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ORIGINAL LABORATORY INVESTIGATION

Superficial and functional imaging of the tricipital lymphatic pathway: a modern reintroduction

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Abstract

Purpose The tricipital, or Caplan's, lymphatic pathway has been previously identified in cadavers and described as a potential compensatory pathway for lymphatic drainage of the upper extremity, as it may drain lymphatic fluid directly to the scapular lymph nodes, avoiding the axillary lymph node groups. The aim of this study was to map the anatomy of the tricipital pathway in vivo in patients without lymphatic disease.

Methods A retrospective review was performed to identify patients with unilateral breast cancer undergoing preoperative Indocyanine green (ICG) lymphography prior to axillary lymph node dissection from May 2021 through January 2022. Exclusion criteria were evidence or known history of upper extremity lymphedema or non-linear channels visualized on ICG. Demographic, oncologic, and ICG imaging data were extracted from a Lymphatic Surgery Database. The primary outcome of this study was the presence and absence of the tricipital pathway. The secondary outcome was major anatomical variations among those with a tricipital pathway.

Results Thirty patients underwent preoperative ICG lymphography in the study period. The tricipital pathway was visualized in the posterior upper arm in 90% of patients. In 63% of patients, the pathway had a functional connection to the forearm (long bundle variant) and in 27%, the pathway was isolated to the upper arm without a connection to the forearm (short bundle variant). In those with a long bundle, the contribution was predominantly from the posterior ulnar lymphosome. Anatomic destinations of the tricipital pathway included the deltotricipital groove and the medial upper arm channel, which drains to the axilla.

Conclusion When present, the tricipital pathway coursed along the posterior upper arm with variability in its connections to the forearm distally, and the torso proximally. Long-term follow-up studies will help determine the significance of these anatomic variations in terms of individual risk of lymphedema after axillary nodal dissection.

Keywords Lymphatics · Anatomy · Lymphedema · Tricipital pathway · ICG lymphography

Introduction

Disruption of the main lymphatic channels during axillary lymph node dissection (ALND) is a major risk factor for breast cancer-related lymphedema (BCRL) and is the most common cause of lymphedema in developed nations [1]. Two other significant risk factors for BCRL include regional lymph node radiation (RLNR) and a body mass index (BMI) > 30 kg/m^2.[2–4] Although our understanding of lymphedema risk factors has advanced in recent decades, there remains no explanation for why one third of patients who undergo axillary lymph node dissection develop BCRL while two thirds of breast cancer patients who undergo the same nodal dissection and oncologic treatment do not

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develop BCRL. Anatomic variations of lymphatic drainage in the upper extremity may help explain this discrepancy [5, 6]. Collateral lymphatic channels in the upper extremity draining to lymph nodes outside of the axilla are postulated to decrease the incidence of BCRL [7–11]. Greater reliance on axillary lymphatic drainage may increase the risk of BCRL after ALND [12–15]. Thus, mapping lymphatic pathways in patients prior to ALND may be an objective indicator of individual risk of BCRL [1]. This mapping can be accomplished using Indocyanine green (IGC) lymphography, which can be performed in an outpatient setting. Therefore, lymphatic mapping is a relatively feasible way to determine individual risk of BCRL prior to nodal dissection. Furthermore, an improved understanding of lymphatic anatomy could help inform preventative approaches and treatment strategies for BCRL.

Our previous investigations of upper extremity collateral pathways have focused on the lateral upper arm pathway (also referred to as the Mascagni-Sappey pathway) [7, 8], and we have demonstrated preliminary results indicating that variations in this pathway could affect lymphedema outcomes [9]. The tricipital pathway is another collateral channel postulated by anatomists to have implications for an individual's risk of lymphedema [10, 11, 16–18].

The tricipital pathway was originally described by Dr. Isidoro Caplan and has previously been referred to as Caplan's pathway, [10] the superficial posterior current [19], or the posterior scapular pathway because of its drainage to scapular lymph nodes [16]. It herein will be referred to as the tricipital pathway given its proximity to the triceps and frequently, the deltotricipital groove. Ciucci and Latorre et al. have observed the presence of this pathway in 5–10% of cadaveric dissections [16, 19]. Ciucci has further described the pathway as a continuation of the posterior radial forearm channel, though less frequently it can originate from the posterior ulnar forearm channel (Ciucci, personal communication). Leduc et al [10] reported instances in which the tricipital pathway was a continuation of both the posterior radial and ulnar forearm channels. The anatomic location of the tricipital pathway has been previously described in the posterior upper arm, traveling obliquely from lateral to medial through the deltotriciptal groove until it forms a nodal station in the scapular lymph nodes [10, 11, 19]. Given this extra-axillary drainage, the tricipital pathway may play a protective role in BCRL development. Others have proposed that damage to this pathway may contribute to the risk of BCRL [17]. Despite an evolving awareness of the tricipital pathway, most existing descriptions are from cadaveric dissections. Although cadaveric specimens have been a foundation for our anatomic knowledge of the tricipital pathway, cadavers do not demonstrate the pathway's *functional* drainage activity in the upper extremity. Of note, visualization of the tricipital pathway has been sporadically observed in patients with lymphedema [18, 20]. However, these studies may not adequately demonstrate the baseline anatomy and prevalence of the tricipital pathway, as lymphatic dysfunction may affect the formation of collateral lymphatic channels [10, 18].

The tricipital pathway has yet to be studied in vivo in patients without lymphatic dysfunction. The goal of this study was to visualize and map the superficial anatomy of the tricipital pathway using ICG lymphography in patients without clinical evidence of lymphedema. By quantifying the prevalence and describing anatomic variations of the tricipital pathway, we hope to deepen our insight into the role this pathway may play in the pathophysiology of BCRL.

Methods

Study design

A retrospective review of our Lymphatic Surgery REDCap [21, 22] database was performed. Institutional review board approval was obtained (Protocol # 2021P000859). Consecutive patients with unilateral breast cancer undergoing preoperative ICG lymphography were identified. All ICG lymphography interpretations were collected and stored in the Lymphatic Surgery Database. Exclusion criteria were evidence or known history of lymphedema in the upper extremity prior to ICG lymphography or non-linear channels visualized on ICG, as non-linear channels are indicative of lymphatic dysfunction. Patient demographics, cancer treatment, and operative data were extracted. Parametric data are presented as mean and standard deviation (SD) while non-parametric data are represented as median and inter-quartile range (IQR). For inferential analysis, Fisher's exact test and a univariate logistic regression model were used to assess association between BMI, age, laterality, the use of chemotherapy, and taxane-based regimens in the presence of the tricipital pathway or tricipital pathway phenotype. Descriptive statistics were performed using Microsoft Excel 2021 (Microsoft, Redmond, WA, USA), and inferential analysis was performed using Stata (StataCorp, College Station, TX, USA).

ICG lymphography

ICG injections were performed under sterile conditions by one of two members of the lymphatic surgery team (DS or ET). Intradermal injections of 0.1 cc of stock (2.5 mg/cc) ICG solution (Akorn Inc., Lake Forest, IL, USA) with 25 mg of albumin per cc were performed at six sites along the upper extremity. Lymphatic anatomical mapping was performed immediately following ICG injection. The first four injections were performed consecutively as follows: 1 cm

proximal to the first and fourth web spaces on the dorsum of the hand and 1 cm proximal to the wrist crease on both the radial and ulnar sides of the volar forearm. The superficial lymphatics of the hand and forearm were then mapped. A fifth injection to visualize the lateral upper arm pathway was performed overlying the cephalic vein, 4 cm proximal to the antecubital crease using ultrasound guidance, as previously described [5, 8, 9, 23]. A peri-olecranon injection was placed posteriorly on the upper arm, 4 cm proximal to the radial aspect of the olecranon (Ciucci, personal communication) (Fig. 1). A near-infrared imaging device was used to visualize the superficial lymphatic channels of the upper extremity as previously described [9, 23]. Image acquisition and interpretation were performed by one of two members of the lymphatic surgery team (DS or ET). Anatomic data were analyzed by a member of the research team (RF).

In the forearm, we identified anterior radial and ulnar lymphatic channels as those arising from radial and ulnar wrist crease injections, respectively. The posterior radial channel of the forearm was identified as that arising from the 1st webspace injection. The posterior ulnar channel of the forearm was defined as the pathway arising from the 4th webspace injection. Continuations of these pathways to the upper arm were labeled as medial upper arm, lateral upper arm, or tricipital pathway. The lateral upper arm pathways were defined as those coursing along the cephalic vein (identified utilizing ultrasonography prior to injection) in the lateral upper arm. The medial upper arm channels were those that coursed towards the basilic vein in the medial upper arm. The bicipital pathways were defined as those coursing through the anterior upper arm between the cephalic and the basilic vein. The tricipital pathways were defined as those coursing along the posterior surface of the upper arm.

Fig. 1 Indocyanine green (ICG) injection placed 4 cm proximal to the radial aspect of the olecranon for targeted visualization of the tricipital pathway

Results

Patient demographics and cancer characteristics

Thirty consecutive ICG lymphographies from May 2021 through January 2022 were analyzed. All patients were female with a mean age of 55 years (SD 14) at the time of surgery and a median BMI of 26 kg/m^2 (IQR 23–31). Prior to ICG lymphography, 67% of patients were treated with neoadjuvant chemotherapy ($n=20$) and of these patients, 70% ($n=14$) received taxane-based regimens. Prior to ICG lymphography, all patients had confirmed node-positive breast cancer, established via sentinel lymph node biopsy (SLNB) (70%), core needle biopsy (23%), or fine needle aspiration (7%). The median number of lymph nodes removed at the time of SLNB was 3 (IQR 2–4). All ALNDs were performed following ICG lymphography. The median number of nodes removed during ALND was 17 (IQR 14–21), and the median number of positive nodes was 1 (IQR 0–4). Patient demographics, oncologic treatment characteristics, and operative data are displayed in Table 1.

Anatomic analysis

All ICG lymphography was performed ipsilateral to the site of oncologic disease. Linear (non-diseased) superficial lymphatic channels were visualized in the hand, forearm, and upper arm following ICG injections in 100% of patients ($n=30$). The tricipital pathway was visualized in 90% of patients ($n=27$).

Connectivity and contributions from forearm channels

Sixty-three percent of patients ($n=19$) had visualization of the tricipital pathway before the peri-olecranon injection, and therefore, the tricipital pathway was a continuation of a primary forearm channel, which was termed a "long bundle" (Fig. 2A). In 27% of all patients ($n=8$), the tricipital pathway was not visualized until after the peri-olecranon ICG injection in the distal upper arm (Fig. 2B). This variation was termed a "short bundle," [9, 24] as these did not receive contributions from the forearm channels (Video, Supplemental Digital Content 1). Of the 19 patients with a long-bundle tricipital pathway, 68% ($n=13$) had a contribution from the posterior ulnar forearm channel, 21% ($n=4$)

Table 1 Patient demographics and oncologic characteristics at the time of ICG lymphography

Total *n*	30
Age, years, mean (SD)[a]	55 (14)
Body mass index, kg/m^2, median (IQR)[b]	26 (23–31)
Extremity imaged *n* (%)	
Left	16 (53)
Right	14 (47)
Race, *n* (%)	
Caucasian	22 (73)
Asian	1 (3)
Other	1 (3)
Unknown	6 (20)
Ethnicity, *n* (%)	
Hispanic or Latinx	3 (10)
Non-Hispanic or Latinx	20 (67)
Unknown	7 (23)
Neoadjuvant chemotherapy status n (%)	
Neoadjuvant chemotherapy	20 (67)
Taxane-based	14 (70)
Axillary oncologic intervention	
Sentinel lymph node biopsy n (%)	20 (70)
Lymph nodes removed in SLNB[d], median (IQR)	3 (2–4)
Axillary lymph node dissection, *n* (%)	30 (100)
Total nodes removed during ALND[c], median (IQR)	17 (14–21)
Positive nodes removed during ALND, median (IQR)	1 (0–4)

[a]*SD* Standard deviation, [b]*IQR* inter-quartile range, [c]*ALND* axillary lymph node dissection, [d]*SLNB* sentinel lymph node biopsy

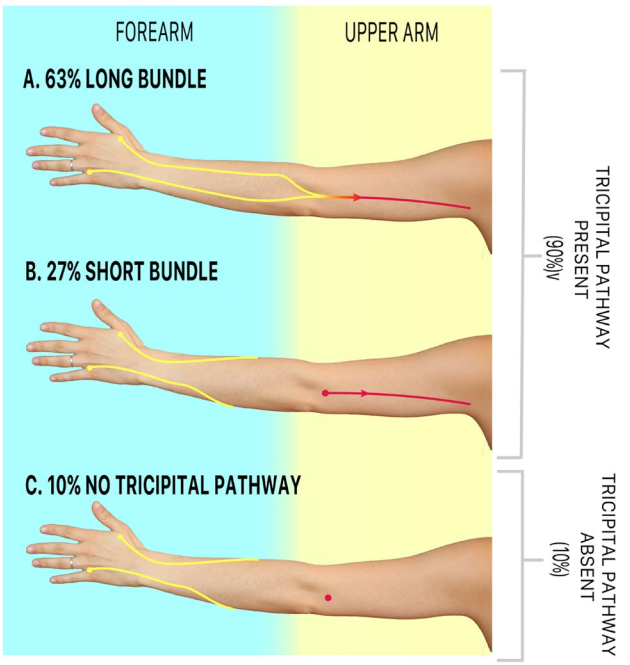

Fig. 2 Schematic demonstrating the variability in connections from the forearm lymphatic channels (yellow) to the tricipital pathway (red) with the long-bundle scenario **A** indicating a functional connection from one or both forearm channels, whereas the short-bundle scenario **B** is visualized after the targeted ICG injection (red dot) over the tricipital pathway

had a contribution from the posterior radial forearm channel, and 11% ($n=2$) had contributions from both the posterior ulnar and radial forearm channels (Fig. 3). There were no instances in which the tricipital pathway was supplied directly from either of the volar forearm channels.

Contributions from the lateral upper arm channel

There were two instances in which the lateral (cephalic) upper arm channel gave off a branch that traveled posteriorly and connected to the tricipital pathway (Fig. 4). In both cases, the tricipital pathway originated from the posterior ulnar forearm channel without any contribution from the radial forearm channel.

Anatomic destinations

In those with a tricipital pathway, 48% ($n=13$) had a tricipital pathway that entered the torso via the deltotricipital groove on the posterior surface of the upper arm. The other major anatomic destination of the tricipital pathway was the medial upper arm channel in the anterior upper arm (44%, $n=12$). There were two patients

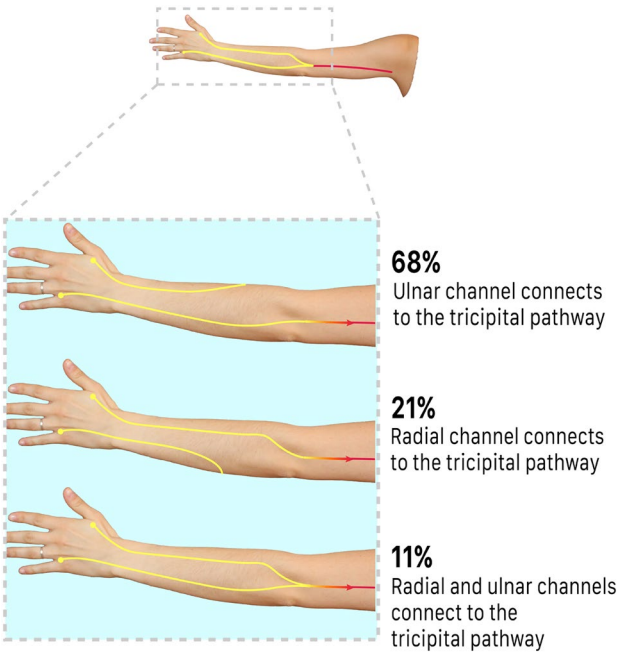

Fig. 3 Variable forearm contributions to the long-bundle tricipital pathway

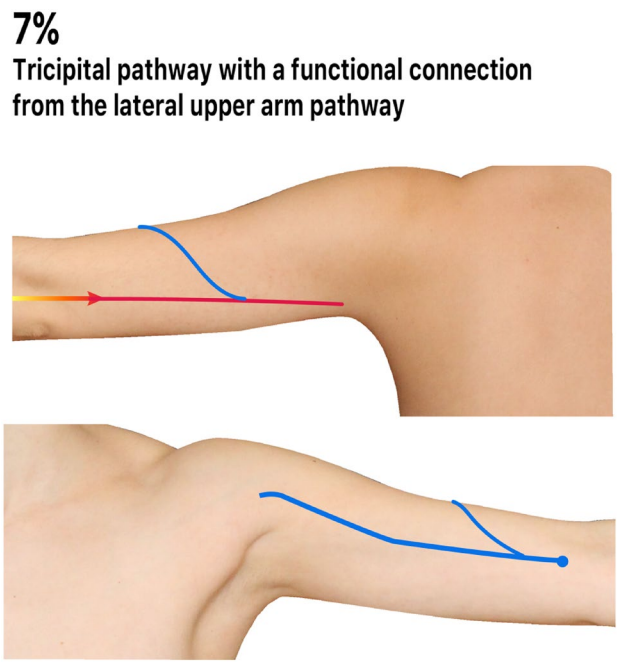

Fig. 4 A functional branch from the lateral upper arm pathway (blue) to the tricipital pathway

that had a tricipital pathway with unclear termination, as the channel ended abruptly in the upper arm and could not be traced proximally past the middle one third of the posterior upper arm (Fig. 5).

Discussion

In this study, the tricipital pathway was imaged using ICG lymphography in patients without clinical evidence of lymphatic disease. In this cohort of 30 individuals, the tricipital pathway was visualized in 90% of patients, originated from the posterior forearm channels when present as a long bundle (63%), and generally passed along the deltotricipital groove (48%) or terminated as it connected to the medial channel in the anterior upper arm (44%).

In previous studies [16, 19], the tricipital pathway was identified in less than 10% of cadaveric dissections. This discrepancy suggests that using standardized ICG lymphography in vivo can provide additional information beyond cadaveric studies [6, 25–27]. Additionally, this difference may be due to the targeted ICG injection performed proximal to the olecranon, which allowed for dependable visualization of the tricipital pathway.

This study is the first to report variability in the tricipital pathway's functional connections to the forearm (i.e., long- and short-bundle anatomy). We have previously described similar patterns of variable connection from the forearm channels to the lateral upper arm channel [23] and observed that the short-bundle lateral upper arm channel may be a risk factor for the development of BCRL, due to the presence of a watershed region between the forearm and upper arm [9, 24]. We, therefore, suspect that the presence of a short bundle tricipital pathway may have similar implications for patients, as watershed areas of lymphatic drainage have been described at the junction between the posterior forearm and upper arm [24].

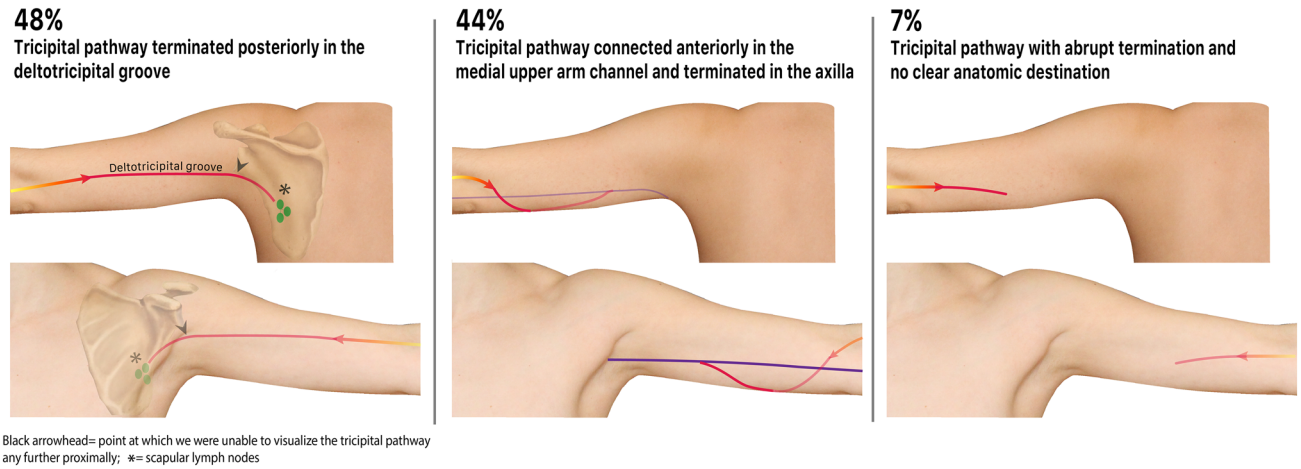

Fig. 5 Schematic showing the anatomic destinations of the tricipital pathway with the black arrowhead representing the point and which the tricipital pathway was unable to be visualized any further proximally secondary to depth of penetration of ICG imaging and the continued pathway depicted in this figure is the expected course of the tricipital pathway to the scapular lymph nodes (marked with an*) based on previous anatomic descriptions

Overall, the origins of the tricipital pathways observed in the current study are consistent with previous cadaveric dissections such that, when the tricipital pathway was connected to the forearm (long bundle), it was a continuation of the ulnar or radial posterior forearm lymphatic channels [10]. Of the 19 patients with the long-bundle tricipital, the majority (79%) had a tricipital pathway that had a visible connection to a posterior ulnar forearm channel and fewer patients (21%) had connections to the posterior radial channel alone (Fig. 3). Of note, this finding differs from the findings of Ciucci, who observed that the most common forearm contribution to the tricipital channel was from the posterior radial channel. We believe that the predominantly ulnar connection described in the current study may be critical for the drainage of lymph from the ulnar forearm, and we postulate that those lacking this connection may be more susceptible to developing BCRL, which has been characterized by fluid predominance along the ulnar side of the forearm [28].

The tricipital pathway was visualized in the deltotricipital groove upon entry to the torso in 48% of cases. This anatomic destination corroborates previous descriptions of the tricipital pathway in patients with lymphedema and cadaveric specimens [11, 16, 19, 29]. Although the limited depth of penetration (1–2 cm) of ICG imaging prevents us from tracing these pathways to their destination, scapular nodes would be the expected destination of these pathways entering the deltotricipital groove based on prior cadaveric dissections. The current study also identified an alternate trajectory of the tricipital pathway in nearly half of the cases, in which the tricipital transitioned to the anterior aspect of the upper arm and terminated in the medial upper arm channel, which traces along the basilic vein. Notably, we have previously demonstrated that the medial channel reliably drains to the axillary nodal basin [7, 23]. Therefore, when the tricipital pathway terminates in the medial channel, it may not be able to serve as an alternative lymphatic drainage pathway.

When present as a long-bundle variant, the tricipital pathway usually has contribution from the posterior ulnar forearm. The anatomical course of the long-bundle tricipital pathway, therefore, corresponds to the dominant regions of fluid distribution in the lymphedematous extremity of patients with BCRL [28]. We suspect that a lack of formation or utilization of the long-bundle tricipital pathway may help explain why only one third of breast cancer patients develop BCRL [31] and why the remainder of patients do not.

Our findings also emphasize the importance of the location of ICG injections and ICG imaging for visualizing collateral lymphatic channels. If the presence and location of collateral lymphatic pathways are recognized and mapped preemptively, attempts can be made to protect these pathways during surgery and radiation therapy. Preoperative lymphatic mapping could be used to plan prophylactic lymphovenous bypass to help preserve these critical channels [10, 17, 31]. Moreover, knowledge of patient-specific anatomy can help guide manual lymphatic drainage [18].

About two thirds of patients in our study were treated with neoadjuvant chemotherapy prior to ALND and ICG lymphography. Most of these patients received taxane-based regimens. Inferential analysis of our patients did not demonstrate an association between treatment with taxane-based chemotherapy and the presence or absence of the tricipital pathway or bundle type (long versus short). Previous studies have demonstrated adverse effects of taxane-based chemotherapeutics on lymphatic contractility [32] and risk of lymphedema development [33]. Although this may affect the functional activity of the lymphatic channels, it remains unclear how or if taxane-based chemotherapy may affect anatomic mapping. Additionally, the median number of positive nodes removed during ALND was 1. Therefore, patients had a low burden of metastatic disease which is unlikely to have influenced lymphatic function or anatomy.

Although this study furthers our understanding of lymphatic anatomy, it is not without limitations. The intradermal injections and ICG imaging technique only capture the superficial lymphatics of the upper extremity as ICG imaging has a depth of penetration of 1–2 cm. Therefore, our observations do not demonstrate function and anatomy of the deep lymphatics and any connections that exist between the superficial and the deep lymphatic systems. On a similar note, the tricipital pathway could not be mapped proximal to the deltotricipital groove, likely secondary to the depth of the channel as it traveled proximally. Finally, this study is statistically underpowered.

Conclusion

Our ICG lymphography protocol allowed us to visualize and map the tricipital pathway in the upper extremity. When present, the tricipital lymphatic pathway coursed along the posterior aspect of the upper arm with variations in its connections with the forearm channels and in its final termination. It remains unclear how these anatomic variations affect an individual's risk of breast cancer-related lymphedema. However, long-term follow-up in this cohort will be beneficial for establishing the significance of the tricipital pathway variations and the development of BCRL.

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Author contributions All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by RF, VB, JP, ET, and DS. The first draft of the manuscript was written by RF and all authors commented on previous

versions of the manuscript. All authors have read and approved the final manuscript.

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Data availability The datasets generated during and/or analyzed during the current study are not publicly available due containment of protected health information but are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no relevant financial or other non-financial interests to disclose.

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Beth Israel Deaconess Medical Center Institutional review board, Protocol # 2021P000859.

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