Annals of Anatomy 223 (2019) 32–42

Contents lists available at ScienceDirect

Annals of Anatomy

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

RESEARCH ARTICLE

Deep lymphatic anatomy of the upper limb: An anatomical study and clinical implications

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ARTICLE INFO

Article history:
Received 17 September 2018
Received in revised form 17 January 2019
Accepted 23 January 2019

Keywords:
Upper limb
Deep lymph vessel
Perforating lymph vessel
Lymph node
Lymphscintigraphy

ABSTRACT

Background: The deep and perforating lymphatic anatomy of the upper limb still remains the least described in medical literature.
Materials and Methods: Six upper limbs with the axillary tissue were harvested from three unembalmed human cadavers amputated at the shoulder joint. A small amount of 6% hydrogen peroxide was employed to detect the lymphatic vessels around the deep palmar arch, radial and ulnar neurovascular bundles. A 30-gauge needle was inserted into the vessels and they were injected with a barium sulphate compound. Each specimen was dissected, photographed and radiographed to demonstrate deep lymphatic distribution of the upper limb.
Results: Continuing from the deep lymph vessels of the hand, single or multiple deep collecting lymph vessels have been found along the radial, ulnar, anterior and posterior interosseous neurovascular bundles in the forearm, brachial and deep branchial neurovascular bundles in the upper arm. During their courses, lymph nodes were found setting in the trunk of the radial, ulnar and brachial lymph vessels near or in the cubital fossa, and in the axillar. Perforating lymph vessels have been found near the wrist and in the cubital fossa, which linked the superficial and deep lymph vessels. The direction of lymphatic drainage was from the deep to superficial or superficial to deep vessels.
Conclusion: The deep lymphatic anatomy of the upper limb has been described. The results will provide an anatomical basis for clinical management, educational reference and scientific research.

1. Introduction

The deep lymphatic vessels of the upper limb were presented and described by Bonamy et al. as early as 1844; they travelled with the radial, ulnar and brachial vascular bundle after using the mercury injection technique (Bonamy, 1847), but it lacked some details. It had not presented any tributaries of these vessels such as the deep brachial, anterior and posterior interosseous lymph vessels. Also, it had not described and presented any relationship between the superficial and deep lymph vessels in the upper limb. In subsequent studies, these features of the lymphatic anatomy still remained uncertain (Sappey, 1874; Bartel, 1909; Rouvière, 1938). Since the new technique of the lymphatic injection was established (Suami et al., 2005), some uncertainties of the human lymphatic system have been gradually clarified (Pan, 2015, 2017). Although the knowledge of the superficial lymphatic distribution of the upper limb has been updated (Suami et al., 2007a; Pan, 2015, 2017), the deep lymphatic anatomy still remains partially unclear (Suami et al., 2007b) and is unable to adapt to the development of modern medicine. Therefore, it is important to determine the deep lymphatic anatomy of the upper limb.

In this study, details of the deep lymphatic distribution and the communicating lymph vessels in the upper limb are described and demonstrated by radiographs and photographs.

2. Materials and methods

The investigation was performed with appropriate institutional ethics approval. Exarticulated at the shoulder joints, a total of six upper limbs with the axillary tissue were harvested from three

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https://doi.org/10.1016/j.aanat.2019.01.005
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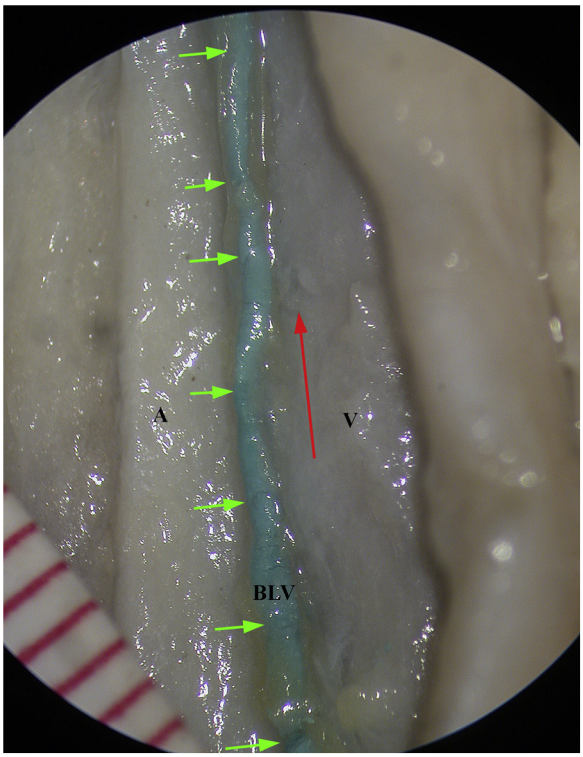

Fig. 1. With multiple vales in the lumen (indicating by green arrows), the brachial lymph vessel (BLV) filled by green injectant travels between the brachial artery (A) and vein (V). The red arrow indicates the direction of the lymph flow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

unembalmed human cadavers (1 male – 72 years old; 2 females – 78 and 80 years old). In four specimens, hands were removed near the wrist for other study purposes.

The experiment commenced in the palm and wrist regions. A small amount of 6% hydrogen peroxide (Zhonglian Chemical Co., Ltd, Suzhou, China) was injected into the tissue around the deep palmar arch and radial and ulnar neurovascular bundles. Under a surgical microscope (Leica Microsystems Ltd, Heerbrugg, Switerland) the distended lymphatic vessels were identified in the area. Each vessel was inserted by a 30-gauge needle (Zhejiang KDL Medical Equipment Group Ltd., Wenzhou, China) and injected with a radio-opaque mixture (Barium Sulphate 15 g: Shanghai Silian Industry Co. Ltd., China; Milk powder 5 g: Heinz Ltd., Qingdao, China; Concentrated poster color - dark green 3 g: Liaoyuan arts and stationery Ltd., Hunang, China; Water 20 ml). Lymphatic vessels were then traced, photographed and radiographed (Digital X-ray Diagnostic System - Multix Select DR: Siemens Healthcare Diagnostic Co. Ltd., Erlangen, Germany) to demonstrate their distribution. The final results were transferred to computer (Dell Vostro 200: Dell Computer Inc. Chinese Division, P.R. China) for image analysis using Photoshop software (Adobe Photoshop CS5 V12, Adobe Systems Software Co., Ltd, Beijing, China).

3. Results

With numerous valves in the lumen, deep collecting lymph vessels of the upper limb were found along the major neurovascular bundles (Figs. 1–3). They travelled tortuously either on the side of adjacent arteries, veins and nerves, or sometimes between them (Figs. 1 and 4). During their courses lymph nodes were found setting in the trunk of the radial, ulnar and brachial lymph vessels near or in the cubital fossa, and in the axillar (Figs. 2C,D, 4 C, 5).

3.1. Radial lymph vessel (RLV)

Continuing from the deep lymph vessels of the palm (deep palma arch and thenar lymph vessels), 1 or 2 RLVs travelled beside the radial neurovascular bundle towards the cubital fossa (Figs. 2, 3A, 4 A, 5 A, 6), where they converged with the ulnar lymph vessel (ULV).

The average diameter of the vessel was 0.4 mm (ranging from 0.3 to 0.6 mm).

3.2. Ulnar lymph vessel (ULV)

Continuing from the deep lymph vessels of the palm (hypothenar lymph vessel), 1 or 2 ULV (Figs. 2, 3A, 4 B, 7) travelled beside the ulnar neurovascular bundle. The vessel received AILV and PILV near the cubital fossa (Figs. 2, 3A indicating by white arrowhead), and then converged with RLV in the cubital fossa (Figs. 2, 3A indicating by white arrow).

In two specimens, one ULV penetrated the deep fascia and travelled in the subcutaneous tissue of the forearm (indicating by * in Fig. 7), upper arm (indicating by * in Fig. 5) and then entered the axillary lymph node.

The average diameter of the vessel was 0.35 mm (ranging from 0.3 to 0.5 mm).

3.3. Anterior interosseous lymph vessel (AILV)

Arising from the deep side of the proximal margin of the pronator quadratus, 1 or 2 AILVs travelled with the anterior interosseous vascular bundle and merged with the ULVs near the cubital fossa (Figs. 2, 3A, 4 C, 8).

Fig. 2. Radiographes of deep lymphatic distribution of the left upper limb.
(A, C) AP view; (B, D) Lateral view. BLV = brachial lymph vessel; DBLV = deep brachial lymph vessel; RLV = radial lymph vessel; ULV = ulnar lymph vessel; AILV = anterior interosseous lymph vessel; PILV = posterior interosseous lymph vessel; DPALV = deep palmar arch lymph vessel; LN = lymph node.

The average diameter of the vessel was 0.3 mm (ranging from 0.2 to 0.5 mm).

Posterior interosseous lymph vessel (PILV)

Arising in the intermuscular septum of the superficial and deep extensor muscles one third of the distance to the distal part of the forearm, the PILV travelled with the posterior interosseous vascular bundle, passed the proximal part of the interosseous membrane and then merged with the ULV near the cubital fossa (Figs. 2, 3C).

The average diameter of the vessel was 0.3 mm (ranging from 0.2 to 0.5 mm).

3.4. Brachial lymph vessel (BLV)

Continuing from the RLV and ULV in the cubital fossa, single (Figs. 2, 3B) or multiple (Fig. 9) BLVs travelled beside the brachial neurovascular bundle and then entered the axillary lymph nodes (Figs. 3, 4, 5B, 7 B, 9 B).

In one specimen, the BLV was formed by RLV and ULV in the inferior margin of the cubital fossa and divided into two major vessels at the superior margin of the cubital fossa. One of them entered the superficial cubital lymph nodes and then continued its course in the subcutaneous tissue of the upper arm, and then entered one of the axillary lymph nodes. The other vessel travelled along the brachial neurovascular bundle and then entered another axillary lymph node (Fig. 10, Specimen 4 in Fig. 11).

The average diameter of the vessel was 0.4 mm (ranging from 0.3 to 0.6 mm).

3.5. Deep brachial lymph vessel (DBLV)

Arising in the intermuscular septum between the lateral and medial heads of the triceps brachii one third of the distance to the distal part of the upper arm, the DBLV traveled along the deep brachial neurovascular bundle, and then merged with the BLV near the inferior border of the teres major (Figs. 2, 3D).

The average diameter of the vessel was 0.3 mm (ranging from 0.2 to 0.5 mm).

3.6. Lymph nodes

During the course of deep lymph vessels of the upper arm, they connected successively with the radial, ulnar, cubital, brachial and axillary lymph nodes (Figs. 5, 8D, 9 B). Most lymph nodes appeared as oval shape; both ends were connected with lymph vessels. The size of lymph nodes varied from 1 mm to 1.1 cm in transverse diam-

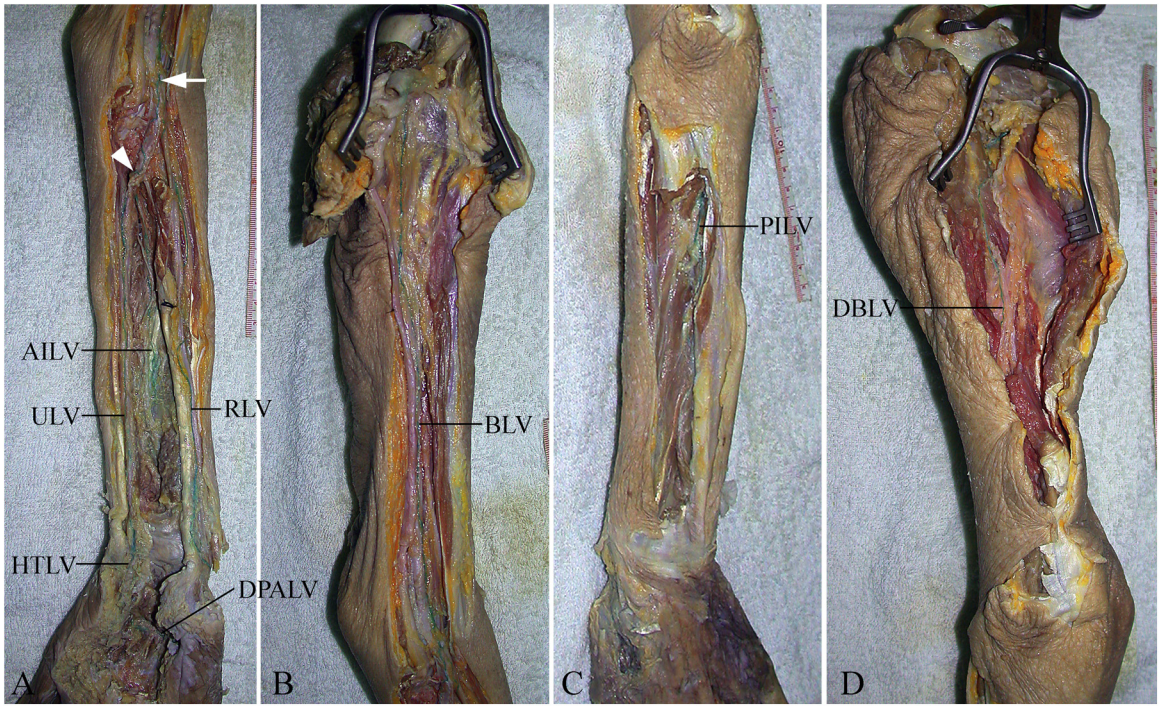

Fig. 3. Photographs of deep lymphatic distribution of the left upper limb.
(A) Anterior view of the forearm showing the distribution of the radial (RLV), ulnar (ULV) and anterior interosseous (AILV) lymph vessels. The black arrowhead indicates where RLV merge with ULV. The white arrowhead indicates where the AILV and PILV (posterior interosseous lymph vessel) merge with ULV. HTLV = hypothenar lymph vessel; DPALV = deep palmar arch lymph vessel. (B) Medial view of the upper arm showing the distribution of the brachial lymph vessel (BLV). (C) Posterior view of the forearm showing the distribution of the AILV. (D) Posterior view of the upper arm showing the distribution of the deep brachial lymph vessel (DBLV).

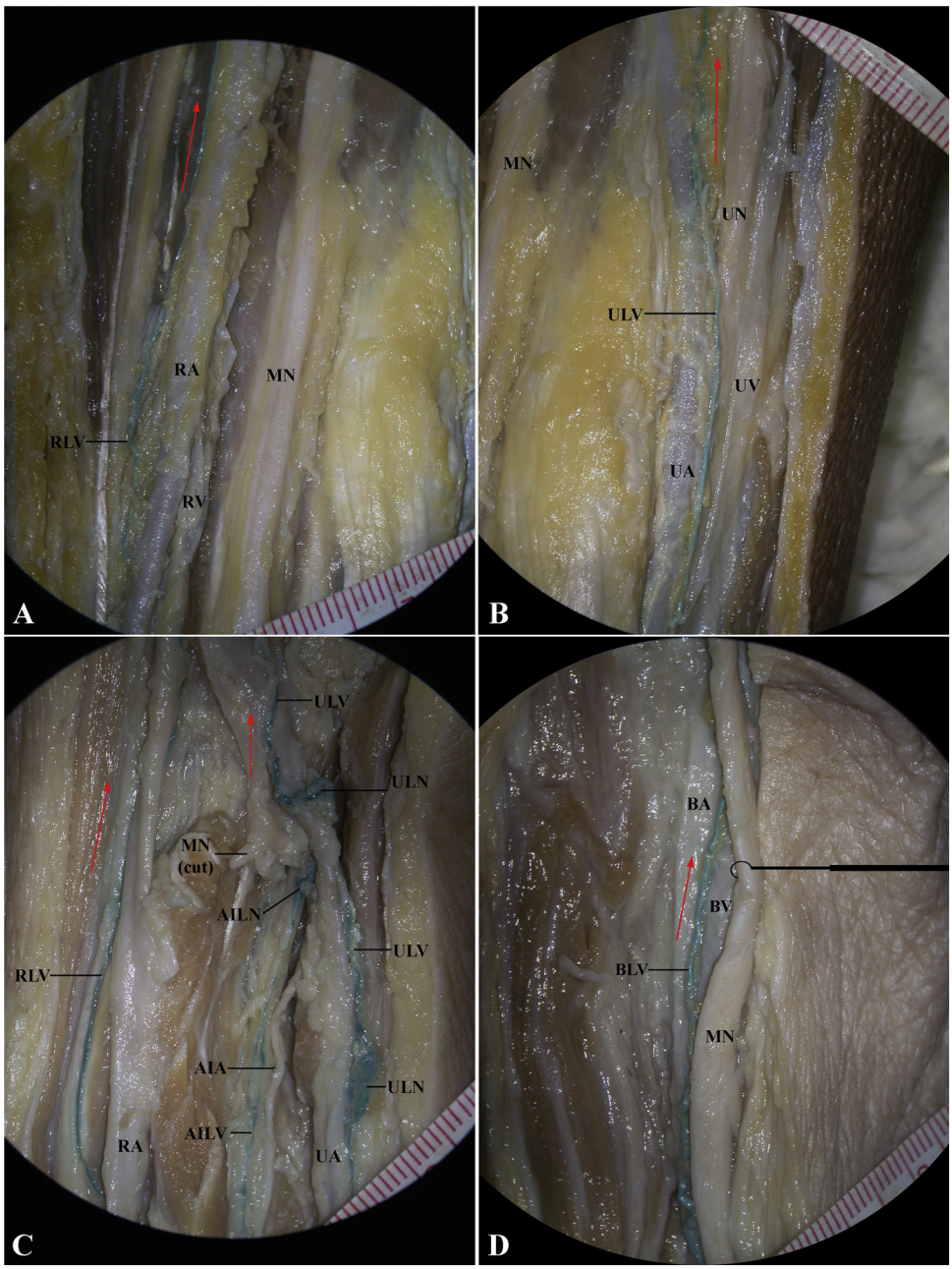

Fig. 4. The relationship between deep lymphatic vessels and adjacent arteries, veins and nerves.
Views in the antero-radial side (A) and antero-ulnar side (B) of the right forearm, the anterior forearm near the elbow (C), the middle of the upper arm (D). RLV = radial lymph vessel; RA = radial artery; RV = radial vein; MN = Median nerve; ULV = ulnar lymph vessel; ULN = ulnar lymph node; UA = ulnar artery; UV = ulnar vein; UN = ulnar nerve; AILV = anterior interosseous lymph vessel; AILN = anterior interosseous lymph node; AIA = anterior interosseous artery; BLV = brachial lymph vessel; BA = brachial artery; BV = Brachial vein.

eter. The number of lymph nodes were different in each individual, details are presented in Fig. 9.

3.7. *Perforating lymph vessels*

Perforating lymph vessels have been found near the wrist and in the cubital fossa, which linked the superficial and deep lymph vessels. The direction of lymphatic drainage was from the deep to superficial or superficial to deep vessels.

In two specimens, one of the ULVs penetrated the deep fascia (Fig. 5) and travelled in the subcutaneous tissue of the forearm, upper arm and then entered the axillary lymph node (Fig. 3).

In one specimen, a branch of the BLV at the superior margin of the cubital fossa entered superficial cubital lymph nodes and then continued its course in the subcutaneous tissue of the upper arm, and then entered one of the axillary lymph nodes. (Fig.10, Specimen 4 in Fig. 11).

In one specimen, a brachial lymph node received the drainage not only from the deep lymph vessel but also from the perforating lymph vessel that originated from the superficial layer (Figs. 5B, 12).

Fig. 5. The relationship between deep lymph vessels and nodes of the right upper limb.
Medial view of the right elbow section. (B) Medial view of the right upper arm. RLN = radial lymph node; DCLN = deep cubital lymph node; BLN = brachial lymph node; ALN = axillary lymph nodes; * = lymph vessels originate from ULV in the forearm and then travel in the subcutaneous; # = perforating vessels (vessels originate from superficial layer in the elbow and then enter deep lymph nodes).

4. Discussion

Although Bonamy et al presented and described that the deep lymphatic vessels of the upper limb ran with the major vascular bundle after using the mercury injection technique (Bonamy, 1847) as early as 1844, it lacked some details. For example, it had only shown that deep lymph vessels ran with the radial, ulnar and brachial neurovascular bundles but it did not show any of their tributaries, such as the deep brachial, anterior and posterior interosseous lymph vessels. Also, it had not described and presented the relationship between the superficial and deep lymph vessels of the upper limb. In subsequent studies, these features of the lymphatic anatomy still remained uncertain, either by direct or indirect lymphatic injections (Sappey, 1874; Bartel, 1909; Rouvière, 1938). However, the anatomical uncertainties of the human lymphatic system have been gradually clarified since the new technique of lymphatic injection had been established (Suami et al., 2005; Pan, 2017).

In this study, we have presented deep lymphatic anatomy of the upper limb. The characteristics of the drainage pattern are described as follows;

1 Continuing from the deep lymph vessels of the palm, single or multiple collecting lymph vessels travelled beside the major neurovascular bundles in the upper limb and then entered axillary lymph nodes.
2 During the course, deep lymph vessels of the upper arm were connected successively with the radial, ulnar, cubital and brachial lymph nodes.
3 Perforating lymph vessels have been found near the wrist and in the cubital fossa, which linked the superficial and deep lymph vessels. The direction of lymphatic drainage could be from the deep to superficial or superficial to deep vessels.

We believe that our results have provided additional information for enriching the lymphatic anatomy in the upper limb.

Lymphaticovenous anastomosis is one of the surgical procedures for treating secondary lymphoedema in the upper limb (Neligan et al., 2015). Accurate anatomical understanding of the lymphatic routes involved may assist in the preoperative preparation and intraoperative management of these patients, thus affecting their postoperative outcome. It has been mentioned that as many anastomoses as possible must be performed in order to obtain the best result in this procedure (Huang et al., 1985). The lymphaticovenous anastomoses were usually performed in the superficial layer (Neligan et al., 2015; Poumellec et al., 2017), which was expected to reduce the lymphoedema not only in the superficial but also deep layers. Results from this study had indicated that

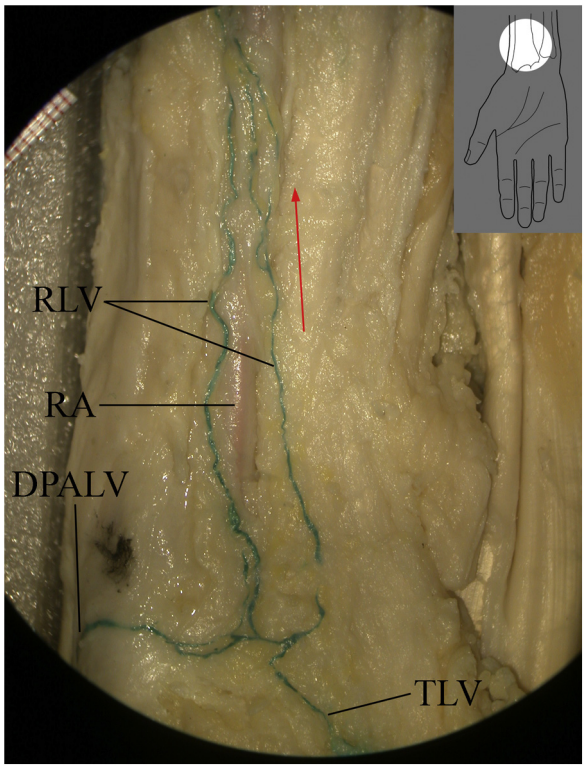

Fig. 6. The origin of the radial lymph vessel.
DPALN = deep palmar arch lymph vessel; TLV = thenar lymph vessel; RLV = radial lymph vessel; RA = radial artery. Red arrow indicates the travelling direction of lymphatic vessels. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

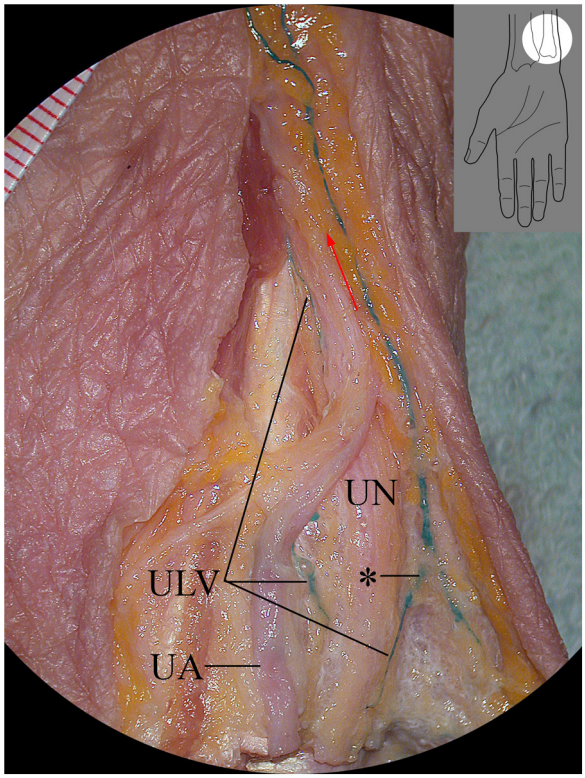

Fig. 7. The origin of the ulnar lymph vessel.
UA = ulnar artery; ULV = ulnar lymph vessel; UN = ulnar nerve; * = perforating vessel (lymph vessel originates from ULV and then travels in the subcutaneous). Red arrow indicates the travelling direction of lymphatic vessels. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

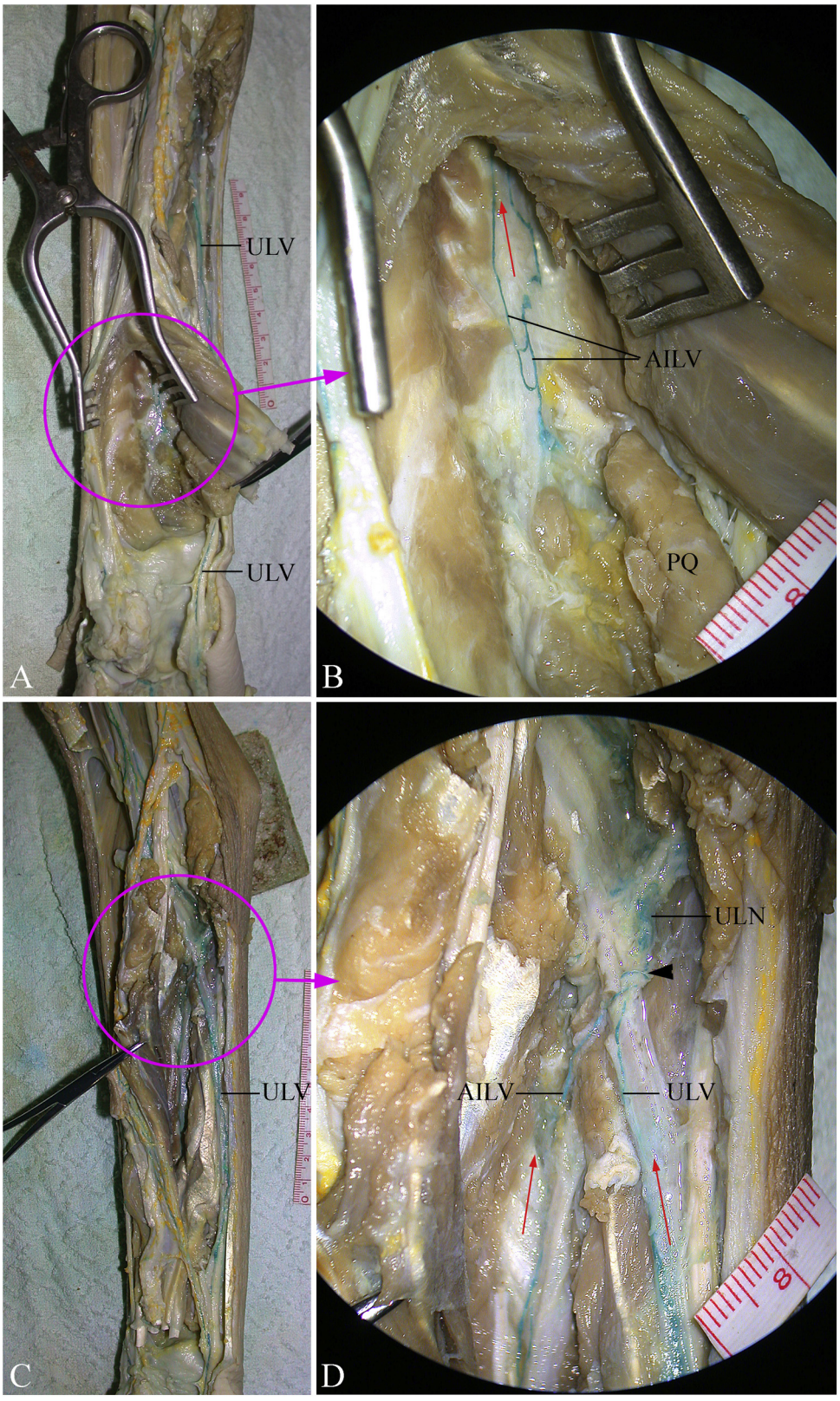

Fig. 8. Distribution of AILV.
(A) Anterior view of the right forearm. (B) Magnified image of the circled area in (A) shows the origin of AILV. (C) Anteromedial view of the right forearm. (D) Magnified image of the circled area in (C) shows where the AILV merges with ULV (indicating by black arrowhead). ULV = ulnar lymph vessel; ULN = ulnar lymph node; AILV = anterior interosseous lymph vessel; PQ = pronator quadratus. Red arrow indicates the travelling direction of lymphatic vessels. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Fig. 9. Distribution of BLV. (A) Medial view of the right upper arm. (B) Medial view of the right axilla. BLN = brachial lymph node; DCLN = deep cubital lymph node; Ole = olecranon; ALN = axillary lymph nodes.

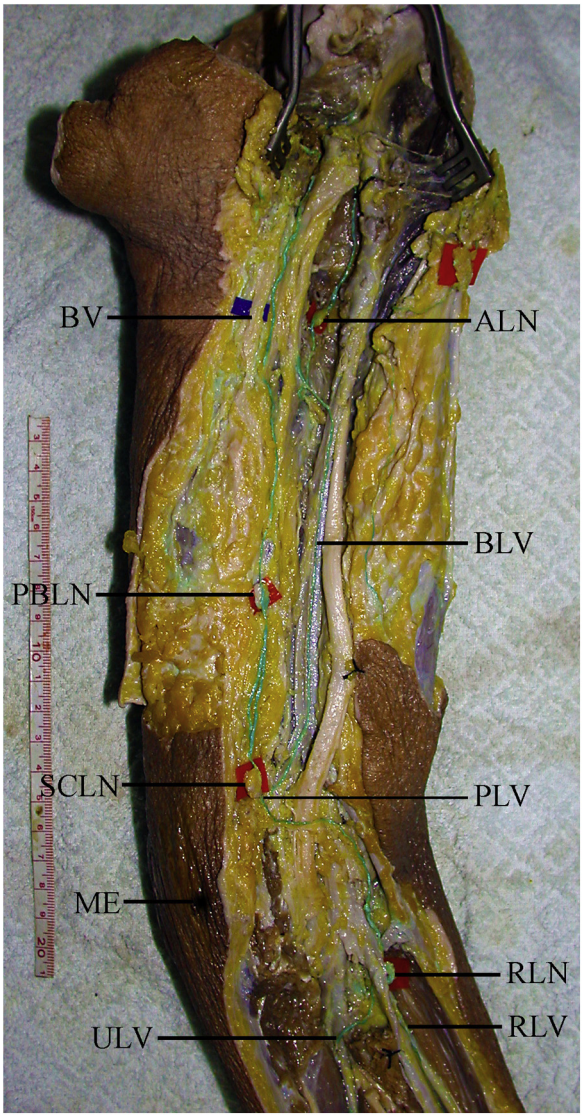

Fig. 10. Distribution of BLV in the left arm.
BV = basilic vein; PBLN = para-basilic vein lymph node; SCLN = superficial cubital lymph node; ME = medial epicondyle; ULV = ulnar lymph vessel; ALN = axillary lymph node; BLV = brachial lymph vessel; PLV = perforating lymph vessel; RLN = radial lymph node; RLV = radial lymph vessel.

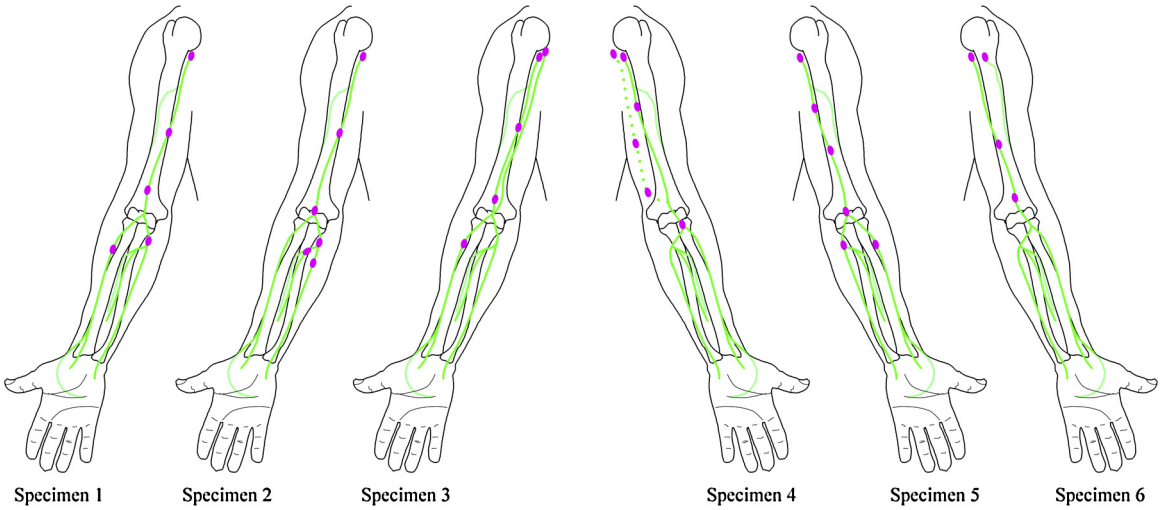

Fig. 11. Sketch of the deep lymphatic distribution in upper limbs.
Green lines = deep lymphatic vessels in upper limbs; Doted green line = superficial lymph vessel; Purple dots = lymph nodes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

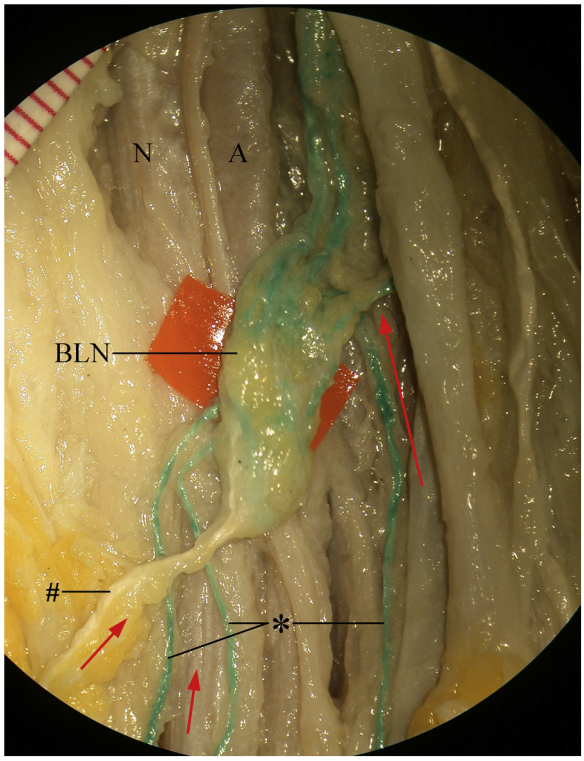

Fig. 12. A brachial lymph node in the right arm.
BLN = brachial lymph node; A = brachial artery; N = median nerve; * = deep lymphatic vessels (filled by the mixture of Barium Sulphate and green poster color); # = perforating lymph vessel (filled by the mixture of Barium Sulphate without poster color). Red arrows indicate the travelling direction of lymphatic vessels. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

deep lymph could be drained to superficial vessels via perforating vessels, which might be the important information for satisfying this explanation.

Lymphoscintigraphy and sentinel lymph node biopsy are important procedures for treating a number of tumors, including melanoma. In the upper limb region, the cubital lymph node could be the sentinel node detected by lymphoscintigraphy if lesions appeared in the hand and forearm (Uren et al., 1999; Thompson et al., 2004; Reynolds et al., 2007). Our previous studies (Pan et al., 2017) and this study show whether lymph vessels from superficial tissue of the hand and forearm or deep tissue of the forearm could enter either superficial or deep cubital lymph nodes via perforating lymph vessel(s) (Figs. 3,5,8,9). This information may help clinicians to find the sentinel lymph node – either in the superficial or deep layers of the cubital fossa during surgical procedure.

5. Conclusion

The knowledge of the deep lymphatic anatomy of the upper limb has been updated. The results will provide an anatomical basis for clinical management, educational reference and scientific research.

6. Author disclosure statement

No competing financial interests exist.

Acknowledgement

Authors would like to pay tribute to the body donors who contributed their bodies for this study and thank their families for assistance. Many thanks to the National Natural Science Foundation of China (No: 31671253), Xuzhou Medical University President special fund (No: 53051116) and the foreign experts special fund from the Department of International Cooperation and Exchange (No: 537101) for supporting this study.

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