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Lymphedema Surgery: Patient Selection and an Overview of Surgical Techniques

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Evaluation of the lymphedema patients with appropriate staging is fundamental for further treatment. Treatment includes compressive decongestive therapy for stage 0 and 1 patients, lymphovenous anastomosis for stage 1 and 2 patients, vascularized lymph node transfer for stage 2 and above patients. Wedge resection, liposuction, and the Charles procedure are alternatives or additions to physiological procedures. The selection of donor lymph node flap and recipient site depends on the patient's lymphedema status and surgeon's expertise.
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LYMPHEDEMA: DEFINITION AND PATHOPHYSIOLOGY

The lymphatic system provides several functions: prevention and clearance of edema, regulation of interstitial fluid homeostasis, immune system transportation and surveillance, and absorption in the gastrointestinal tract [1]. To these effects, the lymphatic system is an essential element of both the circulatory and immune systems.

It is estimated that there are between 600–700 lymph nodes in the body, with main concentrations found in the axilla, groin, mediastinum, and gastrointestinal tract [2]. Lymph fluid is transported into and out of lymph nodes via afferent and efferent lymphatic channels. Recent evidence has also demonstrated lymphaticovenous connections that provide drainage of surrounding tissues into the lymph node as well as out of the node back into the local venous network [3]. When these processes are disrupted, the result is lymphedema.

Up to 250 million people worldwide suffer from lymphedema, which can be divided into two major types [4]. Primary lymphedema results from genetic or developmental anomalies, while secondary lymphedema results from postnatal causes including trauma, infection, malignancy, or radiation to the lymphatic system. Primary lymphedema is further classified based on time of onset into congenital lymphedema, lymphedema praecox, and lymphedema tarda. Congenital lymphedema presents at birth or within the first 2 years of life, lymphedema praecox typically presents around puberty and before the age of 35. In contrast, lymphedema tarda presents in patients over the age of 35 [4]. For the basis of this review, we will focus on secondary lymphedema unless otherwise specified.

Worldwide, the leading cause of lymphedema is filiriasis, a parasitic infection caused by the roundworm *Wuchereria bancrofti*, which mostly affects developing countries [5]. These roundworms infiltrate the lymphatic system causing secondary lymphedema via obstruction. In developed countries, however, the leading cause of lymphedema is the consequence of oncologic therapies [6]. Breast cancer treatment in the forms of lymph node dissection and radiotherapy is the classic precursor of secondary lymphedema, but it is also observed in patients undergoing treatment of solid tumors elsewhere in the body. Whatever the cause, obstruction of or injury to the lymphatic system results in a specific series of events that leads to lymphedema. Fortunately, all patients undergoing these cancer therapies do not develop lymphedema. For example, between 29–49% of patients that undergo axillary lymph node dissection will develop lymphedema, although only 5–7% of patients that undergo sentinel lymph node dissection will suffer the same fate [7,8]. And for the patients that do develop lymphedema, the onset of disease is highly variable and infrequently immediate. On average, these patients develop lymphedema within 8 months of surgery, with 75% developing signs of lymphedema within the first 3 years [9]. This variability in incidence, onset and progression has revealed several independent risk factors for the development of lymphedema: obesity, radiation, infection, and genetics [7,9]. Not only is the timing of lymphedema variable, but the progression of disease also differs widely among patients. To understand this progression, knowledge of the pathophysiology of the disease process is necessary.

Although incompletely understood, the natural progression of lymphedema proceeds from a buildup of protein-rich fluid in the interstitial space, resulting in the early symptoms of soft, pitting edema in the affected extremity [10]. This initial event has been shown to cause inflammation of tissues and stimulation of fibrosis via a number of mechanisms [11,12]. With time, worsening lymphatic function results in adipose deposition in the subcutaneous tissues [13]. All factors feed back in a positive fashion to worsen the symptoms of lymphedema which progresses to a thick, fibrotic,

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fatty, and edematous extremity that is painful and debilitating to a patient's daily activities.

DIAGNOSIS AND STAGING OF LYMPHEDEMA

Diagnosing Lymphedema

In order to adequately treat lymphedema, it is first necessary to have a thorough understanding of the diagnosis and stage of the disease. The common symptoms include: swelling, heaviness, thickening/firmness of tissues, paresthesias, recurrent infections, and occasionally pain. Noticeably, these symptoms could result from a variety of other diagnoses. The differential diagnosis of lymphedema is broad: congestive heart failure, infection, primary/recurrent malignancy, vascular insufficiency, acute venous thrombosis, post-thrombotic syndrome, renal failure, hepatic failure, electrolyte imbalances, hypoproteinemia, and peripheral neuropathies to name a few [14]. With multiple etiologies to extremity swelling possible, the appropriate diagnosis is key.

The astute clinician should be able to accurately diagnose lymphedema. A thorough history and physical exam is the essential first step in this process. Primary and secondary lymphedema causes can be easily identified in the patient's history (e.g., family history, traumatic insult, cancer therapy, radiation history, etc). Comorbidities and medications that may cause edema can be identified and addressed via consultation or a change in medical management of disease. Next, the physical exam will provide many clues. Evaluation of the affected extremity should note size variation, location of scars, open wounds, comparison to unaffected limbs, sensation, and skin condition. Volumetric measurements of the extremity are the mainstay of diagnosing and following the progression or resolution of disease. Although there are many tools available to measure lymphedema (water displacement, circumferential measurements, perometry, and bioimpedence spectroscopy), there is not one universally accepted method. Water displacement offers perhaps the most accurate measurement; however, this is impractical in many situations and thus seldom used. In the senior author's practice, a series of measurements are made based on anatomic locations, namely 15 cm proximal and distal to the knee, 10 cm proximal to the ankle and 10 cm proximal and distal to the elbow. These measurements are compared to the non-affected limb, allowing a quantitative measurement of lymphedema as well as a method to track progress with time. If the cause of extremity edema remains in doubt after a detailed history and physical examination, common laboratory tests may then elucidate potential systemic causes (e.g., renal insufficiency, hepatic dysfunction, and protein abnormalities).

Once the diagnosis of lymphedema is made, further testing is performed to determine the extent of disease and functional status of the lymphatic system. The current "gold standard" imaging technique for investigating the functional status of the lymphatic system is lymphoscintigraphy (Fig. 1). Lymphoscintigraphy uses a tracer molecule attached to technechium-99m that is injected into the dermis of the foot or hand. Subsequent imaging can then reveal dynamic flow, areas of blockage and/or dermal backflow, giving the clinician a better understanding of how to treat the patient [15,16]. Other modalities that are also used include computed tomography (CT), magnetic resonance imaging (MRI), and infrared imaging following subdermal injection of indocyanine green (ICG). With ICG lymphography, a real-time functional image of the lymphatic drainage can be visualized [17]. After the subdermal injection of indocyanine green into the second and fourth webspaces of the extremity, an infrared camera is used to visualize the presence or absence of fluorescence in draining lymphatic channels (Fig. 2). This assists in not only accurately staging lymphedema but also in surgical management when indicated (see below).

Staging of Lymphedema

Using the above physical exam findings, history of disease and imaging modalities, several classification schemes have been proposed to stage lymphedema. Perhaps the most widely used is the International Society of Lymphology staging system [18]. Briefly, this system is comprised of four stages: stage 0 (latent lymphedema) is when there is lymph flow impairment after injury without measurable signs of edema or swelling; stage 1 (spontaneously reversible lymphedema) is defined by measurable swelling or edema that resolves with elevation or compressive therapy; stage 2 (spontaneously irreversible lymphedema) is progression of edema that does not fully respond to conservative therapies; and stage 3 (lymphostatic elephantiasis) is the final stage in which severe irreversible swelling, fibrosis, and fatty deposition result in thickened, firm tissues in the form of hyperkeratosis. As our understanding of lymphedema has evolved and technologies improved, other staging systems based on clinical presentation, circumferential measurements, physiologic measurements, or a combination thereof have been proposed [18–22].

At our center, we use a modified lymphedema grading system based on symptom severity, circumferential differentiation, and lymphoscintigraphy imaging to determine treatment [23]. In this system, lymphedema is categorized into one of five grades (0-Reversible, I-Mild, II-Moderate, III-Severe, and IV-Very Severe) Table I. We will examine this grading system in more detail below in discussing treatment options; but an accepted staging/grading system that accurately integrates symptoms with quantitative measurements and a functional assessment of the lymphatic system would benefit all involved in the management of this disease process.

TREATMENT OPTIONS FOR LYMPHEDEMA

Conservative Therapies

With an understanding of the disease process, clinical manifestations, diagnostic modalities, and staging of lymphedema, the clinician can then begin to understand how to treat this debilitating disease. The primary goals in the management of lymphedema are simple: to limit patient morbidity while improving patient function and quality of life. In order to accomplish this the clinician must decrease swelling, improve hygiene, reduce infection rates, improve patient mobility, and free them of the burden of daily therapies. Thus, these factors must be noted when evaluating the outcome of any treatment of lymphedema.

There are two major treatment arms for lymphedema: non-surgical and surgical. Non-surgical options have traditionally been the mainstay and continue to be the initial form of treatment for all stages of lymphedema. Compressive decongestive therapy (CDT) is the hallmark of conservative lymphedema management. CDT is performed and maintained by a specialized physiotherapist and the patient, involving the use of compression garments, therapeutic exercise, manual lymphatic decompressive massage, and meticulous hygiene [18,24]. Other modalities used have included topical laser therapy and pneumatic compression pumps [25,26]. Though effective, these therapies have several drawbacks. Not only must the treatment be continued indefinitely to remain effective, but there is also wide variability in the quality of the therapies and the quality of the compression garments [27]. The economic and personal burden of this form of therapy often diminishes a patient's quality of life, resulting in depression, anxiety and, unfortunately, non-compliance [28]. Naturally, clinicians have looked for other treatment modalities to improve patient quality of life and decrease the economic burden of lymphedema.

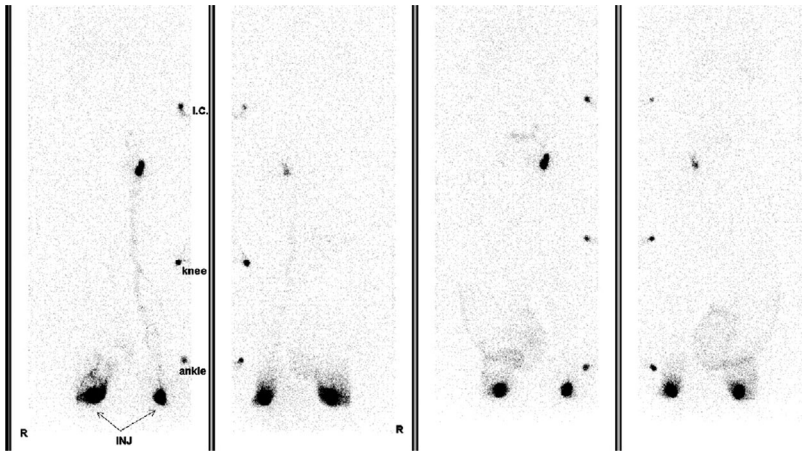

Fig. 1. Tc^{99} lymphoscintigraphy of a patient over time with advanced lymphedema of the right lower extremity. The right lower extremity shows no uptake or transportation in the lymphatic system and dermal backflow; whereas the left lower extremity shows dynamic uptake and flow with collection of radiolabeled Tc^{99} in the left inguinal lymph node basin. From left to right, 5 min A-P view, 5 min P-A view, 2 hr A-P views, and 2 hr P-A view. (R, right; INJ, injection site; I.C., iliac crest).

Debulking Procedures

Surgeons, in particular, have been trying to cure lymphedema since 1901, when Charles performed a debulking procedure for scrotal lymphedema [29]. Since that time there have been several described surgical techniques. These options can be divided into debulking procedures and physiologic procedures. Perhaps the best known debulking procedure is the Charles procedure, described in 1912 [30]. This procedure involves surgically excising the skin and soft tissues of the affected extremity down to the deep fascia and using the skin as a graft for coverage. Due to the disfiguring nature of the procedure, the Charles procedure is reserved for only the most severe cases of lymphedema. Other debulking procedures include wedge excisions and liposuction.

Liposuction, or suction-assisted lipectomy, can be used alone or in combination with other procedures to treat lymphedema [31]. Although compressive or pneumatic therapy can decrease fluid in the extremities, lymphedema also results in the deposition of adipose tissue in the subcutaneous tissues as mentioned previously. This buildup of fatty tissue is not responsive to CDT, and liposuction provides a method to remove it in the non-pitting, lymphedematous limb. Unfortunately, it carries risks of hematoma, seroma, further damage to the lymphatic system, and also does not alleviate the need for continuous compressive therapy postoperatively [32]. Despite these shortcomings, liposuction has been shown to sharply decrease edema as well as infection rates in the lymphedematous extremity with good long-term follow up, and it remains a major tool in the treatment of lymphedema [33,34].

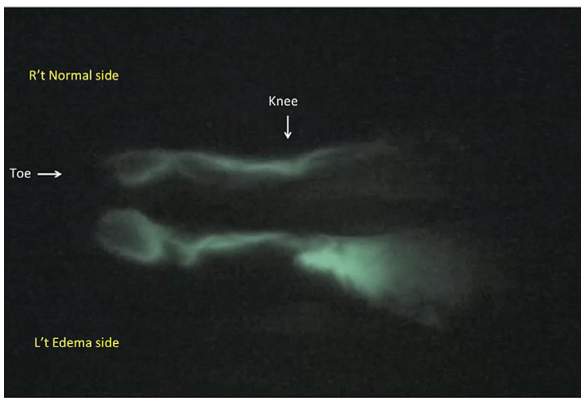

Fig. 2. Indocyanine green (ICG) lymphography of bilateral lower extremities demonstrated visualization of lymphatic drainage under infrared light. The right lower extremity shows normal uptake and drainage of the lymphatic system. The left lower extremity shows functioning lymphatic channels below the knee. A lack of functioning lymphatic channels in the left thigh above the knee results in dermal backflow of the ICG under infrared light.

Lymphaticovenous Anastomosis

With the advent of microsurgical techniques came a new wave of surgical options for the management of lymphedema, which fall into the category of physiologic procedures. The most commonly practiced procedures include lymphaticovenous, or lymphovenous, anastomsosis (LVA) and vascularized lymph node transfer (VLNT). These surgeries aim to tackle the physiologic impairment that results in lymphedema, namely bypassing the areas of damaged lymphatics by diverting lymph into the venous system or by replacing the lost lymph nodes and channels, respectively.

LVA was first described in 1969 [35]. This procedure aimed to overcome obstructions in the lymphatic system by diverting lymph into the venous system prior to the areas of obstruction. Although initial reports of this technique were discouraging, advancements in the optics of operating microscopes, the development of super-fine, atraumatic instruments, and improvements in imaging modalities have improved our ability to perform this technique. Despite these improvements, there is still no accepted method for LVA.

Different surgeons vary the timing, number, location, and configuration of anastomoses. LVA has been performed at all stages of lymphedema and even in a prophylactic manner following lymphadenectomy [36]. But it is generally agreed upon that LVA is easier and more effective the earlier it is performed [21]. With regards to location, some clinicians advocate for bypasses in multiple levels of the affected extremity (e.g., wrist, forearm, and arm) while others have called into question the need for multiple anastomoses [37]. Theoretically this can increase the chances of a successful shunt, but it may also result in further disruption of an already limited lymphatic system. Additionally, proximal LVA may not receive distal lymph fluid,

TABLE I. Cheng's Grading Scale for the Surgical Treatment of Lymphedema

Grade	Symptoms	Circumference differentiation (%)	Lymphoscintigraphy	Management
0	Reversible	<9	Partial occlusion	CDP
I	Mild	10–19	Partial occlusion	LVA, liposuction, CDP
II	Moderate	20–29	Total occlusion	VLN transfer, LVA
III	Severe	30–39	Total occlusion	VLN transfer + additonal procedures
IV	Very severe	>40	Total occlusion	Charles procedure + VLN transfer

Circumferential differentiation, circumference of the lesioned limb subtracted from the circumference of the healthy limb and divided by the circumference of the healthy limb, which is measured at 10 cm above and below the elbow, 15 cm above and below the knee, and 10 cm above the ankle. [Reprinted with permission from Patel KM, Lin CY, Cheng MH: A prospective evaluation of lymphedema-specific quality-of-life outcomes following vascularized lymph node transfer. Ann Surg Oncol 2015;22:2424-2430.] (CDP, complex decongestive physiotherapy; LVA, lymphovenous anastomosis; VLN, vascularized lymph node)

as lymphatic valvular incompetence is a result of lymphedema. To further complicate matters, the decision to perform end-to-end versus end-to-side or side-to-end lymphovenous anastomoses has yet to be fully elucidated.

For whatever technique is employed, there are consistent factors that influence the success of LVA. First, a suitable lymphatic channel must be identified. This can be done using a distally injected dye (e.g., patent blue) and/or ICG lymphography. Infrared fluorescence with indocyanine green can be used to map functioning channels prior to making the incision (Fig. 2). On exploration, the dye can then be seen traveling through functioning lymphatics (Fig. 3). A lack of functioning lymphatics and/or suitable lymphatics that are only located deeper in the subcutaneous tissues preclude identification with these methods. Next, a suitable vein must be identified for anastomosis. A suitable vein must be of compatible size, in the proper location, and show minimal, if any, backflow when divided. Larger veins may have increased intraluminal pressure which can result in venous reflux into the lymphatic channel following anastomosis [38]. Not only does this prevent improvement in lymphedema, but it may also result in significant ecchymosis and worsening lymphedema of the extremity. Koshima et al. have aimed to overcome this problem with the use of supermicrosurgical techniques, where the size of the lymphatic channels and veins used are less than 0.8 mm in diameter [39]. And finally, lymphatic vessels are extremely thin walled and collapse easily. Long-term maintenance of anastomotic patency following LVA cannot be ensured, but immediate patency can be demonstrated with patent blue dye or ICG lymphography. Improvement in lymphedema following LVA likely depends on all of the above factors.

Even with significant variance in surgical techniques, LVA has established itself as an essential tool in the management of lymphedema. In long-term follow up of 90 patients that underwent LVA, O'Brien and colleagues found objective improvements in 42% of patients, subjective improvements in 73% of patients and an average volume reduction in all patients of 44% [40]. Chang et al. also recently published a prospective analysis of LVA in 100 consecutive patients 12 months after LVA, finding a mean volume reduction of 61% in early-stage upper extremity lymphedema and 17% in advanced-stage lymphedema [21]. Of note, greatest improvement were observed in early stage lymphedema of upper extremity cases with a plateau of improvement after 1 year. Other studies have corroborated these findings while noting decreased volume, decreased rates of infection and relief of the use of compressive garments after LVA [41–43]. Complications of LVA are unusual and minimal, including infection, lymphatic fistula and wound healing problems.

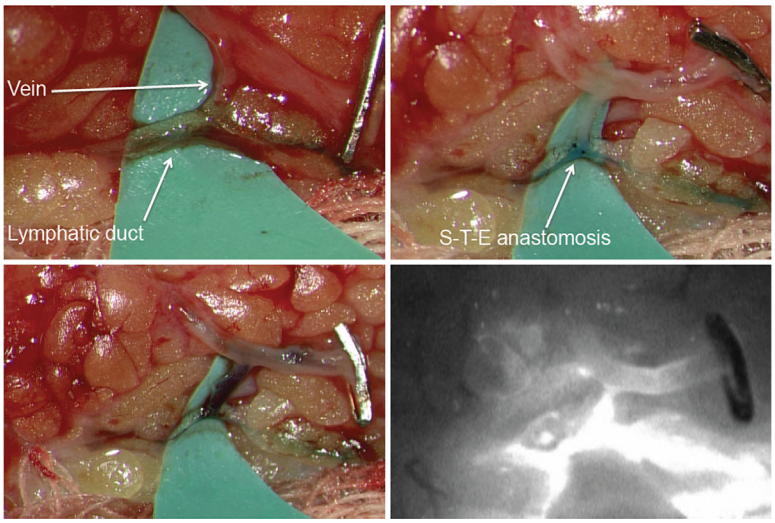

Fig. 3. Example of lymphovenous anastomosis. The top left photo demonstrates a functioning lymphatic duct draining distally injected patent blue dye as well as a small venule to be used for anastomosis. The top right photo shows the side-to-end lymphovenous anastomosis. The bottom two photos show the patent blue dye (left) and ICG (right) traversing the anastomosis, ensuring patency. (S-T-E, side-to-end anastomosis; ICG, indocyanine green).

Vascularized Lymph Node Transfer (VLNT)

Of the current surgical therapies for lymphedema, VLNT is the newest addition. Although non-vascularized lymph nodes were previously attempted in animal models, their viability was variable at best [44,45]. But transplanting vascularized lymph nodes to a lymphedematous area (replacing like with like) makes sense and has shown promising results [3,10,46,47]. In this new field, however, there remain many unanswered questions with regards to mechanism of action, donor site selection, recipient site selection, and postoperative care. Here, we will touch on these issues and provide the advantages and disadvantages of each option.

There is no accepted mechanism by which VLNT improves lymphedema; however, there are two leading theories. The first is that the VLNT functions as a "sponge" or "pump," taking up lymph into the nodes and directing it into the venous circulation through naturally occurring lymphovenous connections in the transplanted tissues [3,47]. To confirm their hypothesis, Cheng et al. injected ICG directly into the edge of a VLNT or a cutaneous flap in both animals and humans [3]. Fluorescence was then observed in the donor vein and then recipient vein of the VLNT group, indicating lymph uptake and drainage by the VLNT group although no fluorescence was observed in the veins of the cutaneous flap group.

The other proposed mechanism for VLNT is via lymphangiogenesis, or by the stimulation of efferent and afferent lymphatic connections between the VLNT and the recipient bed. In this theory, the VLNT contains lymphangiogenic mediators that act locally to stimulate in-growth and inosculation of lymphatic vessels to the VLNT lymphatic network [48–50]. The main lymphangiogenic mediators proposed for this are vascular endothelial growth factors (VEGF). Animal studies have been able to demonstrate improved success in lymph node transfer with the addition of VEGF; however, VEGF-C and VEGF-D are known to promote lymphatic metastasis in several human tumors precluding its application in humans [50]. Despite the limitations in our understanding of the mechanism, VLNT has been found to be both safe and efficacious in the treatment of lymphedema. The mechanism is likely a combination of the proposals above as well as factors that have not yet been described.

Despite the unknown mechanism of action, VLNT has become an essential element in the treatment of lymphedema, with many authors demonstrating excellent results. Several VLNTs have been described. These include the groin flap, submental flap, supraclavicular flap, omental flap, and thoracic lymph node flap [3,6,10,27,46,47]. Each flap has its own advantages and disadvantages. The groin flap is the most commonly used flap for VLNT. This flap is based off the superficial circumflex iliac vessel or the medial artery of the common femoral artery. It offers several advantages including an inconspicuous scar, reliable anatomy, the presence of multiple lymph nodes, and the ability to harvest this flap with an abdominally based flap for total breast reconstruction [51–54]. The disadvantages of the flap include the small size of the donor artery, short vascular pedicle, and the potential for iatrogenic lymphedema of the lower extremity following harvest [55]. To prevent this last devastating complication, a number of studies have investigated the lymph drainage patterns of the lower extremity and lower abdominal wall. Generally, it has been found that lymph nodes draining the lower extremity are located medial to the femoral artery in the femoral triangle, although those draining the lower abdomen are found lateral and more superficial to the femoral artery [17,53,56,57]. Additionally, Dayan et al. have described "reverse lymphatic mapping" which identifies lymph nodes draining the lower extremity by radionucleotide labeling and lymph nodes draining the lower abdomen with indocyanine green fluorescence [58]. Although the risk of iatrogenic lymphedema following groin VLNT is low, it is a real risk that should be discussed with the patient. All efforts to prevent this complication should be employed.

The submental flap is another flap that is gaining popularity for its use in VLNT (Fig. 4). This flap is based off the submental artery and carries up to six level 1A and 1B lymph nodes [52]. The advantages of this flap include the number of lymph nodes, reliable anatomy, size of submental and facial artery, ease of harvest, limited potential for iatrogenic lymphedema, and flap thickness [59]. The disadvantages include the potential for damage to the marginal mandibular nerve during dissection, platysma palsy and the resulting scar on the upper neck. To offset these potential disadvantages, the surgeon may increase the size and length of the pedicle by including the facial artery in the flap, perform dissection of the marginal mandibular nerve with the

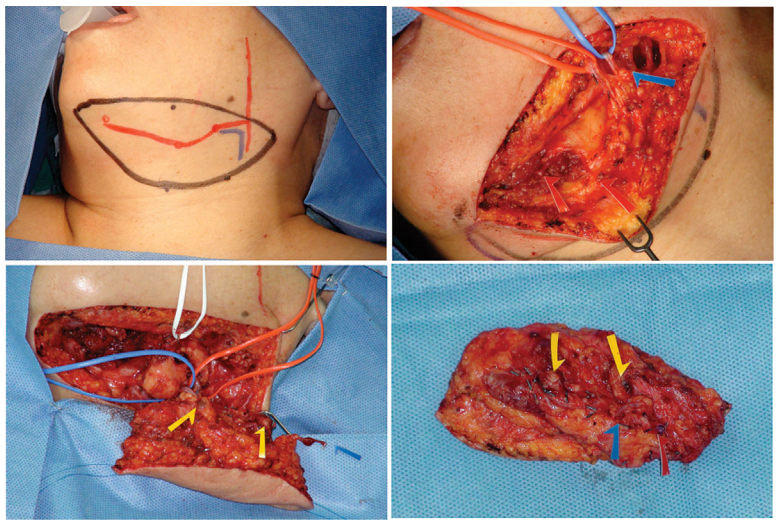

Fig. 4. Intraoperative planning, dissection, and harvest of the submental vascularized lymph node flap 10 × 5 cm. The top left photo shows the preoperative markings of the facial and submental vessels. The anterior incision is made first to identify and isolate the facial artery distal end (red vessel loop) and facial vein (blue vessel loop). Dissection then proceeds from an anterior to posterior direction, including submental perforators to the skin paddle (red arrows). If the marginal mandibular nerve is encountered (white vessel loop), it is dissected using the operative microscope and protected. Care is taken to include the lymph nodes (yellow arrows) around the submental vessels with the flap.

assistance of the operating microscope and employ a plastysma-sparing approach during harvest. Meticulous closure is needed to prevent a conspicuous scar on the neck, though this has not been a major concern of the patients in the senior author's practice.

The other, less frequently used flaps in VLNT include the omental flap, supraclavicular flap, and the thoracic flap [10,60–63]. Although the omental flap offers the potential for a large number of lymph nodes to be harvested, this flap lacks a cutaneous component for coverage and demands entry into the peritoneal cavity for harvest. Entry into the peritoneal cavity carries the inherent risks of damage to surrounding structures and the potential formation of intraperitoneal adhesions. Additionally, limited data is available on the long-term sequelae of omentum flap harvest with regards to digestion and intraperitoneal immune maintenance. For now, this VLNT should only be used in select circumstances.

The supraclavicular VLNT is based off the transverse cervical vessels. It is a thin flap with an inconspicuous donor site that is attractive to many patients. Recent studies have shown a lower density and number of lymph nodes in this flap compared to the groin and submental flaps [52]. Additionally, care must be taken when harvesting this flap from the left side, as the potential for damage to the thoracic duct is present. Another drawback is potential injury of the supraclavicular nerve, which may cause numbness of the lateral upper chest wall. Finally, the thoracic VLNT is based on long thoracic or thoracodorsal artery branches that carry level I axillary lymph nodes [10]. This flap may be easily accessed during surgeries that aim to remove the significant scarring in the axilla resulting from previous axillary lymph node dissection. The donor vessels are of sufficient size and length for anastomosis, and the number of lymph nodes that can be harvested is adequate. The flap is not without its limitations, however, as it carries the inherent risk of causing iatrogenic lymphedema to the upper extremity. Other disadvantages include an unreliable vascular pedicle from the thoracodorsal or lateral thoracic artery, the need to sacrifice the thoracodorsal nerve and the likelihood of requiring two separate anastomoses. As with the groin flap, several studies have investigated the lymphatic drainage of the upper extremity and thorax to identify the correct lymph nodes to carry with the flap [64]. Reverse lymphatic mapping can also be used to identify the proper nodes to take and those to leave behind as well [58]. The multitude of options available for VLNT allows for a patient- and disease-specific approach to be employed by the operating surgeon.

Once a particular flap has been chosen, the next decision to be made is the recipient site for flap transfer. The ultimate decision of recipient site is based on a number of factors including location of lymphedema (upper vs. lower limb), recipient vessel availability, previous surgeries scar, cosmetic appearance, and the surgeon's experience with individual recipient sites. The described recipient sites for the upper extremity include the axilla, elbow and wrist, while the groin, posterior knee, and ankle have been proposed for lower extremity recipient sites. In general, surgeons who propose the use of the axilla or groin for recipient sites after previous surgery in these areas point to the extensive scar removal along with the placement of well-vascularized tissue in its place as potential advantages [10]. Additionally, flaps in these areas are also more easily hidden, providing a better cosmetic outcome. On the contrary, surgeons that prefer distal recipient locations cite the ease of recipient bed dissection, placement of the VLNT according to the level of lymphedema in the extremity as well as the "pump" theory for lymphedema clearance as advantages [65]. As mentioned previously, the pump theory proposes that the VLNT acts as a pump, with the lymph node flap absorbing lymphatic fluid from the surrounding tissues, and draining it into the venous circulation through naturally occurring lymphovenous connections [3]. A distally based VLNT can thus begin to function immediately. Proximal lymphedema then may progress distally to be absorbed by the flap and cleared in a similar manner (Fig. 5). The untoward cosmetic appearance of a distal flap can be addressed in subsequent surgeries by removing the skin from the flap upon resolution of edema and improved pliability of remaining skin. Excellent results have been shown using all of the techniques described above, giving the surgeon a number of possibilities to treat lymphedema.

INDIVIDUALIZED CARE FOR THE LYMPHEDEMA PATIENT

With a thorough understanding of lymphedema care, the surgeon is now able to custom-tailor a treatment plan for any patient. In the senior author's practice, each patient undergoes a complete workup prior to the development of an individualized treatment plan. If surgery is chosen, the patient then follows a specific postoperative protocol based on their clinical response. This final section will focus on individualized care of

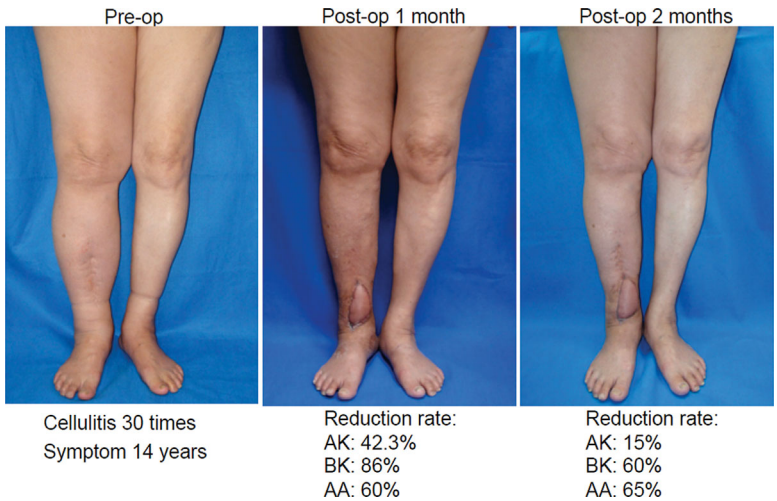

Fig. 5. Example of a vascularized submental lymph node transfer to the right ankle for Grade III lymphedema. Note the greater initial improvement in the right lower leg at 4 weeks postop. With time, gravity assists in transporting the upper leg edema distally, where it is pumped into the venous circulation by the lymph node flap. (AK, 15 cm above knee; BK, 15 cm below knee; AA, 10 cm above ankle).

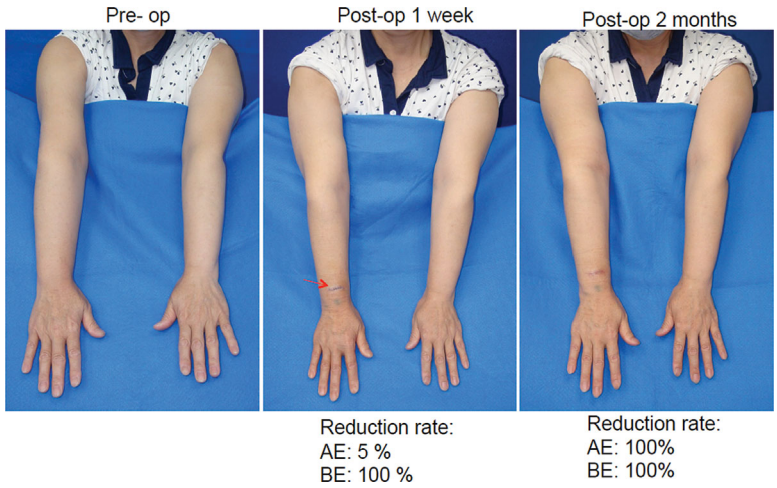

Fig. 6. Preoperative and postoperative photos of a patient with Grade II lymphedema of the right upper extremity treated with lymphovenous anastomosis (red arrow points to incision site). The patient experienced lymphedema for 1 year. This was associated with two episodes of cellulitis and was unresponsive to CDT. (CDT, complex decongestive therapy; AE, 10 cm above elbow; BE, 10 cm below elbow).

the lymphedema patient and is based on the senior author's current practice.

The initial clinic visit is begun with a full history and physical exam for every patient. During the physical exam, particular attention is focused on the circumference differentiation between the affected and unaffected limbs (in unilateral disease).

All patients with lymphedema undergo Tc^{99} lymphoscintigraphy to assess for partial versus total lymphatic flow obstruction in the affected extremity. Based on the above findings, the senior author has developed a grading system that determines the subsequent treatment pathway [23] Table I. Patients are graded based on severity of symptoms, circumference differentiation and partial versus total occlusion on Tc^{99} lymphoscintigraphy. For grade I–IV lymphedema, surgery is recommended.

An individualized treatment plan is then determined based on subsequent imaging studies for patients with grade I to IV lymphedema. Patients with grade I and II lymphedema undergo lymphodynamic evaluation using ICG lymphography. This is performed via subdermal injections into the dorsal skin of the second and fourth webspaces of the fingers or toes. Images are obtained at 15 min and then again at 24 hr post-injection. Indocyanine green injection allows for evaluation of dermal backflow as well as the presence and location of open, functioning lymphatic channels. Lymphovenous anastomosis is chosen for those patients that demonstrate open and functioning lymphatic channels (Fig. 6). If LVA is chosen for a patient, it is the senior author's preference to perform 1 or 2 anastomoses using supermicrosurgery techniques, with the anastomosis performed in an side-to-end (lymph-to-vein) fashion to allow for lymph to drain into the vein from both proximal and distal directions (Fig. 3). Patent blue that was injected distal to the planned incision to allow for easier detection of lymphatic channels can then be seen draining from the lymphatic channel into the vein, confirming patency of the LVA. ICG fluorescence may also be used to verify a patent anastomosis. Postoperatively, patients are monitored for 2–3 days in the hospital prior to discharge. They are then advised to slowly resume activity as tolerated and to discontinue all physiotherapy and compressive garment use.

For patients with grade II to grade IV lymphedema and no functioning lymphatics on ICG fluorescent imaging, a VLNT is recommended for treatment. Patients with grade IV lymphedema are also given the option to undergo partial wedge excision or the Charles procedure in addition to the VLNT. The choice of VLNT is based on surgeon preference, patient preference for donor site, and the availability of sizable lymph nodes as identified by preoperative ultrasonography [52]. Given these factors, the most commonly used VLNT for the senior surgeon now is the submental VLNT. This is placed in a distal location in the extremity in accordance with the "pump" mechanism and natural effects of gravity [66]. Postoperatively, patients are monitored in the hospital for 2 weeks. At this time, the patient undergoes a progressive dangling protocol. The patient is advised to return to normal activity as tolerated, and all physiotherapy and compression wrapping are discontinued. All patients are placed on aspirin, montelukast, and ibuprofen postoperatively for 3 months.

Once discharged from the hospital, patients are monitored closely in the clinic. After the initial postoperative period, patients are seen on a monthly basis. Grade III and IV patients with excessive adiposity of the subcutaneous tissues are scheduled for adjunctive debulking procedures 6–12 months following the initial surgery. Surgical outcomes are evaluated by patient's subjective improvement, circumferential measurements, frequency of cellulitis episodes, and via patient reported health-related quality of life outcome metrics [23]. The majority of patients show immediate improvement. For those that show a limited response, Tc^{99} lymphoscintigraphy and ultrasound are used to workup potential etiologies. Based on these studies, progressive venous outflow obstruction from scarring is the most common mechanism for a limited response following VLNT. These patients are taken back to the OR 6–12 months after their initial surgery to remove the scar surrounding the venous outflow or to revise the venous anastomosis. At this time, excess flap skin paddle can be removed to improve the cosmetic appearance. Decreasing edema and increasing pliability of the tissues following VLNT frequently allow for complete removal of skin paddles postoperatively. This is done on an elective basis.

With the above protocol in place, the senior author has demonstrated predictable clinical results. A consistent evaluation of the postoperative outcomes of these challenging patients over the past years is the basis for this protocol.

CONCLUSIONS

Lymphedema is an exciting field with many unanswered questions. The interested clinician is challenged to use a variety of tools in the diagnosis, treatment, and management of lymphedema. From simple

excision to supermicrosurgery, a variety of surgical modalities have been shown to improve, and sometimes reverse, the devastating effects of this disease. It is our opinion that a consistent approach to the treatment of lymphedema along with a critical evaluation of one's results over time is the best way to advance this field towards the ultimate goal of a cure for our patients.

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