Anatomy and Physiology

of the Lymphatic System

Manual Lymph Drainage Certification

For your convenience, a list of acronyms is provided in the Resources Directory of this manual.

Klose Training
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Table of Contents

Anatomy of the Lymphatic System

The Components of the Lymphatic System[1]

The lymphatic system is present throughout the human body and consists of lymph vessels and a number of organs, all of which contain lymphatic tissue.[3]

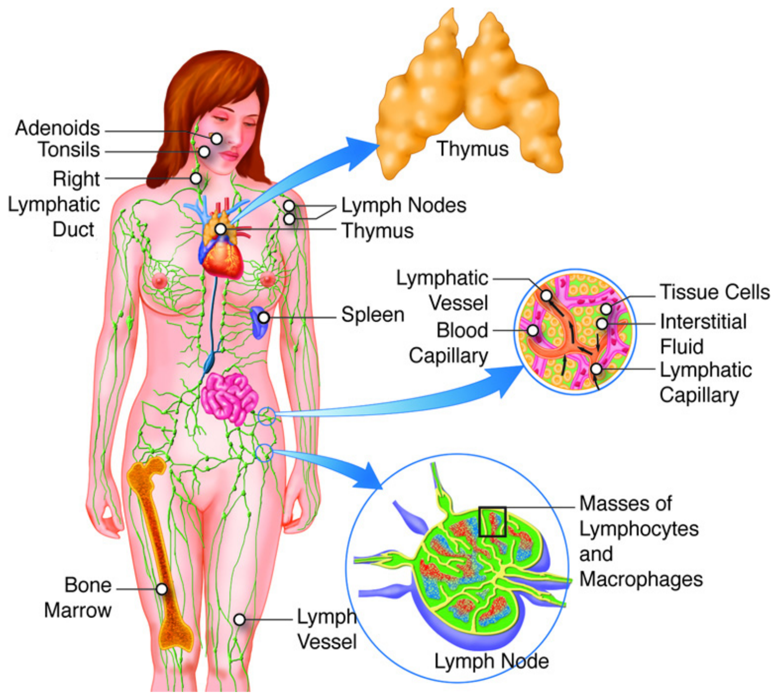


Fig. 1 The components of the lymphatic system. *savingstudentsmoney.org*

The lymphatic structures in the body are:

- **Lymph vessels (aka lymph collectors) -** transport protein-rich fluid (lymph) from the tissues (interstitium) to the lymph nodes, and eventually to the central venous system.
- **Lymph nodes** (LN) - are filtering stations for the lymph fluid and serve as a storage place for white blood cells (lymphocytes).
- **Spleen** – is used to dispose of aged red blood cells (erythrocytes) and serves as a storage place for blood (plasma).
- **Thymus** – serves very important immunological functions in the early years of life; also referred to as "thymus gland" because of its secretion of hormones, making it also part of the endocrine system.
- **Tonsils** – serve immunological functions.
- **Bone marrow** – Bone marrow is a primary lymphoid organ that produces lymphocytes and other blood cells, including red blood cells, white blood cells and platelets.
- **Lymphocytes** – are white blood cells which the body uses to fight off infections, bacteria and foreign matter.
- **Peyer's patches** – are aggregations of lymphoid tissue (aggregated lymphoid nodules) found in the lowest part of the intestine. Because the lumen of the gastrointestinal tract is exposed to the external environment, much of it is populated with potentially pathogenic microorganisms. Peyer's patches are important for the immune surveillance of the intestinal lumen.

The Functions of the Lymphatic System[4-6]

Lymph vessels absorb interstitial (tissue) fluid, mainly from the skin and subcutaneous tissues, and transports it into regional lymph nodes, from there through deeper lymph vessels into the venous circulation. From the intestines, the lymph vessels (aka lacteals) absorb nutritional fatty acids. This intestinal lymph is called chyle. In addition, the lymphatic organs have very important immunological functions. Lymphocytes (white blood cells) are stored in lymph nodes. These lymphocytes have the ability to recognize foreign cells, substances, microbes, and cancer cells and respond to them, i.e. destroy and eliminate them from the body.

The functions of the lymphatic system in summary:

- It returns protein and water from the interstitium to the cardiovascular system.
- It absorbs protein, fat and fat-soluble vitamins (chyle) through the intestinal lymph vessels (lacteals).
- It recognizes and responds to foreign cells, microbes, and cancer cells (serves important immunological functions).

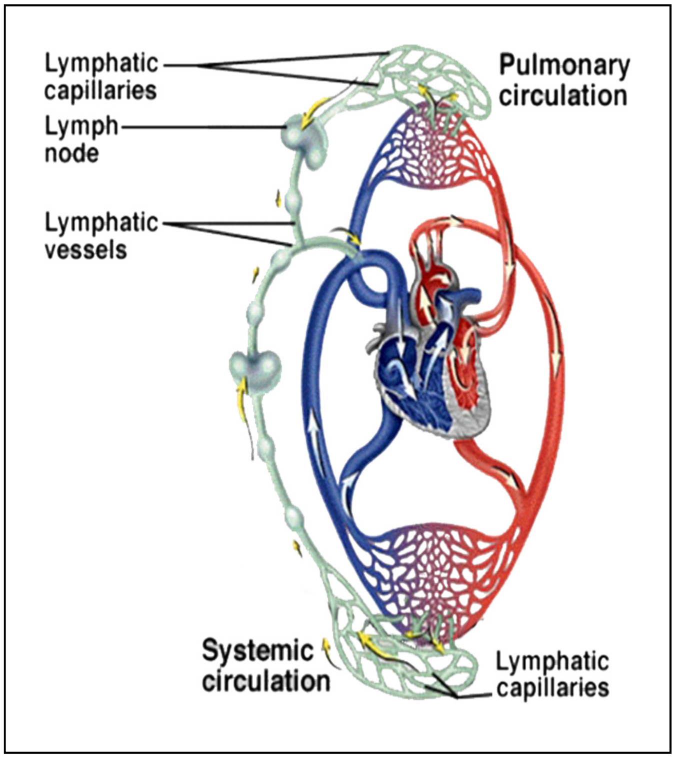


Fig. 2 This diagram shows the relationship between the blood circulatory and lymphatic systems. Nutrients and oxygenated blood are transported through the high-pressure arterial system (red) into the blood capillaries, after the nutrients and oxygen exchange has occurred, the venous system (blue) carries the deoxygenated blood back to the heart. However, protein molecules and some water that have gone from the blood capillaries into the tissues have to be picked up by the lymphatic system (light green) to be returned to the systemic circulation.

Note: More about the functions of the lymphatic system will be covered later in this section.

The Superficial Lymphatic System[4-6,11]

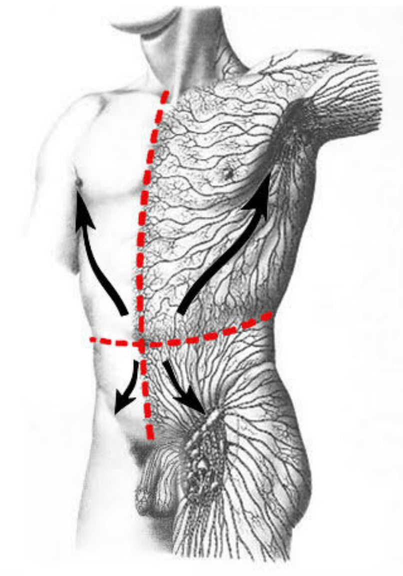


Fig. 3 Drawing of the superficial lymphatics by the French anatomist Marie P.C. Sappey, from 1879. It illustrates the superficial lymph vessels (collectors) draining the upper and lower trunk quadrants to the regional lymph nodes of the axilla and inguinal region. The lymphatic tributary regions are delineated by lymphatic watersheds (red dashed lines).
Modified from ibdenver.com

Fig. 4 Updated illustration of the superficial lymphatic system by Heroo Suami, MD, PhD. It shows the superficial lymphatic drainage system of the whole body.[11] The upper trunk quadrants and the arm draining into the axillary LN. The lower trunk quadrants and the legs are draining toward the inguinal LN. Lymphatic tributary regions are also referred to as lymphosomes and are delineated (separated) by lymphatic watersheds. See next page.
Journal of Surgical Oncology 2017

The Important Lymphatic Watersheds

Lymphatic watersheds delineate (separate) lymphatic tributary regions (aka lymphosomes)[11]. The tributary regions for the axillary lymph nodes are the upper extremities, the upper trunk quadrants, and the mammary glands (breasts). Alternately, it can be said that the axillary lymph nodes are the "regional" lymph nodes for the upper extremities, upper trunk quadrants, and the breasts.
See Tables 1-3 later in the anatomy section for the tributary regions of lymph nodes.

The important watersheds on the trunk are the:

1. Median-sagittal (vertical) WS
2. Transverse (horizontal) WS
3. Clavicle WS
4. Spine of scapula WS
5. Chaps (gluteal) WS

A. Right upper trunk quadrant
B. Left upper trunk quadrant
C. Right lower trunk quadrant
D. Left lower trunk quadrant

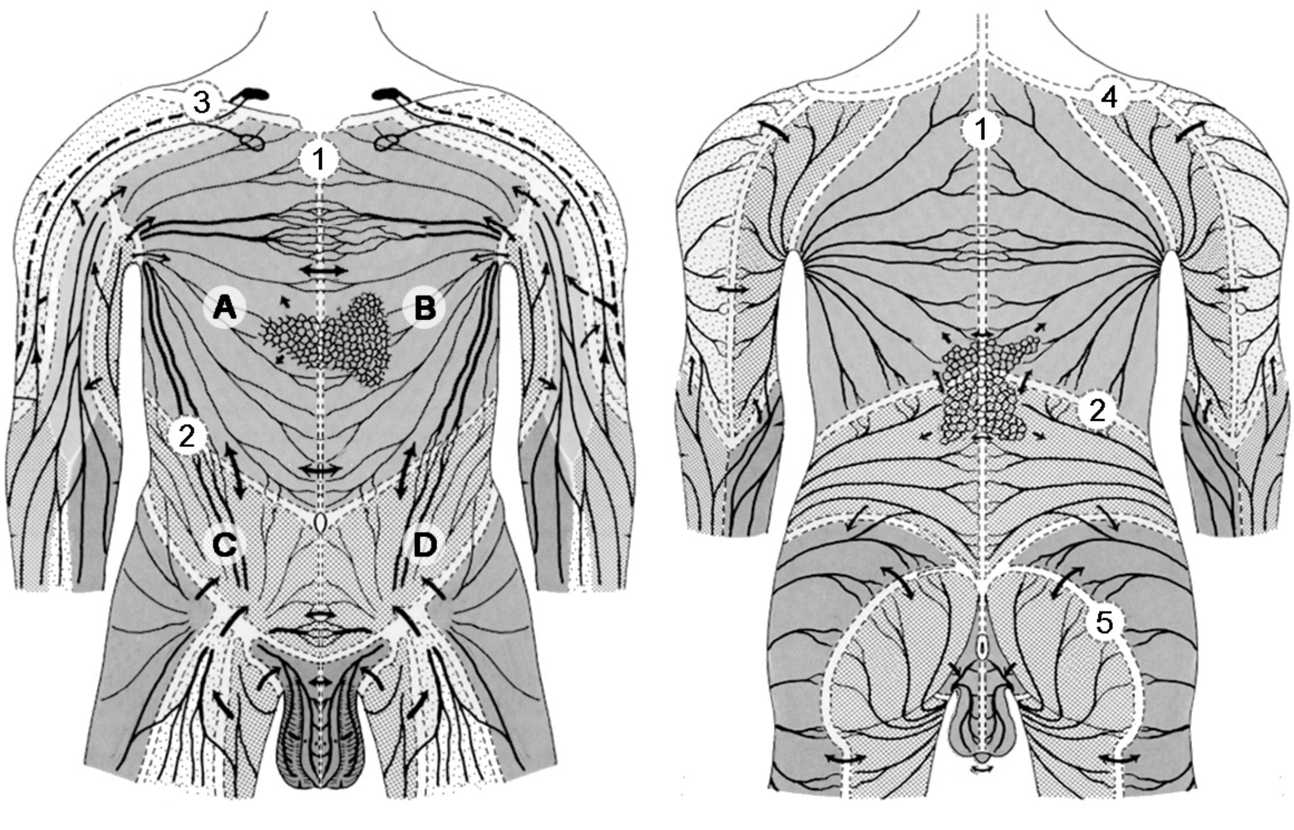


Fig. 5 Important Lymphatic Watersheds of the anterior and posterior trunk.
Modified from Földi's Textbook of Lymphology

Note: Students are encouraged to use a highlighter or colored pencil to draw in (color) the 5 important watersheds

Lymph Vessels (Collectors) of the Skin[1]

Looking at the skin as a 3-dimensional organ, we can identify the epidermis (most outer layer, #3), the subdermal layer (#6) with its subcutaneous adipose tissue and the fascia (#7). Lymph capillaries are located superficially (#4), near the blood capillary loops (blood capillary loops are not shown in the below diagram, Fig. 6). Lymph capillaries form a plexus (network) throughout the body's surface.

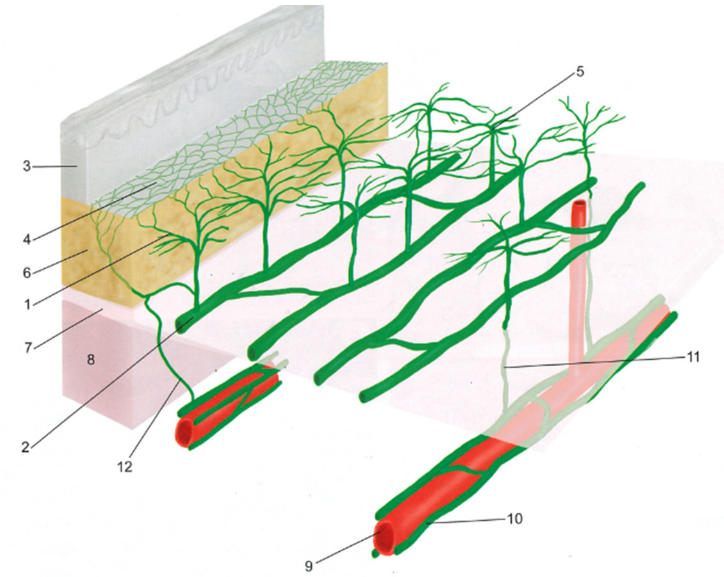


Fig. 6

Lymphatic drainage of the skin. **1** Pre-collector **2** Subcutaneous collector (lymph vessel) **3** Skin with epidermis **4** Superficial cutaneous capillary network **5** Deep cutaneous network (precollectors) **6** Subcutis **7** Fascia **8** Subfascial layer **9** Artery **10** Deep perivascular lymph vessels **11** Connection between precollector and deep collector **12** Connection between precollector and deep lymph vessels
Földi's Textbook of Lymphology

Lymph Capillaries[1,3-6]

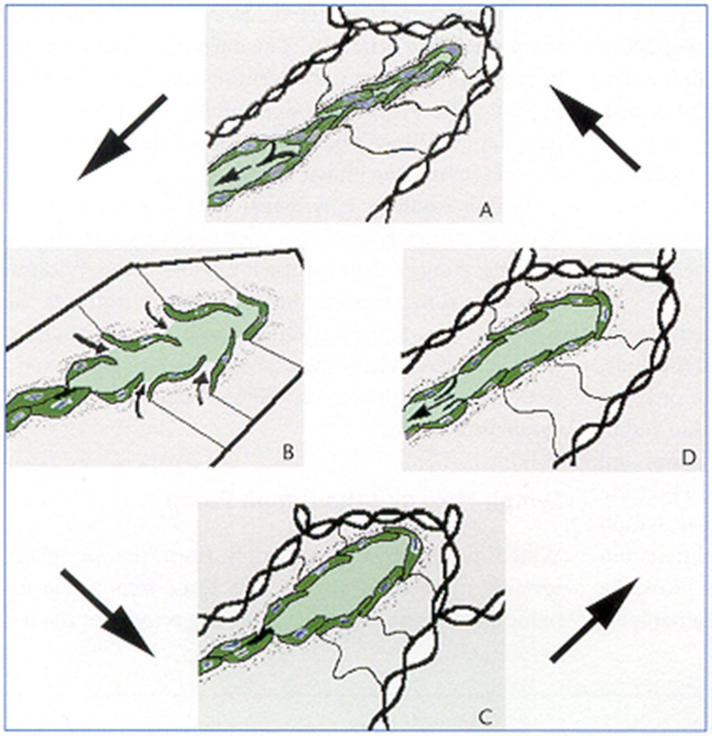
Lymph capillaries are larger than blood capillaries and are structurally adapted to ensure the absorption of large molecules, i.e. proteins from the interstitium. The lymph capillaries originate in tissue spaces and form an extensive plexus (network) throughout the body's surface. In the soft connective tissue of the skin and mucous membranes, lymph capillaries are located close to the blood capillaries. Their wall is made of flat endothelial cells that overlap each other. Because the overlapping ends of the endothelial cells open and close as needed for the absorption of fluid, they are sometimes referred to as "swinging flaps." Anchoring filaments attach to the endothelial cells of the lymph capillary and the surrounding tissues. Any increase of interstitial fluid produces a pull on the anchoring filaments that opens the lymph capillary even more, allowing a passive influx of fluid into the small vessel. (Fig. 7)

The important characteristics of the lymph capillaries:

- They are made up of flat endothelium cells with anchoring filaments.
- They form an extensive network just below the epidermis.
- They have a larger diameter than blood capillaries.
- They are able to absorb interstitial fluid (protein and water) as necessary.
- There are no valves inside the lymph capillaries.

The Opening Mechanism of the Lymph Capillary[1]

Lymph Formation*



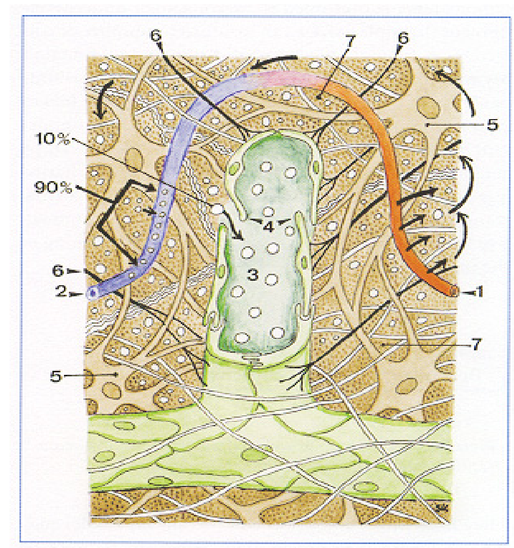


Fig. 7 + 8 Opening mechanism of a lymph capillary. *Földi's Textbook of lymphology*

A. The initial lymph vessel is empty and collapsed. The subsequent precollector is filled with lymph. The anchoring filaments and the fiber network are relaxed as a result of low interstitial pressure.

B. Filling phase: The interstitium is filled with fluid and thus the interstitial pressure exceeds the pressure in the initial lymph vessel. The interstitial fiber network and the anchoring filaments are tense, causing the outer swinging flaps of the lymph vessel to be pulled outward. At the same time, the fluid flowing inside the lymph vessel pushes the inner flaps inward causing the inlet valves to open.

C. The initial lymph vessel is filled with lymph* The pressure in the initial lymph vessel exceeds the interstitial pressure and thus the inlet valves are closed.

D. The pressure inside the initial lymph vessel opens the valve to the precollector and thus the lymph flows towards the precollector.

* *Interstitial fluid travels through pre-lymphatic (tissue) channels from the blood capillary to the lymph capillary. <u>Once interstitial fluid has entered into the lymph capillary, it has become lymph.</u> On its way to the central venous system, lymph fluid will be filtered by lymph nodes and becomes more concentrated with protein. Therefore, interstitial fluid is different from lymph fluid.*

Pre-collectors[1]

The pre-collectors connect the lymph capillaries to the larger transporting vessels (collectors). Pre-collectors possess absorbing functions for fluid like the capillaries but in some areas resemble transporting vessels containing smooth-muscle cells and valves.

Lymph Collectors[1]

In structure, the collectors resemble veins but have thinner walls and valves in shorter intervals. The valves are passive and determine the direction of flow. They prevent the return of fluid and guarantee transport from distal to proximal or to the regional lymph nodes.

Depending on the diameter of the vessel, valves are evident every 0.6 – 2 cm in the collectors and every 6 – 10 cm in the thoracic duct. The section of the collector between a distal and a proximal valve is called a lymphangion.

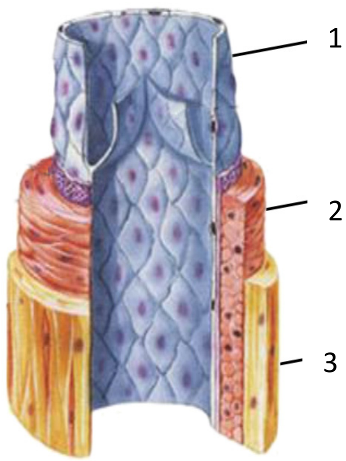
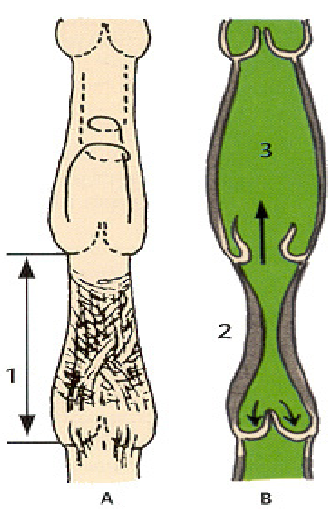


Fig. 9

Diagram of the wall structure of a vein. Like veins, lymph collectors also consist of a three-layer wall and bicuspid valves. The three layers are: **1 Tunica intima** (inner layer) - composed of endothelial cells and a basal membrane, **2 Tunica media** (middle layer)- composed of smooth muscle cells, and **3 Tunica externa** (outer layer) - made of soft collagenous connective tissue. *Modified from Fox, Stuart I, Human Physiology 4th Edition, Brown Publishers*

A **lymphangion[1]** is the smallest functional unit of the lymph collector. It is bordered by a distal and proximal valve. The lymphangion is characterized by:



- Muscle tissue and bicuspid valves
- Autonomic NS innervation and
- Intrinsic contractions (6-10 x/min)

Fig. 10 Structure and function of lymphangion:
A - Arrangement of musculature
B - Normal function
1 – Lymphangion
2 - Contracted segment (emptying phase)
3 - Relaxed segment (filling phase)
NOTE: Arrows indicate direction of flow.
Modified from Földi's Textbook of Lymphology

In contrast to circulation of the blood where the heart is acting as a pump, lymph is transported by the intrinsic contractions of the lymphangia, a process referred to as lymph-angio-activity. The frequency of contractions is determined by autonomous regulation through the sympathetic nervous system and the lymph volume. When lymph volume stretches the vessel wall, its smooth muscle responds with a contraction. The frequency of contractions amounts to 6-10 x/min at rest but may increase to 10 times that amount during exercise. An increase of lymph fluid due to physical activity, heat, or inflammation results in an increase in lymph time volume due to increased pulsation frequency and higher filling amplitude of the lymphangia. In addition, lymph transport is supported by **extrinsic factors** such as:

- the contraction of the skeletal muscle (muscle and joint pump)
- arterial pulsation, respiratory pressure changes
- negative pressure in central veins
- external pressure such as with Manual Lymph Drainage (MLD).

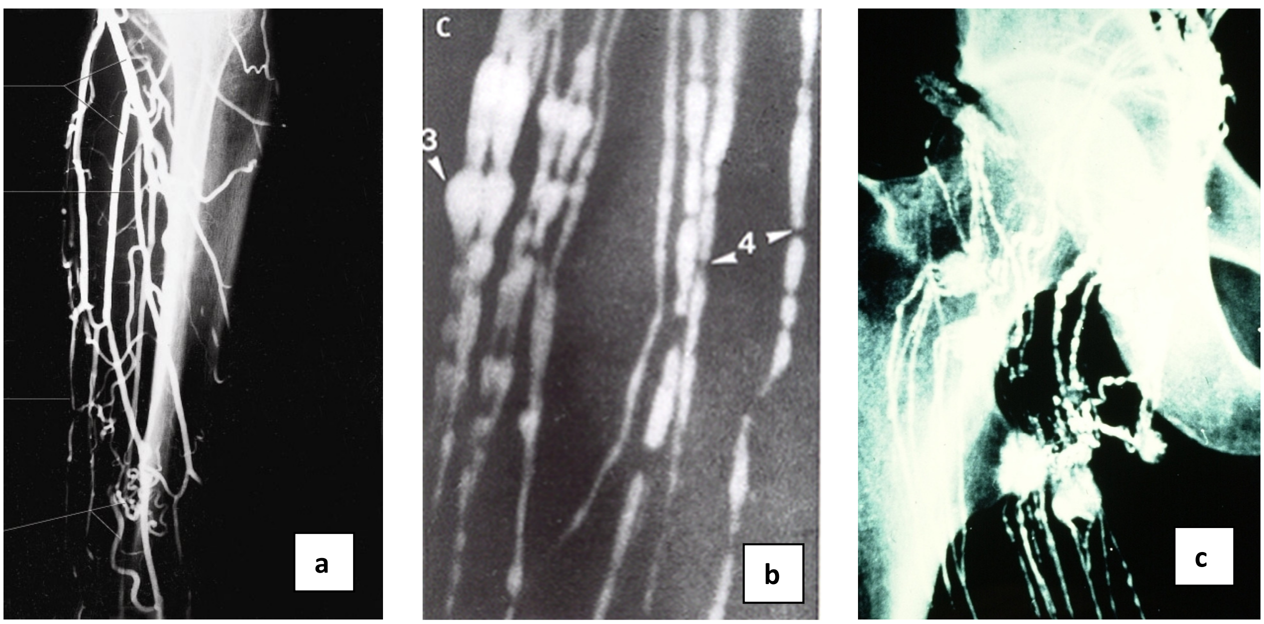


Fig. 11 Comparison of a venogram of the lower extremity veins (a) vs. a lymph-angiogram (aka lymphography) of the lower extremity collectors (b) and lymph nodes (c).

Collectors are differentiated as either superficial or deep, based on location. The superficial collectors are located in the subcutaneous fat tissue and drain the skin and the subcutis. The individual collectors run relatively straight and are connected with each other through numerous connections (anastomoses). In the extremities and the trunk the deep collectors are located below the fascia. They are usually larger in diameter than the superficial collectors and they drain related muscles, joints, and ligaments. As a rule, they run within a sheath along with the deep arteries and veins. Like the veins, superficial and deep collectors are networked via so-called perforators (cross connections).

Indocyanine Green Imaging of the Lymphatic System

New technology using indocyanine green (ICG) enables us to visualize the superficial lymphatic system in real time. Indocyanine green (ICG) is a green colored medical dye. After injection into the skin ICG is taken up by the lymphatics to map lymphatic function, using a special infra-red camera. Depending on the camera settings, the images are recorded in black and white or green.

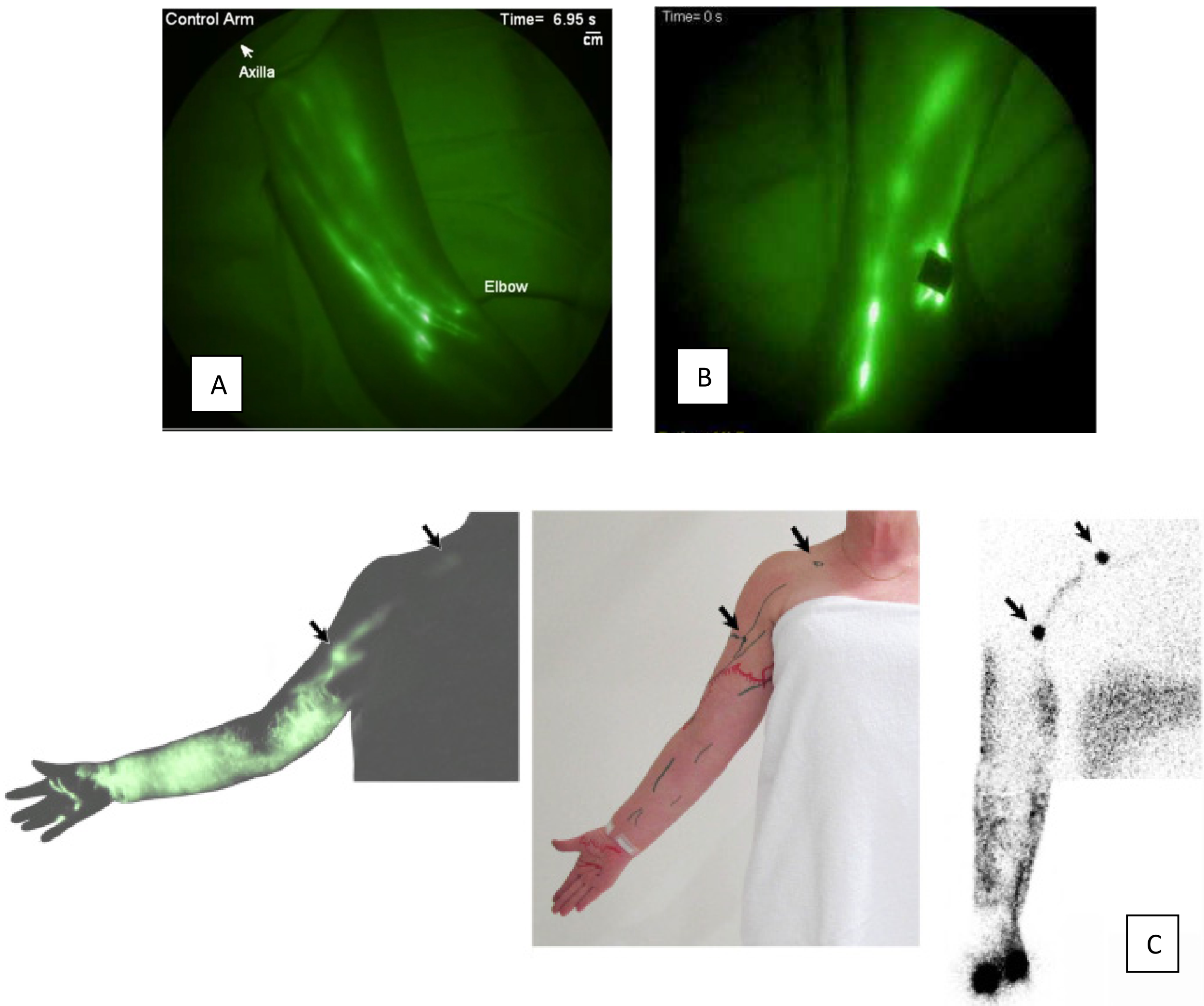


Fig. 12 A and B: Translation of Near-Infrared Fluorescence Imaging Technologies: Supplemental Video 1 & 2; *YouTube* C: ICG lymphography in a patient with lymphedema. Comparison of ICG lymphography and tracing photo (left and center) and Lymphoscintigraphy image (right) in the same patient. *Suami et al. 2019*

The Deep Lymphatic System

Lymph Trunks and Ducts[1,8,10]

Large lymph vessels are referred to as trunks and ducts. Lymph trunks collect fluid from the organs, the extremities and the related quadrants of the trunk. The ducts eventually transport approx. 4-6 liters per day (equals ~4-6 quarts per day) of lymph into the venous circulation.

The largest lymphatic vessel in the human body is the thoracic duct. It is approx. 2 – 5 mm in diameter and 40 cm long. Deep in the trunk, it parallels the spine from L2 to the left venous angle (juncture between the left internal jugular and subclavian veins). Because it penetrates the diaphragm and runs through the chest into the root of the neck, it can be subdivided into an abdominal, thoracic, and cervical part. The abdominal portion of the thoracic duct is a sack-like enlargement which is called the cisterna chyli.

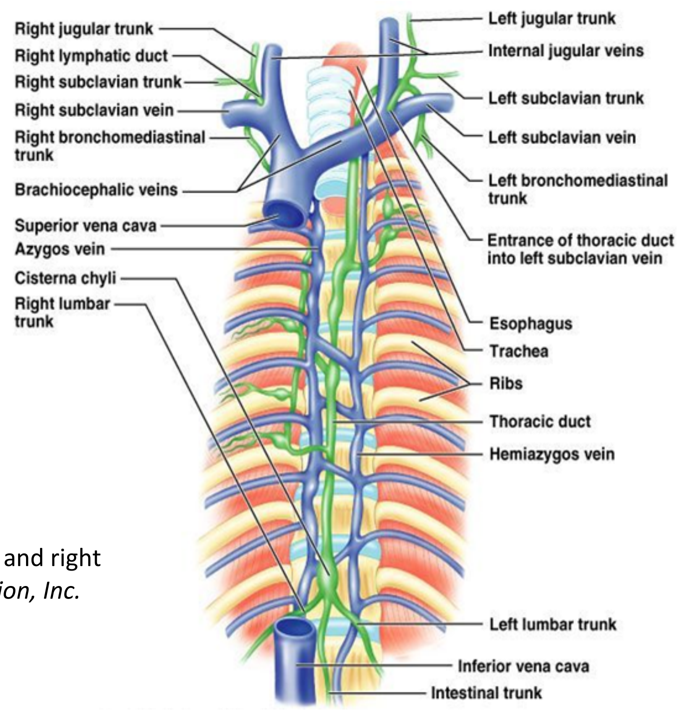


Fig. 13 Illustration of the thoracic duct and right lymphatic duct. *Pearson Education, Inc.*

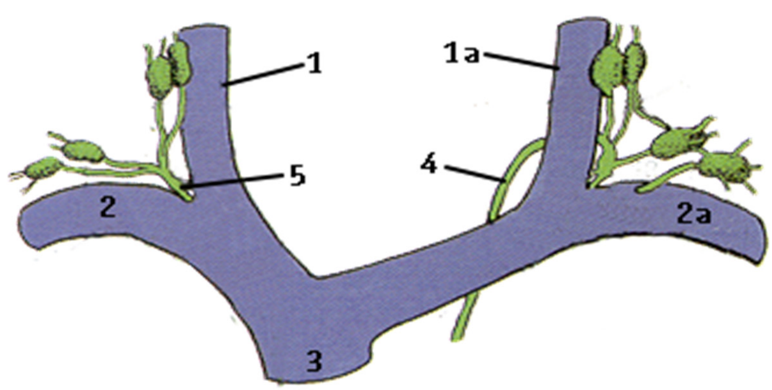


Fig. 14 Right and left venous angles: **1 and 1a** Internal jugular veins **2 and 2a** Subclavian veins **3** Superior vena cava **4** Thoracic duct **5** Right lymphatic duct. *Modified from Földi's Textbook of Lymphology*

From the **upper extremities (UE)** and the adjacent trunk quadrants, the fluid is transported into the axillary lymph nodes, and from there, via the bilateral subclavian trunks, into the thoracic duct on the left side and the right lymphatic duct on the right. The cervical lymph nodes drain lymph via the bilateral jugular trunks into the thoracic duct on the left, and right lymphatic duct on the right. From the bronchi, lungs, and the mediastinum, the lymph fluid reaches the ducts via the broncho-mediastinal trunks.

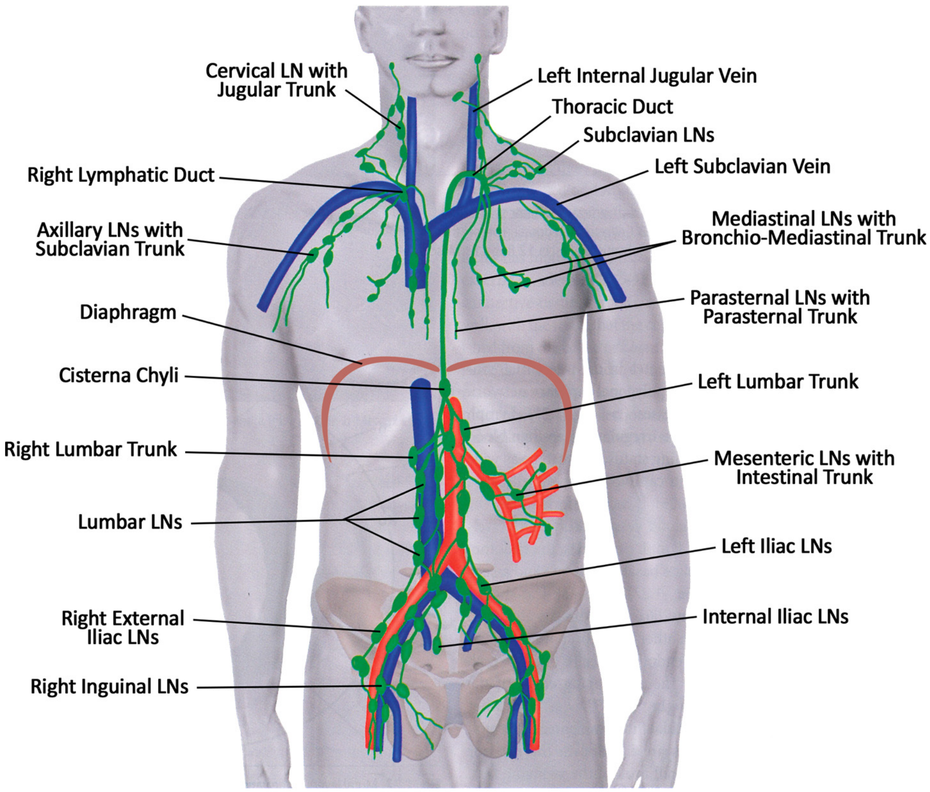


Fig. 15 Major lymphatic trunks and ducts of the human body. *Modified from Földi's Textbook of Lymphology*

The **lymphatic trunks of the upper body** are:

- **Right and left jugular trunk** - from the cervical lymph nodes to the thoracic duct (left side of body) and the right lymphatic duct (right)
- **Right and left subclavian trunk -** from the axillary lymph nodes to the thoracic duct (left) and the right lymphatic duct (right)
- **Right and left broncho-mediastinal trunk** - from the bronchi, lungs and mediastinum to the thoracic duct (left) and the right lymphatic duct (right)

From the **lower extremities (LE)** and the adjacent trunk quadrants, lymph is transported into the inguinal lymph nodes and from there, via the right and left lumbar trunks, to the cisterna chyli, the beginning of the thoracic duct. The intestinal trunk also transports fluid to the cisterna chyli from the small intestines. After a meal, due to the absorption of fat into the intestinal trunk, the contents of the intestinal lymph vessels appear cloudy (milky-white) in color. Because of its milky-white appearance, the intestinal lymph is called chyle.

The **lymphatic trunks of the lower body** are:

- **Right and left lumbar trunks** - from the inguinal lymph nodes to the cisterna chyli
- **Intestinal trunk** - from the small intestines to the cisterna chyli

The central (deep) lymphatic trunks and ducts are arranged asymmetrically. The lymph fluid of the lower body (everything below the diaphragm), as well as the left upper body, is carried via the thoracic duct to the left venous angle. The right upper body is eventually drained via the right lymphatic trunk into the right venous angle (Fig. 16).

The thoracic duct drains approx. ¾ of the body's lymph into the left venous angle (subclavian vein). The right lymphatic duct drains approx. ¼ of the body's lymph into the right venous angle (subclavian vein).

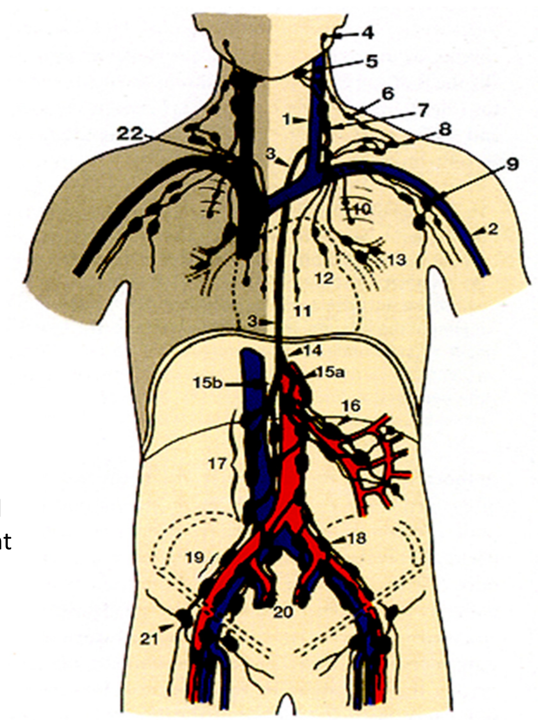


Fig. 16 Three-quarters of the body empties lymph fluid via the thoracic duct into the left venous angle.
The right upper quadrant, right upper extremity and the right side of the head and neck drain via the right lymphatic duct into the right venous angle.
Földi's Textbook of Lymphology

Lymph Fluid and Lymph Nodes[1]

Lymph fluid (lymphatic load) consists of:

- **Protein**
- **Water**
- **Cells (RBCs, WBCs, lymphocytes)**
- **Waste products and other foreign substances**
- **Fat (intestinal lymph, aka chyle)**

75-100 grams of protein are transported by the lymph vessels per day. This equals approximately ½ the amount of proteins circulating in the systemic circulation. In addition, the lymphatic system is able to carry foreign protein, lymphocytes, cancer cells, cell debris, and bacteria. From the interstitium, water is also absorbed and transported through the lymphatic system. In the small intestines, long-chain triglycerides, cholesterol, and the fat-soluble vitamins A, D, E and K are absorbed into the lymphatic system. The intestinal lymph is called chyle.

There are **600-700 lymph nodes** in the human body. The majority of lymph nodes are found in the abdomen (intestines), but the head and neck region also contain a large quantity. Other lymph node stations are found in the axilla and inguinal areas. Lymph nodes vary in size and shape. They are 2 – 30 mm long and are oval, round, bean, or kidney-shaped. A strong connective-tissue capsule protects a dense filter-like network inside.

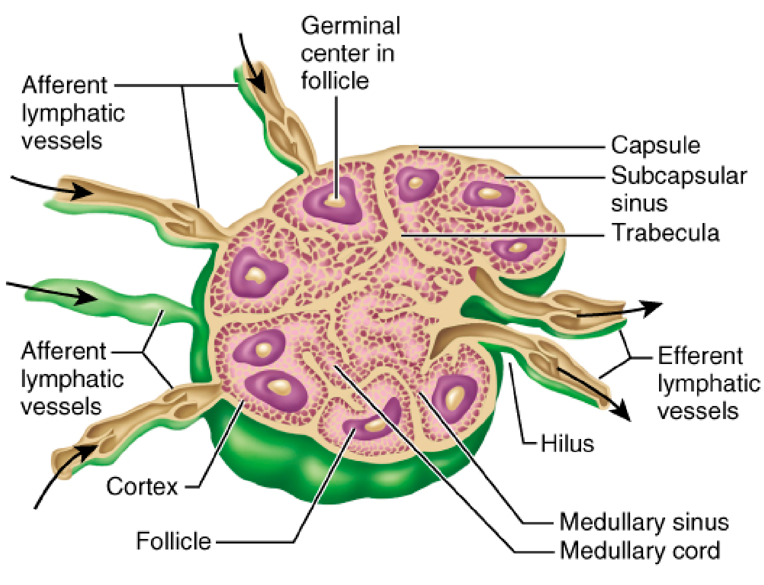


Fig. 17 Lymph node with afferent and efferent lymph vessels. *hypervibe.com*

The functions of the lymph nodes are:

- **Filtration of noxious matter** such as bacteria, toxins and dead cells. Due to the branched sinus system, the lymph flow is slowed, allowing macrophages to better catch and phagocytize harmful substances.
- **Storage of lymphocytes** (white blood cells). Lymphocytes are important in fighting infections and enhancing the body's immune capabilities.
- **Regulation of the concentration of protein in the lymph.** As the lymph flows through the node, excess water is reabsorbed into blood capillaries.

Lymph nodes are generally located in adipose tissue and are therefore not palpable. Enlarged, easily-palpable nodes are always suspicious. Frequently, infections in the drainage areas of the nodes will cause enlargement and pressure-sensitivity. However, enlarged lymph nodes can also be indicative of malignant disease (cancer). In slender, athletic people, inguinal lymph nodes are easily palpable because the upper-thigh fascia forms a firm backing so that the lymph nodes cannot move away under palpation.

Lymph nodes have more afferent than efferent lymph vessels. Numerous afferent lymph vessels carry lymph into the node(s), whereas a small number of efferent lymph vessels leave the nodes at the "hilus." The lymph-node hilus is also the place where arteries and veins enter and exit.

Each lymph node and lymph node group receive lymph from a specific region of the body. In regard to the superficial lymph system, these regions are delineated by "lymphatic watersheds." On the trunk, the direction of flow changes at the lymphatic watersheds. Lymph vessels on either side of the watershed transport lymph fluid to the left/right side of the trunk and to the upper (axillary)/lower (inguinal) lymph nodes, respectively.

Lymph Nodes and their Tributary Regions

Table 1 Lymphatic tributary regions of the head and neck region

Lymph Node Group	Location	Tributary Areas	Drainage
Submental LN	2-3 nodes below the chin	Lower lip, gums, tip of tongue, chin	Deep cervical lymph nodes
Submandibular LN	5-8 nodes in the area of the submandibular glands	Lips, external cheeks, medial eye lids, teeth, gums, tongue, floor of mouth, cheek mucosa, nose	Deep cervical lymph nodes
Preauricular LN	2-4 nodes in front of the ear at the parotid gland	Front of the auricle, lateral eye lids, parotid, forehead	Deep cervical lymph nodes
Retroauricular LN	1-2 nodes behind the ear	Auricle (chiefly posterior surface), neighboring scalp, middle ear	Deep cervical lymph nodes
Occipital LN	2-3 nodes above insertion of the trapezius muscle	Skin of posterior head, base of head	Deep cervical lymph nodes
Cervical LN	Along the sternocleidomastoid muscle and the internal jugular vein, in the supraclavicular fossa	Ear, parotid gland, jaw angle, neck, back of head, tonsils	Deep cervical lymph nodes and jugular trunk
Supraclavicular LN	Supraclavicular fossa	Lymph fluid from cervical LN, skin between clavicle and spine at scapula WS's	Jugular trunk

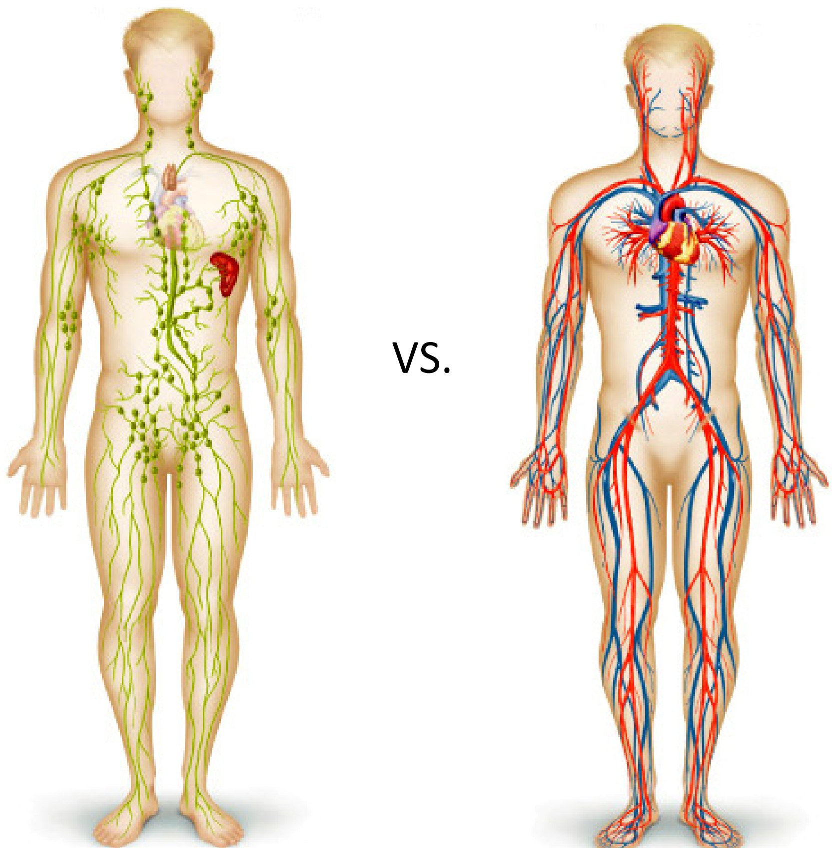
Table 2 Lymphatic tributary regions of the upper body

Lymph Node Group	Location	Tributary Areas	Drainage
Axillary LN	25-30 nodes prefascial in the armpit, grouped around the large vessels	Upper extremities, upper trunk quadrants and breasts	Deep axillary lymph nodes, infra and supraclavicular nodes, subclavian trunk
Pectoral LN	Next to the major pectoral muscle, in the area of the third serratus digitation	Breasts, especially lateral quadrants	Deep axillary lymph nodes
Cubital LN	Cubital fossa	Ulnar skin of forearm, bones, muscle and connective tissue of forearm and hand	Deep axillary lymph nodes

Table 3 Lymphatic tributary regions of the lower body

Lymph Node Group	Location	Tributary Areas	Drainage
Lumbar LN	Lumbar area	Testicles/ovaries, uterus, kidneys, adrenal glands	Lumbar trunks
Iliac LN	Pelvis	Inguinal lymph nodes, bladder, prostate, seminal vesicles, uterus, upper portion of vagina	Lumbar trunks
Inguinal LN	Approx. 10 nodes prefascial in the groin	Lower trunk quadrant (trunk wall below navel line, lumbar and gluteal region), external genitals, lower extremities	Pelvic lymph nodes (lumbar trunks)
Popliteal LN	Popliteal fossa	Skin, deep parts of the lower leg	Deep inguinal lymph nodes

Comparison between Lymph Flow and Blood Flow[1,3,4,6,8,9]



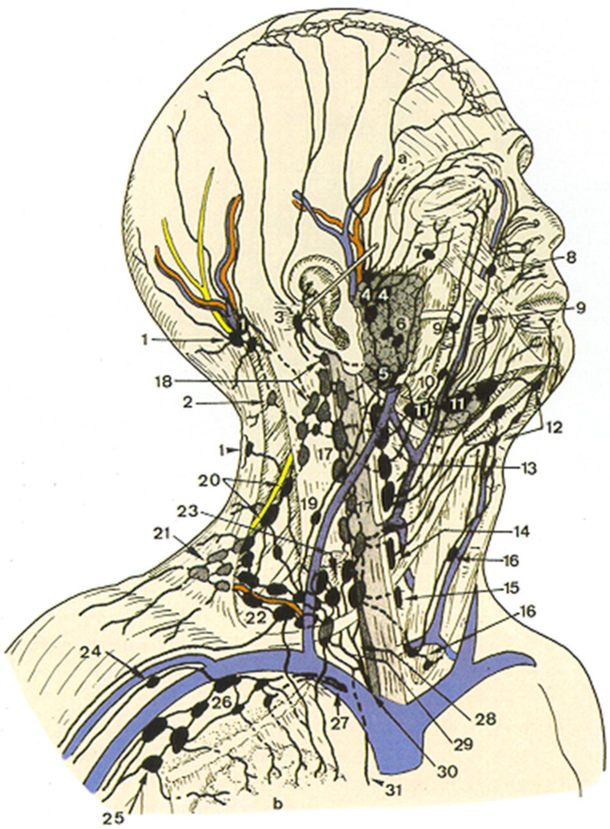
A VS. B

Fig. 18 Diagram of the lymphatic system (A) and the blood circulatory system (B).

Table 4 Comparison of the lymph system versus blood circulatory system

LYMPH SYSTEM	BLOOD CIRCULATORY SYSTEM
One way	Circular
Approx. 4-6 liters/day	Approx. 7200 liters/day (5 liters/minute)
Fluid moved by intrinsic contractions of lymph collectors	Fluid moved by central pump (heart) and calf muscle pump
Peripheral lymphatic pressure is unaffected by dependency	Dependency significantly increases venous pressure
Obstruction leads to collection of *high* protein fluid (>1.5gm/dl)	Obstruction leads to collection of *low* protein fluid (<1.0 gm/dl)
Long latency period between injury and clinical appearance	Long latency period between injury and clinical appearance
Lymph is filtered by lymph nodes	Blood is filtered by the kidneys, liver, and spleen

Illustrations of Important Lymph Node Locations[1]



Cervical (Head & Neck) Lymph Nodes

Fig. 19 Lymph nodes of the head and neck.

1. Occipital lymph nodes - Occipital region and upper part of the skin of the neck.
3. Retroauricular lymph nodes - Parietal area (posterior auricle)
4. Preauricular/parotid lymph nodes - Forehead, upper eye lid, and lateral part of the lower eye lid (auricle)
11. Submandibular lymph nodes - Nose, upper and lower lip, medial part of the lower lid, cheek
12. Submental lymph nodes - Chin, medial part of lower lip

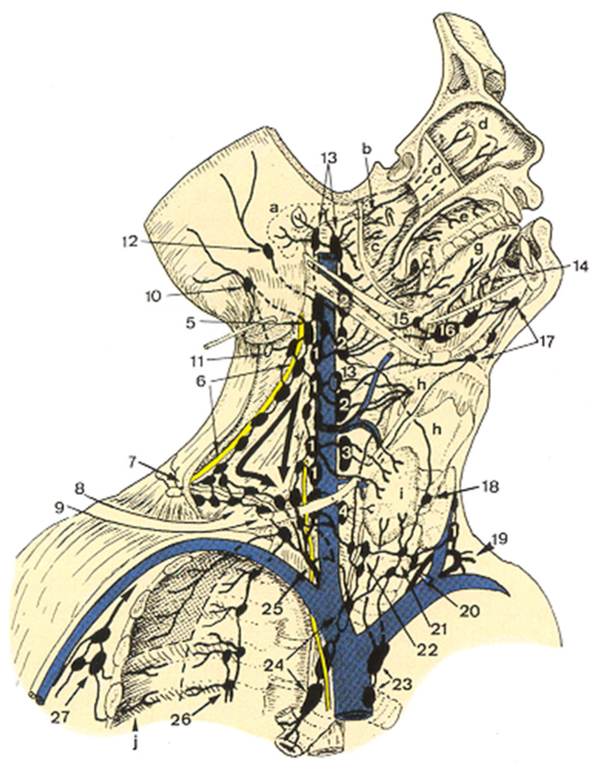
Földi's Textbook of Lymphology

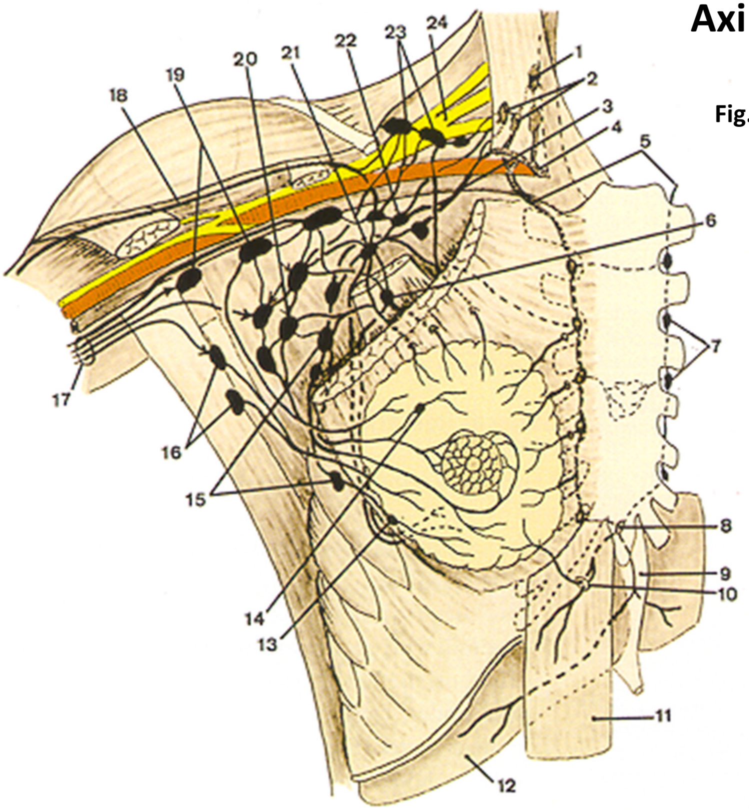
Deep Cervical Lymph Nodes

Fig. 20 Deep cervical lymph nodes.

1. Internal jugular lymph nodes
6. Lymph nodes accompanying the accessory nerve
8. Supraclavicular lymph nodes

Földi's Textbook of Lymphology





Axillary & Parasternal Lymph Nodes

Fig. 21 Axillary lymph nodes.

1.+2. Jugular lymph nodes
3. Subclavian trunk
4. Right lymphatic duct
5. Parasternal trunk
6. lymph node (interpectoral LN)
7. Parasternal lymph nodes
8. Prepericardic l.n.
9. Falciform ligament
10. Epigastric pathway
11. Rectus abdominis muscle
12. Liver
13. Paramammary lymph node
14. Premammary lymph node
15. Pectoral lymph nodes
16. Subscapular lymph nodes
17. Medial upper arm bundle
18. Deltoid bundle
19. Lateral axillary lymph nodes
20. Central axillary lymph nodes
21. Subpectoral lymph nodes
22. Infraclavicular lymph nodes
23. Supraclavicular lymph nodes
24. Brachial nerve plexus

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Level 1-3 Axillary Lymph Nodes

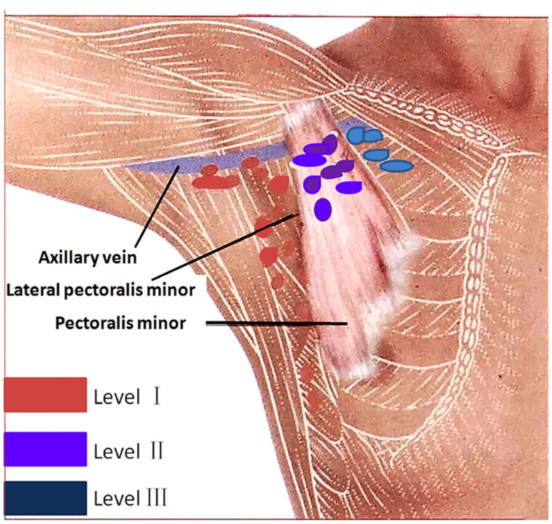

Fig. 22 Three levels of axillary lymph nodes.
figshare.com

Intercostal Lymph Nodes and Collectors

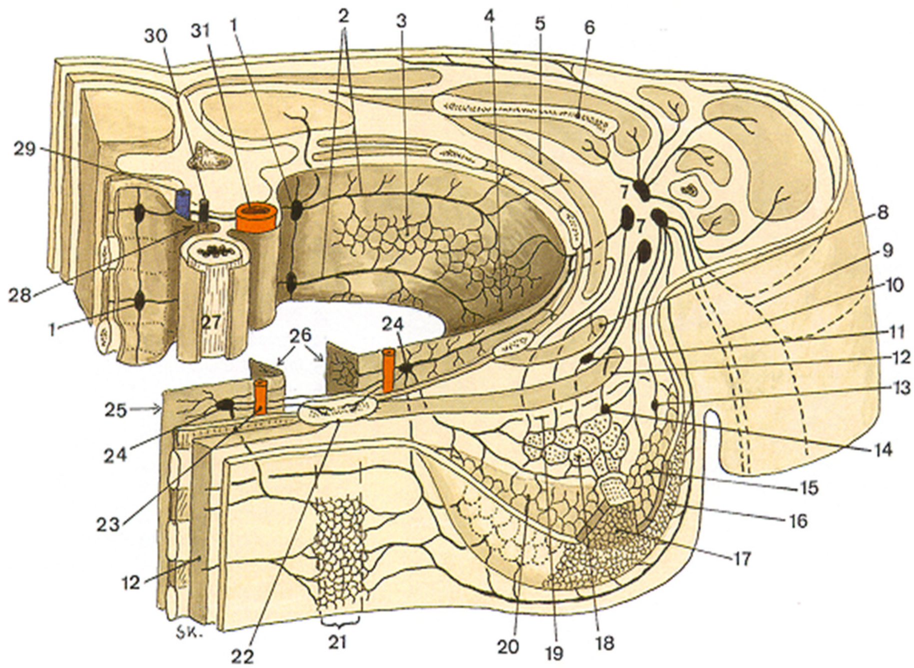

Fig. 23 Intercostal lymph nodes and collectors

1. Intercostal (paravertebral) lymph node
2. Intercostal collector
3. Lymph vessel plexus of the pleura
7. Axillary lymph nodes
10. Medial upper arm bundle
21. Sagittal (median) watershed
22. Parasternal lymph nodes
24. Thoracic duct

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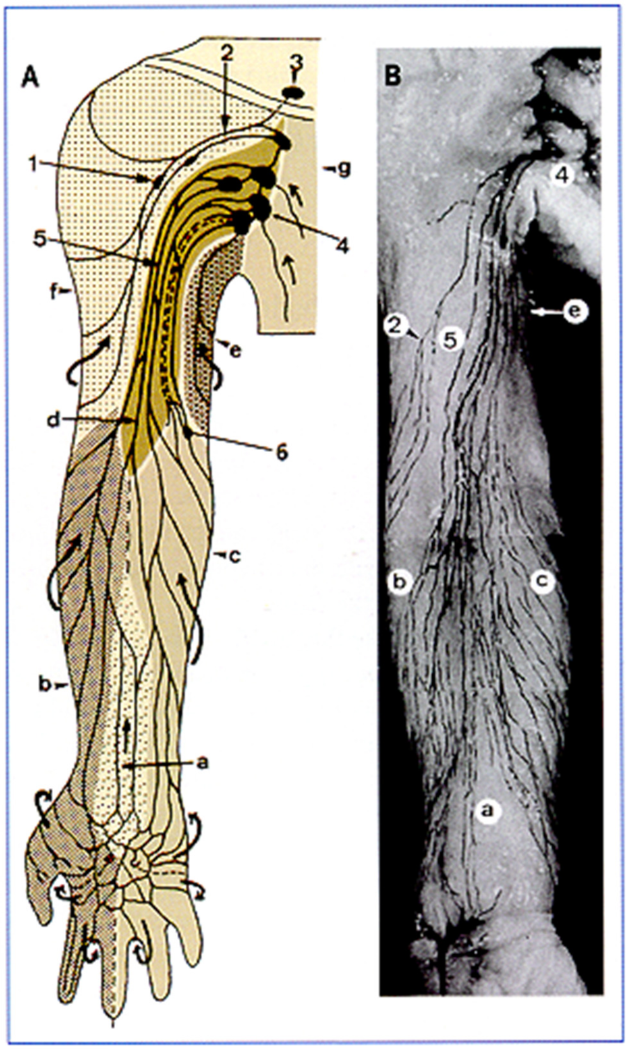
Lymph Vessels and Drainage Areas of the Upper Extremity



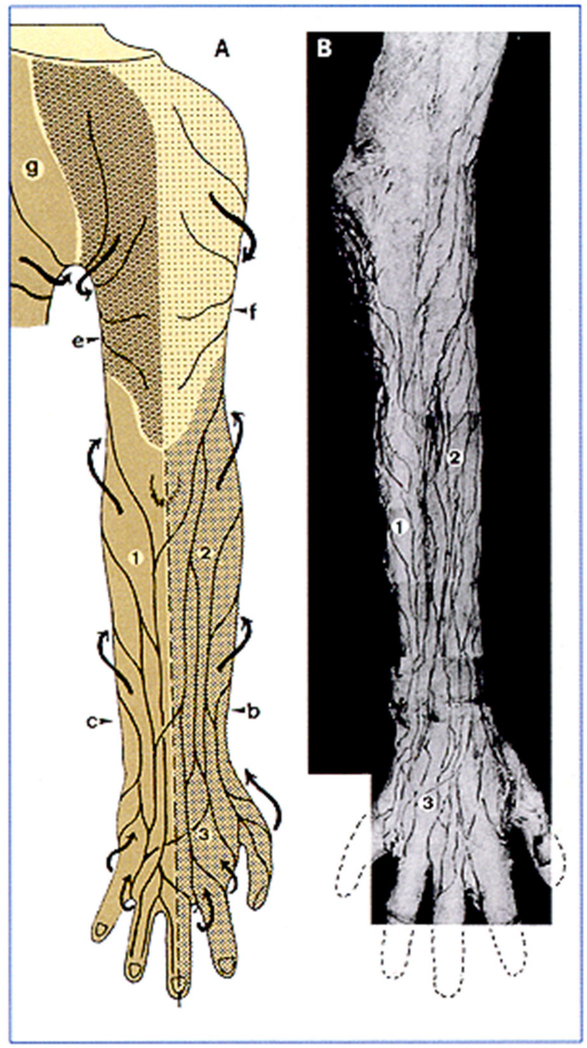


Fig. 24 and 25 Lymph vessels of the upper extremity.

a. Medial forearm bundle
b. Radial forearm bundle
c. Ulnar forearm bundle
d. Medial upper arm bundle
e. Dorso-medial upper arm bundle
f. Lateral upper arm bundle
g. Upper trunk quadrant

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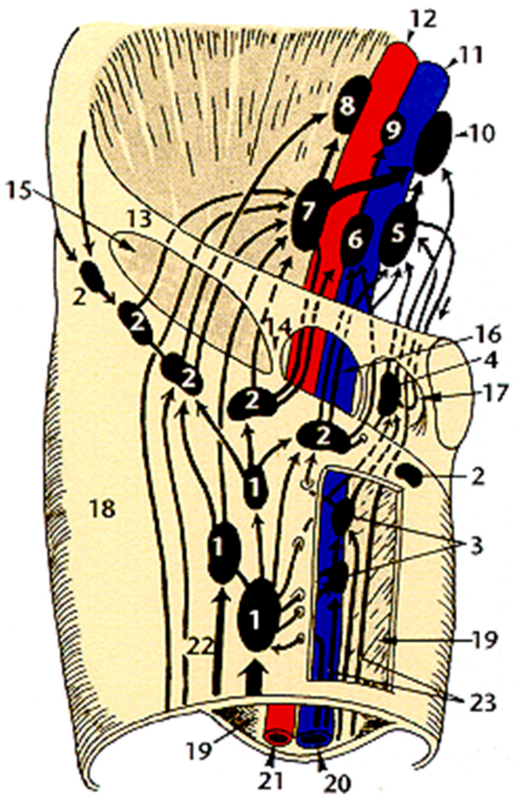
Inguinal Lymph Nodes



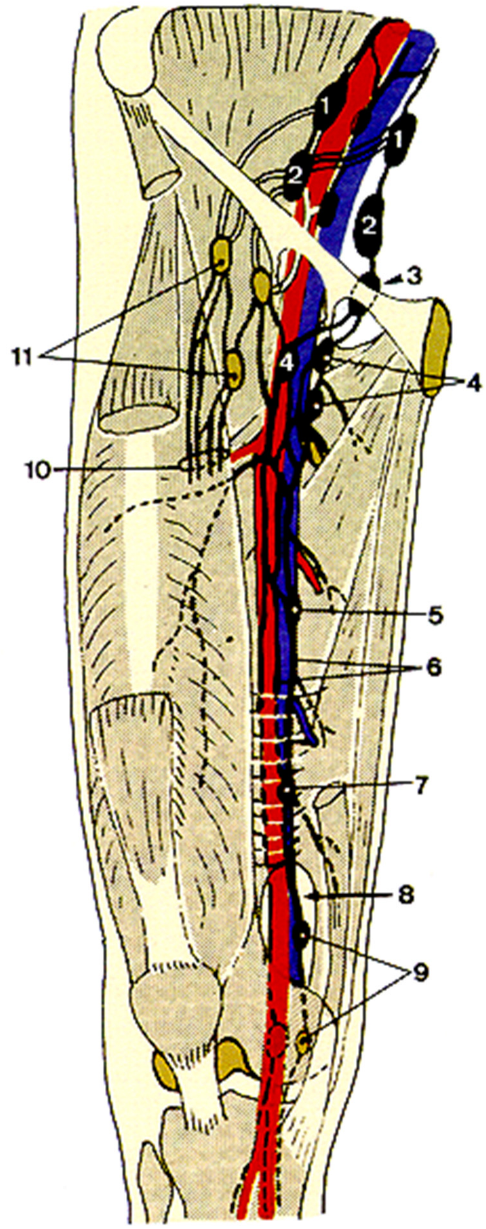


Fig. 26 and 27 Inguinal lymph nodes.
1-2. Superficial inguinal nodes
3. Deep inguinal nodes
4. Rosenmüller's node
5-10. Iliac (pelvic) nodes
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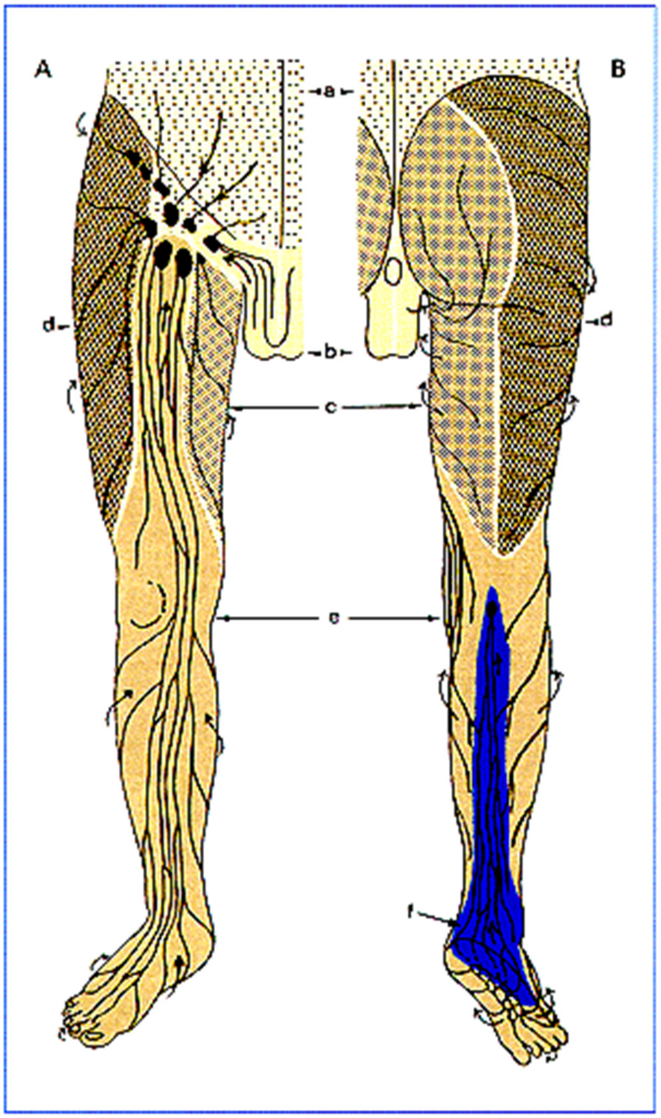
Lymph Vessels and Drainage Areas of the Lower Extremity



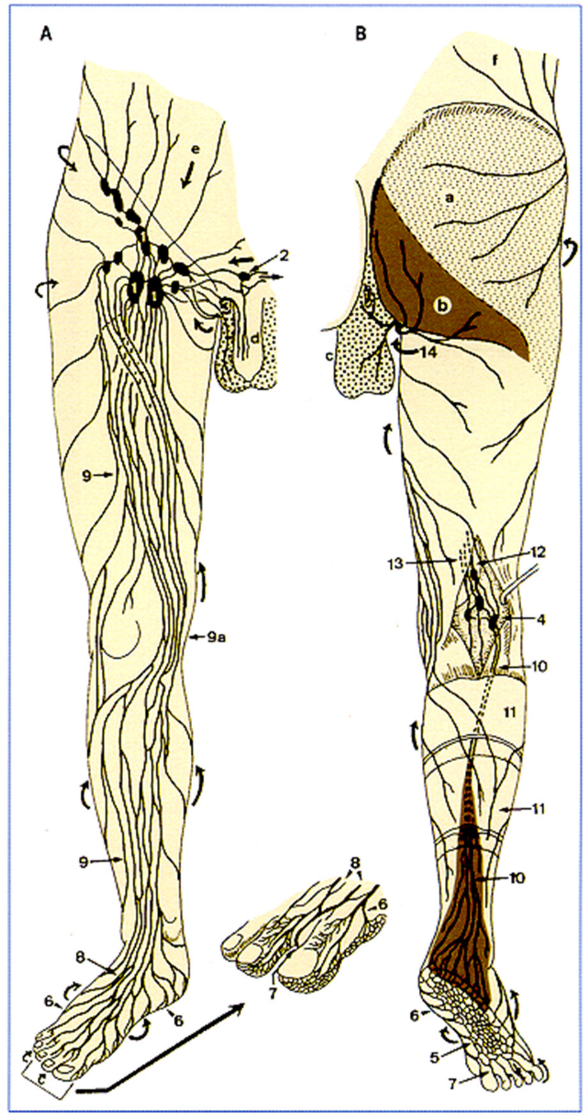


Fig. 28 and 29 Lymph vessels and drainage areas of the lower extremity.
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Lymphatic Anastomoses[1]

Lymph collectors connect across lymphatic watersheds! These connections are referred to as anastomoses and are utilized in Manual Lymph Drainage for moving fluid from a congested to a healthy part of the body. The most prominent areas where lymphatic vessels connect are across the sternum (chest), the upper thoracic spine (back), supra-pubic area (front), sacrum (back) and on the flank (between the anterior and posterior axillary lines).

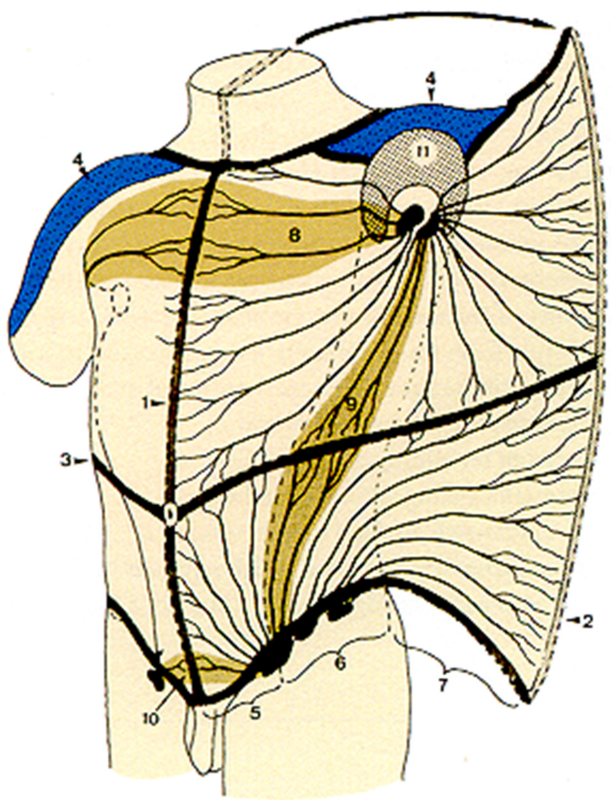

Fig. 30 Lymphatic Anastomoses Pathways

1. Median-sagittal (vertical) WS
2. Posterior sagittal WS
3. Transversal (horizontal) WS
4. Drainage area of the lateral upper arm bundle
5. Anterior thoracic and abdominal walls
6. Lateral thoracic and abdominal walls
7. Posterior thoracic and abdominal walls
8. Axillo-axillary (inter-axillary) anastomoses
9. Axillo-inguinal anastomoses
10. Inter-inguinal anastomoses
11. Amputation plane of the shoulder

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Bonus Pictures

Fig. 31 and 32 Lymph collectors of the lower extremity in a cadaver. *Anatomy Department of the University of Zurich, Switzerland*

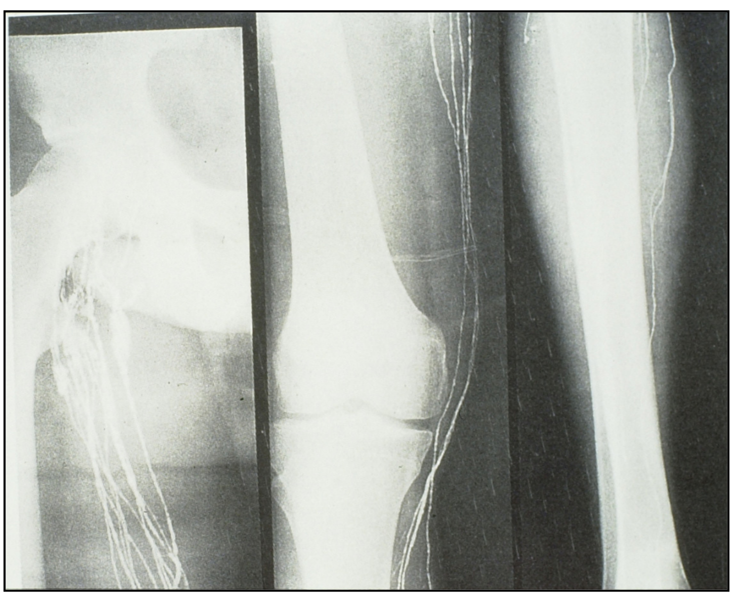

Fig. 33 and 34 Lymphangiogram of the lower extremity. Healthy lymph collectors (left) and dilated lymph collectors in patient with primary lymphedema (right). *N. Browse, 1986*

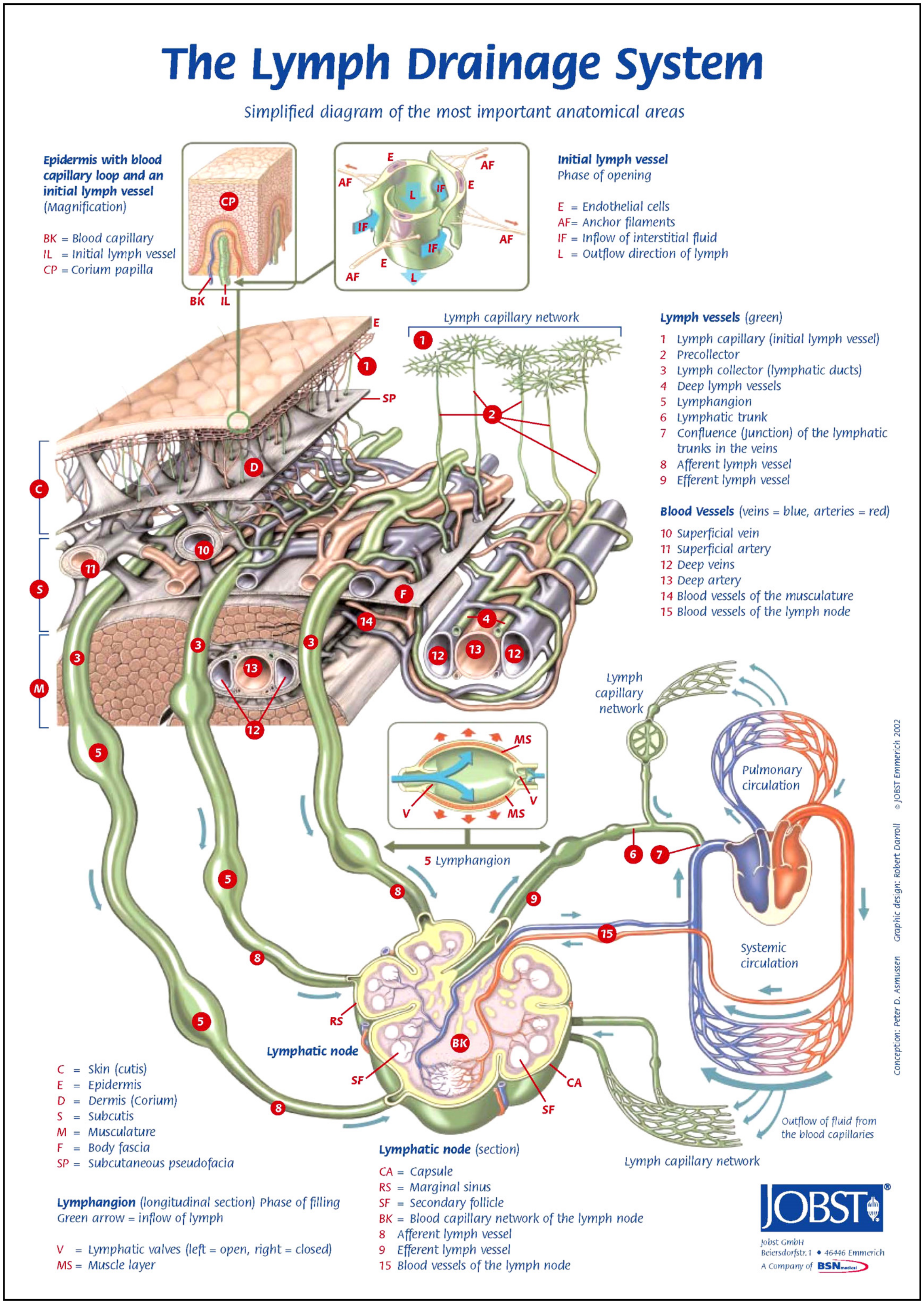

Fig. 35 Lymph Drainage System Poster available for download at: jobstcompressioninstitute.com/Resources/Literature

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Physiology and Pathophysiology of the Lymphatic System

Introduction

A healthy lymphatic system is crucial to maintain homeostasis in the body. Therapists working with MLD must have a basic understanding about its function as well as the fluid dynamics at the capillary level. It is important to understand not only the normal functions of the lymphatic system, but also the conditions which may cause changes the fluid exchange in the tissues. This will impact the function of the lymphatic system.

The Functions of the Lymphatic System [2,3,4,5,6]

1. **The lymphatic system prevents edema by returning protein and capillary filtrate (water) to the systemic circulation.**

   The lymphatic system transports fluid (lymph) from the interstitium back into the systemic circulation, thus preventing fluid accumulation (swelling/edema) in the tissues (Fig. 1). Most important is the removal of protein molecules from the tissues because they cannot be removed by absorption directly into the blood capillaries. The return of proteins from the interstitium to the blood is an essential function without which we would die within about 24 hours.

2. **The lymphatic system absorbs fat and fat-soluble vitamins from the small intestine.**

   Lymph capillaries of the small intestine, called lacteals, absorb fat and fat-soluble vitamins. After the ingestion of fat, the lymph fluid from the small intestine takes on a milky-white appearance and is referred to as “chyle” or “chylous fluid.” The intestinal lymph trunk transports chyle into the cisterna chyli and from there into the thoracic duct before the fluid enters into the left subclavian vein.

3. **The lymphatic system provides immune surveillance by recognizing and responding to foreign cells, microbes, viruses and cancer cells.**

   The lymphatic system circulates lymphocytes and other white blood cells and makes them available to fight off bacteria and viruses that are potentially harmful to the human body.

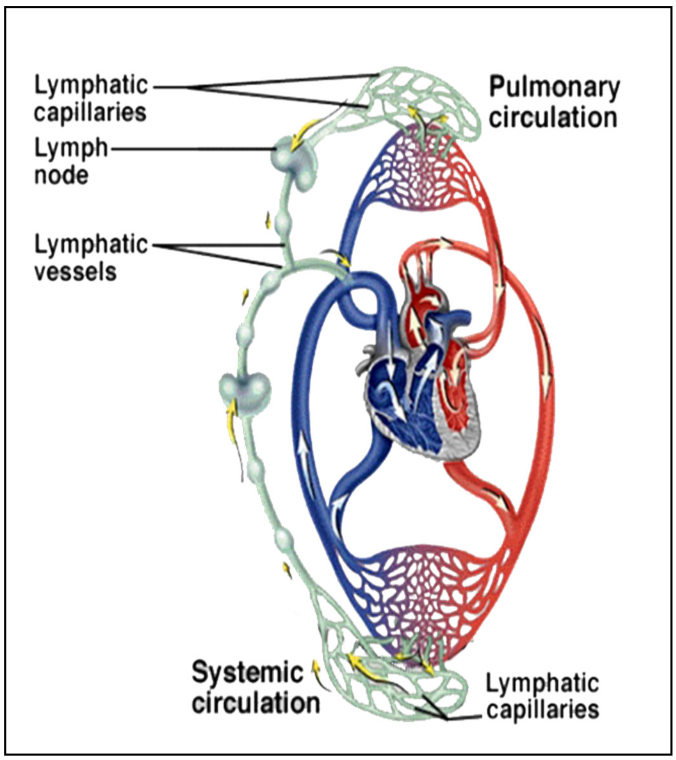

Fig. 1 Diagram of the relationship between the blood circulatory and lymphatic systems.

The Interstitium and the Fluid Exchange at the Capillary Level [4,5]

To understand the development of lymph fluid, we need to take a closer look at the fluid exchange at the capillary level and where in the body it occurs. The exchange of nutrients, oxygen and water happens between the blood capillaries and the tissues (interstitium). The two processes that are necessary for this exchange are diffusion and filtration. Let's start by taking a look at the interstitium.

The Interstitium

The **interstitium** is where the nutrient and fluid exchange occur. It can be compared to a gelatinous substance and is the "glue" that keeps our cells together and provides a support structure for our organ systems.[3] Approximately 1/6 of the human body consists of interstitium which is made up of proteoglycan filaments, collagen fiber bundles, and fluid.

Blood capillaries release water through filtration and allow some proteins into the interstitium. However, the protein concentration in the interstitial fluid is always lower than in the plasma (blood).

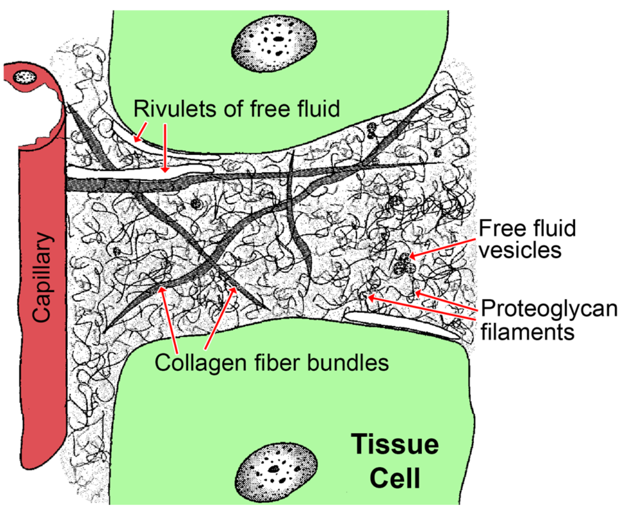

Fig. 2 The structure of the interstitium. Proteoglycan filaments are everywhere in the spaces between the collagen fiber bundles. Free fluid vesicles and small amounts of free fluid in the form of rivulets occasionally also occur.

To understand the interstitium, imagine the interstitium as a bowl of Jello with pineapple pieces in it. The pineapple pieces represent the tissue cells and the Jello is the "glue" that holds the tissue cells together. Without the Jello, the pineapple pieces (cells) would be loose and unable to form tissue.

Now, let's take a look at the two processes that facilitate the fluid and oxygen exchange in the interstitium.

Diffusion

Diffusion is the most important process for the nourishment of the tissues! It is the movement of molecules of a substance (gas or liquid) from a place of higher concentration to one of lower concentration. Diffusion is caused by the tendency of the molecules to strive toward equilibrium. This movement of the molecules depends on the size of molecules, the difference in concentration, distance, the total cross-sectional surface and temperature.

Filtration[4,8,9]

Filtration is an additional process which allows water to leave the blood capillary network. This water (filtrate) along with protein found in the interstitium must be removed and returned into the circulatory system by way of the lymphatic system.

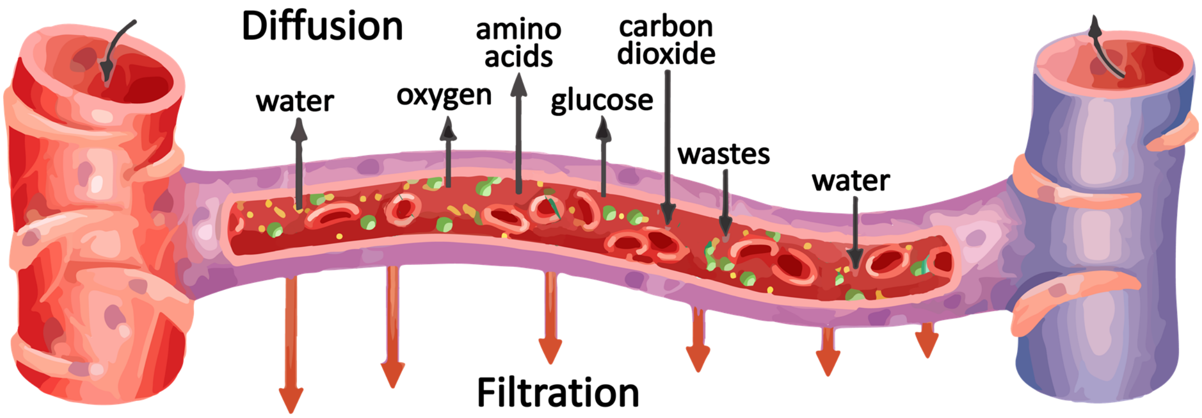

Fig. 3 Diffusion (upper part of the diagram) occurs continually in the human body, e.g. the wall of the blood capillaries is permeable for plasma and small organic and small inorganic molecules. The entire exchange of oxygen and carbon dioxide happens through diffusion. **Fluid movement though filtration** (lower part of diagram). The entire filtrate will become part of the lymphatic load which needs to be removed from the interstitium by the lymphatic system.

Lymphatic Load

The term Lymphatic load (LL) is used to describe the substances that are moved through the lymphatic system. The main components of lymph fluid are protein, water, cells and fat. Remember; Nutrients and oxygenated blood are transported through the high-pressure arterial system into the blood capillaries. After the nutrients and oxygen exchange has occurred, the venous system carries the deoxygenated blood back to the heart. However, protein molecules that have gone from the blood capillaries into the tissues along with the water filtrate have to be picked up by the lymphatic system to be returned to the systemic circulation.

Normal Lymphatic Drainage

Transport Capacity and Safety Function of the Lymphatic System[4,5,6,8]

The term lymph time volume (LTV) describes the amount of lymph which is transported by the lymphatic system over a period of time. For example, the lymph time volume of the thoracic duct is estimated to be up to 4-6 l/day in humans. The normal lymph time volume equals about 10% of the maximum possible transport in a healthy lymphatic system. (Fig. 4)

If necessary, the lymphatic system is able to activate its safety function and respond to an increase in lymphatic load by increasing its lymph time volume (Fig. 5). The lymphatic system is limited in how much lymph it can handle by the filling capacity of the lymphangions and the maximum frequency of lymphangion contractions. This maximum amplitude and frequency is called the transport capacity (TC) of the lymphatic system.

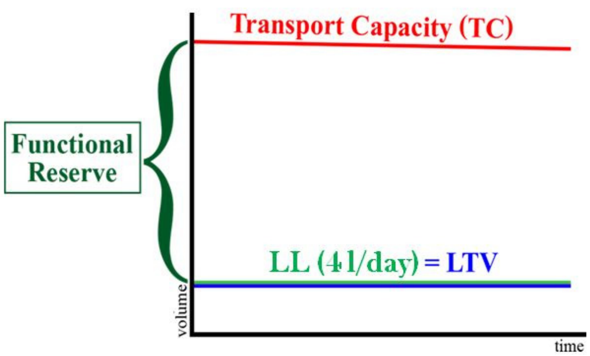

Fig. 4 Diagram showing the relationship between the normal lymph load and the transport capacity. Because the lymph time volume is only about 10% of the maximum transport capacity, the lymphatic system has a large functional reserve.

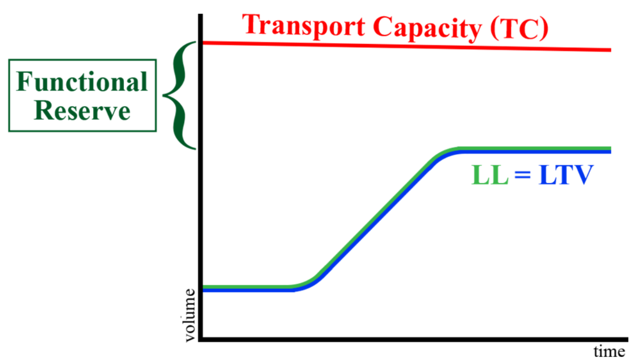

Fig. 5 Diagram showing how the lymphatic system responds to an increase of interstitial fluid (water and/or protein load) - with an increase in lymph capillary uptake and activation of the motor function of the lymph vessels. (The lymphatic system is working harder to meet the increased demand.)

Blood Capillary Pressure[4]

Under normal circumstances, the load on the lymphatic system will fluctuate. It will increase and decrease based on normal physiological processes, e.g. activities of daily living (ADLs). For example, exercise will increase the blood supply to our muscles and skin, which results in an increase in blood capillary pressure, which leads to an increase in filtration. This process is referred to as Active Hyperemia. Let's take a closer look, starting with the blood capillary pressure.

The average blood pressure in the aorta is 100 mmHg; at the largest vein (vena cava), it is only 2–4 mmHg. The blood pressure undergoes a steep drop at the small arteries and **arterioles**.

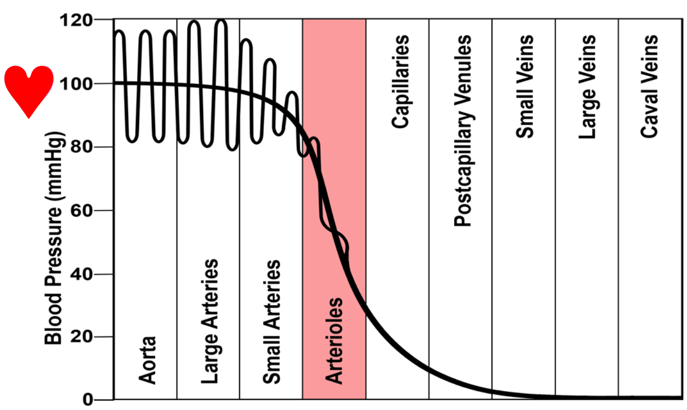

Fig. 6 Diagram showing the average blood pressure in different parts of the systemic circulation.

The muscle in the wall of the precapillary arteriole is regulated by the sympathetic nervous system. This accounts for the resting arterial tone. The vasomotor activity of the precapillary arterioles is regulated by the O^2 concentration and the metabolism of the tissues as well as other influences such as thermal and hormonal fluctuations.

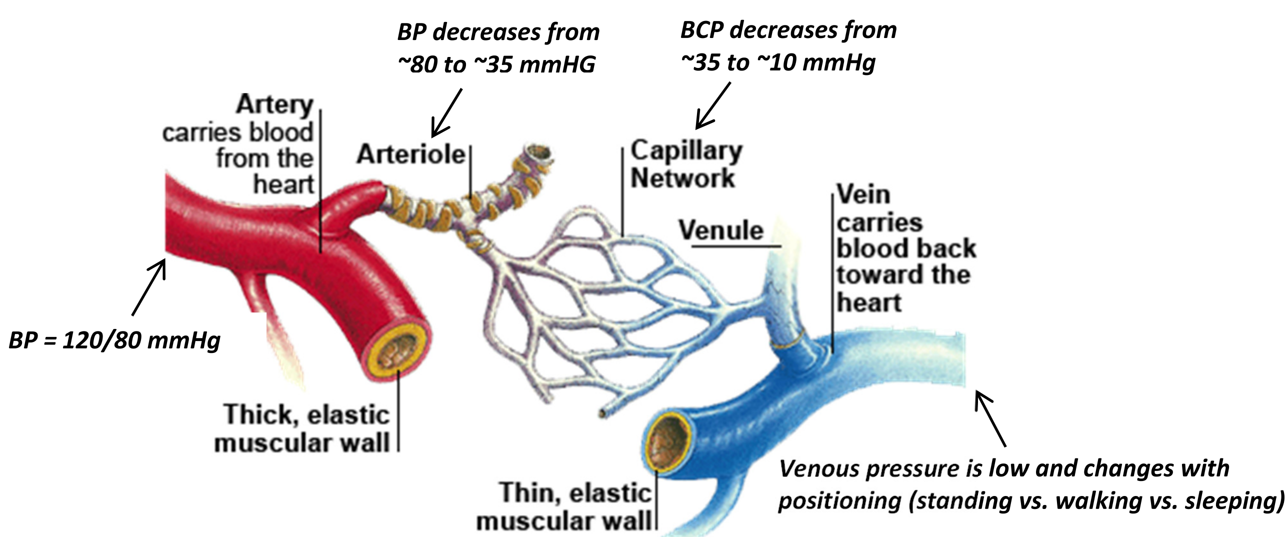

Fig. 7 Precapillary arterioles are rich in smooth muscle fibers. Postcapillary venules have much less muscle tissue in their walls. *Emaze.com*

Active and Passive Hyperemia[4]

Increase in Lymphatic Load through Active Hyperemia:

In cases of increased blood flow from the arterial side, filtration will increase. Therefore, the lymphatic load and lymph time volume will also increase. As long as the lymphatic system is able to adjust to the demand no further consequences for the body are expected, i.e. no edema (swelling) will develop.

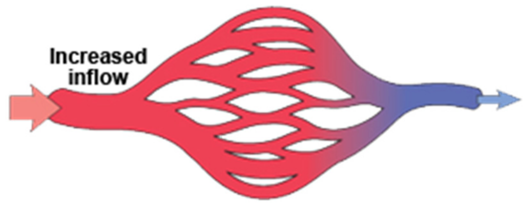

Fig. 8 Comparison of normal capillary perfusion (left) and increased capillary volume in *active* hyperemia (right).

Examples of conditions that will cause Active Hyperemia and subsequent increase the lymphatic load are:

- **Exercise:** Physical activity (exercise) will cause an increase in blood flow which will require the lymphatic system to return more fluid back to the systemic circulation. This is a normal physiological process!
- **Massage:** Vigorous (deep tissue) massage will cause an increase in blood flow which will require the lymphatic system to return more fluid back to the systemic circulation. This is a normal physiological process!
- **Application of heat:** the application of a heating pad will cause an increase in blood flow which will require the lymphatic system to return more fluid back to the systemic circulation. This is a normal physiological process!
- **Inflammation**: Inflammation is the body's response to an illness, injury or something that doesn't belong in the body, like germs or toxic chemicals. It is a normal and important process that facilitates healing, but it will also cause an increase in blood flow which will require the lymphatic system to return more fluid back to the systemic circulation.

Fig. 9 Patient with BLE lymphedema and cellulitis of the LLE.

Increase in Lymphatic Load through Passive Hyperemia:

In cases of venous obstruction (e.g. blood clot) or poor venous return, there is more blood volume in capillaries which increases blood capillary pressure. This state is called **passive hyperemia.** As a consequence of passive hyperemia, BCP increases leading to increased filtration – lymphatic load increases.

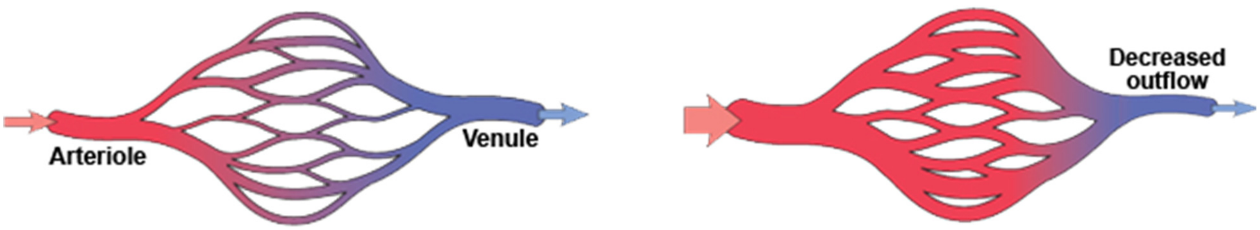

Fig. 10 Comparison of normal capillary perfusion (left) and increased capillary volume through *passive* hyperemia (right).

Passive Hyperemia is usually caused by a pathology, such as:

- **Congestive heart failure (CHF):** In CHF, the heart is not strong enough to pump the blood into the pulmonary circulation, therefore venous blood backs up within the venous system and the capillaries, which causes an increase in blood capillary pressure and increased filtration. This will require the lymphatic system to work harder. However, because of chronically high venous pressure the lymphatic system will not be able to compensate. This patho-physiological process can cause bilateral edema, usually of the lower extremities because of the client's upright position. (Fig. 11). Very often, clients with chronic CHF experience shortness of breath even after light-moderate physical activity and are unable to lay flat in bed.
  MLD in clients with <u>untreated CHF</u> is contraindicated!

Fig. 11 Patient with BLE edema from congestive heart failure.

- **Chronic venous insufficiency (CVI):** Venous insufficiency may be compared with a sluggish venous return. Blood volume backs up into the distal veins where it causes increased pressure (including the capillaries) and increased filtration. The lymphatic system will try to compensate (work harder) to prevent edema and the feeling of heaviness in the legs. CVI is not a contraindication for MLD, however it is important for this client to wear compression.

- **Deep venous thrombosis (DVT):** An acute DVT is a local obstruction in the venous system, usually the lower extremity, however it can also occur in the upper extremity, especially in cancer patients (Fig. 12). The blood clot prevents normal venous return and increases the pressure in the venous system and blood capillaries distal from the clot. An acute (untreated DVT) is a pathophysiological process which can cause pain, discoloration of the affected area and unilateral edema.
  MLD in clients with an <u>untreated DVT</u> is contraindicated!

- **Tumor growth:** A tumor (usually malignant) can cause venous obstruction. The tumor prevents normal venous flow and increases the pressure in the venous system and blood capillaries distal from the tumor site.
  An <u>untreated malignancy</u> is a contraindication for MLD!

Fig. 12 Patient with LUE lymphedema exacerbated by DVT in the left subclavian vein.

Increase in Lymphatic Load through Hypoproteinemia

Hypoproteinemia is a condition where there is an abnormally-low level of protein in the blood. The decrease of plasma protein in the systemic circulation causes increased capillary filtration. As a consequence of hypoproteinemia, lymphatic load increases.

Hypoproteinemia can be caused by:

- **Malnutrition:** Not enough protein intake over a prolonged period of time.
- **Malabsorption Syndrome:** Loss of nutrients and proteins, for example after bariatric surgery (gastric sleeve or bypass surgery).
- **Hepatic failure (liver disease):** Failure to build and supply enough protein molecules into the systemic circulation, e.g. liver cirrhosis.
- **Nephrotic syndrome (kidney disease):** Loss of protein through the urine.
- **Protein-losing enteropathy**: (intestinal disorder); Loss of protein through the stool.

Performing MLD on a client with edema caused by hypoproteinemia is not contraindicated, however, the cause of the condition must be medically treated!

Fig. 13 Patient with BLE edema as a result of malnutrition and subsequent low protein concentration in the plasma.

Remember: **Active Hyperemia** (increase blood supply to the capillaries), **Passive Hyperemia** (venous obstruction or decreased venous return)**, and/or Hypoproteinemia** (decreased plasma protein concentration) can overwhelm the lymphatic system. If the lymphatic system is able to compensate, no visible and/or palpable signs of edema will exist. If the lymphatic system is unable to compensate, or injured, edema will start to develop on the basis of either a high output failure (aka dynamic insufficiency), low output failure (aka mechanical insufficiency), or a combination of the two.

High and Low Output Failure of the Lymphatic System[4]

High Output Failure

In high output failure, the lymphatic load exceeds the transport capacity of a healthy lymphatic system. **The result of high output failure is edema.** (Fig. 14)

Edema as a result of high output failure is usually low in protein (<1.0 gm/dl protein) and is NOT lymphedema. High output failure of the lymphatic system can be caused by conditions such as congestive heart failure or chronic venous insufficiency. It may also occur from venous obstruction such as with deep venous thrombosis or a tumor growth obstructing the venous return.

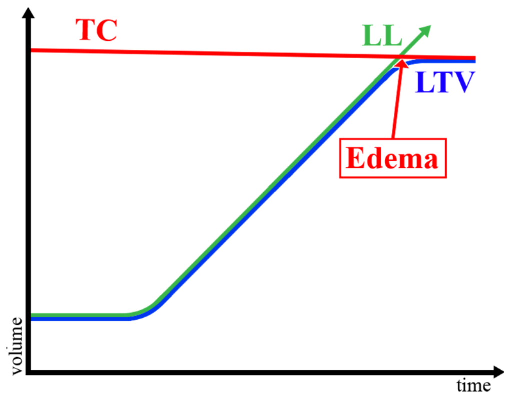

Fig. 14 Edema arises when the increased lymphatic load (LL) exceeds the transport capacity (TC) of a healthy lymphatic system. The lymph time volume cannot exceed the transport capacity of a healthy lymphatic system.

Low Output Failure

In low output failure, the lymph system is unable to remove the necessary lymphatic load from the interstitium due to organic or functional causes. **The result of low output failure is lymphedema!** (Fig. 15)

Examples of *organic* lymphatic failure include valvular insufficiency, thrombosis, and sclerosis of the lymph vessels. Examples of *functional* lymphatic failure include obstruction of the lymphatic vessels by tumor growth, or scarring from surgery and/or radiation.

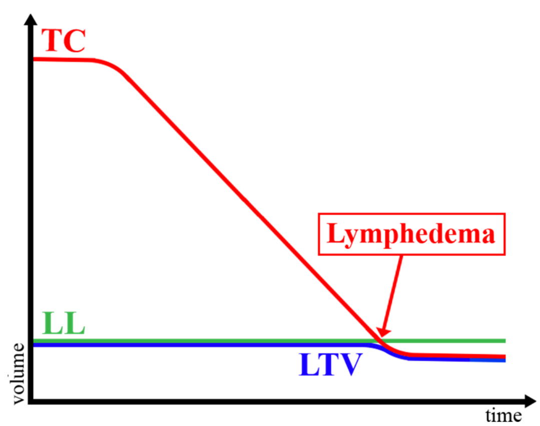

Fig. 15 In low output failure, the transport capacity drops below the physiological level of lymph load which leads to lymphedema.

Combined Lymphatic Insufficiency

Combined lymphatic insufficiency is a mixture of high and low output failure of the lymphatic system. The lymphatic system is impaired so transport capacity is reduced. At the same time, the lymph load is higher than normal. (Fig. 16)

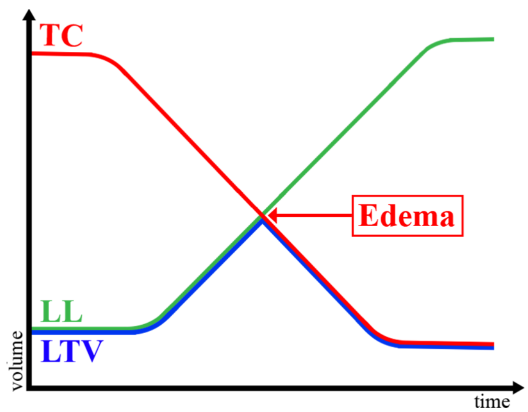

Fig. 16 Combined lymphatic insufficiency. Combination of high and low output failure.

Here are three examples of combined lymphatic insufficiency:

1. **Post-surgical or post-traumatic edema**: In case of surgery or trauma, the lymphatic system is temporarily impaired and is unable to fulfill its normal task, i.e. the removal of the lymphatic load. At the same time, because of the tissue injury, the body increases blood volume to the area in an effort to facilitate healing. This will increase the lymphatic load. *Remember: Lymph vessels will try to reconnect and repair and the process of healing can be facilitated by the application of MLD.*

2. In a patient with **congestive heart failure,** the lymphatic load increases and can cause high output failure. If the condition becomes chronic, the lymphatic system can become fatigued and develop low output failure in addition to the existing high output failure.

3. If a patient with **primary lymphedema suffers from a secondary pathology,** such as chronic venous insufficiency or congestive heart failure, the transport capacity is reduced because of the congenital impairment of the lymphatic system. In addition, the lymphatic load can be higher than normal.

Edema versus Lymphedema

Edema, or excess fluid in the body tissues, occurs primarily in the extracellular compartment (interstitium). Extracellular edema results from either abnormal leakage of fluid across capillaries from the plasma to interstitial spaces (increased filtration), or from failure of the lymphatic system to adequately return fluid from the interstitium to the blood.

Lymphedema develops from low output failure due to a damaged or malformed lymphatic system. The lymphatic system can be damaged through surgery, radiation, or some type of dysplasia.

Edema can also be classified as *generalized* edema (concerning the whole body) or *local* edema (present in only one part of the body). Any combination of extracellular, intracellular, generalized, and local edema is possible.

Factors in Edema/Lymphedema Development in Summary

Any one of the following items, alone or in combination, can cause the development of edema:

1. **Increased capillary (hydrostatic) pressure (active or passive hyperemia)**
2. **Decreased plasma proteins (hypoproteinemia)**
3. **Increased capillary permeability**
4. **Blockage of lymphatic return (lymphedema)**

1. Increased capillary hydrostatic pressure may be caused by:

A. Excessive retention of salt and water

B. Decreased arteriolar resistance - heat, exercise, inflammation

C. High venous pressure
- Heart failure
- Local venous block
- Failure of venous pumps, e.g. paralysis, immobilized body part, valvular insufficiency

2. Decreased plasma proteins (hypoproteinemia) may be caused by:

A. Loss of protein
- In urine (nephrosis)
- In the intestinal tract (enteropathy)

B. Loss of protein from damaged skin
- Burns
- Wounds

C. Failure to produce protein
- Liver disease
- Malnutrition

3. Increased capillary permeability may be caused by:

A. Immune response resulting in histamine or other vasodilator release

B. Toxins

C. Bacterial infections

D. Medications

4. Blockage of lymphatic return (lymphedema) may be caused by:

A. Blockage of lymph nodes by:
- Cancer
- Infection
- Filarial parasites
- Scar tissue
- Other

B. Lymphatic dysplasias

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