeliköz B. Use of free anterolateral thigh perforator flap in the treatment of chronic postburn palmar contractures. *Burns*. 2008;34(2):275–280.
9. Smit JM, Dimopoulou A, Liss AG, et al. Preoperative CT angiography reduces surgery time in perforator flap reconstruction. *J PlastReconstrAesthetSurg*. 2009;62(9):1112–1117.
10. Karunanithy N, Rose V, Lim AK, Mitchell A. CT angiography of inferior epigastric and gluteal perforating arteries before free flap breast reconstruction. *Radiographics*. 2011;31(5):1307–1319.

11. Knitschke M, Baumgart AK, Bäcker C, et al. Computed tomography angiography (CTA) before reconstructive jaw surgery using fibula free flap: Retrospective analysis of vascular architecture. *Diagnostics (Basel)*. 2021;11(10):1865.
12. Ahn L, Christensen J, Fruge S, et al. Pre-Operative vascular imaging in lower extremity free flap reconstruction: Comparison between imaging modalities. *MICROSURGERY*. 2024;44(7).
13. Duymaz A, Karabekmez FE, Vrtiska TJ, Mardini S, Moran SL. Free tissue transfer for lower extremity reconstruction: a study of the role of computed angiography in the planning of free tissue transfer in the posttraumatic setting. *Plast Reconstr Surg*. 2009;124(2):523–529.
14. Pu LL. A comprehensive approach to lower extremity free-tissue transfer. *PlastReconstrSurg Glob Open*. 2017;5(2):e1228.
15. Macedo LS, Rusig RP, Silva GB, Cho AB, Hsiang Wei T, Bernardelli Iamaguchi R. Computed tomography angiography and microsurgical flaps for traumatic wounds: What is the added value? *Clin Hemorheol Micro*. 2021;78(3):237–245.
16. Lee ZH, Daar DA, Yu JW, et al. Updates in traumatic lower extremity free flap reconstruction. *PlastReconstrSurg*. 2023;152(5):913–918.
17. Nelson JA, Fischer JP, Haddock NT, et al. Striving for normalcy after lower extremity reconstruction with free tissue: The role of Secondary esthetic refinements. *J ReconstrMicrosurg*. 2016;32(2):101–108.
18. Govshievich A, Bauder A, Kovach SJ, Levin LS. Aesthetic considerations in extremity salvage and reconstruction. *PlastReconstrSurg*. 2023;151(4):679e–687e.
19. Mucke T, Wolff KD, Rau A, Kehl V, Mitchell DA, Steiner T. Autonomization of free flaps in the oral cavity: A prospective clinical study. *Microsurg*. 2012;32(3):201–206.
20. Wong FK, Fruge S, Meulendijks MZ, et al. Secondary surgery after lower extremity free flap reconstruction. *PlastReconstrSurg*. 2023;152(5):1118–1124.
21. Hur GY, Seo DK, Lee JW. Contracture of skin graft in human burns: effect of artificial dermis. *Burns*. 2014;40(8):1497–1503.
22. Odei B, Rwigema JC, Eilber FR, et al. Predictors of local recurrence in patients with myxofibrosarcoma. *Am J Clin Oncol*. 2018;41(9):827–831.
23. Mardourian M, Wiesemann GS, Sachse CC, Nichols DS, Hagen JE, Chim H. Hardware salvage in the lower extremity after flap coverage: 10-Year single center outcomes analysis. *PlastReconstrSurg Glob Open*. 2023;11(7):e5105.
24. Viol A, Pradka SP, Baumeister SP, et al. Soft-tissue defects and exposed hardware: a review of indications for soft-tissue reconstruction and hardware preservation. *Plast Reconstr Surg*. 2009;123(4):1256–1263.
25. Alam DS, Khariwala SS. Technical considerations in patients requiring a second microvascular free flap in the head and neck. *Arch Otolaryngol Head Neck Surg*. 2009;135(3):268–273.
26. Heller L, Levin LS. Lower extremity microsurgical reconstruction. *Plast Reconstr Surg*. 2001;108(4):1029–1041.
27. Serafin D, Voci VE. Reconstruction of the lower extremity. microsurgical composite tissue transplantation. *Clin Plast Surg*. 1983;10(1):55–72.
28. Hong JP, Park CJ, Suh HP. Importance of vascularity and selecting the recipient vessels of lower extremity reconstruction. *J ReconstrMicrosurg*. 2021;37(1):83–88.
29. Yu ZJ. Combined transplantation of free tissues. *PlastReconstrSurg*. 1987;79(2):222–236.
30. Arnold PG, Yugueros P, Hanssen AD. Muscle flaps in osteomyelitis of the lower extremity: a 20-year account. *Plast Reconstr Surg*. 1999;104(1):107–110.
31. Gonzalez MH, Tarandy DI, Troy D, Phillips D, Weinzweig N. Free tissue coverage of chronic traumatic wounds of the lower leg. *Plast Reconstr Surg*. 2002;109(2):592–600.
32. Piwnica-Worms W, Stranix JT, Othman S, et al. Risk factors for lower extremity amputation following attempted free flap limb salvage. *J Reconstr Microsurg*. 2020;36(7):528–533.