Vascularized lymph vessel transplant (VLVT): our experience and lymphedema treatment algorithm

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Abstract: Supermicrosurgical lymphaticovenicular anastomosis (LVA) and vascularized lymph node transplant (VLNT) are established surgical procedures for fluid-predominant extremity lymphedema. LVA is most effective for early disease, while VLNT is effective for more advanced lymphatic injury. However, the devastating complication of donor-site lymphedema has been reported following VLNT. Contour deformity caused by the bulky VLNT flaps further decreases the appeal of this procedure. Vascularized lymph vessel transplant (VLVT) has emerged as a promising new alternative to VLNT. This novel technique has challenged the accepted belief that incorporation of lymph nodes (LNs) into a flap is necessary for the physiologic treatment of advanced lymphedema. First described with the first dorsal metatarsal artery (FDMA) flap, the superficial circumflex iliac artery perforator (SCIP) and thoracodorsal artery perforator (TDAP) flaps were later on described as additional options for VLVT. Outcomes of VLVT have been found to be mostly equivalent to those of VLNT in alleviating symptoms and improving quality of life (QoL). By not sacrificing LNs, it theoretically reduces donor site morbidity. To date, donor-site lymphedema as a sequela of VLVT harvest has not been reported. As with other modalities for the treatment of lymphedema, an understanding of the progression of this disease and careful patient selection is imperative for the successful implementation of VLVT. A review of the literature, combined with the senior author's experience with these novel techniques, was utilized to generate an updated algorithm for the surgical treatment of extremity lymphedema.

Keywords: Lymphedema; lymphaticovenicular anastomosis (LVA); supermicrosurgery; vascularized lymph vessel transplant (VLVT); vascularized lymph node transplant (VLNT)

Introduction

The surgical treatment of lymphedema has become a hot topic in the field of reconstructive surgery. Advancements over the past few decades have given rise to a myriad of efficacious options for these patients. While lymphedema cure is now a clinical reality (1), there still is no consensus on the management of this chronic, morbid condition. Supermicrosurgical lymphaticovenicular anastomosis (LVA) and vascularized lymph node transplant (VLNT) are established "physiologic" techniques for the treatment

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Figure 1 Arm circumference is measured at the elbow crease and at 5-cm intervals proximally and distally. Volume is calculated using a truncated cone formula.

of fluid-predominant lymphedema (2). Because it requires functioning lymphatics, the success rate of LVA is significantly higher in early-stage disease (2,3). VLNT is traditionally indicated for more advanced disease (2,4). While VLNT is effective reducing limb volume and the associated morbidity, iatrogenic donor-site lymphedema is an ever-present possibility. The potential to cause the very disease this procedure is intended to treat may be viewed as an unacceptable risk. The appeal of this procedure is further diminished by contour deformities in the recipient limb caused by the bulky flap (2,4).

VLNT is theorized to work through "bridge" and "pump" mechanisms. The former proposes that transplanted nodes stimulate lymphangiogenesis via VEGF, connecting them with recipient-site lymphatic vessels (5-7). The latter posits that arteriovenous perfusion gradients allow the transplanted nodes to act as sponges or pumps, drawing lymph into the circulation through established lymphovenous connections in the transferred tissues (8-10). However, increasing experience with VLNT strongly suggests that the active therapeutic component of VLNT is the lymphatic vessels, not the nodes themselves (11-17). It has long been observed that standard free tissue transfer without nodal tissue can incidentally improve or restore lymphatic outflow of recipient sites (18-20)— a phenomenon thought to be due to a lymph-vessel-stimulated bridge mechanism (21). Similarly, nodes are not thought to be the major players in the collection and pumping of lymph; while the endothelial cells lining intranodal channels do have contractile function, the smooth muscles lining the transplanted lymph vessels are the main drivers of lymph transport (22-27). This new

understanding has raised the possibility of restoration of lymphatic outflow without lymphatic anastomosis or lymph node (LN) transplant, giving rise to a new addition to the armamentarium for treating extremity lymphedema: vascularized lymph vessel transplant (VLVT).

Diagnostic evaluation

Classically, diagnosis of lymphedema has been clinical, relying on the Kaposi-Stemmer sign (inability to pinch skin of the affected extremity) and a significant increase in limb volume from baseline (while there is no universal consensus on this criteria, a 10% increase is most commonly used). Volumetric changes may be measured via three-dimensional (3D) optoelectronic perometry, water displacement, 3D volumetric scanning with an iPad app, or volume calculations derived from circumference measurements (*Figure 1*). Other often-discussed signs are swelling that does not respond appropriately to elevation or diuretics, blunted, squared-off digits, and skin changes (2,28-31). However, the refinement of diagnostic imaging has revealed that these clinical features have poor sensitivity, positive and negative predictive value, and accuracy (28,32). Venous insufficiency, congestive heart failure, lipedema, renal failure, and venous thrombosis, to name a few, may all exhibit these "classic" clinical signs (28,30,31). Another flaw to this diagnostic strategy is that volumetric measurement relies on the assumption that disease severity correlates with limb volume—in intermediate-to-advanced lymphedema, a solid disease component develops and this assumption no longer holds true (32). Several qualitative questionnaires assessing lymphedema symptomatology and its impact on quality of life (QoL) exist. While they similarly are not sufficient for definitive diagnosis, they serve as a key component of a comprehensive diagnostic evaluation (32-35).

Anecdotally, our practice frequently encounters patients who have been diagnosed with these aforementioned techniques, without any proper confirmatory study. Imaging to confirm the diagnosis of lymphedema and stratify disease severity is imperative. Indocyanine green (ICG) lymphography is quickly replacing lymphoscintigraphy as the gold standard in lymphedema diagnosis (2,32,36). This technique measures lymph vessel pump function, velocity, and distribution in real time (32,37). Because it can visualize lymphatic function and dermal backflow patterns, it can effectively stage disease (*Figure 2*) (32,36,38). Following definitive diagnosis and staging with ICG lymphography, adjunctive modalities can further define the disease state and determine fluid- or solid-
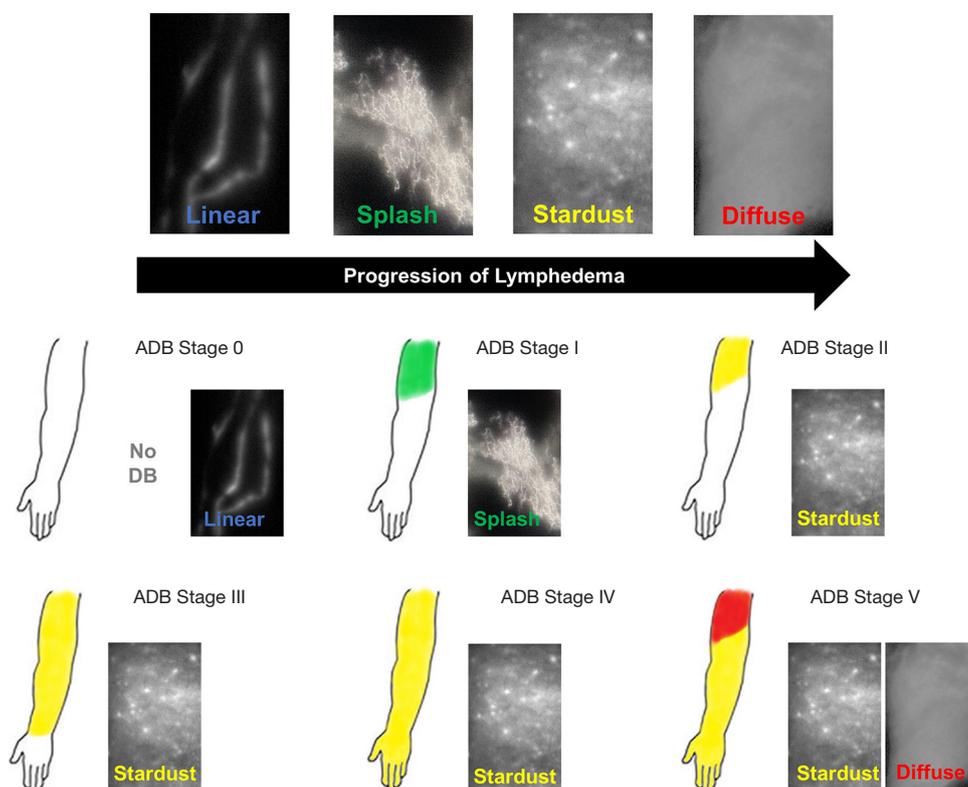
Figure 2 ADB lymphographic staging system first described by Yamamoto *et al*. Linear drainage patterns indicate preserved lymphatic function, while DB patterns (splash, stardust, and diffuse) indicate impaired function. Stage 0: no pathological pattern is present; linear drainage pattern may be seen. Stage I: splash DB pattern, frequently in the proximal aspect of the limb. Stage II: stardust DB pattern in the proximal limb. Stage III: stardust DB pattern involving the proximal and distal limb, excluding the hand. Stage IV: stardust DB pattern involving the entire limb, including the hand. Stage V: diffuse DB pattern, frequently in the proximal limb. ADB, arm dermal backflow.

predominance (39). Quantitative bioimpedance spectroscopy (BIS) is a painless, cost-effective technique to determine the amount of extracellular fluid in an extremity (29,31). Magnetic resonance imaging (MRI) can differentiate fluid from fibrosis and lipodystrophy, the structural components of solid-predominant lymphedema (29).

There is no consensus on the quantitative threshold of tissue bulk that distinguishes these two states. Qualitatively, solid-predominance is a state in which bulky lipodystrophy and fibrosis have become the main drivers of morbidity. Physical exam will show little-to-no pitting and these patients will not experience significant volume reduction even after aggressive complex decongestive therapy (CDT) (40). MRI will demonstrate significant lipodystrophy and/or subcutaneous fibrosis (2,41). In contrast, fluid-predominant lymphedema is demonstrated by prominent pitting on physical examination, minimal lipodystrophy and fibrosis

on MRI, and significant limb fluid excess on BIS. It is noted to demonstrate dramatic (if temporary) volume reduction in response to CDT, even in advanced disease (31,32,41).

Conventional surgical treatment options

Vascularized lymph node transplant

Traditionally, the superficial circumflex iliac artery (SCIA)-based groin flap served as the workhorse of VLNT, due to reliable anatomy, abundant LNs, and well-hidden scar (9,30,42,43). Overall complication rates are low; reported adverse effects include infection, delayed wound healing, lymphorrhea, reexploration, flap loss, and contour deformity requiring secondary debulking procedures (44-46). Iatrogenic donor-site lymphedema had long been discussed as a potential complication (47-49), but it remained theoretical until 2013, when two independent reports of
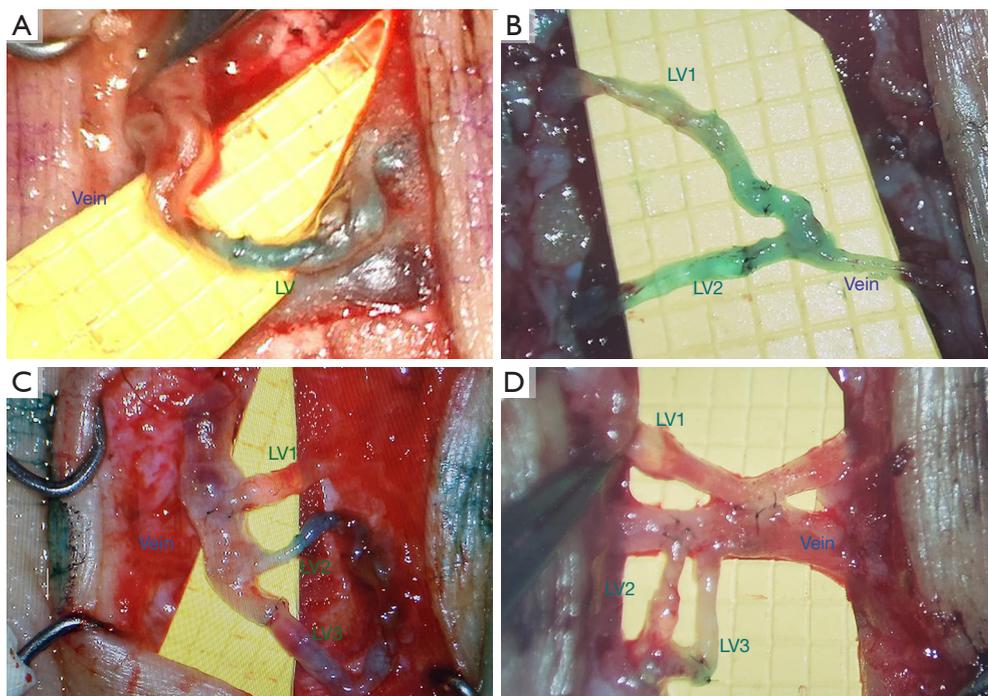
Figure 3 The common lymphaticovenicular anastomotic configurations can be used in combination to maximize drainage pathways. (A) Simple end-to-end anastomosis. (B) End-to-end anastomosis to two venous branches. (C) End-to-side (LV1) and end-to-end anastomosis to two venous branches (LV2 and LV3). (D) Side-to-side (LV1), end-to-side (LV2), and end-to-end (LV3) anastomosis. We recommend that surgeons train in all of these configurations in order to efficiently address the difficult vessel positioning and size and number mismatch commonly encountered during LVA. LVA, lymphaticovenicular anastomosis.

this complication were published (50,51). The potential for this devastating complication spurred an explosion of alternative VLNT flaps, including the submental (52-54), supaclavicular (55,56), lateral thoracic (57,58), omental (59,60), and jejunal (13,61) flaps. While these carry a lower risk of donor-site lymphedema (30,45,58,62), each carries its own set of disadvantages: marginal mandibular nerve damage (submental), spinal accessory or phrenic nerve injury (supraclavicular), intercostobrachial nerve injury (lateral thoracic), and violation of the peritoneum or bowel ischemia (omental, jejunal) (3,13,54,57-60,63).

### Supermicrosurgical lymphaticovenular anastomosis

The advent of supermicrosurgery has facilitated LVA with small, low-pressure venules ranging from 0.1–0.6 mm (64). The use of smaller vessels allows for anastomosis in the distal extremities, circumventing the degradation of lymph vessels' pumping function, which begins proximally (65). A number of anastomotic configurations are available to overcome unfavorable pressure gradients, vessel size

mismatch, difficult vessel positions, or vessel number mismatch. Named in a lymphatic-to-vein convention, these include end-to-end, end-to-side, side-to-side, side-to-end, lambda, double end-to-side, ladder, and "octopus" anastomosis (*Figure 3*) (31,66,67). While LVA is efficacious, it requires supermicrosurgical technique and costly equipment not available at all centers (2-4,66). Post-radiotherapy fibrosis and post-surgical perivascular scarring must be minimal; otherwise, resultant venous hypertension could still cause reflux into the anastomosed lymphatic channels, worsening lymphedema over time (2,3,30). Intra-operative ICG is required following anastomosis in order to confirm patency and flow (2). An additional barrier to entry is the wide heterogeneity of patient selection, timing, and number, location, and configuration of anastomoses (30,64,65).

Vascularized lymph vessel transplant

Background

LVA and VLNT dominated the field until Koshima *et al.*'s
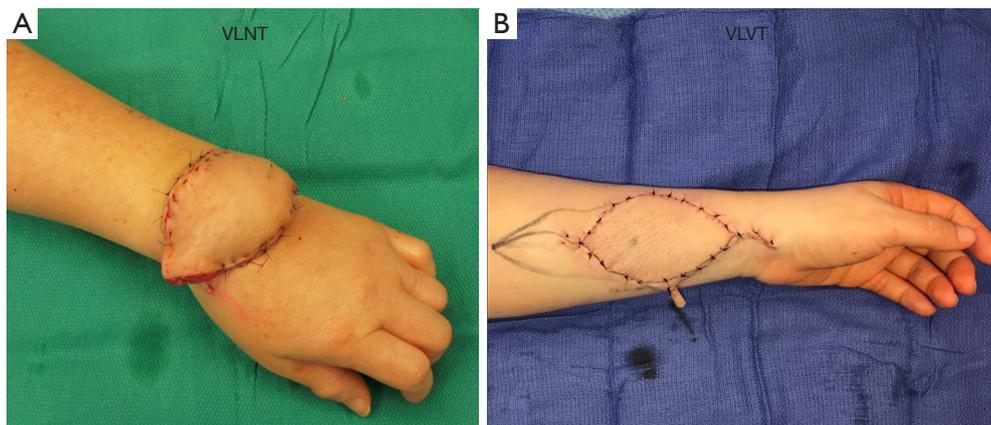
Figure 4 Comparison of VLNT and VLVT flap inset. (A) The tissue bulk associated with VLNT flaps disrupts anatomic contour, causing a "Rolex" deformity. (B) Contour deformity is avoided with the much-thinner VLVT flap. Reproduced under CC BY License from Chen *et al.* (4). VLNT, vascularized lymph node transplant; VLVT, vascularized lymph vessel transplant.

seminal 2016 paper describing the successful management of severe lower extremity lymphedema with a lymphadiposal flap based on the first dorsal metatarsal artery (FDMA) (68). This novel approach challenged the accepted belief that treatment of lymphedema requires the incorporation of cumbersome LNs into free flaps (4). Advancements in lymphography now facilitate precise pre- and intraoperative visualization of superficial lymph vessels, facilitating intentional inclusion in flaps and proper orientation in recipient sites (19). The senior author experienced favorable outcomes with FDMA-based VLVT (4). However, the location of the donor site precluded the flap's use in bilateral lower extremity disease. Additionally, FDMA flap harvest frequently caused devascularization of the skin over the first metatarsal space, resulting in donor wound breakdown (4). Nevertheless, the success of the procedure encouraged us to search for alternative donor sites for VLVT.

The SCIA perforator (SCIP) flap's role in groin flap-based VLNT makes its anatomy familiar to plastic surgeons. It has a high density of superficial lymph vessels and an excellent track record as a superthin flap. The distinct visual difference between the small superficial fat lobules and large deep fat lobules makes for an easy plane of dissection. This technique allows for the preservation of LNs and other deep structures, reducing the risk for complications such as lymphorrhea and wound dehiscence. Results of SCIP flap-based VLVT show highly favorable outcomes without the contour deformity associated with classic groin flap-based VLNT (*Figure 4*) (4,31,69-75). Due to its superior outcomes, SCIP-based VLVT replaced VLNT as our go-to

treatment for those with upper extremity lymphedema who are not LVA candidates. Following the success of SCIP-based VLVT, we applied the same principle to develop thoracodorsal artery perforator (TDAP)-based VLVT to treat lower extremity lymphedema. The lateral thoracic region is another area rich with lymphatic vessels (58). By performing a thin flap harvest superficial to the superficial fascia, lateral thoracic LNs are preserved. Our results with this technique have shown similar efficacy to SCIP-based VLVT with minimal donor-site morbidity.

Pre-operative evaluation

Vascular anatomy can be imaged preoperatively with computed tomography angiography (CTA), allowing the more robust-appearing side to be chosen for harvest. Preoperative vascular imaging can be especially helpful for TDAP flaps, as TDAP vascular anatomy and perforator location is more variable than that of the SCIP flap. It is, however, not uncommon for CTA to miss small perforators (<0.3 mm) that are subsequently found upon surgical exploration. Thus, a negative CTA is not an absolute contraindication to perforator flap harvest (*Video 1*). However, when vessels are detected on CTA, this can expedite intra-operative surgical planning and dissection; therefore, in our experience, it is still worthwhile to routinely pursue pre-operative imaging, despite its limitations. Duplex ultrasound, particularly high-resolution duplex ultrasound, is a powerful alternative modality that can detect vessels as small as 0.18 mm. However, it is
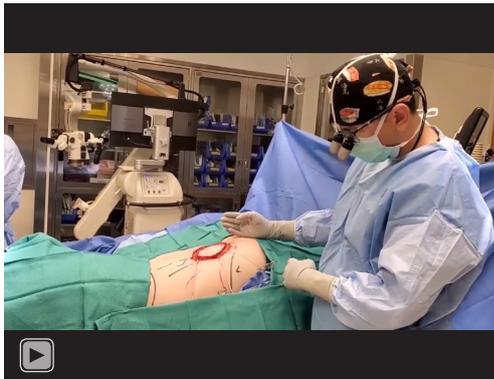
Video 1 Preoperative imaging is helpful to characterize the TDAP flap's variable anatomy. However, these supermicrosurgery-range vessels can sometimes be missed on CTA. In this illustrative case, preoperative CTA was negative for thoracodorsal perforators. However, upon surgical exploration, two suitable perforators were found. CTA, computed tomography angiography.
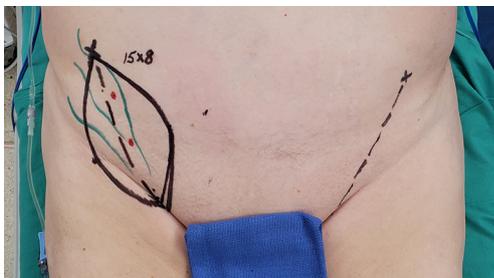
Figure 5 SCIP-based VLVT flap. Superficial lymphatics (green) are mapped with intradermal ICG injection. A line marking the groin crease to the ASIS is drawn, and SCIPs (red) are identified along this line with Doppler ultrasound. An elliptical flap is designed over the perforators and mapped lymphatics. SCIP, superficial circumflex iliac artery perforator; VLVT, vascularized lymph vessel transplant; ICG, indocyanine green; ASIS, anterior superior iliac spine.

limited by a steep learning curve and operator dependency (76-78).

Surgical technique

SCIP flap

0.25% ICG is injected intradermally lateral to the anterior superior iliac spine (ASIS) to map superficial groin lymphatic vessels. A line from the groin crease to the ASIS is marked, and SCIPs are identified along this line with Doppler ultrasound. Flap width is determined with a pinch test to ensure the ability to primarily close the donor site, and a SCIP flap is designed over the perforators and mapped lymphatics (*Figure 5*). The inferolateral incision is made, allowing for cephalad-directed, lateral-to-medial dissection. The dissection plane is immediately superficial to Scarpa's fascia, ensuring exclusion of LNs from the flap. After confirming perforator entry into the flap, the superomedial skin incision is made and retrograde pedicle dissection is performed until adequate pedicle length is achieved. The adiposal surface of the flap is scanned with SPY Elite (Stryker Corporation, Kalamazoo, MI, USA) to confirm the presence of lymphatic vessels in the flap. Following flap harvest, the donor site is closed primarily in a layered fashion (4).

TDAP flap

Lymphatics are mapped with intradermal ICG injection of the fifth intercostal space at the midaxillary line. Perforators are identified with Doppler ultrasonography 8–10 cm inferior to the axillary apex and 1–2 cm inside the lateral border of the latissimus dorsi. A flap is designed around the perforators and marked lymphatics (*Figure 6*). The posterior incision is made and dissection proceeds posteriorly along the superficial fascial plane. The committing anterior incision is made after confirming perforator location. Following flap harvest, the donor site is closed primarily in a layered fashion (79-81).
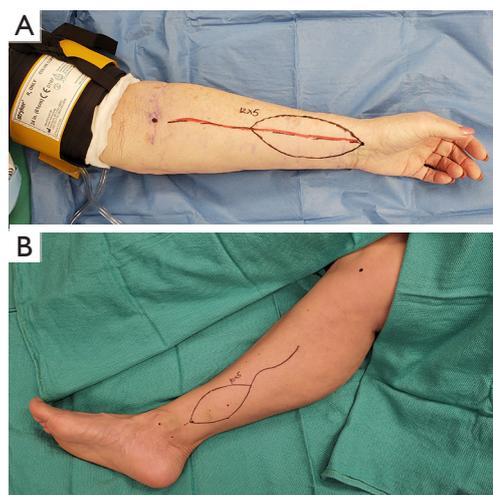
Vascular anastomosis and flap inset

The VLVT flap is inset distally. In order for lymphangiogenesis to effectively "bridge" between the flap and recipient site, the direction of lymph flow in the flap must be concordant with that of the native lymphatics. Thus, the flap must be oriented so that the axiality of lymphatic vessels is compatible (19). In the upper extremity, the radial aspect of the wrist is used with the radial artery as the recipient vessel. In the lower extremity, it is inset along the medial aspect of the lower leg using the posterior tibial artery as a recipient (*Figure 7*). The flap arterial pedicle is often smaller than 0.8 mm, necessitating supermicrosurgical technique. When a suitable recipient perforator is present, end-to-end perforator-to-perforator anastomosis is performed. However, recipient vessels are often too large, which would result in excessive arterial inflow. Surgeons should therefore anticipate the need to perform end-to-side anastomosis. End-to-end venous anastomosis is performed between the flap venous pedicle
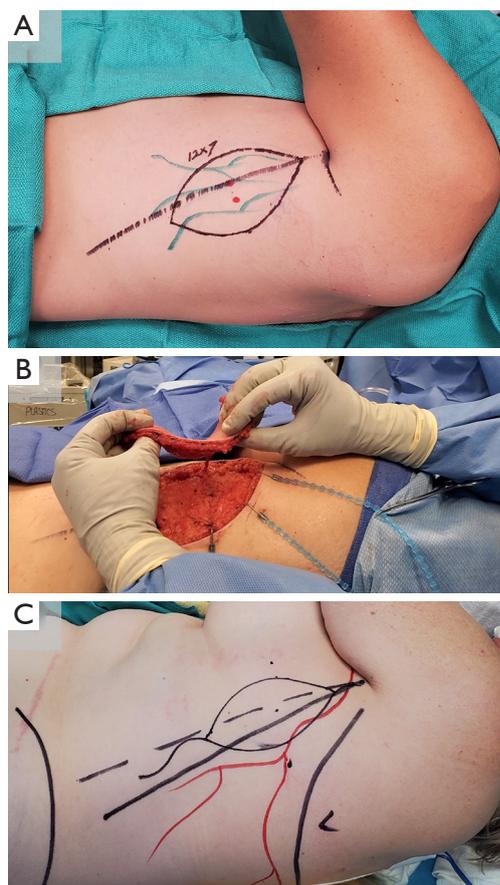
Figure 6 TDAP-based VLVT flap. (A) Superficial lymphatics (green) are mapped with ICG. Perforators (red) are identified with Doppler 8–10 cm inferior to the axillary apex and 1–2 cm inside the lateral border of the latissimus dorsi muscle. A TDAP flap (black) is designed around the perforators and marked lymphatics. (B) Dissection proceeds superficial to the superficial fascia and a thin flap is elevated. (C) A negative preoperative CTA is not an absolute contraindication to TDAP flap harvest. In these patients, the location of the thoracodorsal artery (red) can be reasonably estimated by delimiting the latissimus dorsi muscle (thick black lines). TDAP, thoracodorsal artery perforator; VLVT, vascularized lymph vessel transplant; ICG, indocyanine green; CTA, computed tomography angiography.

Figure 7 The VLVT flap is inset distally. (A) In the upper extremity, the radial aspect of the wrist is used with the radial artery (red) as the recipient. (B) In the lower extremity, it is inset along the medial aspect of the lower leg using the posterior tibial artery as the recipient. VLVT, vascularized lymph vessel transplant.

and a recipient pedicle venae comitante. It is often possible to use venous couplers, but surgeons should be prepared to perform suture anastomosis in the event of small vein size or size mismatch (*Figure 8*). In keeping with the principles of VLVT and VLNT, no lymphatico-venicular or lymphatico-lymphatical anastomoses are performed. Following revascularization, a full-thickness skin excision

with dimensions identical to the VLVT flap is made to facilitate inset.

Postoperative care

The recipient limb is elevated for 1 week postoperatively. A progressive, graduated bandage compression protocol is then initiated in the second postoperative week; patients are rapidly advanced from brief compression to 16 hours per day. One month postoperatively, patients recommence CDT, including transitioning into newly fitted 30–40 mmHg compression garments for 16 hours per day. Weaning of compressive garments may begin at 6 months postoperatively. Postoperative surveillance is conducted via the same set of diagnostic studies performed preoperatively, allowing comparison to patient baselines. In the senior author's practice, this consists of ICG lymphography to confirm and monitor improvement, BIS to evaluate fluid and solid disease components, 3D volumetric scanning, and a lymphedema-specific QoL assessment (32) to track symptomatology. These are performed at 3, 6, 12 months, and then annually to track patient progress.

Pitfalls and considerations

The only notable VLVT complication thus far in the senior
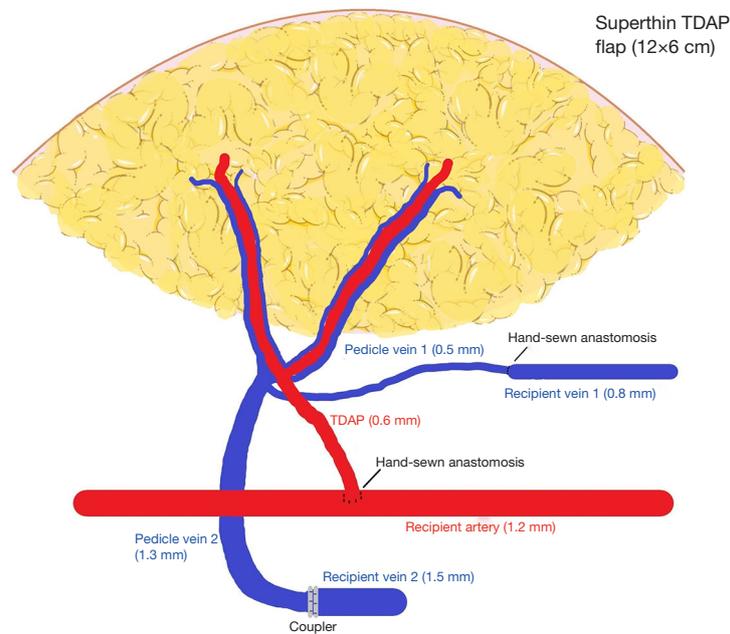
Figure 8 Superthin TDAP-based VLVT flap. In our experience harvesting superthin TDAP flaps, it is not uncommon to encounter two perforators, and there is a great variability in the course of these vessels. In this particular illustrated case, two arterial perforators joined together to continue as one artery deep to the superficial fascia, and four venae comitantes continued as two veins. The size mismatch between the flap and recipient arterial pedicles often necessitates supermicrosurgical end-to-side anastomosis. Venous anastomosis can often be performed with couplers; however, anastomosis with nylon suture may be necessary if the flap veins are particularly small. TDAP, thoracodorsal artery perforator; VLVT, vascularized lymph vessel transplant.

author's practice has been one case of partial (<5%) flap loss that was successfully managed with wound care.

For VLVT, we advocate for either the SCIP or the TDAP flap, due to the aforementioned limitations of the FDMA flap. Regardless of the flap chosen, harvest of a superthin flap likely requires the use of perforator vessels and consequently, supermicrosurgical technique (81,82). Surgeons must be aware that TDAP perforators frequently originate from an intercostal or lateral thoracic vessel, rather than from the thoracodorsal. This considerable anatomic variability, in combination with the previously discussed limitations of CTA, can lead to increased difficulty when utilizing the TDAP flap. However, provided that perforators can be located and adequate pedicle length can be achieved, harvesting this flap on these alternative vessels is still feasible (80,81).

While Scarpa's fascia facilitates ease of SCIP flap dissection in patients of normal BMI, using this plane in obese patients results in an excessively thick flap requiring secondary debulking surgery (*Figure 9*) (72). Previously,

the senior author circumvented this by raising the flap along a non-anatomic plane superficial to the superficial fascia 5 mm deep to the skin (4,74). However, with further experience, we have abandoned this technique because it does not consistently include the superficial circumflex iliac vein. We now recommend adhering to the plane immediately superficial to the superficial fascia as the plane of dissection because it is safe and easier. The TDAP can be similarly bulky in obese patients. Defatting after flap elevation is feasible, but tedious (79). In general, the senior author prefers to use SCIP-based VLVT due to the flap's more reliable anatomy. In those cases where it is unavailable (i.e., in patients with gynecological cancer or compromised lower extremity lymphatics), TDAP is chosen.

Lymphedema management algorithm and discussion

Treatment selection is guided by the severity of injury seen
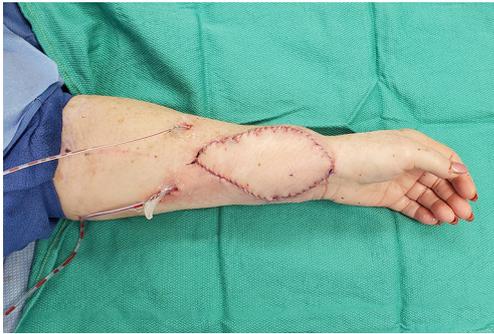
Figure 9 In patients of a normal BMI, elevating a flap superficial to Scarpa's fascia (SCIP) or superficial fascia (TDAP) results in a thin flap devoid of contour deformities (*Figure 4*). In obese patients, dissection along these planes may result in a bulky flap requiring secondary debulking surgery. Defatting after flap elevation is also possible, but tedious. SCIP, superficial circumflex iliac artery perforator; TDAP, thoracodorsal artery perforator.

on ICG combined with individual patient needs. Generally, one should offer the least invasive procedure that will still offer satisfactory outcomes (*Figure 10*) (2-4,32,83-85). CDT, traditionally considered first-line, has not been shown to cure or fundamentally impact the disease course. Surgery, which can halt, or in select cases, even reverse progression, is typically offered to patients who have failed therapy (3,30,40). However, with no standardization of CDT, it is difficult to define what constitutes an adequate trial or treatment failure. The rigor of lymphedema therapy is another complicating factor—success requires lifelong commitment to a strict regimen (2). We therefore discourage the categorization of CDT as first-line and surgery as second-line; with careful patient selection, both are effective options. In younger patients or in patients with severe disease who cannot tolerate the rigor of CDT, early initiation of an aggressive surgical plan may be appropriate, even if they have only trialed therapy for a short time. In patients with early disease, providers have more time to adjust CDT to their tolerance.

Physiologic procedures such as LVA, VLNT, and now, VLVT restore drainage of the affected limb. Thus, they are most appropriate for fluid-predominant lymphedema (12,41). To date, no direct comparisons of VLNT and VLVT have been published. However, in the experience of the senior author and his practice, they perform identically. One must speculate, then—do LNs truly serve a purpose in VLNT? In practice, there is no consistent evidence different LN flaps—which often contain different numbers of nodes—produce different outcomes (12,14,15). The sole study comparing different VLNT flaps within a single institution did not demonstrate a significant difference (16). More controlled efforts to establish a correlation between the number of LNs and the effectiveness of the flap have yielded mixed results (13,17). It is difficult to compare VLNT flaps with and without skin paddles in a controlled manner, but an increasing understanding of the dermal and subcutaneous lymphatic system strongly suggests that this lymphadiposal tissue is essential for efficacy of the flap (11,86). This, combined with lymphatic channels' abilities to absorb lymph and stimulate lymphangiogenesis, supports the senior author's argument that vessels—not nodes—are the therapeutic components of these flaps (18-24). Due to the novel nature of VLVT, long-term outcome data is limited; further follow-up is warranted to characterize long-term efficacy and sequelae. To date, the senior author has demonstrated highly favorable reduction of lymphedema volume and symptoms with a minimal rate of morbidity. After this group's initial publication on VLVT in 2019 (4), the senior author has since had a select number of patients discontinue the wearing of compression garments entirely. These outcomes have led the senior author's practice to phase VLNT out in favor of VLVT.

Supermicrosurgical LVA comes with a steep learning curve. While it is conceptually simple, the nuances of this procedure take extensive experience to master. There is much discussion in the literature about technical competency in supermicrosurgical anastomosis. However, achieving favorable results requires more than this. Understanding lymphatic and venous physiology and pathophysiology is imperative for proper selection of surgical sites and vessels (87). These obstacles are daunting, but in the senior author's opinion, mastering LVA is a worthwhile pursuit for beginning surgeons; in experienced hands, it is an incredibly powerful procedure.

There is no clear indication for when surgeons should stop offering LVA in favor of VLVT. For beginning surgeons, we recommend a black-and-white approach. If an abundance of linear ICG patterns are present, LVA is expected to be technically straightforward. VLVT should be performed in the absence of linear patterns as this indicates a paucity of available healthy lymphatics. Advanced lymphedema surgeons may adopt a more nuanced perspective, incorporating individual judgment and patient expectations. Functioning lymphatic vessels can frequently be found upon intraoperative search with high-resolution duplex ultrasound in patients with no linear ICG patterns. If
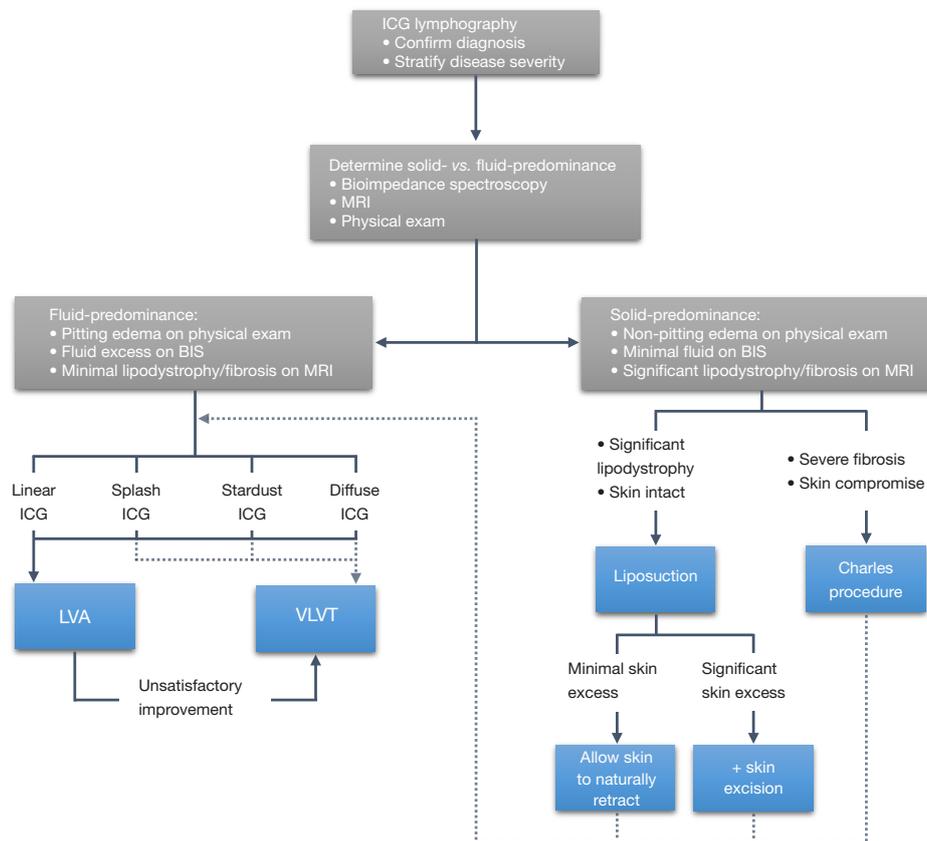
Figure 10 Algorithm for the management of extremity lymphedema. Imaging with ICG lymphography is imperative to confirm the diagnosis and stratify disease severity. Early disease is marked by linear patterns, while more advanced disease is marked by the absence of linear patterns and/or the presence of DB patterns (splash, stardust, or diffuse). BIS, MRI, and physical exam are then employed to ascertain fluid- or solid-predominance. Fluid-predominant lymphedema is best treated by a physiologic procedure. For early-stage disease, LVA is recommended. Traditionally, severe disease is treated by VLNT; the senior author's practice has phased this procedure out entirely in favor of VLVT. There is no clear indication for when VLVT becomes more appropriate than LVA. For beginning surgeons, VLVT is recommended for advanced disease. For experienced lymphedema surgeons, LVA often remains feasible in advanced disease, as long as functioning lymph vessels can be found intraoperatively. Solid-predominant lymphedema is best treated by debulking procedures, most commonly liposuction (with or without skin excision). Physiologic procedures can be performed in a staged manner following debulking. ICG, indocyanine green; DB, dermal backflow; BIS, bilateral impedance spectroscopy; MRI, magnetic resonance imaging; LVA, lymphaticovenicular anastomosis; VLVT, vascularized lymph vessel transplant; VLNT, vascularized lymph node transplant.

these vessels can be anastomosed, LVA can remain feasible and effective even in patients with severe disease (88,89). Because one cannot make evidence-based recommendations on which procedure is more appropriate, providers should actively involve patients in the decision-making process. Preoperative discussions should include both LVA and VLVT, with the possible exception of those early cases where LVA is the clear-cut recommendation. The choice often hinges on the degrees of morbidity and recovery the patient is willing to accept. For severe disease treated with

LVA, patients must be counseled that escalation to VLVT may be necessary should LVA be unsuccessful.

LVA and VLNT can be performed simultaneously in a "cocktail" approach. Proponents argue that they provide synergistic benefits—we do not share this opinion (85). LVA and VLNT have contrasting indications and should ideally not be combined. In lymphedema severe enough to require VLNT, there is significant lymphatic injury with poor-quality channels. Because LVA requires functioning lymph vessels to be successful, it is not expected to work in these cases.

Video 2 Surgeons may encounter significant skin excess following liposuction, indicated by the "flying squirrel sign". This skin can be safely excised concurrent to debulking, rather than allowing it to slowly contract over time.
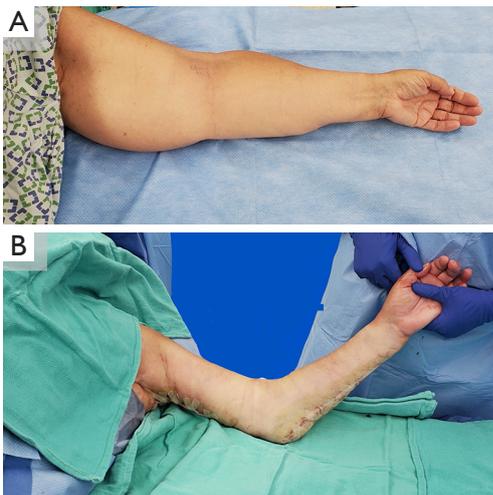
Figure 11 A liposuction patient with solid-predominant lymphedema, with significant lipodystrophy. (A) Pre-operatively, the limb appears bulky and has contour irregularities. (B) The limb is significantly less bulky following circumferential liposuction. Excision of excess skin is fast and easy because the flap has already been extensively undermined by the liposuction.

In contrast, in patients selected for LVA, LVA should likely be sufficient by itself without the addition of VLNT (41). Should surgeons desire to explore this "cocktail" approach, LVA combined with VLVT—a less morbid procedure—may be appropriate.

Patients with a significant solid disease component should be offered non-physiologic procedures such as liposuction,

which can effect powerful volume and symptom reduction in patients with late-stage lymphedema (2,40,90,91). Traditionally, when staging liposuction and physiologic treatment, most surgeons perform physiologic procedures first, perhaps due to early concerns that liposuction could further damage lymphatics or worsen the progression of disease. However, liposuction has not been found to cause injury; on the contrary, it triggers lymphatic regeneration, improving drainage on lymphoscintigraphic and ICG lymphographic studies (40,92-95). Moreover, when performing liposuction second, surgeons must either avoid their anastomoses, thereby potentially undertreating the patient, or risk ruining their reconstruction. Staging LVA or VLNT following liposuction has been shown to improve outcomes—removing lipodystrophy and improving drainage can set the stage for a more effective reconstruction (91,96). To date, the senior author has performed VLVT following liposuction in one patient, with highly favorable results. The excess skin created following liposuction is traditionally allowed to contract over time. However, it has been shown that concurrent skin excision is safe and effective (*Video 2*, *Figure 11*) (40,97). Skin excision may, on occasion, reveal fibrotic fascia with a cement-like appearance. A concurrent fascial release may be appropriate to mitigate the theoretical risk of chronic compartment syndrome.

Conclusions

Surgical treatment of extremity lymphedema effects clinically significant improvements in symptomatology and QoL. VLVT based on the SCIP flap and now, the TDAP flap, presents a promising alternative to VLNT. Further research is warranted to understand long-term outcomes and refine patient selection.

Acknowledgments

Footnote

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