

Robotic-assisted Lymphovenous Anastomosis of the Central Lymphatic System

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Background: Recent advances in robotic microsurgery have enabled the application of robotic technology in central lymphatic reconstruction. Although the use of microsurgical robots demands careful consideration of associated costs and potentially prolonged operating times, it may offer improved surgical approaches and enhanced accessibility to deeper anatomical structures such as the thoracic duct (TD).

Methods: We report on successful reconstruction of the central lymphatic system using the Symani Surgical System in four patients with lesions of the central lymphatic system. The patients were of different age (range: 8 mo–60 y) and had variable conditions, including central conducting lymphatic anomaly and other rare anomalies of the central lymphatic pathways.

Results: Depending on the underlying pathology, a cervical access (n = 1) or median laparotomy (n = 3) was chosen to access the TD and perform anastomosis with a nearby vein. In all patients, anastomoses were patent, and chyle leakage decreased postoperatively. From a surgical perspective, the Symani Surgical System improved the precision of the microsurgeon and accessibility to the deep-lying TD.

Conclusion: Considering the high morbidity and rarity of pathologies of the central lymphatic system, robotic-assisted microsurgery holds substantial promise in expanding and improving the microsurgical treatment for central lymphatic anomalies. (*Plast Reconstr Surg Glob Open* 2024; 12:e6164; doi: 10.1097/GOX.0000000000006164; Published online 16 September 2024.)

INTRODUCTION

Advancements in robotic technology have only recently made it possible to use robotic systems in reconstructive lymphatic surgery. During the last years, the number of preclinical and clinical studies demonstrating the feasibility of robotic-assisted (super) microsurgical procedures is rapidly increasing.^{1–14} Although the application of microsurgical robots requires careful consideration of the associated costs and potentially longer operating times, they can enable smaller surgical approaches and provide easier access to anatomically deeper structures.³ The latter

is particularly important when performing surgery of the central lymphatic system. Central lymphatic surgery is not only rare, but also technically difficult due to the anatomical location of the thoracic duct (TD). Recently, we have published the benefits of using the Symani Surgical System for the reconstruction of the central lymphatic pathways.¹

Although lesions and anomalies of the central lymphatic system are rare, they are associated with a high morbidity and mortality. Depending on the anatomical location involved, patients may exhibit chyle leakage, recurrent chylothorax, or chylous ascites, all of which predispose to infections and additional complications due to an ongoing protein and fluid loss, resulting in a mortality rate of up to 50%.^{15,16} As described previously by our group, initial treatment relies on conservative approaches, which include a diet consisting of medium-chain triglycerides or a full parenteral diet.^{17,18} This regimen may be supplemented with drugs aimed at reducing chyle production, such as octreotide. If conservative

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treatment fails, lymphangiography-guided interventions represent the second line of therapeutic approach, with good success rates and a low risk for complications.^{19–22} Considering, that an occlusion of the TD carries the risk of protein losing enteropathy, lower extremity lymphedema, or worsening of lymphatic reflux with a fistula at a different location, microsurgical reconstruction of the central lymphatic system has opened new frontiers to treat rare central lymphatic lesions by TD-vein anastomoses.^{17,18,23}

METHODS

We report on the four patients with a central lymphatic lesion who received microsurgical reconstruction with the aid of the Symani Surgical System (Medical Microinstruments, Inc., Wilmington, Del.) at the department of plastic surgery and hand surgery between June 2023 and March 2024. All patients were operated on by the senior author. Approval was granted by the Cantonal Ethics Committee of Zurich, Switzerland (ethical approval no.: 2021-02351). Written consent was obtained from all patients or from their parents in the case of minors. Additional consent was acquired from patients whose pre-, intra-, or postoperative images are shown.

CASE PRESENTATION

An 8-month-old infant was referred to our department with a history of severe bilateral chylothorax and protein-losing enteropathy due a catheter-associated venous thrombosis following asphyxia and reanimation after birth (Fig. 1A). Magnetic resonance lymphangiography (MRL) showed an occlusion of the TD at the level of the left venous angle (Fig. 1B). Both recanalization using conventional lymphangiography and conservative treatment were unsuccessful, so the decision was made to perform a lymphatic reconstruction. At the beginning of the surgery, an interventional radiologist performed an

Takeaways

Question: Can the Symani Surgical System be used for reconstruction of the central lymphatic system?

Findings: The robotic technology allowed for thoracic duct-vein anastomosis in four patients with rare anomalies of the central lymphatic system. The Symani Surgical System improved precision and access to the deep-lying structures. All anastomoses were patent, and clinical symptoms improved in all patients.

Meaning: The Symani Surgical System has great potential to expand the microsurgical treatment possibilities for central lymphatic disorders.

intranodal inguinal indocyanine green (ICG) injection at both groins (Fig. 2). Afterwards a cervical access was chosen to reach the TD at its confluence with the venous angle (Fig. 3A, B). The enrichment of ICG enabled the TD to be quickly identified in the fluorescence mode of the microscope (Fig. 3C). The TD and a branch of the left external jugular vein were dissected and prepared for anastomosis with conventional microinstruments (Fig. 3D). The wrapped Symani Surgical System with its NanoWrist microinstruments was placed. Visualization was performed with a 3D exoscope integrated into an optical microscope (KINEVO 900, Carl Zeiss AG, Oberkochen, Germany). End-to-end anastomosis of the TD and a branch of the left external jugular vein was performed to reconstruct the lymphatic drainage into the venous system. [See Video (online), which displays robotically-assisted TD-vein anastomosis with the Symani Surgical System. The 8-month-old patient had a history of severe bilateral chylothorax, protein-losing enteropathy and multiple venous thromboses since birth. Preoperative MRL showed an occlusion of the TD at the level of the left venous angle. End-to-end anastomosis of the TD and a branch of the left external jugular vein was performed to reconstruct the lymphatic drainage into the venous system.] Patency of the anastomosis was confirmed by

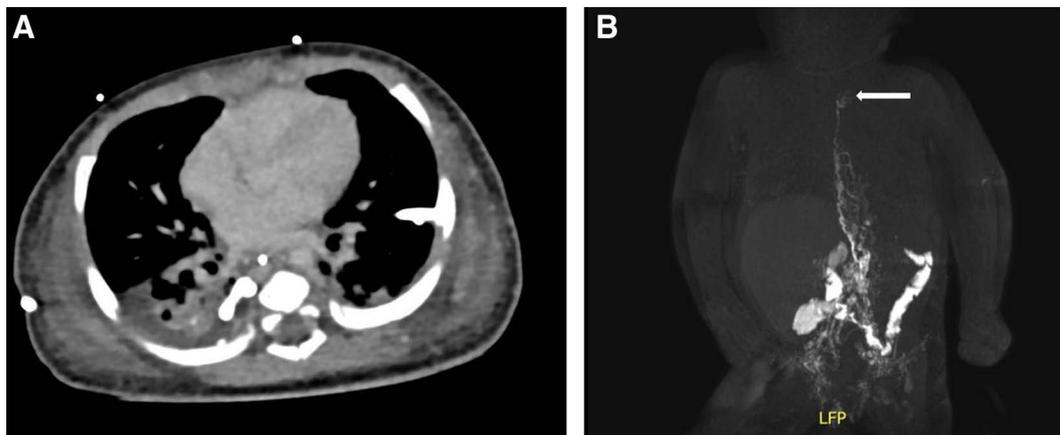


Fig. 1. Congenital central lymphatic flow disorder. A, Thoracic computer tomography of an 8-month-old boy with bilateral chylothorax and bilateral chest drains. B, MR-lymphangiography indicating the stenosis of the TD at the left venous angle (white arrow).

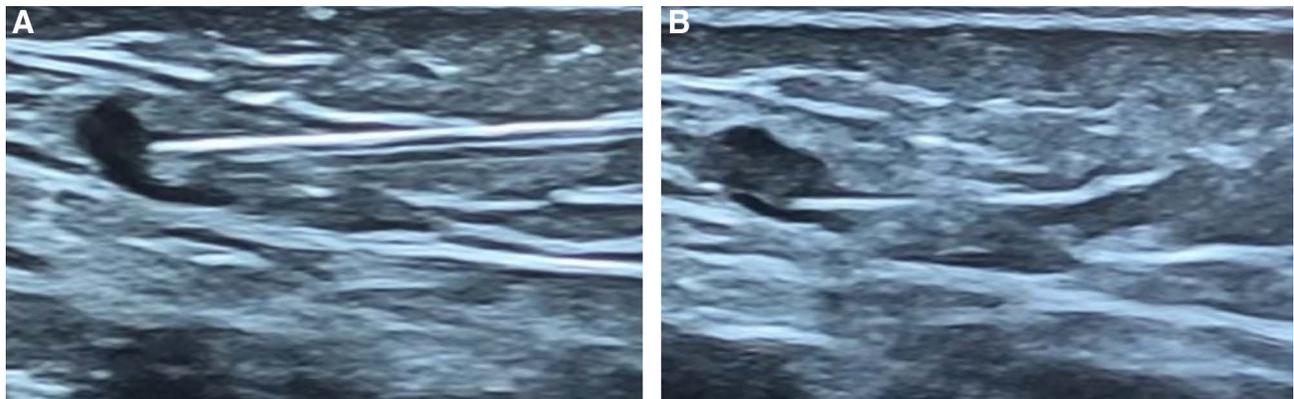


Fig. 2. Ultrasound-guided intranodal injection of ICG. A, Preoperative sonographic-assisted intranodal injection of ICG at the groin. Visualization of the technique. The needle is placed at the cortical-medullary junction and 1.5 mL of ICG is injected. B, Microbubbles contained within the ICG solution can be visualized to confirm accurate injection.

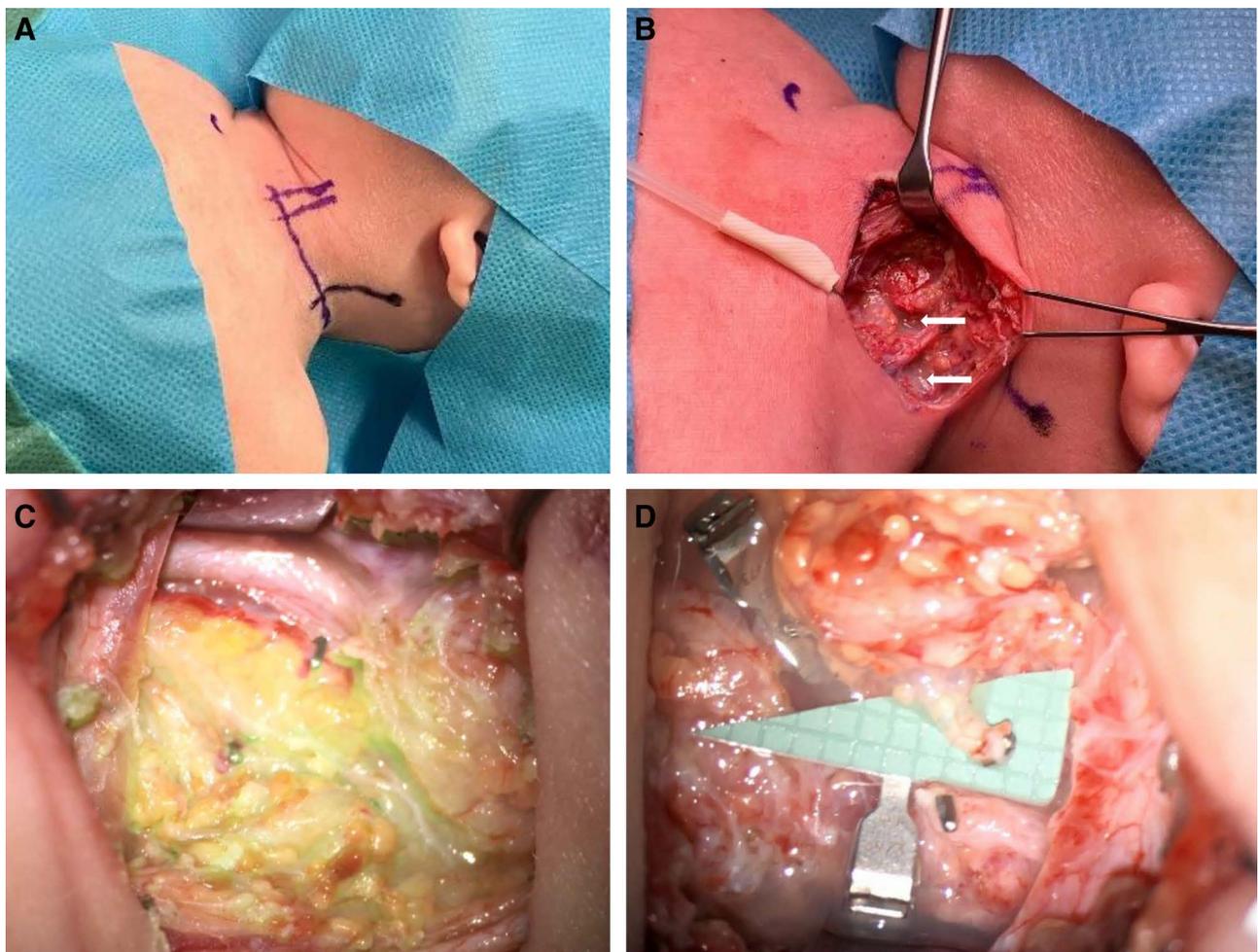


Fig. 3. Intraoperative findings in the neck. A, Preoperative view with skin markings, showing the cervical supraclavicular access, carotid artery, and external jugular vein. B, After incision of the skin, a continuous leakage of chyle was observed (white arrows). C, ICG overlay mode confirms a diffuse leakage of chyle. D, Preparation of the TD.

ICG-flow. In this particular case, the use of the robotic system was of great advantage. In contrast to a manual approach, the robotic-assisted setup makes the operation

independent from the operating table. This will prevent repetitive focus changes or intrinsic movements of the operation field under the high magnification when, for

Table 1. Patient Characteristics and Operative Details

Patient	Preoperative Condition	MRL	Lymphangiography	Surgical Access	Anastomosis	Duration of Surgery (min)	Duration of Anastomosis (min)	Follow-up	Outcome
1 (47 y)	Lower extremity edema, abdominal pain and reduced physical capacity	Aneurysmal dilatation of the left paramedian lymphatic duct and dilated lymphatic cisterns along the iliac lymphatic pathways	Embolization	Median laparotomy	Intraabdominal end-to-side anastomosis of left OV with lymphatic cyst	508	23	11 mo	Complete regression of symptoms; MRL proved drainage from the aneurysmal dilatation into the ovarian vein
2 (10 y)	CCLA with bilateral chylothorax	TD abruption, thoracic lymphatic malformation on the right and lymphatic reflux on the left	Embolization	Median laparotomy	LVA between sub-diaphragmal lymph vessel and omental vein; MLL	410	35	7 mo	Subsequent interventional embolization
3 (60 y)	CCLA with bilateral chylothorax and lower extremity lymphedema	TD not detectable, abruption of retroperitoneal lymphatic pathways at the level of lumbar vertebra 2	None	Median laparotomy	Intraabdominal end-to-end anastomosis of TD and right GEV, para-aortal and iliac LVA on the left	480	23	5 mo	Regression of chylothorax
4 (8 mo)	Bilateral chylothorax	TD stenosis at the level of the angulus venosus sinister, multiple venous thrombosis	Recanalization	Neck	End-to-end anastomosis of TD and branch of the left EJ	273	19	2 mo	Partial regression of chylothorax

CCLA, central conducting lymphatic anomaly; EJ, external jugular vein; OV, ovarian vein; GEV, gastroepiploic vein.

example, resting the hands within the operative field and operating on a small patient. In addition, the use of the Symani Surgical System minimizes the incision of the sternocleidomastoid muscle covering the TD, because its movements are significantly smaller and more precise and therefore only require a small surgical field.

RESULTS

Four patients with anomalies of the central lymphatic system received microsurgical central lymphatic reconstruction (Table 1). The age of the patients varied from 8 months to 60 years. Preoperative MRL was performed in all patients to localize the underlying anomaly of the central lymphatics. In two patients who were diagnosed with a central conducting lymphatic anomaly, MRL showed an abruption of the TD, causing bilateral chylothorax and even chylopericardium in one patient. The third patient was diagnosed with a retroperitoneal central lymphatic cyst, which led to lower extremity edema, abdominal pain, and reduced physical capacity. The youngest patient had severe bilateral chylothorax as described above.

Regardless of the etiology, all patients, except the patient with the retroperitoneal central lymphatic cyst, underwent initial conservative treatment for at least 6 weeks. In addition, a conventional lymphangiography was performed to aim for recanalization or embolization depending on the etiology of the lesion.

The surgical treatment was carefully planned on the basis of the preoperative MRL and in interdisciplinary collaboration with radiologists and visceral surgeons. For

an underlying central lymphatic lesion, a cervical access ($n = 1$) (Fig. 3) or median laparotomy ($n = 3$; Fig. 4) was used to reach the TD. At the beginning of the surgery, an interventional radiologist performed an intranodal inguinal indocyanine green (ICG) injection, which enables the central lymphatic pathways to be localized with a near infrared camera and the ICG mode of the microscope. In all patients, the TD (Fig. 3D and Fig. 5A) could be identified successfully. After preparation of a nearby vein (Fig. 5B), end-to-end TD vein anastomosis (Fig. 5C) was performed using the Symani Surgical System. A patent anastomosis with washout was documented in all patients (Fig. 5D). Complete regression of symptoms was observed in the patient with the retroperitoneal cyst (Fig. 4) with a visible drainage over the anastomosis on postoperative MRL. In the remaining patients, chyle leakage decreased steadily.

DISCUSSION

In this work, we demonstrate the successful use of the Symani Surgical System for microsurgical anastomosis of the TD in different anatomical locations. In general, the central lymphatic system can be accessed via three different locations: the neck, the thorax, and the abdomen (Fig. 6).²⁴ The choice of access requires a thorough interdisciplinary evaluation to define the area in which the reconstruction of lymphatic flow shall be performed. This will be influenced by the pathophysiology of the underlying condition and the specific pattern of lymphatic flow disorder and leakage, for example, into the pleural

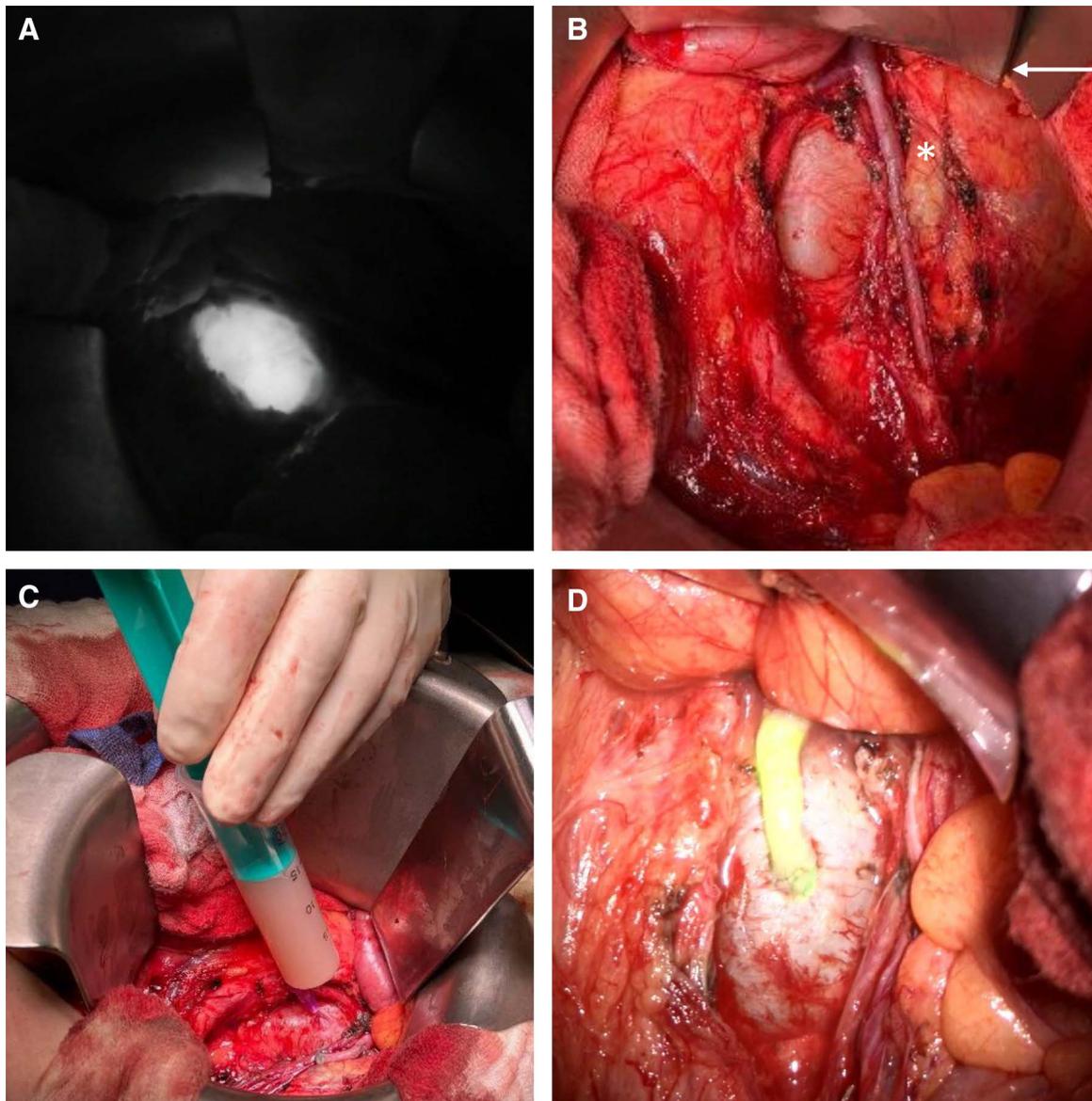


Fig. 4. Central lymphatic dilatation. A, Localisation of the cyst using a near-infrared camera. B, Macroscopic view of the central lymphatic cyst (white asterisk) and adjacent left ovarian vein (white arrow). C, Puncture with partial drainage of the cyst. D, Successful anastomosis between cyst and left ovarian vein. The near-infrared overlay mode of the exoscope showed ICG flow over the anastomosis which confirmed its patency.¹ Reproduced with permission from Wolters Kluwer Health from Weinzierl A, Puipe GD, et al. First-in-human use of a microsurgical robotic system for central lymphatic reconstruction. *Plast Reconstr Surg Glob Open.* 2023;11:e5484. © 2023 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of The American Society of Plastic Surgeons. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

or abdominal cavities. In particular, the venous pressure has to be considered. An elevated venous pressure (eg, in Fontan patients) may impair lymphatic drainage in general.²⁵ However, additional surgical injury to the central lymphatic system may significantly worsen the lymphatic congestion. Although in a healthy patient the central venous pressure will be between 3 and 8 mm Hg,²⁶ it can be significantly higher in a patient with a Fontan circulation.²⁷ Ideally, valve-bearing veins are primarily chosen

as recipient veins (V. jug. ext., V. ovarica, etc.) to prevent backflow. Venous interposition grafts, including valves are options to prevent venous backflow into the central lymphatic vessel and can be sonographically marked and harvested from the proximal thigh (Figure 7).

Apart from the technical advantages offered by the microsurgical robotic system, our case series adds to the growing body of literature on TD vein anastomosis to treat central lymphatic obstruction of different etiologies.

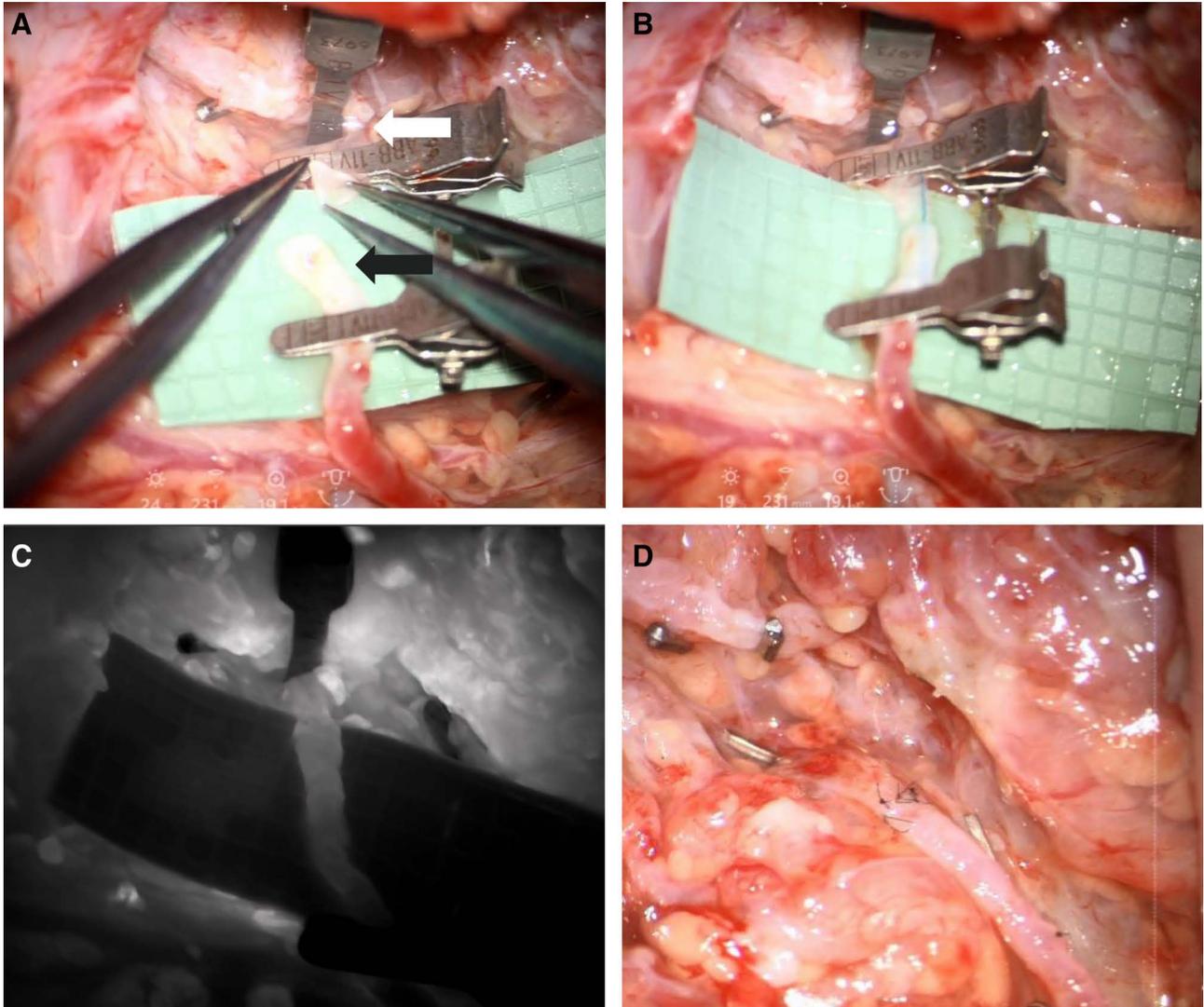


Fig. 5. A, Preparation of the TD (white arrow) and a nearby branch of the external jugular vein (black arrow). B, An inserted blue 6-0 suture acts as intravascular stent (IVAS) to stabilize the vessels. C, Patency of the anastomosis is confirmed by ICG-flow. D, Completed thoracic duct-vein anastomosis with chylous washout into the vein.

In our experience, treatment by TD vein anastomosis is successful in about 70%–80% of patients, which is also reflected in the current literature and in our previous publications.^{23,28–40} Success rates particularly depend on accurate determination of the etiology of the central lymphatic obstruction. In fact, isolated iatrogenic lesions of the TD are much easier to reconstruct compared with congenital anomalies in which multiple lesions are usually present in addition to an impaired lymphatic peristalsis.²³ The post-operative course will also depend on whether the lymphovenous anastomosis was performed caudal to a potential leakage site, for example, within the abdomen for chylothorax in which the distal part of the TD may be ligated physically preventing lymphatic flow into the pleura. In this case the chyle leakage may stop immediately due to the interruption of flow and shunting of chyle into the venous system via the newly created LVA. However, in congenital malformations, multiple lymphatic collaterals and

aberrant pathways may be present supporting the flow of chyle and have to be treated by additional sclerotherapy and pharmacological treatment (eg, sirolimus).^{15,41} If the anastomosis is performed distal to the presumed leakage site (eg, in a thrombotic occlusion within the neck), the antegrade flow of chyle into the vein must be provoked by intermittent clamping of existing drains. Otherwise, the chyle will take the way of least resistance in the beginning after lymphovenous reconstruction [eg, via the body cavity into an existing drain (often additionally under suction)]. It therefore requires an experienced team to surveil the drainage amounts postoperatively and to find an equilibrium in which the chyle will drain into the venous system rather than into the existing pathways and cavities, which may usually take several weeks.

The Symani Surgical System proved to be particularly beneficial in patients in whom the main obstruction of the TD was located in the abdomen. The Symani Surgical

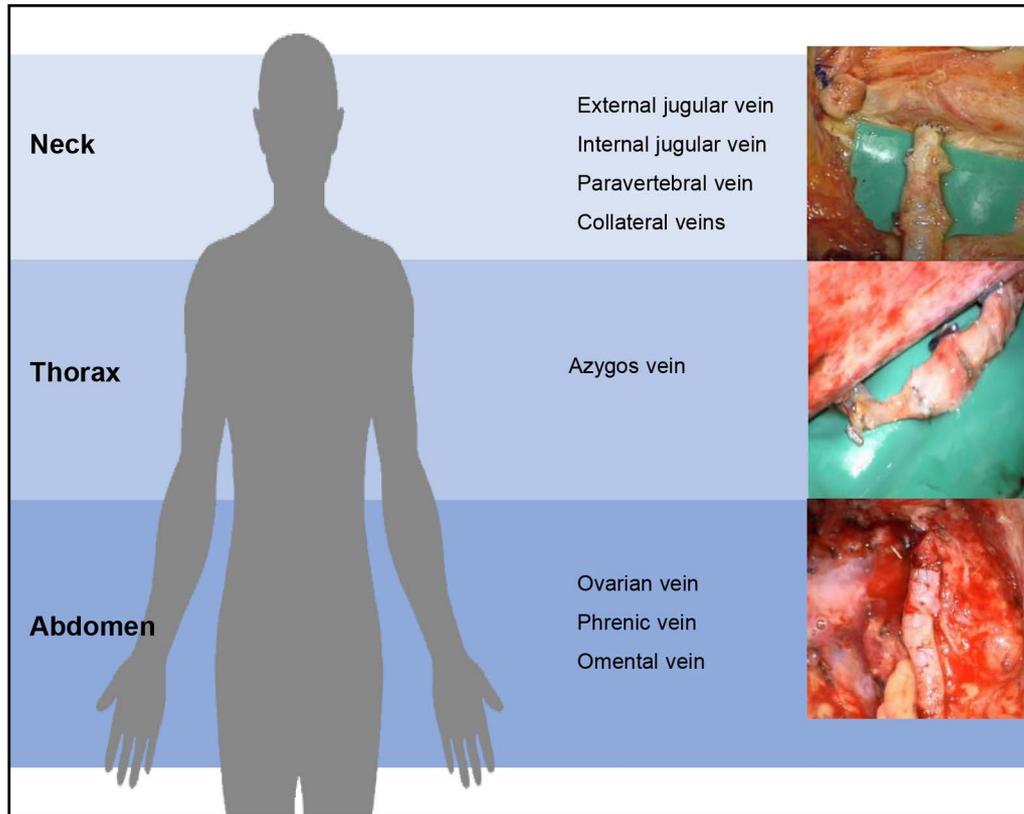


Fig. 6. The central lymphatic system can be accessed via neck, thorax, and abdomen. Depending on the location of the underlying lesion, various recipient vessels may be considered.⁵⁰ Reproduced from Weinzierl A, Grünherz L, Puippe GD, et al. Microsurgical central lymphatic reconstruction—the role of thoracic duct lymphovenous anastomoses at different anatomical levels. *Front Surg.* 2024;11:1415010. © 2024 Authors. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

System not only simplifies access by laparotomy but also makes it easier to operate with microinstruments in a plane that is otherwise difficult to reach. In contrast, in most of the currently reported cases, TD vein anastomosis is performed at the level of the left neck,^{28,29,31,32,34–36,42} whereas only a few authors chose an access by thoracotomy^{30,33,37} or laparotomy.^{23,38} Considering that the access to the anatomically deep central lymphatic system remains challenging, other surgical treatments, such as multiple LVAs or lymph node to vein anastomosis have been proposed to bypass proximal lymphatic impairment.^{43,44} Also, in recurrent chylous and lymphatic ascites, performing multiple LVAs on the thigh or at different levels of the leg has been suggested to bypass proximal lymphatic impairment.^{44–46} Other treatment approaches for chylous ascites represent the lymphatic cable flap by Chen⁴⁷ or a microsurgical peritoneal-venous anastomosis as described by Kovach and coauthors.⁴⁸ Coupler anastomoses may be feasible to connect lymphatic trunks and veins, if there is one vessel and the lumen is larger than 1 mm. However, depending on the location, this is not necessarily easier than suture anastomosis (narrow access, eg, epigastrium) and the coupler handle (current models) may be too short in the abdomen.

We have previously demonstrated that the Symani Surgical System, with flexible, free-moving robotic arms and seven degrees of freedom, allows for smaller surgical approaches and simplifies access to anatomically deeper structures.³ Even if additional muscle has to be incised, the Symani Surgical System with its very precise movements requires a much smaller surgical field and thus favors a less traumatic procedure. Other advantages include superior precision for microsurgical anastomosis in vessels with a diameter below 1 mm while simultaneously improving the ergonomic position of the surgeon, who sits at the comfortable console next to the operating table.⁴⁹ Hence, there is enough space for a second team of microsurgeons to operate in parallel with a second microscope at a nearby anatomic region. With its potential to enable teleoperation, the Symani Surgical System holds immense promise for the future, particularly addressing challenges in treating rare diseases. In fact, the microsurgeon may operate the Symani Surgical System from distant locations, transcending geographical barriers and expanding access to specialized surgical techniques such as central lymphatic reconstruction. In addition, we have noticed that the robotic-assisted setup makes the

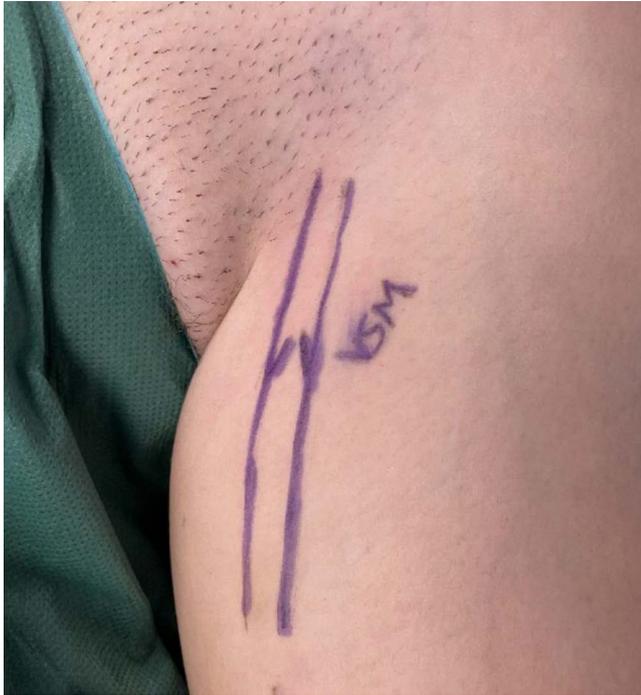


Fig. 7. Preoperative marking on the saphenous vein including a valve based on sonography at the level of the proximal thigh. Harvesting of the vein and its use as an interposition graft can prevent venous backflow into the central lymphatic vessel.

operation independent from the operating table (eg, in infants and small children). This will prevent repetitive focus changes or intrinsic movements of the operation field under the high magnification when, for example, resting the hands within the operative field. Regarding the time to perform anastomosis, we have recently shown that times for robotic-assisted anastomosis approach anastomotic times after a steep learning curve, in particular, in lymphovenous anastomoses.⁴ Similarly, the preparation and handling of the Symani Surgical System should not require any additional time if the surgical team has been trained accordingly. However, the difficult setup of operating deep within the body on small vessels with long microinstruments may prolong anastomotic and operating times in general in these cases, independent from using a robotic system.

Present constraints of the Symani Surgical System for central lymphatic reconstruction involve predetermined angles in relation to the alignment of its two robotic arms, meaning that as the arms are lowered, the gap between them increases at the skin level, potentially necessitating longer incisions for surgery at even greater depths. Nevertheless, advancements in the technology, such as the introduction of flexible arms, may address this issue in the future.

In conclusion, the Symani Surgical System has been successfully used for TD vein anastomosis at different anatomic locations. Considering the high morbidity coupled with the rarity of the central lymphatic system pathologies, microsurgical reconstruction necessitates meticulous planning

by a specialized and interdisciplinary team of surgeons. We believe that the Symani Surgical System holds promise for broadening the scope of microsurgical reconstruction for central lymphatic anomalies in the future.

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DISCLOSURES

Dr. Lindenblatt acts as a consultant and scientific advisor for Medical Microinstruments (MMI). All the other authors have no financial interest to declare in relation to the content of this article.

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