Anatomic Variations in Head and Neck Reconstruction

**Bien-Keem Tan, M.B.B.S., F.R.C.S.,¹ Chin-Ho Wong, M.B.B.S., M.R.C.S.,¹
and Hung-Chi Chen, M.D., F.A.C.S.²**

ABSTRACT

Head and neck reconstruction is a technically challenging procedure. Variations encountered in the recipient vessels and commonly used flaps add to the complexity of surgery. This article reviews the commonly encountered variations in the recipient vessels in the neck with emphasis on alternatives and techniques to circumvent these variations. Flaps commonly used in head and neck reconstruction are also reviewed in detail. Furthermore, safety, potential pitfalls, and technical pearls are highlighted.

KEYWORDS: Recipient vessel, head and neck, reliability, anomaly, flap selection

The development and refinement of microsurgery has revolutionized head and neck reconstruction.¹ Microvascular free tissue transfer expands the armamentarium of the reconstructive surgeon, allowing elaborate reconstruction of complex defects. Though free tissue transfer has eliminated many of the problems associated with the use of pedicled flaps, the use of free flaps has introduced new challenges and dimensions in head and neck reconstruction. Foremost among these new dimensions are the anatomic variations in the head and neck region and common flaps used, which can profoundly affect the operation and surgical outcome.

This article will describe the anatomic variations of donor vessels (the external carotid artery and its branches) and the recipient vessels of commonly used flaps in head and neck reconstruction. The ensuing discussion relates mainly to microvascular free tissue transfer as this is where slight anatomic variations can have a significant impact on reconstructive techniques.

Where relevant, local pedicled flaps are also analyzed. Techniques for overcoming pitfalls related to these anatomic variations will be explored (see Table 1).

VARIATIONS OF THE EXTERNAL CAROTID ARTERY AND ITS BRANCHES

The external carotid artery and its branches are the usual recipient vessels in head and neck microsurgical free tissue transfer. The external carotid commonly gives off six branches, three anteriorly (superior thyroid, lingual, and facial), two posteriorly (occipital, and posterior auricular), and one medially (ascending pharyngeal).²⁻⁴ The anteriorly directed vessels are most favorably oriented and are therefore most commonly used in head and neck reconstruction. These are, in order of frequency: the superior thyroid artery, the facial artery, and the lingual artery. In secondary cases, the transverse cervical artery and the superficial temporal artery are

¹Department of Plastic, Reconstructive and Aesthetic Surgery, Singapore General Hospital, Singapore; ²E-Da Hospital, I-Shou University, Kaohsiung County, Taiwan.

Address for correspondence and reprint requests: Bien-Keem Tan, M.B.B.S., F.R.C.S., Department of Plastic, Reconstructive and Aesthetic Surgery, Singapore General Hospital, Outram Road, Singapore 169608 (e-mail: bienkeem@singnet.com.sg).

Advances in Head and Neck Reconstruction, Part I; Guest Editors,

Samir Mardini, M.D., Christopher J. Salgado, M.D., and Hung-Chi Chen, M.D., F.A.C.S.

Semin Plast Surg 2010;24:155-170. Copyright © 2010 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662.

DOI: <http://dx.doi.org/10.1055/s-0030-1255333>.

ISSN 1535-2188.

Table 1 Summary of the Most Common Flaps, Their Anatomic Variations, and Pitfalls and Surgical Tips in Their Use

Flap	Anatomic Variation(s)	Pitfall(s)	Solution/Modification Required
Radial forearm flap	High origin of radial artery	Risk of median nerve injury	Stop dissection once the cubital fossa is reached without attempting to expose the bifurcation
	Superficial ulnar artery	Ulnar artery damage	Beware of any thick-walled, subfascial vessel on the ulnar aspect of the forearm
	Superficial dorsal antebrachial artery	Inaccurate Allen test if not concomitantly occluded with the radial artery	Both branches must be occluded
	Distal origin of the radial artery	Radial artery deep to the pronator teres	The pronator teres muscle may have to be disinserted
Fibula osteocutaneous flap	Trifurcation anomalies:		
	Hypoplasia/ aplasia of the anterior tibial and/or posterior tibial arteries	Foot ischemia	Preoperative angiogram or intraoperative examination of the anterior and posterior tibial vessels prior to ligation of the peroneal artery
	Absence of septocutaneous perforators to the skin flap component	Loss of skin flap necessitating use of a second flap	Use of musculocutaneous perforators coming through the soleus muscle to vascularize the skin flap
ALT flap	Variable lateral thigh perforator anatomy	The skin vessel of the ALT flap can be musculocutaneous or septocutaneous. It may also be absent (very rare).	Either septocutaneous or musculocutaneous perforators are equally reliable in perfusing the skin flap
		The pedicle can either be the descending or the oblique branch of the lateral circumflex femoral artery	Either the descending branch or the oblique branch can be used as the flap pedicle
Jejunum flap	Duplication of mesenteric artery and vein to flap	Intramural communicating channels are inadequate, resulting in ischemia and consequent breakdown of the mucosal barrier	Full revascularization by anastomosing all arteries and veins supplying the flap
Lower trapezius myocutaneous flap	Pedicled flap based on the SCA and the DSA	Insufficient reach, venous congestion	Inclusion of both the SCA and the DSA allows extension of the skin component of the flap up to the posterior axillary fold, increasing its reach. Including the DSA increases reliability in the event that the SCA has been ligated during neck dissections.

ALT, anterolateral thigh; DSA, dorsal scapular artery; SCA, superficial cervical artery.

available alternatives. The specific choice of recipient vessels for a given case depends on the location of the defect, the quality of the available vessels, and the pedicle length of the flap.

The superior thyroid artery is commonly spared in radical neck dissection. It arises as the first branch of the

external carotid artery and runs almost vertically downward toward the superior pole of the thyroid gland with the superior laryngeal nerve in close proximity behind it. Before reaching the gland it gives off the infrahyoid, sternomastoid, superior laryngeal, and cricothyroid branches. Occasionally, the sternomastoid branch may

arise directly from the external carotid artery within 1 cm of the origin of the superior thyroid artery itself, in which case the superior thyroid artery would be smaller in caliber.³

The facial artery arises from the carotid artery above the level of the greater horn of the hyoid. It runs upward behind the submandibular gland deep to the stylohyoid and the posterior belly of the digastric. Above the stylohyoid, it turns downward and forward between the lateral surface of the submandibular gland and medial pterygoid muscle to reach the lower border of the mandible. It then takes a tortuous course toward the angle of the mouth and subsequently the medial canthus. Due to its location, the facial artery is commonly ligated in radical neck dissections. In cases where it is congenitally hypoplastic, the facial artery may fail to reach the angle of the mouth (10%) or even be vestigial, failing to reach the face (1%). The territory of the facial artery under such circumstances is taken over by the contralateral facial or ipsilateral transverse facial artery (from the superficial temporal artery).³

The branching pattern of the anterior branches of the external carotid artery varies (Fig. 1).⁴ Variation A is the most common (80%) and the most favorable as the three anteriorly directed vessels are available as potential recipients. When the facial artery is ligated in lymph node clearance, two alternatives remain: the lingual artery and the superior thyroid artery. The facial and lingual arteries may arise from the external carotid as a

common trunk (the linguofacial trunk), with variation B having a low take-off and variation C a high take-off. In variation B, the facial artery may be ligated during neck dissection, but it is likely that the common stem and lingual artery would be left intact. In variation C, the common stem that arises high on the external carotid may be inadvertently ligated if the surgeon is unaware of the anomaly. In such circumstances, the only recipient vessel available in the vicinity would be the superior thyroid artery. Cognizance of such anomalies and pitfalls will reduce confusion and time-wastage when searching for recipient vessels.

The superficial neck veins show considerable variation. However, vessel availability is not an issue, even in cases in which radical neck dissections have been performed, because the internal jugular vein stump is available as an end-to-side recipient vessel. Very rarely, the internal jugular vein is hypoplastic and venous drainage has to depend on the external jugular vein. It is therefore imperative that the resecting surgeon preserve the external jugular vein as a recipient vein for free tissue transfer.

ANATOMIC VARIATIONS IN FLAPS FOR HEAD AND NECK RECONSTRUCTION

The flaps most commonly used in head and neck reconstruction, including the radial forearm flap, the antero-lateral thigh flap, and the fibula osteocutaneous flap, and their anatomic variations will be described in turn. The jejunum flap is also explored because of the unique

Figure 1 The origin of the facial, lingual, and superior thyroid arteries. Variation A is the most common pattern, seen in more than 80% of cases. It is also the most favorable because ample vessels are available as donor vessels. Variations B and C have a common linguofacial trunk with a low and a high take-off, respectively. These may be tied off during resection, leaving only the superior thyroid artery available as donor vessel. (From Anderson JE. Grant's Atlas of Anatomy. 7th ed. Baltimore, MD: Williams and Wilkins; 1978. Reprinted with permission)

requirements of visceral flaps. Finally, the pedicled trapezius myocutaneous flap is analyzed as a useful pedicled flap for head and neck reconstruction.

Radial Forearm Flap

The free radial forearm flap is a workhorse for reconstruction after resection of oral cancers.⁵ It is thin and pliable, has a long pedicle, and has potential for sensory reinnervation.⁶ Its disadvantages are donor site scarring and sacrifice of a major vessel that is often the dominant blood supply of the hand. An Allen test is mandatory before a decision is made to use this flap. When the ulnar artery at the wrist is released while keeping the radial artery compressed, the hand should re-perfuse briskly and completely within 2 to 3 seconds. This flap should not be used in the absence of adequate ulnar perfusion of the entire hand. Although flap harvest is straightforward, anatomic anomalies that may complicate flap harvest include those described in the following five subsections.⁷⁻¹⁰

HIGH ORIGIN OF THE RADIAL ARTERY (BRACHIORADIAL ARTERY) (Fig. 2)

In 10 to 25% of extremities, the radial artery takes off from the brachial artery above the intercondylar line of

Figure 2 High origin of the radial artery. The radial artery originates above the cubital fossa. The close relationship with the median nerve in the cubital fossa is a potential hazard during harvesting. (Adapted From Mordick TG. Vascular variation of the radial forearm flap: a case report. *J Reconstr Microsurg* 1995; 11:345-346)

the humerus or directly from the axillary artery. The radial artery then assumes a normal course in the forearm, running along the medial border of the brachioradialis and superficial to the pronator teres muscle, allowing the flap to be elevated in the usual manner. However, problems may arise when tracing the radial artery into the cubital fossa, where the median nerve may be positioned more laterally than usual. The aberrant radial artery enters the forearm immediately anterior to a more laterally positioned median nerve, which may be inadvertently damaged by attempting to trace the radial artery proximally to its origin at the brachial artery. The absence of a brachial arterial bifurcation in the cubital fossa should alert the surgeon to this anomaly; in which case, dissection of the radial artery should stop at this level.

SUPERFICIAL ULNAR ARTERY (Fig. 3)

This rare anomaly is reported in ~2% of upper extremities. It is commonly a continuation of an ulnar artery with a high origin. In contrast with the radial artery with a high origin, the superficial ulnar artery has a markedly abnormal course in the forearm. It takes a serpentine course from the cubital fossa toward the wrist, initially running medially superficial to the flexors and later assuming a more lateral position to the flexor carpi ulnaris near the wrist.

Figure 3 Superficial ulnar artery. The ulnar nerve may be mistaken for the basilic vein and ligated during flap elevation. (Adapted From Mordick TG. Vascular variation of the radial forearm flap: a case report. *J Reconstr Microsurg* 1995; 11:345-346)

Because it lies just deep to the fascia of the forearm, the superficial ulnar artery may easily be damaged when raising the flap. When elevating the flap from the ulnar side under pneumatic tourniquet, the artery may be mistaken for the basilic vein and ligated. This is the superficial ulnar artery “trap” as described by Fatah et al.¹⁰ To avoid this complication, any large, thick-walled vessel encountered in the course of flap harvest should be regarded with suspicion. The superficial ulnar artery is deep to the deep fascia, whereas the veins are superficial to this plane. Hence, any vessel located beneath the deep fascia should be carefully examined. Suprafascial radial forearm harvest, as advocated by Wei, will avoid this complication by limiting dissections to the superficial fascia.¹¹ The tourniquet should be deflated and the vessel checked for pulsation as a final confirmation before proceeding further.

This anomaly can be detected preoperatively by careful palpation of the cubital fossa and forearm over the flexor carpi ulnaris muscle. If a superficial ulnar artery is identified prior to operation or intraoperatively (prior to division of the radial artery), one should use the contralateral arm or a different flap. If one is already committed to the radial forearm flap, the superficial ulnar artery should be repositioned under the flexor tendons prior to skin grafting. This is because this superficially located artery is inadequately protected by skin grafts and is susceptible to trauma. The patient should be informed of this anomaly.

DISTAL ORIGIN OF THE RADIAL ARTERY LOCATED DEEP TO THE PRONATOR TERES MUSCLE (Fig. 4)

In this situation, the radial artery originates more distally from the brachial artery, at the level of the pronator teres muscle. Because the artery is deep to the pronator teres, no septocutaneous perforators are given off in its proximal course. This anomaly does not preclude the harvest of a distally placed skin paddle but would make a proximally placed skin paddle less reliable. Also, it would be necessary to dissect the pronator teres to uncover the proximal portion if more pedicle length were needed. The muscle is repaired once harvest is completed.

SUPERFICIAL DORSAL ANTEBRACHIAL ARTERY (Fig. 5)

In this rare anomaly, the radial artery bifurcates in its distal course. The aberrant branch, termed the superficial dorsal antebrachial artery, passes laterally superficial to the long tendons of the thumb. This anomaly can be detected preoperatively by palpating along the radial dorsal surface of the forearm. The clinical significance of this anomaly is that interpretation of the Allen test could be misleading if the aberrant branch is not occluded simultaneously, as the aberrant branch maintains distal perfusion even when the radial artery is occluded. Hence, an inadequate contribution to hand circulation

Figure 4 Distal origin of the radial artery, deep to the pronator teres muscle. The pronator teres needs to be detached from its insertion to expose the pedicle. (Adapted From Mordick TG. Vascular variation of the radial forearm flap: a case report. *J Reconstr Microsurg* 1995; 11:345-346)

from the ulnar artery is not detected. If noted intraoperatively, adequacy of the ulnar collaterals should be confirmed prior to division of the radial artery. The radial forearm flap has been used successfully in the presence of this anomaly without any ischemic problems.

HYPOPLASTIC ULNAR ARTERY

Rarely the ulnar artery is absent, the hand being supplied solely by the radial artery. This is an absolute contraindication to the use of the radial forearm flap. Fortunately, this anomaly is easily detected by the absence of the ulnar pulse and a positive Allen test.

Fibula Osteocutaneous Flap

The fibula osteocutaneous flap with a distally sited skin paddle, as described by Wei, is a well-established design for composite defects in the head and neck region.^{12,13} In this discussion, anatomic variations of the bone flap and the skin paddle will be explored separately.

VARIATIONS OF THE OSSEOUS BLOOD SUPPLY

The spectrum and prevalence of trifurcation arterial anatomic variants have been well documented by

Figure 5 Superficial dorsal antebrachial artery. The radial artery bifurcates in its distal third, and the Allen test should be performed with both branches occluded at the same time. (Adapted From Mordick TG. Vascular variation of the radial forearm flap: a case report. *J Reconstr Microsurg* 1995; 11:345-346)

radiology studies.¹⁴⁻¹⁸ In the context of harvesting the fibula flap, anatomic variations that may complicate flap harvest include those that increase risk of post-operative pedal ischemia and those that complicate intraoperative identification of vasculature resulting in harvesting the wrong pedicle. It should be noted that the current discussion pertains to lower-limb anatomic variations. More often than not, it is atherosclerosis and peripheral vascular disease that result in post-operative pedal ischemia rather than surgical damage to vessels because of aberrant anatomy.

The anterior tibial artery is commonly the dominant vessel supplying the foot via the dorsalis pedis artery, with smaller contributions from the posterior tibial artery (see the detailed angiographic classification of trifurcation variations by Kim et al¹⁶; Fig. 6). In brief, type I refers to branching that occurs at the “normal level” (below the inferior border of the popliteus muscle). Type II has a high division at the level of the knee joint, and type III has hypoplastic or aplastic branches with altered supply to the foot. Type III variant may pose a risk to vascular supply of the lower limb after harvesting the fibula. Usually, hypoplasia and aplasia involve the anterior tibial artery and/or posterior tibial artery with the peroneal artery taking over the blood supply to the foot. This is related to the embryologic development of lower-limb vasculature.¹⁸ The degree of reliance on the

peroneal artery for the foot blood supply varies, depending on whether it is mild hypoplasia of the anterior tibial artery and/or the posterior tibial artery or severe hypoplasia in rare anomalies such as peroneal arterial magna, in which the peroneal artery exists as the only supply to the foot. Various studies have indicated that the peroneal artery is the major contributor to the vascular supply of the foot in ~7 to 12% of all lower limbs. Because the peroneal artery is procured with the fibula, the foot is at risk in such situations.

Furthermore, examination by way of palpating the dorsalis pedis and posterior tibial pulses may fail to detect the anomaly, as distal circulation is reconstituted by communications between the three major arteries. If detected preoperatively by conventional angiography, computed tomography (CT), or magnetic resonance angiography, the presence of such anomalies would be a relative contraindication to fibula flap harvest. The contralateral leg or a different donor site should be chosen. Chow et al reported on the preoperative multidetector CT angiographic evaluation of the leg prior to flap harvest and noted that imaging findings altered their operative plan in 2 of 20 patients because of anatomic variants.¹⁹ This explains why there is an increasing tendency to recommend patients for preoperative angiographic evaluation. In contrast, Lutz et al prospectively evaluated the use of preoperative angiography on 120

Figure 6 Trifurcation branching variations. Type I refers to branching that occurs at the normal level. Type II refers to a high division at the level of the knee joint. Type III refers to hypoplastic or aplastic branches with altered supply to the foot. A, B, and C are the respective subtypes. PT, posterior tibial artery; PR, peroneal artery; AT, anterior tibial artery. (From Kim DS, Orron DE, Skillman JJ. Surgical significance of popliteal arterial variants. A unified angiographic classification. *Ann Surg* 1989;210:776-781. Reprinted with permission.)

lower limbs and concluded that routine preoperative angiography of the donor leg is not justified.²⁰ Of the 120 lower limbs, 119 fibula flaps were harvested without any adverse sequelae to the leg. The authors believed that accurate intraoperative evaluation can detect patients in whom harvesting the peroneal artery would result in foot ischemia. They recommended preoperative angiography only for patients with abnormal pedal pulses and previous trauma to the leg.

Trifurcation variations can also complicate intraoperative identification of vessels. Of relevance is the level of the origin of the posterior tibial artery from the tibioperoneal trunk. To maximize pedicle length during flap harvest, the peroneal artery is traced proximally to its take-off from the posterior tibial artery and ligated just distal to that point. In patients with a high origin of the posterior tibial (at the level of the knee) with a long anterior tibial/peroneal trunk, the trunk may be mistakenly ligated, resulting in the sacrifice of two major vessels of the lower limb.

VARIATIONS OF THE SKIN PADDLE BLOOD SUPPLY

The skin component of the fibula osteocutaneous flap introduces further anatomic uncertainty. Wei et al have demonstrated that the distally placed skin paddle can be reliably vascularized by septocutaneous vessels from the peroneal system running in the posterior crural septum.^{12,13} Very rarely, they originate from the posterior tibial artery.²¹ Therefore, it is important to trace the septal vessel to its origin early on in the dissection. More commonly, in 5 to 10% of cases, no sizable septocutaneous perforators are present in the septum. Options in these instances include harvesting the bone alone and a separate soft tissue flap such as the radial forearm flap; switching to the contralateral lower limb; or attempting to salvage the skin paddle by using musculocutaneous perforators coming through the soleus muscle.^{22–26} The last option would entail preserving and dissecting out the musculocutaneous perforator of the soleus muscle supplying the skin paddle; in essence, raising the flap as a perforator flap. Various authors have shown this to be a viable option in situations where septocutaneous perforators are absent.²⁷ However, in contrast with the situation of a normal septocutaneous perforator in which the vessel arises consistently from the peroneal artery, the origin of these musculocutaneous perforators is variable, arising from the peroneal, posterior tibial, or even tibioperoneal trunk. Consequently, when using musculocutaneous perforators to vascularize the skin paddle component of the fibula osteocutaneous flap, one should be aware that the perforator may diverge away from the pedicle of the fibula flap (i.e., the peroneal artery). In a divergent system, two sets of microvascular anastomoses are needed, which significantly complicates reconstruction (Fig. 7). The distal run-off of the

Figure 7 Occasionally (5 to 10% of cases), no septocutaneous perforator is seen in the distal leg. In such situations, a soleus musculocutaneous perforator can be used to vascularize the skin island. Unlike its septocutaneous counterpart, which constantly arises from the peroneal vessels, the origin of the musculocutaneous perforator tends to be more variable. In this cadaveric specimen, the soleus musculocutaneous perforator (black arrow) was dissected intramuscularly to its origin at the posterior tibial artery (yellow arrow). In such situations, use of the musculocutaneous perforator would necessitate a “double free flap” type of reconstruction.

peroneal artery may be used as recipient vessels for the second flap.^{12,13}

INCLUSION OF THE LATERAL HEMISOLEUS WITH THE FIBULA OSTEOSEPTOCUTANEOUS FLAP

The fibula osteoseptocutaneous flap provides very robust bone and skin components. Occasionally, in composite head and neck defects with significant tissue loss, bulk is insufficient to obliterate dead space and to replace the volume of tissue loss. In this setting, the use of a second soft tissue flap may be indicated.²⁸ However, the use of a second free flap adds significantly to the complexity and duration of surgery. The hemi-soleus muscle can reliably be included with the fibula osteoseptocutaneous flap to provide the needed bulk.^{29,30} The lateral hemi-soleus is consistently supplied by large muscle branches (usually two) arising from the proximal portion of the peroneal artery.²⁹ The benefit of raising this “chimeric”-type flap, consisting of bone, skin, and muscle components supplied by separate vessels arising from the peroneal artery, is that it affords greater versatility when inseting the flap. Separate components have greater degree of freedom to be moved into the area where they are needed. In contrast, the conventional approach of harvesting the bone with a “cuff” of soleus muscle is limited in its usefulness as the muscle remains tethered to the bone.

Anterolateral Thigh Flap

Song originally described the anterolateral thigh (ALT) flap as based on septocutaneous vessels running the septum between the rectus femoris and the

vastus lateralis (VL).³¹ This, however, constituted only a minority of cases and contributed to the initial opinion that the ALT flap was unreliable. Multiple studies have focused on the anatomic variations of the ALT flap, and several authors have classified its vascular variations.^{32–34} Such classifications are unnecessarily cumbersome and may cause further confusion, especially in the hands of less experienced surgeons. From our current understanding of the ALT flap, the variations potentially encountered can simply be classified on the basis of:

- The course of the skin vessels supplying the anterolateral thigh. These can be either musculocutaneous (88%) or septocutaneous (12%) (Fig. 8).
- The pedicle of the flap, which can be either the descending branch or the oblique branch of the lateral circumflex femoral artery (LCFA).³⁵

In either case, the variation does not affect reliability, and the ALT flap can be safely procured with meticulous technique. The only contraindication to the harvest of the ALT flap is a “true” absence of sizable (>0.5 mm at the subfascial level) skin vessels in the anterolateral thigh. However, this occurrence is exceedingly rare (1%).³⁵

THE OBLIQUE BRANCH OF THE LATERAL CIRCUMFLEX FEMORAL ARTERY

The oblique branch of the LCFA is a previously unnamed branch that, when present, runs between the descending and the transverse branches of the LCFA. In our 88 cases, a distinct oblique branch was noted in 31 (35%) patients. The vessel is usually visible lateral to the descending branch in the upper part of the thigh once the intermuscular septum is opened. It runs for a

variable distance in the intermuscular septum before piercing the substance of the VL, usually in the proximal third of the muscle. It may take its origin from the descending branch, the transverse branch, the LCFA, the profunda femoris, or even directly from the femoral artery.³⁵

A SAFE APPROACH TO THE ANTEROLATERAL THIGH FLAP

Harvesting a fasciocutaneous ALT flap: The fasciocutaneous flap can be based on either septocutaneous vessels or musculocutaneous perforators. With meticulous intramuscular dissection technique, both types of vessels are equally reliable. The pedicle of the flap is usually the descending branch of the LCFA.³⁴ Occasionally, however, the vessels supplying the anterolateral thigh region originate exclusively from the oblique branch of the LCFA. In this situation, the oblique branch can reliably and safely be used as the flap pedicle. It should be noted, however, that the oblique branch is usually a little smaller (mean diameter 1 to 1.5 mm) and shorter than the descending branch. Appropriately sized recipient vessels should therefore be selected. If a longer and larger-caliber pedicle is needed, the vessel can be traced proximally to include higher-order branches such as the descending or transverse branch or even taking the LCFA if necessary.³⁵

Modified technique of harvesting the ALT myocutaneous flap: The harvest of the myocutaneous ALT flap has been described previously. The conventional method of harvesting the flap is easy and expedient.³⁴ However, occasionally this approach results in a muscle component that is healthy, but the skin component is non-viable. This has been attributed to poorly defined “anatomic variations” that preclude the harvest of myocutaneous flaps in certain patients. The exact anatomic explanation for this occurrence has hitherto not

Figure 8 (A) Preoperative picture of the left thigh of a patient showing the distribution of perforators detected by Doppler sonography. (B) Intraoperative view of the same patient showing the presence of a large septocutaneous perforator in the septum between the VL muscle and the rectus femoris muscle (held by a retractor). Note that its position corresponds with the Doppler marking. (C) Intraoperative view showing the ALT flap based on two perforators: one septocutaneous (proximal), the other musculocutaneous (distal).

been documented. Based on current understanding of the vascular anatomy of the anterolateral thigh, failure of the skin component of the flap can now be pinpointed to the (unrecognized) presence of the oblique branch of the LCFA in such patients.³⁶ In most patients, the descending branch supplies both the VL muscle and the anterolateral thigh skin through myocutaneous or septocutaneous vessels. However, in cases where an oblique branch is present, it may be the dominant supply of the anterolateral thigh skin. Harvesting the flap in the conventional method would result in division of the oblique branch when the VL muscle is cut proximally. Failure to include the oblique branch would then compromise skin integrity.

A slight modification in the approach to ALT myocutaneous flap harvest is proposed to safeguard against such anatomic variation.³⁷ The medial incision is made, and the flap is elevated to the intermuscular septum. The skin vessels to be included with the flap are then selected and the intermuscular septum opened. The descending branch and the oblique branch (if present) can usually be seen. The perforator supplying the skin is then traced to its origin by unroofing the muscle over the musculocutaneous perforators. Septal vessels are also followed to their origin. Unroofing of musculocutaneous perforators is safe, minimally devascularizes the muscle, and can be done quickly with minimal bleeding. This is because the majority of branches from the perforator supplying the VL muscle usually run medially, laterally, and posteriorly, with very few running anteriorly. Once the anatomy is defined, three scenarios are possible. First, skin and muscle are supplied by the descending branch. This is the most common situation, and flap harvest can be completed in the usual manner, taking a segment of the VL muscle with a skin island. Second, the skin is supplied by the descending and oblique branches. In this situation, so long as there is at least one sizable skin vessel originating from the descending branch, the oblique branch contribution can be cut and flap harvest completed in the usual manner. Third, the skin is supplied exclusively by vessels arising from the oblique branch. In such situations, the oblique branch must be included with the flap to nourish the skin. If only a small piece of muscle is needed, the flap can be harvested with the oblique branch as the pedicle, leaving the descending branch in situ. If a large piece of the VL muscle is needed, both the descending branch and the oblique branch should be included with the flap.³⁷

In certain situations, perforators may be too small or absent. A logical, stepwise approach is undertaken in such circumstances (Fig. 9):

1. Using the same linear incision and extending it proximally, the upper thigh is explored for a perfora-

Figure 9 Thigh flaps based on the perforators originating from the lateral circumflex femoral arterial system. A, ALT flap based on perforators from the descending branch. Strategy adopted when there are no perforators arising from the descending branch: shift to B, flap based on the transverse branch; or to C, tensor fascia lata flap, or to D, anteromedial thigh flap.

tor that originates from the transverse branch of the lateral circumflex femoral artery. The pedicle would be shorter in this case.

2. The flap is converted into a tensor fascia lata flap, which is supplied by the transverse or ascending branch of the lateral circumflex femoral artery. Perforator dissection and primary debulking may be done to reduce the volume of this flap, which is normally thicker than the ALT flap.
3. A switch is made to the ALT flap,³⁸ which is supplied by a branch of the lateral circumflex femoral artery or a branch of the descending branch itself. The perforator is found in the septum between the rectus femoris and the vastus intermedius muscles. Although the skin paddle has been shifted medially, the usual ALT flap muscle components may still be included as they share the same source artery.
4. A switch is made to the opposite thigh if all efforts prove futile. The anatomy can be different and perforators more easy to dissect.

Figure 10 Variations in the blood supply of the jejunal flap. (A) Double jejunal arteries. (B) Double jejunal veins. A, jejunal artery; V, jejunal vein.

Jejunal Flap

The jejunal flap plays a central role in pharyngoesophageal reconstruction. The jejunal flap is anatomically, biochemically, and physiologically different from skin and muscle flaps commonly used in reconstruction. Anatomic variations of this visceral flap have rarely been reported. Anatomy texts describe the anatomy of the jejunal flap as predictable, with four to six jejunal arteries arising from the superior mesenteric artery, traveling between the two layers of the omentum to supply the jejunum. Each artery is accompanied by a single vein that drains into the superior mesenteric vein.^{1,39-42}

In the series of 120 jejunal free flaps performed over a 5-year period by the senior author (H-C.C.), three (2.5%) patients with anatomic variants of the classic description were noted. The anatomic variations consisted of double jejunal arteries in two patients and double jejunal veins in one (Fig. 10). In the first patient, revascularization using one artery was inadequate, resulting in partial flap necrosis and infection. The flap was eventually discarded. This led to a more cautious ap-

proach in the second patient, in whom two arterial anastomoses were performed. The flap survived. In the third patient, in whom there were two veins, only one venous anastomosis was performed. The flap was congested initially, but the color gradually improved and it survived.

DOUBLE JEJUNAL ARTERIES

When there are two arteries feeding a flap, whether or not a single inflow is adequate depends on the overlap between the individual vascular territories and the communicating channels that exist between the two subsystems (Fig. 11). In skin, for example, several levels of communication between vascular territories exist, and they occur in the septal, fascial, and subdermal plexuses. A similar pattern does not exist in the jejunum. Instead, it has a segmental blood supply, as this ensures maximal blood delivery to tissues of high metabolic activity. In jejunum, straight arteries (vasa rectae) deliver blood to the bowel without precapillary communications.^{1,42} Thus, any devascularized segment relies solely on the

Figure 11 (A) The harvested jejunal flap. (B) Close-up view of the pedicle. Note that the proximal segment is supplied by two jejunal arteries (A1 and A2, red arrows) and one jejunal vein (V, blue arrow). The distal segment is supplied by a single artery (a, red arrow) and vein (v, blue arrow).

collateral circulation within the bowel wall, which may be inadequate.

Unlike skin and muscle flaps, jejunal flaps tolerate ischemia poorly, and “nonlethal” ischemia can lead to a breakdown in the mucosal barrier, resulting in bacterial translocation and infection.⁴³ Olding and Jeng⁴⁴ used the term *nonlethal ischemia* to denote an ischemic insult that causes partial bowel necrosis, ultimately manifesting as anastomotic leaks, fistulas, and intestinal stricture. In addition, the basal blood flow of the jejunal flap decreases after transfer to the neck because of recipient arteries of smaller caliber. This decrease in flow is explained by Poiseuille’s formula, which states that flow varies directly with the fourth power of the radius of a vessel. Thus, on account of the segmental nature of jejunal blood supply and its susceptibility to ischemic injury, two arterial anastomoses should be performed when double jejunal arteries are encountered.

DOUBLE JEJUNAL VEINS

The pattern of venous drainage parallels that of the arterial system, which is segmental in nature. Tsuchida et al demonstrated in a rabbit model that jejunum arterial clamping for 30 minutes did not show any histologic evidence of irreversible reperfusion injury. In contrast, venous clamping for 5 minutes showed injury with hemorrhage in the lamina propria, and irreversible injury was seen after 30 minutes with massive hemorrhage in all layers of the jejunal wall.⁴⁵ This suggests that the jejunum is even more susceptible to venous congestion than to arterial insufficiency. Therefore, to ensure optimal venous outflow, anastomoses of all veins present should be performed when this variant is encountered.

Lower Trapezius Musculocutaneous Flap

Since its original description by Baek et al in 1980,⁴⁶ the lower trapezius musculocutaneous flap has become a popular flap for head and neck reconstruction because of its ability to reach the scalp, temple, midface, and neck. The trapezius is a flat triangular muscle and can be divided into three portions based on blood supply. The upper third is supplied by the occipital artery, the middle third by the superficial cervical artery (also known as the superficial branch of the transverse cervical artery), and the lower third by the dorsal scapular artery (also known as the deep branch of the transverse cervical artery).

VARIATIONS IN ARTERIAL ANATOMY

Traditionally, the superficial cervical artery (loosely called the transverse cervical artery) has been regarded as the sole dominant artery of the flap. However, recent studies have shown the dorsal scapular artery to be

Figure 12 A latex-injected specimen of the trapezius muscle showing the relative distribution of the superficial cervical artery (SCA) and the dorsal scapular artery (DSA). SA, subclavian artery.

codominant, as it has an equally large caliber and supplies a significant proportion of the trapezius muscle^{47–49} (Figs. 12 and 13). The superficial cervical artery originates from the thyrocervical trunk and

Figure 13 Microangiogram showing the intramuscular distribution of the superficial cervical artery (SCA) and the dorsal scapular artery (DSA).

Figure 14 Flap design. Top: traditional technique. Bottom: extended flap technique. SCA, superficial cervical artery; DSA, dorsal scapular artery. (From KC Tan, BK Tan. Extended lower trapezius island myocutaneous flap: A fasciomyocutaneous flap based on the dorsal scapular artery. *Plast Reconstr Surg* 2000;105:1758-1763. Reprinted with permission.)

crosses the posterior triangle of the neck to reach the trapezius muscle. The dorsal scapular artery, on the other hand, arises from the subclavian artery, runs deep to the levator scapulae, and emerges from between the rhomboid minor and major muscles to supply the lower trapezius.⁴⁷⁻⁴⁹ In 60% of cases, the dorsal scapular artery has an origin separate from the superficial cervical artery. In 40% of cases, they form a common trunk, which is known as the “true” transverse cervical artery.

In 97% of trapezius muscle specimens, the dorsal scapular artery is present (Figs. 12 and 13) and coexists with the superficial cervical artery. A flap based on these two vessels can have a long skin extension reaching the posterior axillary crease (Fig. 14). This is described as the extended lower trapezius flap (Fig. 15).⁴⁷ Flaps based on either one of the vessels have been described.⁴⁸ When based solely on the superficial cervical artery, the flap’s skin paddle is sited more cephalad (Fig. 14), which is the traditional design. As the superficial cervical artery traverses the posterior triangle, there is a possibility of damaging the vessel during neck dissection, and hence one should check that it is intact before elevating the flap. When the flap is based on the dorsal scapular artery alone, the skin paddle is sited more caudally. It can be extended 10 to 15 cm beyond the lateral border

of the lower trapezius muscle.⁴⁷ Neck dissection does not pose a risk to the vascular supply in this design as the artery runs deep and is not exposed.

In 3% of anatomic specimens, the dorsal scapular artery is absent, and in its place is a descending branch of the superficial cervical artery (Fig. 16). This is not a large vessel but an offshoot from the arborized portion of the superficial cervical artery. When intending to elevate an extended flap, the presence of the dorsal scapular artery needs to be confirmed by locating it along the medial border of the scapula before committing oneself. If it is absent, the skin paddle is shifted to a more superior location.

VARIATIONS IN THE VENOUS ANATOMY

The superficial location, variability, and fragility of the superficial cervical veins (transverse cervical veins) explain why more trapezius flaps die of venous rather than arterial insufficiency.⁵⁰ The veins draining the trapezius flap are usually more superficial than their accompanying artery. They may run deep or superficial to the omohyoid muscle and may accompany or diverge from the superficial cervical artery as they travel across the base of the neck from lateral to medial. They terminate in the external jugular vein or subclavian vein.⁵⁰

The dorsal scapular veins exist as two or three venae comitantes accompanying the dorsal scapular artery.⁵¹ They run deep to the omohyoid and levator scapulae muscles and drain into the subclavian vein. By virtue of their deep location, they are seldom exposed during neck dissection.

From a clinical standpoint, it is always advantageous to have two sets of draining veins by incorporating both the superficial cervical and dorsal scapular venous systems. Technically, what this means is to include the two codominant arteries, as veins follow arteries. If the patient has had a neck dissection, it is crucial to include the dorsal scapular system, as one cannot be certain about the presence of the superficial cervical veins. If it is a virgin neck and one is intending to raise the flap purely on the superficial cervical system, the following provisions should be made:

- For a cephalic defect, the superficial cervical veins should be dissected first as the reach and axis of the flap is determined largely by the anatomy of the veins. This is because the veins are shorter than the superficial cervical artery and more prone to flow interruption when stretched.
- For a cervical, easy-to-reach defect, one should avoid exploring the neck altogether to minimize trauma to the veins. Remember, some tributaries may be so superficial as to terminate in the external jugular vein.

Figure 15 (A) Intraoperative view of a patient with a large preauricular skin defect after neurofibrosarcoma resection. (B) Design of the extended lower trapezius myocutaneous flap. (C) Flap elevation. The dorsal scapular artery is clearly seen and preserved. (D) The flap is tunneled upwards subcutaneously and inset. (E) Frontal view of the patient 1 year postoperatively.

Figure 16 A rare variation (3% of specimens): The dorsal scapular artery (SA) is absent and in its place is the descending branch of the superficial cervical artery (SCA).

ACKNOWLEDGMENTS

Special acknowledgment is given to Mr. Miguel Cabalag for his editorial assistance. We thank Ms. Jane Wong for preparing the illustrations.

REFERENCES

- Wong CH, Wei FC. Microsurgical free flap in head and neck reconstruction. *Head Neck* 2009;(Epub ahead of print)
- McMinn RMH, ed. *Last's Anatomy: Regional and Applied*. 8th ed. Edinburgh, Scotland: Churchill Livingstone; 1990:327–328
- Cormack GC, Lamberty BGH. *The Arterial Anatomy of Skin Flaps*. 2nd ed. Edinburgh, Scotland: Churchill Livingstone; 1994
- Anderson JE. *Grant's Atlas of Anatomy*. 7th ed. Baltimore, MD: Williams & Wilkins; 1978
- Song R, Gao Y, Song Y, Yu Y, Song Y. The forearm flap. *Clin Plast Surg* 1982;9:21–26
- Wong CH, Lin JY, Wei FC. The bottom-up approach to the suprafascial harvest of the radial forearm flap. *Am J Surg* 2008;196:e60–e64
- Mordick TG. Vascular variation of the radial forearm flap: a case report. *J Reconstr Microsurg* 1995;11:345–346
- Rodríguez-Niedenführ M, Vázquez T, Nearn L, Ferreira B, Parkin I, Sañudo JR. Variations of the arterial pattern in the upper limb revisited: a morphological and statistical study, with a review of the literature. *J Anat* 2001;199(Pt 5): 547–566
- Sasaki K, Nozaki M, Aiba H, Isono N. A rare variant of the radial artery: clinical considerations in raising a radial forearm flap. *Br J Plast Surg* 2000;53:445–447 [Comment in *Br J Plast Surg* 2001;54(2):180–181]
- Fatah MF, Nancarrow JD, Murray DS. Raising the radial artery forearm flap: the superficial ulnar artery “trap”. *Br J Plast Surg* 1985;38:394–395
- Lutz BS, Wei FC. Microsurgical workhorse flaps in head and neck reconstruction. *Clin Plast Surg* 2005;32: 421–430, vii
- Wei FC, Chen HC, Chuang CC, Noordhoff MS. Fibular osteoseptocutaneous flap: anatomic study and clinical application. *Plast Reconstr Surg* 1986;78:191–200
- Wei FC, Seah CS, Tsai YC, Liu SJ, Tsai MS. Fibula osteoseptocutaneous flap for reconstruction of composite mandibular defects. *Plast Reconstr Surg* 1994;93:294–304; discussion 305–306
- Lippert H, Pabst R. *Arterial Variations in Man: Classification and Frequency*. Munich, Germany: JF Bergmann Verlag; 1985
- Morris GC Jr, Beall AC Jr, Berry WB, Feste J, De Baake ME. Anatomical studies of the distal popliteal artery and its branches. *Surg Forum* 1960;10:498–502
- Kim DS, Orron DE, Skillman JJ. Surgical significance of popliteal arterial variants. A unified angiographic classification. *Ann Surg* 1989;210:776–781
- Mauro MA, Jaques PF, Moore M. The popliteal artery and its branches: embryologic basis of normal and variant anatomy. *AJR Am J Roentgenol* 1988;150:435–437
- Senior HD. The development of the arteries of the human lower extremity. *Am J Anat* 1919;25:55–94
- Chow LC, Napoli A, Klein MB, Chang J, Rubin GD. Vascular mapping of the leg with multi-detector row CT angiography prior to free-flap transplantation. *Radiology* 2005;237:353–360
- Lutz BS, Wei FC, Ng SH, Chen IH, Chen SH. Routine donor leg angiography before vascularized free fibula transplantation is not necessary: a prospective study in 120 clinical cases. *Plast Reconstr Surg* 1999;103:121–127
- Tan BK, Wong CH. An anomalous septocutaneous perforator to the skin paddle of the fibula osteocutaneous flap originating from the posterior tibial artery. *J Plast Reconstr Aesthet Surg* 2009;62:690–692
- Jones NF, Monstrey S, Gambier BA. Reliability of the fibular osteocutaneous flap for mandibular reconstruction: anatomical and surgical confirmation. *Plast Reconstr Surg* 1996;97:707–716; discussion 717–718
- Schusterman MA, Reece GP, Miller MJ, Harris S. The osteocutaneous free fibula flap: is the skin paddle reliable? *Plast Reconstr Surg* 1992;90:787–793; discussion 794–798
- Hidalgo DA. Fibula free flap: a new method of mandible reconstruction. *Plast Reconstr Surg* 1989;84:71–79
- Yokoo S, Komori T, Furudoi S, Umeda M, Nomura T, Tahara S. Rare variant of the intrasoleus musculocutaneous perforator: clinical considerations in raising a free peroneal osteocutaneous flap. *J Reconstr Microsurg* 2001;17:225–228
- Weber RA, Pederson WC. Skin paddle salvage in the fibula osteocutaneous free flap with secondary skin paddle vascular anastomosis. *J Reconstr Microsurg* 1995;11:239–241; discussion 242–244
- Wong CH, Tan BK, Wei FC, Song C. Use of the soleus musculocutaneous perforator for skin paddle salvage of the fibula osteoseptocutaneous flap: anatomical study and clinical confirmation. *Plast Reconstr Surg* 2007;120:1576–1584
- Wei FC, Yazar S, Lin CH, Cheng MH, Tsao CK, Chiang YC. Double free flaps in head and neck reconstruction. *Clin Plast Surg* 2005;32:303–308, v
- Wong CH, Ong YS, Chew KY, Tan BK, Song C. The fibula osteoseptocutaneous flap incorporating the hemisoleus muscle

- for complex head and neck defects: anatomical study and clinical applications. *Plast Reconstr Surg* 2009;124:1956–1964
30. Cheng MH, Saint-Cyr M, Ali RS, Chang KP, Hao SP, Wei FC. Osteomyocutaneous peroneal artery-based combined flap for reconstruction of composite and en bloc mandibular defects. *Head Neck* 2009;31:361–370
 31. Song YG, Chen GZ, Song YL. The free thigh flap: a new free flap concept based on the septocutaneous artery. *Br J Plast Surg* 1984;37:149–159
 32. Koshima I, Fukuda H, Utunomiya R, Soeda S. The anterolateral thigh flap; variations in its vascular pedicle. *Br J Plast Surg* 1989;42:260–262
 33. Kimata Y, Uchiyama K, Ebihara S, Nakatsuka T, Harii K. Anatomic variations and technical problems of the anterolateral thigh flap: a report of 74 cases. *Plast Reconstr Surg* 1998;102:1517–1523
 34. Wei FC, Jain V, Celik N, Chen HC, Chuang DC, Lin CH. Have we found an ideal soft-tissue flap? An experience with 672 anterolateral thigh flaps *Plast Reconstr Surg* 2002;109:2219–2226; discussion 2227–2230
 35. Wong CH, Wei FC, Fu B, Chen YA, Lin JY. Alternative vascular pedicle of the anterolateral thigh flap: the oblique branch of the lateral circumflex femoral artery. *Plast Reconstr Surg* 2009;123:571–577
 36. Wong CH, Kao HK, Fu B, Lin JY. A cautionary point in the harvest of the anterolateral thigh myocutaneous flap. *Ann Plast Surg* 2009;62:637–639
 37. Wong CH, Wei FC. Anterolateral thigh flap. *Head Neck* 2010;32:529–540
 38. Koshima I, Soeda S, Yamasaki M, Kyou J. The free or pedicled anteromedial thigh flap. *Ann Plast Surg* 1988;21: 480–485
 39. Michels NA, Siddharth P, Kornblith PL, Parke WW. The variant blood supply to the small and large intestines: its import in regional resections. *J Int Coll Surg* 1963;39:127–170
 40. Kornblith PL, Boley SJ, Whitehouse BS. Anatomy of the splanchnic circulation. *Surg Clin North Am* 1992;72:1–30
 41. Abrams HL. *Angiography*, Vol. 2. 2nd ed. Boston, MA: Little, Brown; 1971:1092–1093
 42. Gardner E, Gray DJ, O'Rahilly R. *Anatomy*. 4th ed. Tokyo, Japan: Igaku-Shoin/Saunders; 1982:386–387
 43. Cuschieri A, Giles GR, Moossa AR. *Essential Surgical Practice*. 3rd ed. Oxford, England: Butterworth-Heinemann; 1995:95–96
 44. Olding M, Jeng JC. Ischemic tolerance of canine jejunal flaps. *Plast Reconstr Surg* 1994;94:167–173
 45. Tsuchida Y, Aoki N, Fukuda O, Nakano M, Igarashi H. Changes in hemodynamics in jejunal flaps of rabbits due to ischemia, venous congestion, and reperfusion as measured by means of colored microspheres. *Plast Reconstr Surg* 1998;101:147–154
 46. Baek SM, Biller HF, Krespi YP, Lawson W. The lower trapezius island myocutaneous flap. *Ann Plast Surg* 1980;5: 108–114
 47. Tan KC, Tan BK. Extended lower trapezius island myocutaneous flap: a fasciomyocutaneous flap based on the dorsal scapular artery. *Plast Reconstr Surg* 2000;105:1758–1763
 48. Haas F, Weiglein A, Schwarzl F, Scharnagl E. The lower trapezius musculocutaneous flap from pedicled to free flap: anatomical basis and clinical applications based on the dorsal scapular artery. *Plast Reconstr Surg* 2004;113: 1580–1590
 49. Angrigiani C, Grilli D, Karanas YL, Longaker MT, Sharma S. The dorsal scapular island flap: an alternative for head, neck, and chest reconstruction. *Plast Reconstr Surg* 2003; 111:67–78
 50. Goodwin WJ Jr, Rosenberg GJ. Venous drainage of the lateral trapezius musculocutaneous island flap. *Arch Otolaryngol* 1982;108:411–413
 51. Rasheed MZ, Tan BK, Tan KC. The extended lower trapezius flap for the reconstruction of shoulder tip defects. *Ann Plast Surg* 2009;63:184–187