JPRAS Open 50 (2026) 68–83

Contents lists available at ScienceDirect

JPRAS Open

journal homepage: www.elsevier.com/locate/jpra

Review Article

"Debulking" the future of lymphedema surgery: A narrative review

Tarini Mudunuri[a,*], Hemalatha Pasupuleti[b], Satyamedha Bathula[c], Bijily Babu[d], Francisco M. Lara-Salazar[e], Meghana Singh[f], Sudharsan Ramapriya[g], Juan E. Zubillaga Gutierrez[h], Sanjeeve R[i], Santiago Lara-Salazar[j], Omar Kasimieh[k], Glorya J. Kuriakose[l], Long Yin Cai[m], Ramsha Ali[n]

[a] *Sri Ramachandra Institute of Higher Education and Research, Sri Ramachandra Medical College, No 1 Ramachandranagar, Chennai, TN, India*
[b] *College of Medical Sciences, P.O. Box: 23, Bharatpur, Chitwan, Nepal*
[c] *St George's University, University Centre, True Blue, St. George's, Grenada, P.O. Box 7 West Indies*
[d] *Department of Surgery, University of Perpetual Help System DALTA, Alabang–Zapote Road, Pamplona 3, Las Piñas City, 1740, Philippines*
[e] *Institute Of Biological Sciences, Autonomous University of Guadalajara, Zapopan, Jalisco, Mexico*
[f] *Gulf Medical University, Ajman, P.O. Box: 4184 United Arab Emirates*
[g] *Kasturba Medical College, Tiger Circle Road, Madhav Nagar, Manipal, Karnataka, India*
[h] *Central University of Venezuela, Luis Razetti School of Medicine, Caracas, Venezuela*
[i] *Coimbatore Medical College and Hospital, No.1, Civil Aerodrome Post, Avinashi Road, Coimbatore, India*
[j] *Department of Physiology, University Center for Health Sciences, University of Guadalajara, Guadalajara, Jalisco, Mexico*
[k] *Department of Medicine, University of the East Ramon Magsaysay Memorial Medical Center, 64 Aurora Boulevard, Quezon City, Metro Manila, Philippines*
[l] *Medical University of Varna, 55 Marin Drinov Str., Varna, 9002 Bulgaria*
[m] *Caribbean Medical University, Pater Euwensweg #25, Willemstad, Curaçao*
[n] *People University of Medical and Health Sciences, Nawabshah (Shaheed Benazirabad), Sindh, 67480 Pakistan*

* Corresponding author.
E-mail address: tarinivegesna@gmail.com (T. Mudunuri).

https://doi.org/10.1016/j.jpra.2026.01.045

ARTICLE INFO

Article history:
Received 29 July 2025
Accepted 25 January 2026
Available online 4 February 2026

Keywords:
Lymphedema
Lymphedema surgery
Lymphovenous anastomosis
Vascularized lymph node transfer
Liposuction
Microsurgery

ABSTRACT

Objective: To summarize and contextualize current and future perspectives in the surgical treatment of lymphedema, exploring new techniques and technologies, integrated treatment modalities, and their real-time clinical applications.

Background: Lymphedema is a debilitating condition caused by impaired lymphatic flow. It diminishes quality of life (QoL) and often leads to other sequential comorbidities. There is no established cure, and the optimal treatment option remains debated. Understanding current and future surgical approaches, especially the preventive and curative role at early stages, would be valuable.

Methods: A literature review was conducted using PubMed, Cochrane, and Google Scholar, including only high-impact systematic reviews, meta-analyses, and randomized controlled trials from the past 10 years.

Results: Lymphovenous anastomosis, vascularized lymph node transfer, and liposuction were among the most discussed surgical treatment options. Benefits include speedy volume reduction, greater QoL, and better wound healing. Microsurgical techniques greatly aided early-stage lymphedema. Fibrotic, irreversible lymphedema cases were better treated with reductive procedures and improved QoL. On the flip side, we are encountering limitations in standardization, resources, and the need for adjunctive conservative therapy while trying to make surgical treatment the mainstay. Technological advances like imaging and robotics, and future innovations like regenerative medicine show potential, but further high-quality, long-term studies are necessary for standardized, cost-effective, and widely accessible care.

Conclusion: Modern surgical treatment for lymphedema offers safer, more effective, and more individualized solutions. To make these procedures a part of mainstream, multidisciplinary care, further development must go into training, standardizing protocols, and making them accessible.

Introduction

Lymphedema was described in text as early as the 6th century, yet there is no official treatment protocol. It affects nearly 250 million individuals worldwide and leads to psychological and physical morbidity, affecting quality of life (QoL).[1]

Primary lymphedema is rare, affecting about 1 in 100,000 people; it occurs in congenital cases of malformed or absent lymphatic vessels and nodes, leading to structural obstruction. Secondary lymphedema is caused by mechanical obstruction of lymphatic vessels by tumors, oncological treatment ramifications, or infections like filariasis.[2] Disease progression often involves inflammation, skin changes, venous ulcers, and cellulitis.[3] Refractory edema with fibrotic changes in later stages cause great psychological distress (cosmetic deformities).[2]

Lymphedema is diagnosed clinically. No gold-standard test exists, but various modalities, including X-Ray lymphography, duplex ultrasound, lymphoscintigraphy, bioimpedance, MRI, CT, fluorescence micro-lymphangiography, and near-infrared fluorescence (NIRF) imaging, are used to confirm, stage, and grade lymphedema[4,5] before planning for conservative or surgical management.

Conservative therapies such as complete decompressive therapies (CDT) are used to manage lymphedema initially. CDT is a multimodality approach that requires multiple therapy sessions for manual lymphatic drainage, daily bandaging, physical therapy, exercise, and skin care.[6] Pharmacotherapy is an adjunctive approach that has shown limited effectiveness in long-term lymphedema management, hence, not considered a standard for care. However, CDT and other conservative therapies' efficacy declines in advanced or resistant cases.[7]

Surgical treatments have advantages: rapid and effective lymph volume reduction, improved functional capacity, long-term symptomatic relief, and a lower recurrence rate. Disease stage, lymphatic architecture, tissue composition, and prior response to conservative therapy decide candidacy for surgical options.[8]

The current agreed upon algorithm recommends initial conservative therapy with compression and lymphatic drainage, followed by reassessment at 6 months to either continue conservative management if symptoms improve or pursue surgical consultation if symptoms persist or worsen.[9]

Microsurgical procedures, such as lymphovenous anastomosis (LVA) and vascularized lymph node transfer (VLNT), are selected based on severity. LVA is a minimally invasive technique performed using indocyanine green (ICG) perioperative imaging.[10] Both LVA and VLNT can be used in mild to moderate lymphedema, severe cases can be treated with VLNT.[11–13] Preventive surgical approaches like Immediate Lymphatic Reconstruction (ILR), which includes techniques such as the Lymphatic Microsurgical Preventive Healing Approach (LYMPHA) or the targeted Lymphatic Axillary Repair approach (T-LAR), aim to reduce the incidence of secondary lymphedema in high-risk patients with comorbidities (including cardiopulmonary and renal issues, chronic venous insufficiency, obesity, and diabetes mellitus).[14] Venous stenting procedures are considered to treat refractory lymphedema of lower extremities caused by chronic venous insufficiency.[15]

Surgical procedures are often effective in early stages when lymphatic pathways remain functional. Beyond stage II, with fibrosis and adipocyte hypertrophy, procedures like subcutaneous excision or liposuction are preferred as debulking techniques for rapid volume reduction and symptomatic alleviation.[7,16] Combined surgical therapies have also demonstrated improved volume reduction and aesthetic outcomes, hence preferred over isolated procedures.[17]

The scope of this review is to provide evidence-based criteria for the advantages of integrating surgical interventions (including microsurgical and reconstructive techniques) over conservative treatments across various clinical presentations, such as early, recurrent, and chronic lymphedema. The aim is to summarize current literature studies on clinical efficacy, safety, and long-term outcomes of surgical interventions as a potential mainstay management of lymphedema. Additionally, it is necessary to explore the limitations in the current surgical guidelines, patient selection, optimal timing of prioritizing surgical management, and integrating these approaches into multidisciplinary care.

Methods

A literature review was conducted using PubMed, Cochrane, and Google Scholar, original studies, case series, meta-analyses, and systematic reviews in English describing surgical management in patients with lymphedema were included. Case reports, abstracts, and non-human studies were excluded.

Data was qualitatively synthesized and organized thematically to highlight technical considerations, success rates, and limitations associated with each approach, and economic context has been discussed.

Results

Lymphedema represents a real challenge for physicians to diagnose and treat.[1] It is caused by lymphatic dysfunction where the system responsible for fluid balance and immune function experiences accumulation of protein-rich fluid in the interstitial spaces. Eventually, this leads to impaired drainage.[18]

Patient selection and determining surgical treatment options depends heavily on the pathological processes of the disease (Diagram 1).[19]

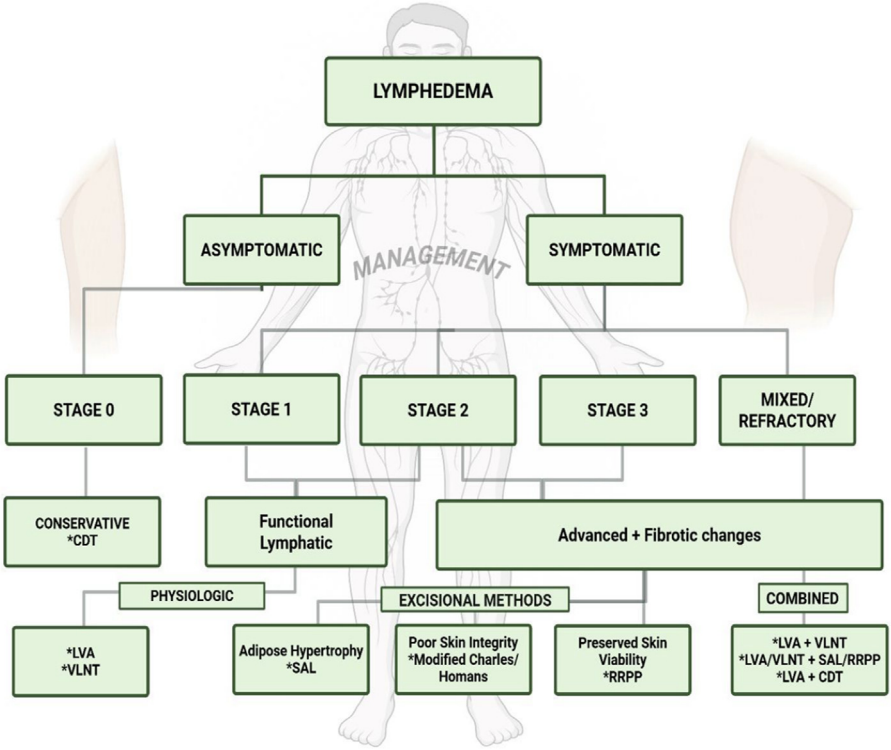

Diagram 1. Shows the algorithm for management of lymphedema.

The International Society of Lymphoedema has developed a staging system for clinical assessment, categorized into 0–3 stages:

- Stage 0- Clinically, an extremity is normal, but lymphatic transport is abnormal.
- Stage 1- Early oedema, which improves when the limbs are elevated.
- Stage 2- Pitting oedema that is not relieved by elevation.
- Stage 3- Fibroadipose deposition and changes in the skin.

Complex Decongestive Therapy (CDT) is the gold standard for limb lymphedema. It consists of two treatment periods: the initial phase helps to reduce limb volume, and the maintenance phase aims for a long-term outcome by using compression therapy, exercises, manual lymphatic drainage, and skin care. CDT requires lifelong patient participation for optimal results.[20,21]

Surgical advancement in the management of lymphedema

The International Society of Lymphoedema suggests surgical management when conservative measures are ineffective or in chronic, unilateral, fibrotic, or resistant cases.[7,14]

Lymphedema surgical management is of two types: physiologic or ablative/excisional. However, a promising prospect is the combination of current methods.[7,22]

1. Physiologic methods

Lymphovenous anastomosis (LVA) and vascularized lymph node transfer (VLNT) are the two physiological methods for restoring normal lymphatic fluid (Diagram 2).[7]

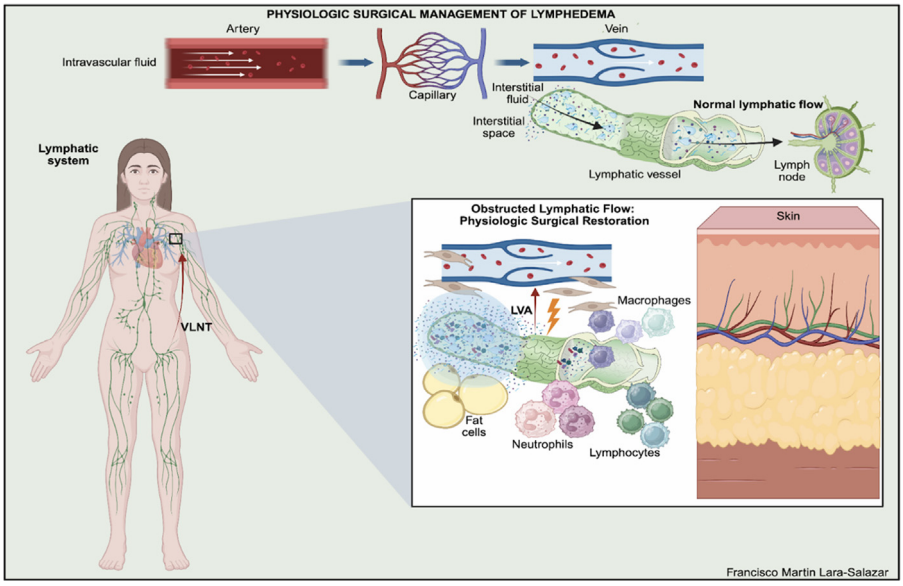

Diagram 2. Physiological methods in the management of lymphedema.

The microsurgical procedure, LVA, uses superficial functional lymphatics connected to veins to redirect lymphatic fluid into the venous system.[21] This is a safe and low-risk procedure that can be performed using minimal incision under local/regional anesthesia.[23] It can slow the development of advanced stages of lymphedema by re-establishing normal lymph drainage and minimizing the limb volume and circumference in initial stages.[24] Disadvantages may include lack of long-term outcome research studies, technical requirements, and disease recurrence due to failure of anastomosis or its fibrosis.[22]

Vascularized lymph node transfer (VLNT) collects a donor soft tissue flap with healthy lymphatics and arteriovenous supply, which is subsequently transplanted to the affected region. This restores lymphatic outflow via immune regulation, lymphangiogenesis, and a pump mechanism.[13] This procedure is used for stage II/III with significant dermal backflow and no functional lymphatic channels on imaging, and when CDT doesn't improve conditions after 1 year.[15]

After VLNT, patients experience significant decrease in limb volume based on technique, site, and follow-up duration. The meta-analysis of Harm Winters et al. showed an average reduction of approximately 40.3% in the volume difference post-VLNT in breast cancer-related lymphedema (BCRL).[25] VLNT also substantially decreased cellulitis episodes.[26] Post-VLNT patients report increased mobility, less discomfort, and improved QoL.[27] Rannikko et al. found that 30% of patients stopped using compression garments after 1 year, increasing to 42% at long-term follow-up. Continued compression may be necessary to prevent recurrence in patients with prior cellulitis.[28]

Better aesthetics and scar removal can be prioritized in VLNT with orthotopic placement (groin, axilla).[29] Precise dissection and reverse lymphatic mapping should be prioritized to prevent critical donor site dysfunction.[30] Complications occur in 21.8% of cases, with seroma most common and rare flap failures reported.[31]

Table 1: Comparing conservative and psychological methods of management.

1. Excisional methods

Charles, Modified Homans, Suction-Assisted Protein Lipectomy (SAPL)/Liposuction and Radical Reduction with Perforator Preservation (RRPP) remove excess adipose or fibrotic tissue in advanced lymphedema cases where conservative treatments and physiological microsurgeries have failed.[22]

Table 1
Comparing conservative and psychological methods of management.

	Conservative	LVA	VLNT
Mechanism	Nonsurgical external pressure	Microsurgical shunt between lymphatics and veins	Microsurgical transfer of functional lymph nodes
Indications	For all stages	Stage I–III	Stage II–III
Goal	Reduce Interstitial Fluid	Diverts lymph to venous	Restores Lymphatic drainage
Invasiveness	Noninvasive	Minimally Invasive	Moderately Invasive
Effectiveness	Symptomatic treatment	Effective in early stages with patent lymphatics	Effective in later stages with fibrosis and loss of patency in lymphatics
Durability	Lifelong	Long term in cases with good patient selection	Long term with the potential for permanent improvement
Imaging	N/A	ICG Lymphography/MR Lymphangiography	Reverse lymphatic mapping/MRI
Risk of cellulitis	High in advanced cases	Reduced in successful cases	Significantly reduced
Recovery	Immediate, but ongoing	1–2 weeks	4–6 weeks
Postoperative compression	Lifelong	Often reduced or discontinued	Discontinue after 6–12 months
Complications	Skin excoriation	Anastomotic failure Infection	Donor site lymphedema Flap failure Infection

The Charles method is a traditional excision and graft resurfacing technique. It has been associated with graft failure, poor aesthetics, lymphedema recurrence, infection, wound breakdown, and amputation.[32] It has since been modified to include Charles' approach, which provides for delayed skin grafting and negative pressure wound therapy to enhance graft take and wound repair time.[33] Homans modified the Charles procedure to preserve healthy overlying skin, improving cosmetic outcomes. However, it is still invasive and carries risk of seroma, thus limiting its application to selected cases.[34,35]

Liposuction removes excess fibroadipose tissue in non-pitting, irreversible, advanced lymphedema. It is safe, less invasive, and unlikely to worsen the affected limb's lymphatic drainage, and recurrence rates are low.[36] However, patients require continuous compression and CDT. Liposuction is not curative.[22] However Håkan Brorson study highlights Liposuction is considered as an effective and compelling option for managing excessive adipose volume and is also emerging option to be currently used as a standardized treatment protocol for patients with lymphedema stage III.

RRPP is a skin-preserving alternative that combines conventional excisional techniques with microsurgical principles of perforator flap dissection.[30] It offers better cosmetic and healing properties, improves flap survival, and reduces total lymphedema by 52% without postoperative complications. RRPP is preferred for severe lymphedema with fibrotic/solid tissue resistance to SAPL.[37]

Table 2: Comparing excisional methods.

Combined approaches

Resistant BCRL can be managed with combined LVA and VLNT, offering complementary benefits. Park et al. report no added operative time or complications in a limited sample size.[38] Combining physiological and reductive surgical methods optimizes lymphatic drainage, minimizes fibrofatty tissue buildup and reduces the need for compression therapy.[30,39] The Modified Charles operation and VLNT are effective for advanced lymphedema.[32] Laser liposuction with VLNT improves skin tonicity, reduces lymph stasis and volume without donor morbidity, achieving greater circumference reduction in stage III than LVA or VLNT alone in stage II.[40] Combination surgery requires thorough preparation, multidisciplinary teams, and depends on disease stage, surgeon expertise, and patient selection.[32] This approach lowers cellulitis rates and enhances QoL.[41]

A study was done to address the limitations of single-modality surgery for cancer-related lymphedema, and it was found that a one-stage regional approach combining supramicrosurgical lymphatico-venular anastomosis with lymph-sparing liposuction safely improved limb volume, symp-

Table 2
Comparing excisional method.

	Modified Charles	SALP	RRPP
Mechanism	Excision down to fascia, followed by split thickness skin grafting	Liposuction under tourniquet; No lymphatic restoration	Excision of fibroadipose tissue, preserving skin flaps with identified perforator
Indications	Advanced with poor skin integrity	Advanced with adipose hypertrophy	Advanced with preserved skin viability
Goal	Radical excision of skin and subcutaneous tissue	Remove excess adipose tissue while preserving skin	Debulking of tissue while preserving skin perfused by perforator
Volume reduction	Very high	High	High and more physiological
Skin management	Skin removed and replaced with graft	Skin preserved	Native skin preserved via perforator
Aesthetic outcome	Poor due to grafting and scarring	Good contour if compression maintained	Good
Recovery	Prolonged for graft healing	Short to moderate – Dependent on compression	Moderate (faster than Charles if flaps are well vascularized)
Postoperative compression	Need persists	Essential lifelong	Often reduced, especially if combined with VLNT
Complications	Graft loss, infection, poor cosmesis	Bleeding, hematoma, recurrence if compression fails	Flap necrosis if perforator damaged; technically demanding

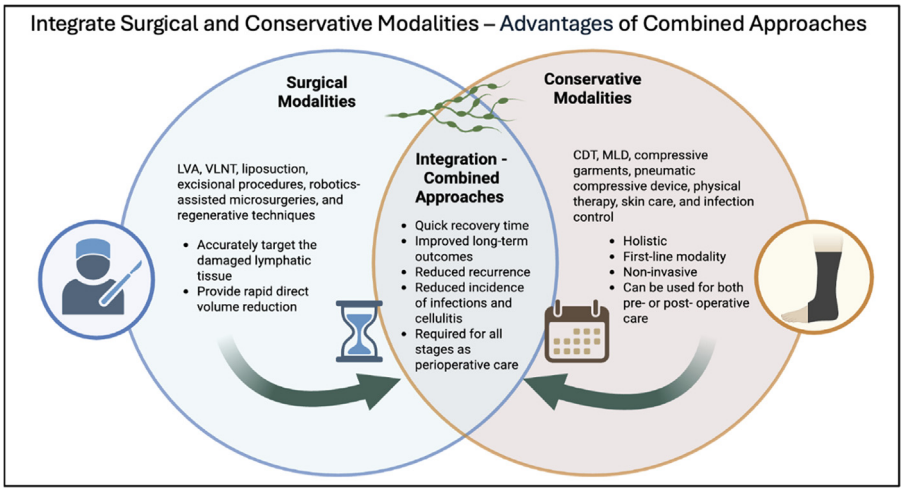

Diagram 3. Describing the intersection of surgical and conservative treatment.

toms, and functional outcomes by simultaneously restoring lymphatic drainage and removing fibro-fatty tissue.[42]

SALP is a less invasive procedure that reduces edema and symptoms but does not fix lymphatic drainage, so it must be combined with Continuous Compressive Therapy.[43]

Conservative and surgical methods yield better results, but large, well-organized, reviewed, and reported randomized controlled trials are lacking in assessing and comparing treatments (Diagram 3). However, there are some current international randomized trials, including the SurLy trial, which evaluates the advantages of reconstructive lymphatic surgery when combined with conservative treatment for lymphoedema[44] and the LYMPH trial, which compares the benefits of combination of CDT and microsurgical procedures in the treatment of BCRL.[45]

Table 3
A summary of treatment options and their limitations.

	Conservative: CDT	Physiological: LVA, VLNT	Excisional: Modified Charles, Homans, SAL, RRPP	Combined: VLNT + SAL, RRPP + VLNT LVA + Conservative
Goal	Reduce swelling, maintain function	Enhance lymphatic flow	Remove fibroadipose tissue to reduce volume	Functional and structural correction
Indications	Stage 0–1, Supportive therapy in all stages	Stage 2–3 with functional lymphatics	Stage 2–3 with tissue hypertrophy	Mixed stage or refractory cases
Advantages	Widely available, noninvasive, Improves symptoms	Targets root cause May improve or reverse progression Moderate volume reduction	Significant volume reduction, useful in advanced disease	Comprehensive effect, tailored treatment, may reduce need for compression therapy
Limitations	Not curative, requires lifelong compliance	Less effective in late/fibrotic limbs	Invasive, does not restore lymph flow, risk of wound healing issues/flap failures	Complex planning, high cost, longer recovery, requires specialized team

Table 3: A summary of treatment options and their limitations.

1. Modern approaches and advancements

Immediate lymphatic reconstruction (ILR), a preventive LVA done during axillary dissection, was found to reduce BCRL by one-third and improve QoL and symptoms.[46] Additionally, there is evidence that ILR may benefit various cancer types following lymphatic surgery.[47]

Fibro-Lipo-Lymph-Aspiration with a Lymph Vessel Sparing method (FLLA-LVSP) following LVA offers a quick recovery, enhanced aesthetic benefits, decreased limb volume, and only requires compression therapy at night.[48]

Vascularized Omental Lymphatic Transplantation (VOLT) is a promising method for reducing lymphedematous limb circumference, but more research is required, given the lack of consensus regarding the best donor site for lymph nodes in VLNT[43] and the significant side effect of iatrogenic secondary lymphoedema.[49] Vascularized Lymph Vessel Transfer (VLVT) is a newer, less-known microsurgical procedure with potential in preventative management of extremity wounds.[47]

Technological advancements

Lymphedema requires prompt screening and timely intervention.[2] Different surveillance programs with baseline limb measurements pre- and postoperatively and routine follow-ups are now being developed,[8] and artificial intelligence machine learning models are being widely implemented.[50]

Presurgical investigations and comprehensive patient evaluations are critical. Clinical status, functional impairment, response to conservative therapy, and imaging examinations, and staging (ISL, Campisi, and Cheng) inform decision-making and guide surgical planning. Postsurgical assessment requires quantitative measurements of limb circumference and quality-of-life scores to track outcomes over time.[2]

Imaging tailors diagnosis and treatment planning.[2] Lymphoscintigraphy is the traditional gold standard but is limited by its low sensitivity in early disease and poor image quality.[29] ICG lymphography can detect disease earlier and map lymphatic flow and dermal backflow patterns, even with minimal volume changes.[8] Vargo et al. report ICG detects dysfunction 8–23 months earlier than volume-based methods, a huge headstart.[51]

Water displacement volumetry and tape measure circumference are still helpful, but newer methods like BIS and tissue dielectric constant detect early fluid changes before visible edema. As a result of BIS's integration with routine surveillance, fewer individuals developed clinical lymphoedema fol-

lowing therapy for breast cancer. Photoacoustic imaging (PAI) offers promising, non-invasive visualization using ultrasound signals from light pulses.[51]

Biotechnology research and development

The emerging advancement in biotechnology in lymphedema management helps to re-establish lymph flow using tissue engineering, where growth-promoting factors (e.g., VEGF, FGF, HGF), scaffolding, and stimulation by mechanical means.[52,53] While facing challenges such as low cell survival, cell-based therapies employing LECs, ECFCs, iPSC-derived LECs, and MSCs demonstrate potential benefits.[52] Mechanical simulation can enhance lymphatic sprouting, though concerns remain overdosing, cell sources, and patient variability.

Novel therapeutic targets[54] include:

- Therapeutic approaches that stimulate lymphatic vessel growth through the use of lymphangiogenic factors, such as VEGF-C gene therapy.
- Anti-inflammatory agents: The anti-inflammatory drug ketoprofen decreases levels of inflammatory cytokines while promoting the growth of new lymphatic vessels.
- The administration of Tacrolimus reduces T-cell activity, which results in better limb volume and enhanced QoL.
- Antifibrotic therapies: The inhibition of TGF-1 reduces fibrotic tissue development while enhancing the flow of collateral lymphatic vessels.

Artificial intelligence and lymphedema

Artificial intelligence (AI) in lymphoedema management enhances early detection and interventions of the disease. There are promising domains of AI applications in lymphoedema management, such as machine learning, fuzzy models, and robotics. Machine learning helps evaluate the data and minimize human errors, and directs the early detection of disease and rehabilitation. In public health, it estimates disease prevalence and maps risk areas. In clinical practice, it guides early intervention and improves long-term outcomes. Blood tests and biomarkers are reliable for early detection and minimize errors in patient-input data. Fuzzy models can evaluate the risk of developing lymphedema and its severity.[55,56]

Robotics and intraoperative AI imaging enhance surgical precision and efficiency.[57,58] Robotic-assisted surgery offers lower risk, accuracy, and accessibility in hard-to-reach areas.[55,57]

Limitations in surgical treatment

Although LVA, VLNT, and liposuction have offered new therapeutic possibilities, these surgical approaches face challenges and limitations as stated below (Diagram 4).

I. Lack of standardization in patient selection

Patient selection and staging continue to be limited by the lack of standardized protocols, especially in advanced fibrotic disease and patients with comorbidities like obesity or cellulitis. Although LVA shows a 26% volume reduction in early-stage lymphedema and 24-month outcomes align for VLNT and LVA, surgery hasn't replaced conservative therapy[59] due to gaps in long-term evidence.[8] Additionally, surgical protocols lack standardization in timing, multimodal use, and patient selection. Addressing variability in techniques and outcome metrics is also essential. The absence of robust longitudinal studies and multimodal trials (e.g., LVA + liposuction) limits understanding of technique-specific efficacy and sustained outcomes.[2]

II. Diagnostic and technical limitations

ICG lymphography visualizes only superficial lymphatics, limiting staging in fibrotic disease.[60] MRL offers deeper imaging but is not cost effective and therefore uncommonly used. LVA and VLNT require

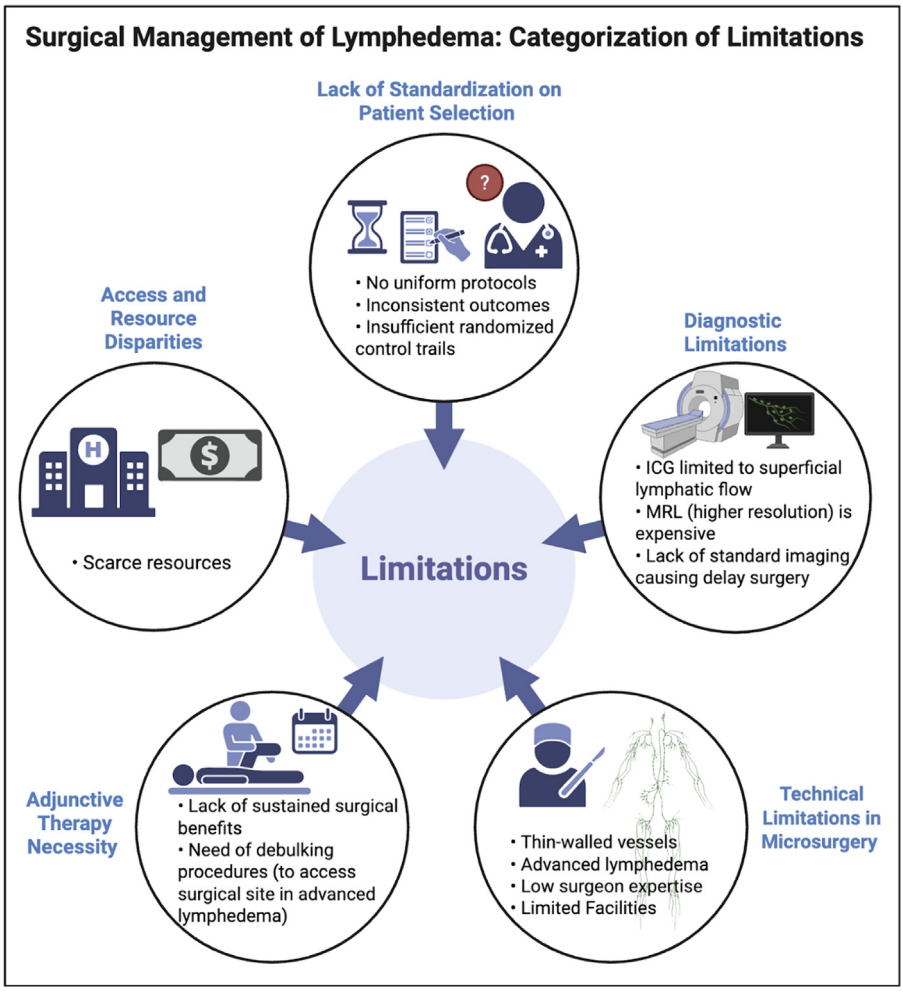

Diagram 4. The limitations of managing lymphedema via surgery.

highly skilled surgeons due to technical challenges or complications such as vessel mismatch and risk of thrombosis.[61] These surgeries are also most effective in early-stage lymphedema. Advanced disease with fibrosis impairs healing and requires debulking first.[17] Even with imaging advances, successful outcomes depend on surgical expertise.

III. The need for adjunctive therapy

Patients continue to require long-term conservative therapies postoperatively to preserve outcomes and prevent worsening of symptoms. Surgical procedures have been shown to provide only transient relief and may require additional debulking procedures (like liposuction/excision in advanced lymphedema) for better accessibility of the surgical site.[62] However, cosmetic limitations and risk-prone effects limit their use.[2] Additionally, studies emphasize combining adjunctive therapies in postoperative care to provide sustained surgical benefits and optimize patient outcomes efficiently.[62] However, involvement of adjunctive therapy can cause an increase in the number of treatment sessions, making it difficult for patients to stay compliant throughout the treatment course.

IV. Access and resource disparities

It is extremely important to address the global disparities in access to treatment. While advancements in surgical techniques are progressing, the availability of trained professionals and resources varies dramatically between countries, further limiting access to care. A study conducted by Schulze et al. considered every country in the world and looked to analyze medical professionals, societies, institutions and industrial companies dedicated to lymphoedema. The results highlighted the vast discrepancy in healthcare being provided across the globe. For example, Pakistan has 4 listed professionals who were trained to treat lymphedema, whereas Germany, a country with half the civilian population, has 432. Similarly, the continent of Africa entirely has 26 clinically active physicians, and studies deem that medical coverage in this field is virtually nonexistent.[63]

From this, we can understand that there are significant barriers to receiving treatment for lymphedema. Another unavoidable factor is the economic burden of the disease. In the United States, two considerations are to be made: patient-borne costs and medical costs from a societal perspective.

Patient-borne costs for BCRL can incur from direct and indirect costs. Direct costs ranged from USD$2306 to USD$2574 per patient per year, while indirect costs (e.g., lost income and unpaid work) ranged from USD$3325 to USD$5545 annually.[63] One study reported an overall average patient-borne cost of A$977 (USD$742.52) per year without specifying cost categories.[64]

Patients with BCRL incurred nearly seven times higher healthcare costs and hospitalization rates. Early intervention through prospective surveillance significantly lowers costs compared to traditional care. While limited data exists for upper limb lymphedema treatment in Europe, studies on lower limb edema show substantial direct and indirect costs, while community-based models offer notable savings and better outcomes.[65]

However, there is a large void to fill in exploring how surgical advancements could affect the cost implications for patients and social services.

Emerging modalities

Throughout the literature studies, current promising outcomes of surgical procedures have been discussed. Furthermore, this review explores and analyses future-promising potential advancements to prevent and reverse early-stage lymphedema (either primary or secondary) and the associated comorbidities (e.g., functional disability, negative impact on QoL). Some emerging modalities aid in enhancing the current surgical management of lymphedema, the prognosis of lymphedema (primary and secondary), and the management of associated comorbidities.

The emerging modalities include:

a. Technological innovations: advanced imaging and surgical planning

Imaging techniques, including advanced ultra-high-frequency ultrasounds and magnetic resonance angiography (MRA), can improve the quality of preoperative planning and intraoperative lymphatic tissue mapping. Advanced real-time visualization of lymphatic vessels intraoperatively can lead to microsurgeons' precision and accuracy, and it can be achieved through an imaging modality called near-infrared fluorescence lymphangiography.[65]

b. Robotic-assisted supermicrosurgery:

Microsurgery has evolved to robotics-assisted super-microsurgical procedures, which involve scaling surgeons' movements, improving precision and accuracy, and allowing surgeons to easily perform delicate procedures like LVA, especially when it is combined and guided by AI.[56] Although robotic-assisted surgeries are available at the macro level, healthcare facilities still need to develop ways to incorporate them into super-microsurgical procedures and make them accessible.[66]

c. Regenerative medicine and biomaterials:

The efficiency of microsurgery has been enhanced with the use of Nanofibrillar collagen Scaffolds (BioBridge) that mimic the endogenous collagen matrix and promote rapid lymphangiogenesis, anastomosis, and wound healing.[65]

d. Emerging surgical techniques:

Lymph node-to-vein anastomosis (LNVA) is an emerging surgical technique that is less invasive and effective at directly connecting lymph nodes and veins for lymphatic fluid flow.[67]

e. Cost-reducing innovations:

- The non-vascularized lymph node transfer (VLNT) procedure does not involve harvesting, transferring lymph nodes, or anastomosing vessels; therefore, unlike VLNT, it reduces the duration and cost.[68]
- Early intervention through a prospective surveillance model significantly reduced treatment costs compared to the traditional model, highlighting the financial benefit of prompt and less invasive care.
- Community-based care models have demonstrated potential for significant cost savings and improved outcomes.[69]

Health system readiness

While recent surgical advancements have significantly improved the therapeutic landscape for lymphedema, a critical next step involves evaluating how these innovations are being incorporated into physician training and clinical education.

A cross-sectional analysis of 103 U.S. plastic surgery residency programs found that even though only 11 programs mentioned lymphedema surgery in their online curriculum, 67 had at least one rotation site with a surgeon performing these procedures. This leaves 33 programs lacking clinical exposure, of which 76% ($n = 25$) did not offer elective time.[70] Schaverien et al. describe the creation of a multidisciplinary academic lymphedema program that integrates surgical and nonsurgical care through multispecialty collaboration efforts. The program emphasizes standardized diagnostics, coordinated treatment, and gives a lot of importance to education and research. It serves as a model for improving patient outcomes and advancing lymphedema care in academic settings.[41]

This comparison highlights a critical gap between surgical practice and formal training in lymphedema care within U.S. plastic surgery residency programs. While many institutions offer clinical exposure through individual surgeons, few have structured curricula or dedicated elective time, potentially limiting residents' comprehensive understanding of lymphedema management. The model proposed by Schaverien et al. underscores the importance of multidisciplinary collaboration, standardized education, and institutional support—elements that could guide future efforts to integrate lymphedema care more effectively into residency training.

Research gaps in lymphedema management

There is insufficient data on the long-term efficacy and safety of emerging surgical and microsurgical interventions such as LVA, VLNT, and SAL due to recent research limited to observational studies, which have higher chances of causing observer and selection bias.[71] These studies use inconsistent study models with various combinations of therapies.[72] The LVA, VLNT, and CDT (decongestive therapy) are safe. However, the inconsistent patient selection, various guidelines, and perioperative follow-up duration mean that the current data are unreliable for standardized treatment protocols.[73] Surgical procedures and conservative treatment have shown promising results when prescribed individually, but their effect in combined management is not apparent.[74] Additionally, liposuction used in severe edema, especially for patients in hospital settings, had few incidences of cellulitis, and these results cannot be generalized because this data is confined to specialized centers like hospitals.[67] Addressing these gaps requires trials and comparative studies, which will help improve guidelines and allow physicians to choose the most effective management for their patients (Diagram 5).

Discussion

Lymphedema, both primary and secondary, and its management has been a global burden to healthcare professionals for many years. Commonly, Lymphedema is diagnosed clinically, and diag-

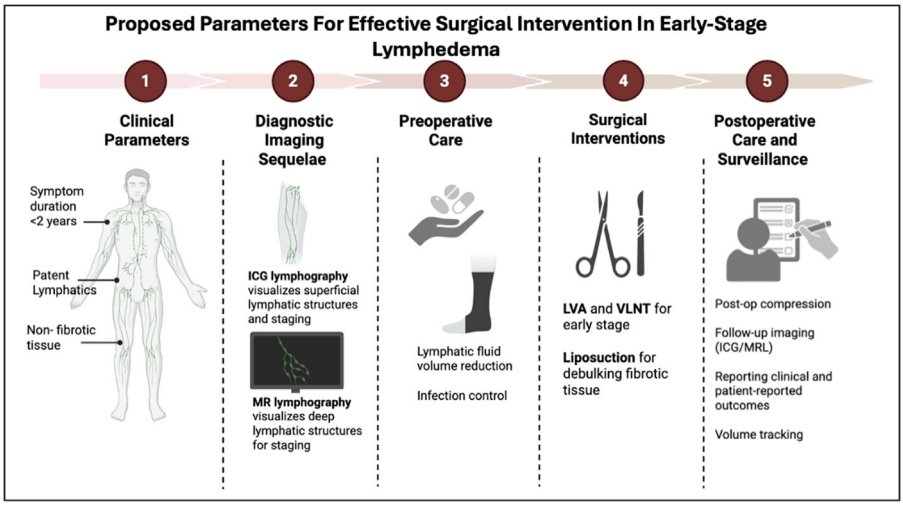

Diagram 5. Highlighting the challenges faced at each step of lymphedema management.

nostic imaging modalities are used to stage and identify the severity. Clinicians opt for treatment modalities based on stage, severity, and patient preferences. Conservative therapies such as CDT, MLD, compressive garments, pneumatic compression device, and physical therapy are first-line management. When lymphedema progresses to advanced stages or becomes refractory to conservative treatments, surgical options include effective fluid volume reduction for rapid symptomatic relief. Surgical interventions can be a preventive measure in early and advanced lymphedema. This review summarizes studies from the literature, in accredited peer-reviewed and PubMed-indexed journals, to provide consolidated knowledge on various surgical techniques. Additionally, supporting information has been supplied from RCTs and many other reviews on recent advancements, efficacy, integration, and combined approaches into multidisciplinary care to treat lymphedema.

Conclusion

Based on the evidence, a specific patient selection criterion is necessary for effective results of early surgical intervention. It should include requirements such as patent lymphatics, within 2 years of diagnosis, less adipocyte accumulation, and absence of fibrotic changes to the tissue. There will be a higher chance of an increase in the effectiveness of surgical intervention when these parameters are combined with proper perioperative care, including conservative therapies and multiple sessions of physical therapy. For advanced Lymphedema, adjunctive debulking methods such as liposuction are used to lower fluid volume and circumference of the leg rapidly. Although LVA, VLNT, and liposuction have offered new therapeutic possibilities, these surgical approaches face challenges and limitations due to a lack of standard guidelines on patient selection, diagnostic limitations, scarce resources, a few specialists available, and technical difficulties within the procedure. Moreover, some procedures need a combination of adjunctive therapies involving multiple surgical interventions or surgical intervention with conservative modalities. This increases the treatment course and number of sessions, and the debulking methods can cause cosmetic deformities leading to difficulties in patients' treatment compliance. Recently, advancements with AI incorporations and growth in robotics-assisted microsurgeries have increased the precision and accuracy of performing delicate surgeries on lymphatic vascular while preserving healthy tissue.

Declaration of competing interest

The authors declare that they have no conflicts of interest relevant to the content of this article. No financial, personal, or professional relationships influenced the writing or submission of this manuscript.

Funding

None.

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