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Klose Training
MLD Certification

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.

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Table of Contents

ANATOMY AND PHYSIOLOGY OF THE LYMPHATIC SYSTEM

Anatomy of the Lymphatic System

Components of the Lymphatic System[1]

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

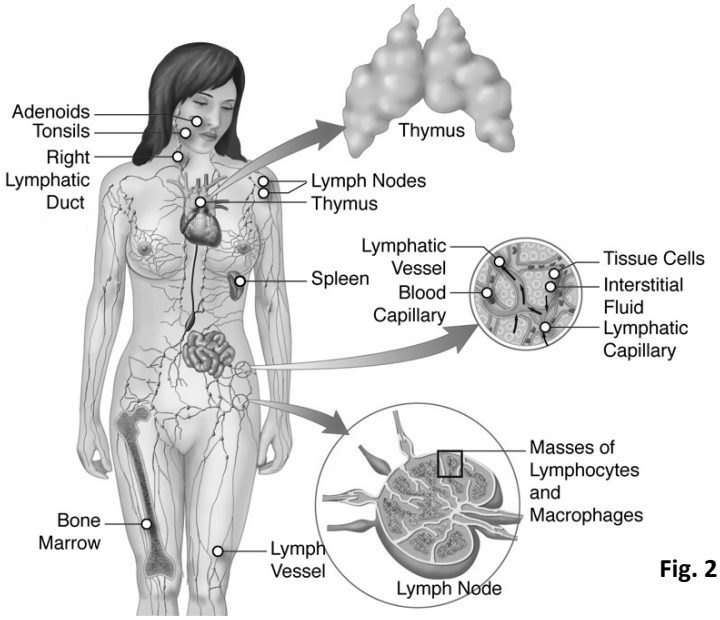

Fig. 2 Components of the lymphatic system. *savingstudentsmoney.org/OLI/AnPpost.html*

The lymphatic structures in the body are:

- **Lymph vessels (collectors) -** collect and transport protein-rich fluid (lymph) from the interstium to the central venous system.
- **Lymph nodes** - 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.
- **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.

Function of the Lymphatic System[4-6]

- Returns protein and water from the interstitium to the cardiovascular system.
- Absorbs protein, fat and fat-soluble vitamins (chyle) through the intestinal lymph vessels.
- Recognizes and responds to foreign cells, microbes, and cancer cells (serves important immunological functions).

Lymph vessels absorb interstitial fluid, mainly from the skin and subcutaneous tissues, and transport it into the venous circulation. From the intestines, the lymph vessels 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.

Below is a drawing of the superficial lymph nodes of the axilla and inguinal region with the collecting lymphatics and lymph trunks leading to them.

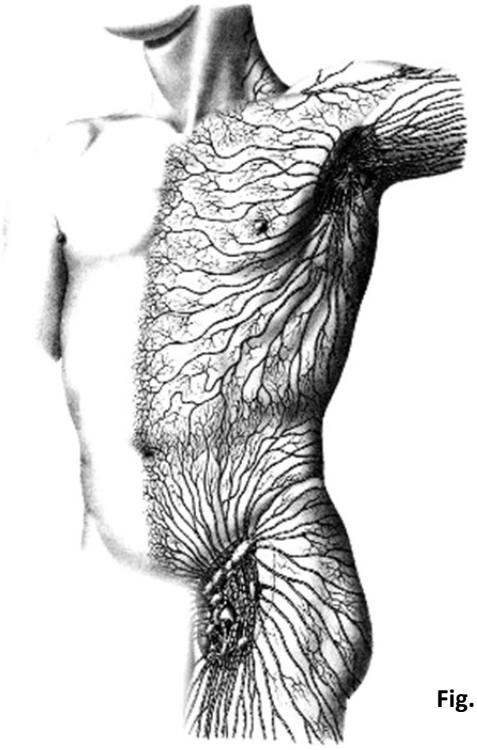

Fig. 3 Marie Philibert Constant Sappey
French anatomist, 1810-1896

Fig. 4 Drawing of lymphatic vessels by Sappey.
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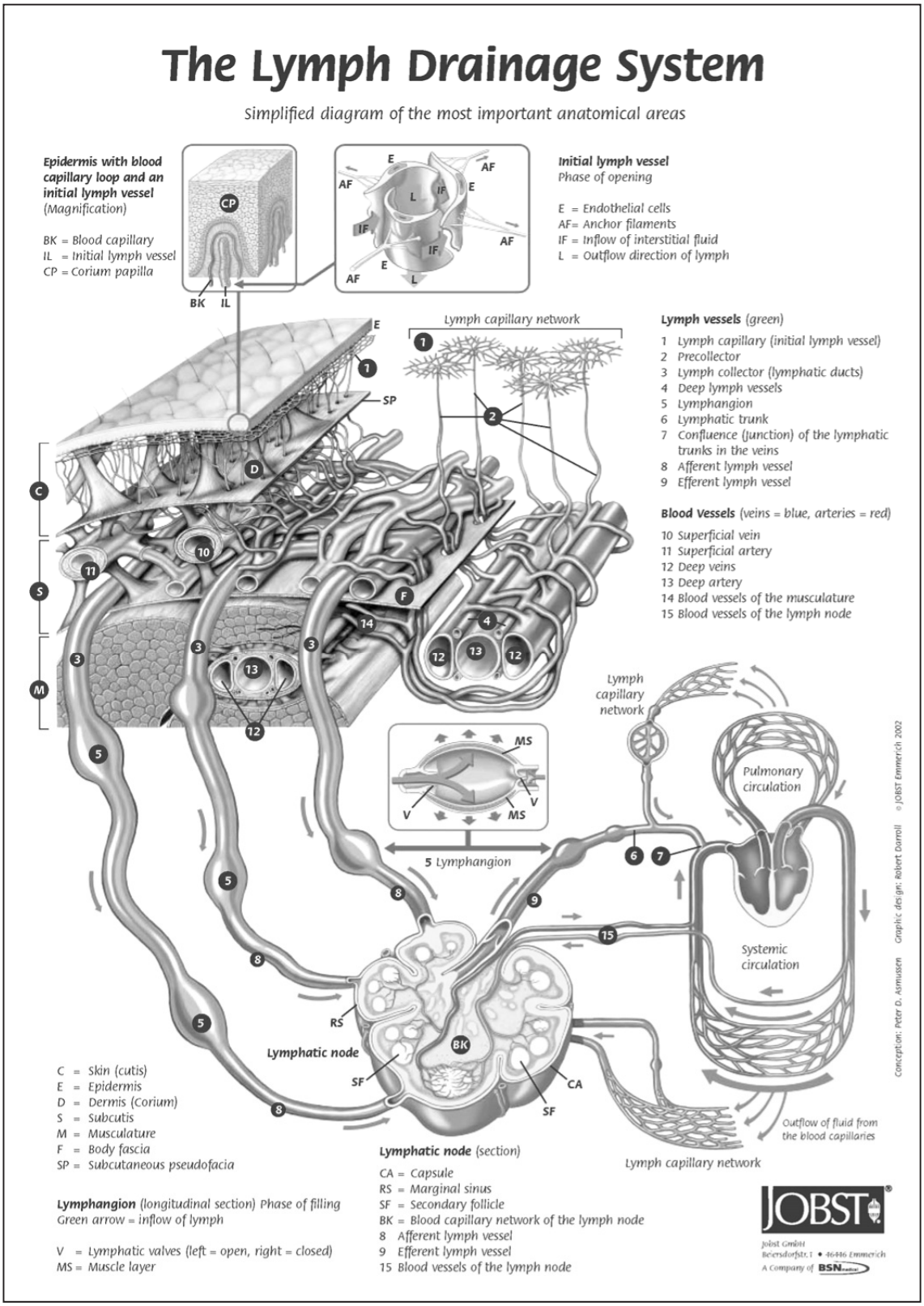

Fig. 5 Lymph Drainage System

Poster available for download at: jobstcompressioninstitute.com/Resources/Literature

Lymph Vessels[1]

Lymph vessels are subdivided into:

- Capillaries (8)
- Pre-collectors (9)
- Collectors (11)
- Trunks (not shown)

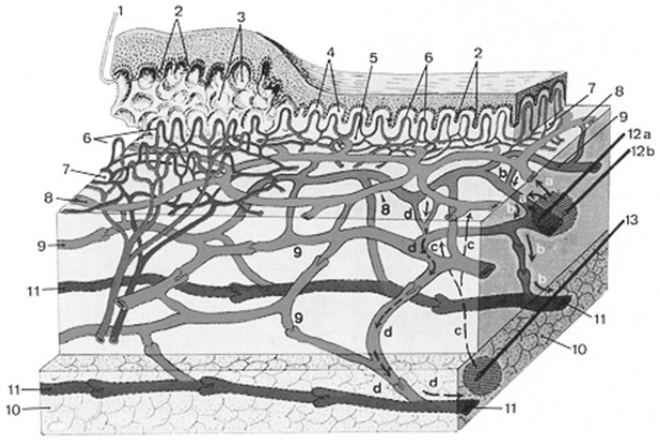

Fig. 6 Lymphatic vessels of the skin.
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Lymph Capillaries[1,3-6]

Lymph capillaries are larger than blood capillaries and are structurally adapted to ensure the absorption of large molecules, i.e. proteins from the interstitium (Fig. 7). The lymph capillaries originate in tissue spaces and form an extensive plexus throughout the body. 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 pores even more, allowing a passive influx of fluid into the small vessel. (Fig. 8)

The important characteristics of the lymph capillaries:

- They are 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 Lymph Capillary and Blood Capillary Loop[1]

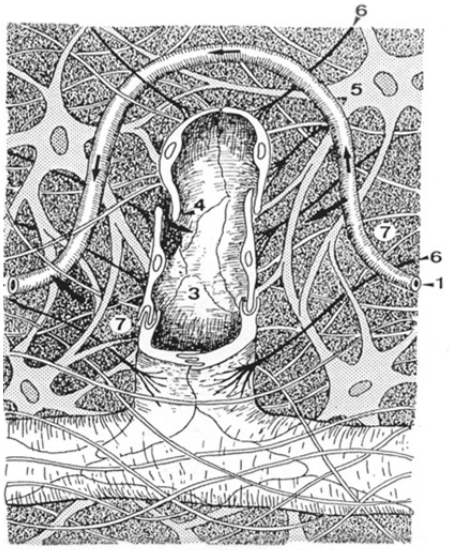

Fig. 7 Lymphatic Capillary

1. Arterial side of the blood capillary
2. Venous side of the blood capillary
3. Lymph capillary
4. Open junction "swinging flap"
5. Fibrocyte
6. Anchoring filaments
7. Interstitial space

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The Opening Mechanism of the Lymph Capillary[1]

Lymph Formation (Fig. 8)

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.

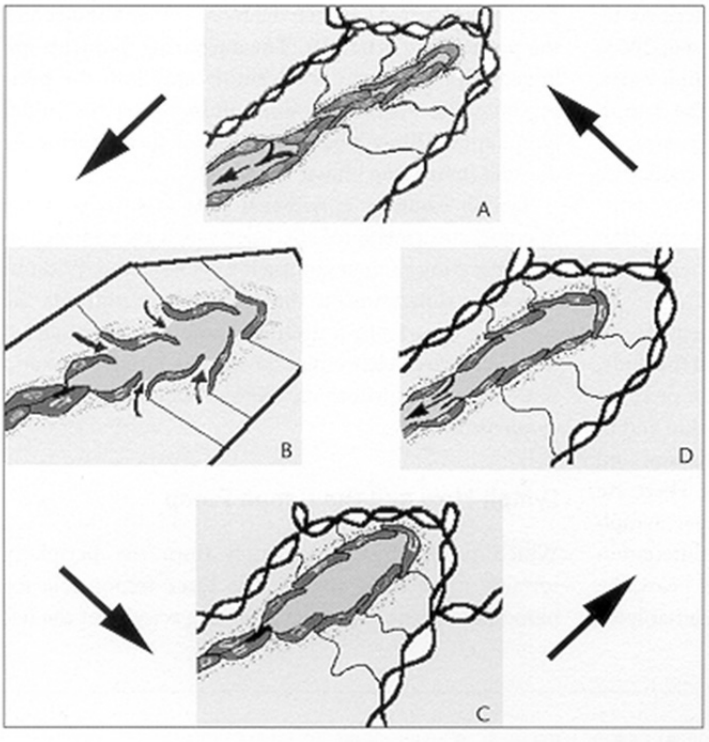

Fig. 8 Opening mechanism of a lymph capillary.
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* Interstitial fluid travels through pre-lymphatic channels from the blood capillary to the lymph capillary. Once interstitial fluid has entered into the lymph capillary, it has become lymph. On its way to the central venous system, lymph fluid will be filtered by lymph nodes and becomes more concentrated with protein. Therefore, interstitial fluid differs from lymph fluid.

Pre-collectors[1]

The pre-collectors channel the lymph fluid into the larger transporting vessels. 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 (Fig. 9) 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.

Like veins, lymph collectors also consist of a three-layer wall and bicuspid valves. The three layers are:

- **Tunica intima** (inner layer) - composed of endothelial cells and a basal membrane
- **Tunica media** (middle layer)- composed of smooth muscle cells
- **Tunica externa** (outer layer) - made of soft collagenous connective tissue

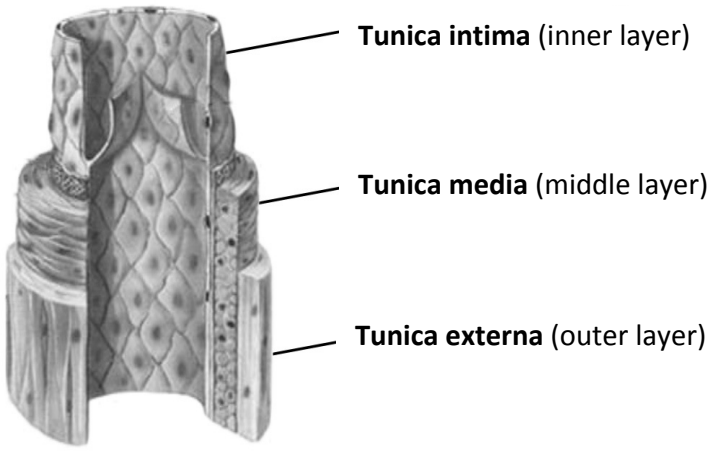

Fig. 9 Diagram of the wall structure of a vein.
Modified from Fox, Stuart I, Human Physiology 4th Edition, Brown Publishers

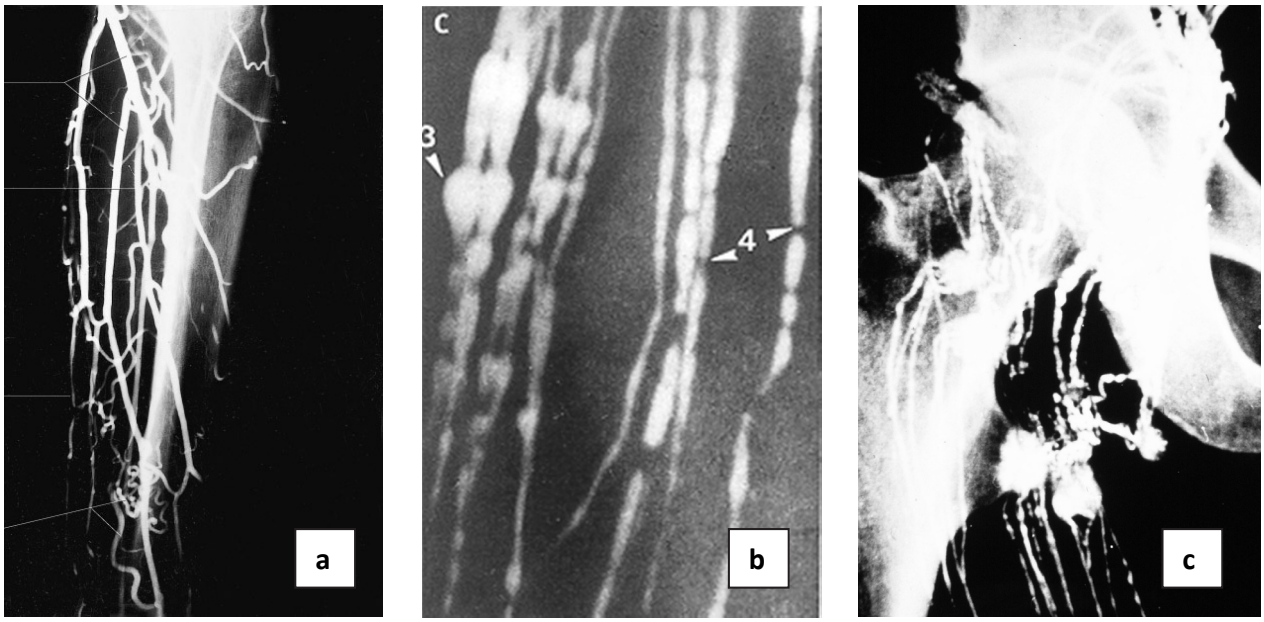

Fig. 10 Comparison of a venogram of the lower extremity veins (a) vs. a lymph-angiogram (aka lymphography) of the lower extremity collectors (b) and lymph nodes (c).

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 lymphangioactivity. 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, and external pressure such as with Manual Lymph Drainage (MLD).

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 anastomoses. The deep collectors are located sub-fascially at the extremities and the trunk. They are usually larger in diameter than the superficial collectors and they drain related muscle, 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).

Lymphangion[1]

The lymphangion 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
- Intrinsic contractions (6-10 x/min)

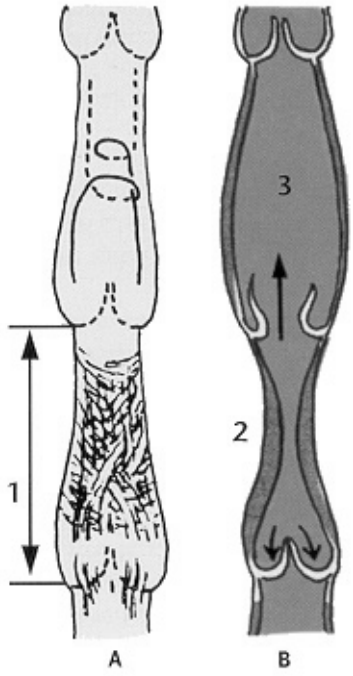

Fig. 11 Structure and function of lymphangion:
A - Arrangement of musculature
B - Normal function

1 – Lymphangion
2 - Contracted segment (emptying phase)
3 - Relaxed segment (filling phase)

NOTE: Arrows indicate direction of flow.

Modified from Foeldi's Textbook of Lymphology

Lymphatic Watersheds and Anastomoses[1]

Lymphatic watersheds delineate (separate) lymphatic tributary regions (Fig. 12). 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

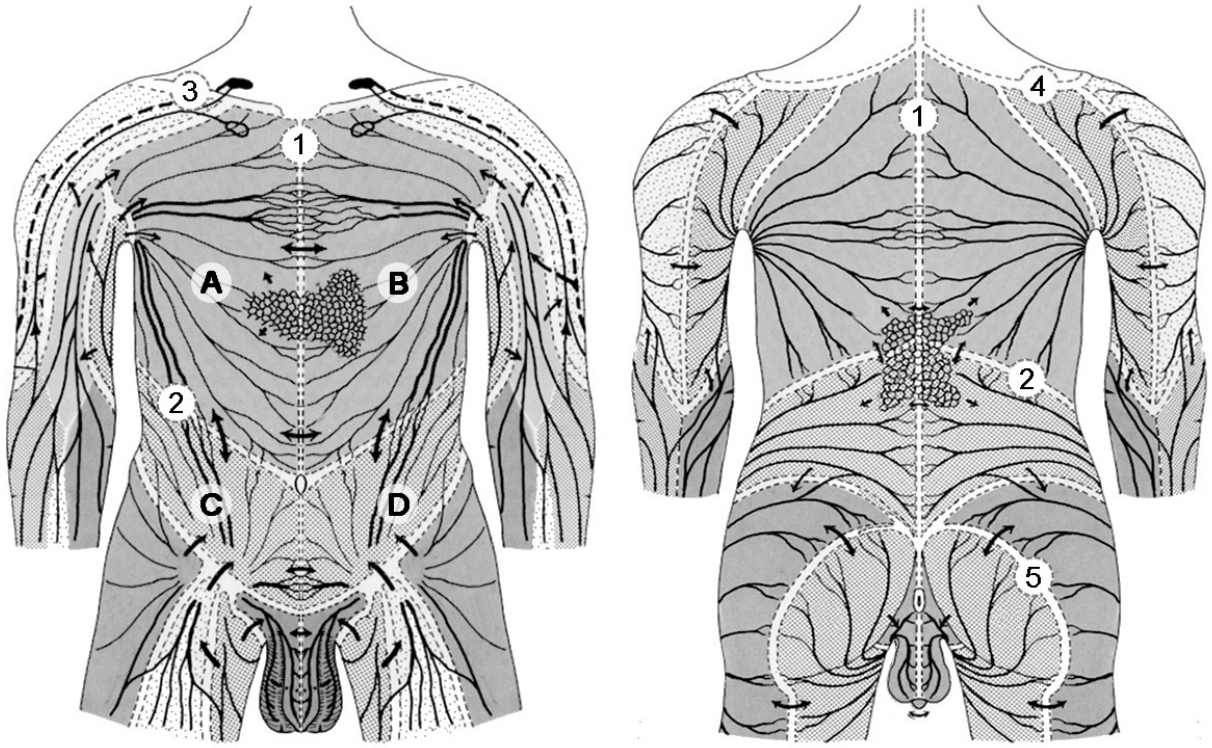

Fig. 12 Lymphatic Watersheds
Modified from Foeldi's Textbook of Lymphology

Lymphatic regions may be referred to as the "tributary regions" or "root areas," e.g. root areas 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.

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).

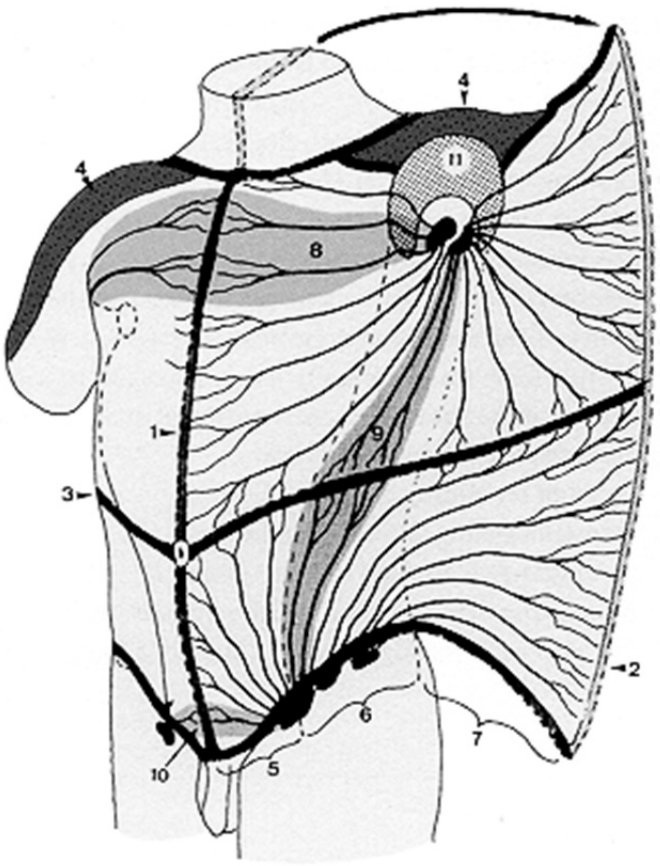

Fig. 13 Lymphatic Anastomoses Pathways

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 (interaxillary) anastomoses
9. Axillo-inguinal anastomoses
10. Interinguinal anastomoses
11. Amputation plane of the shoulder

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Lymph Trunks and Ducts[1,8]

The largest lymph vessels are called trunks and ducts. The trunks collect fluid from the organs, the extremities and the related quadrants of the trunk. The ducts eventually transport approximately 4 liters of lymph into the venous circulation (Fig. 14).

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 venous angle (juncture between the left internal jugular and left 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.

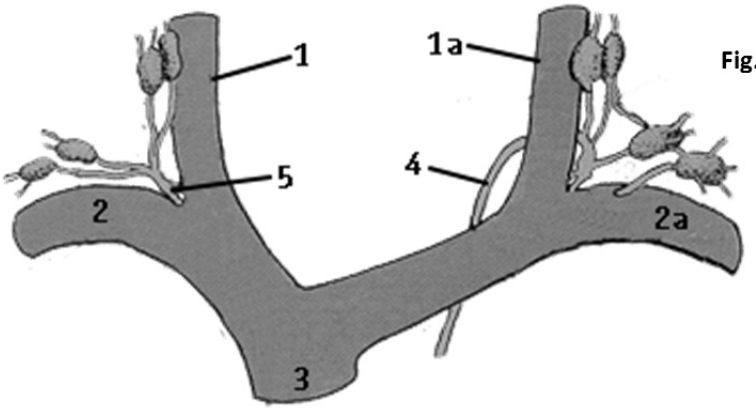


Fig. 14 Right and left venous angles:
1, 1a - Internal jugular veins
2, 2a - Subclavian veins
3 - Superior vena cava
4 - Thoracic duct
5 - Right lymphatic duct
Modified from Foeldi's Textbook of Lymphology

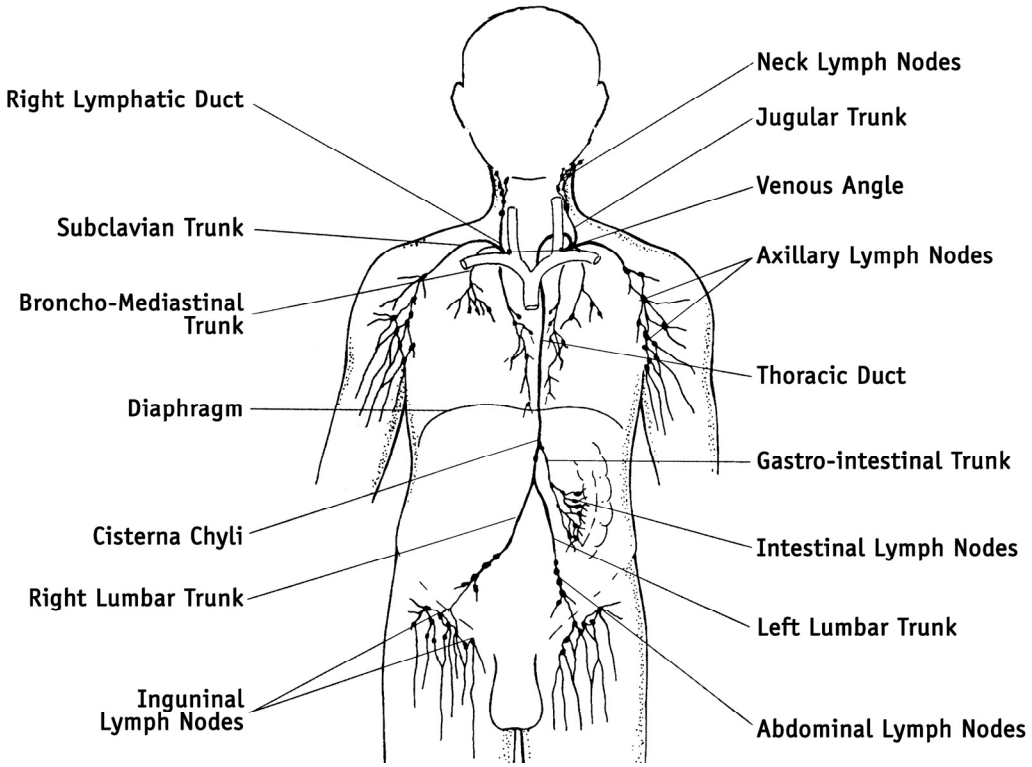


Fig. 15 Major lymphatic trunks and ducts of the human body.

From the lower extremities 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 referred to as 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

From the upper extremities 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 and right lymphatic ducts. From the bronchi, lungs, and the mediastinum, the lymph fluid reaches the ducts via the broncho-mediastinal trunks.

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)

Since 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).

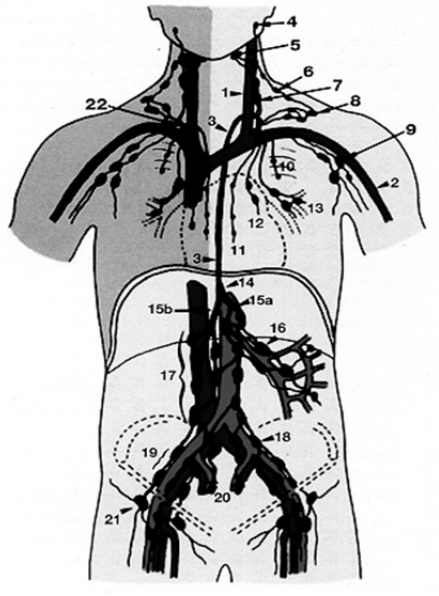


Fig. 16 Three-quarters of the body empties into the left venous angle. *Foeldi's Textbook of Lymphology*

Lymph Fluid and Lymph Nodes[1]

Lymph fluid (lymphatic load) consists of:

- Proteins
- Water
- Cells (RBCs, WBCs, lymphocytes)
- Waste products and other foreign substances
- Fat (intestinal lymph, 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 contains 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.

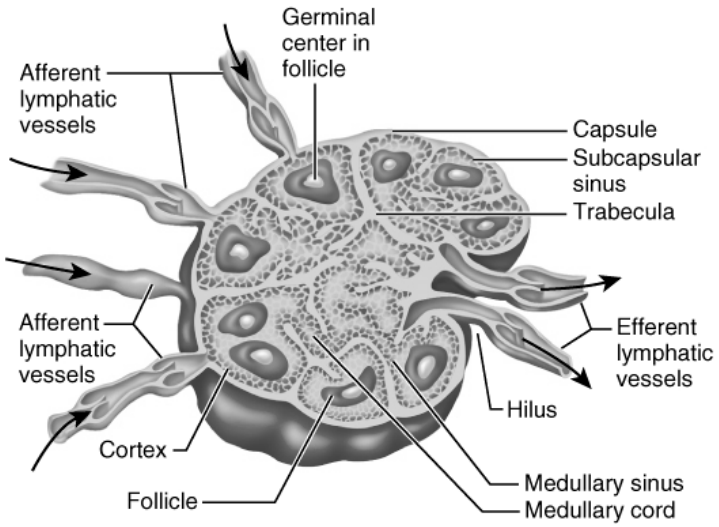


Fig. 17 Lymph node with afferent and efferent lymph vessels.
hypervibe.com

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 receives 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	Deep cervical lymph nodes
Preauricular LN	2-4 nodes in front of the ear at the parotid gland	Front of the auricle, nasal root, lateral eye lids, parotid	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 vesticles, uterus, upper portion of vagina	Lumbar trunks
Superficial Inguinal LN	Approx. 10 nodes prefascial in the groin	Trunk wall below navel line, lumbar and gluteal region, perineum, external genitals, lower extremities	Deep inguinal lymph nodes
Popliteal LN	Popliteal fossa	Skin, deep parts of the lower leg	Deep inguinal lymph nodes

Lymph Flow versus Blood Flow[1,3,4,6,8,9]

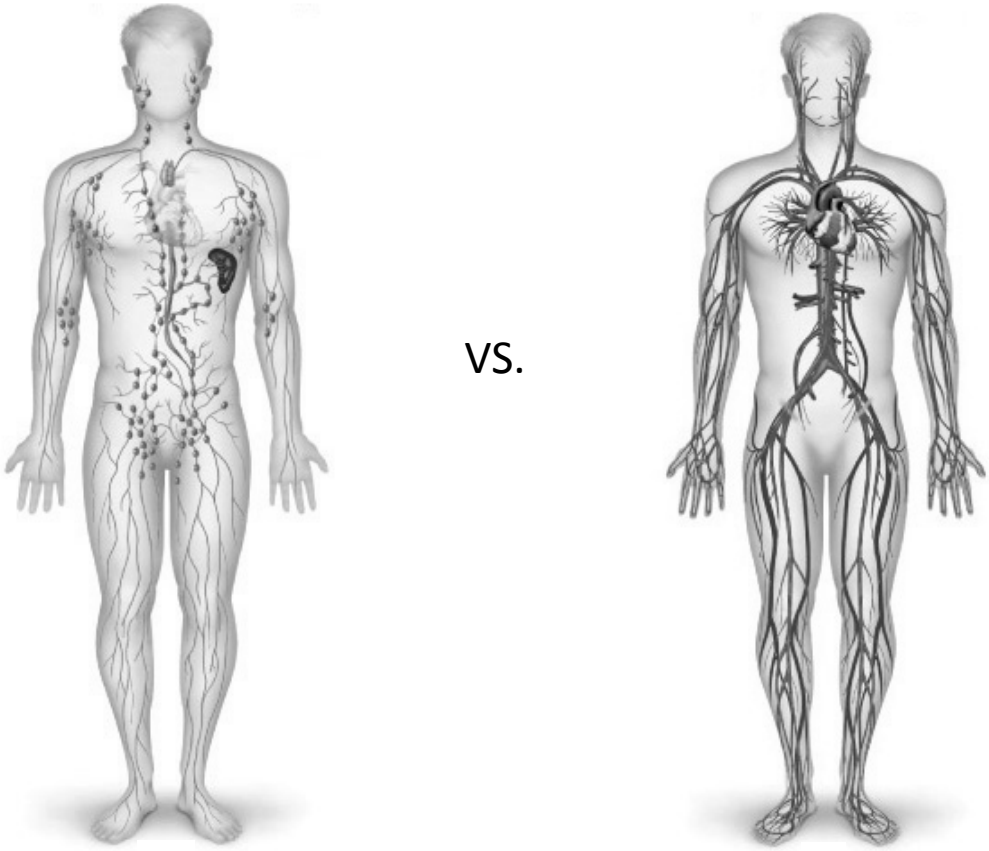
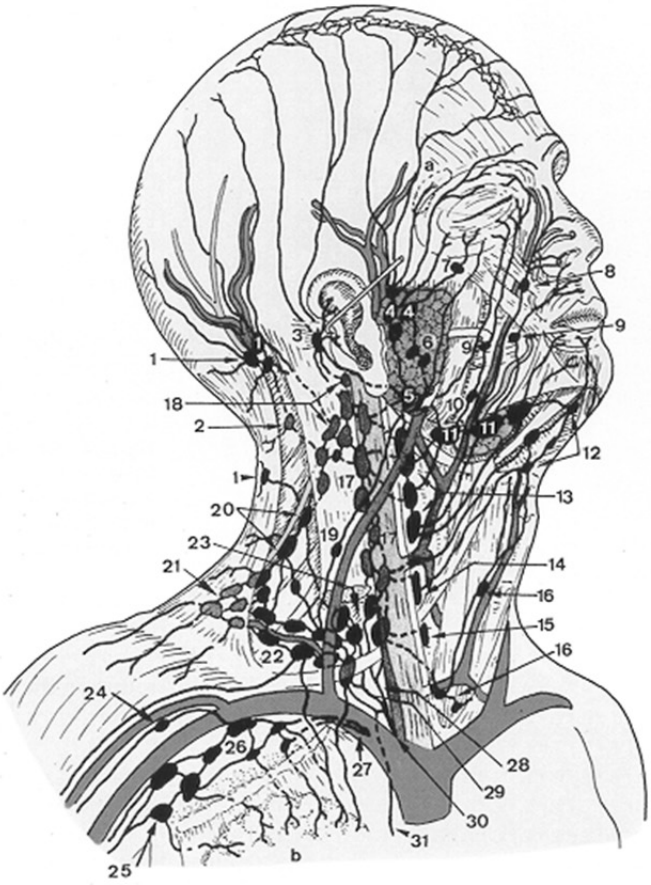


Fig. 18 Diagram of the lymphatic system (A) and the blood circulatory system (B).

Table 4 Lymph system versus blood circulatory system

LYMPH SYSTEM	**BLOOD CIRCULATORY SYSTEM**
One way	Circular
Approx. 4 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
No continuous column of fluid	Continuous column of fluid
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

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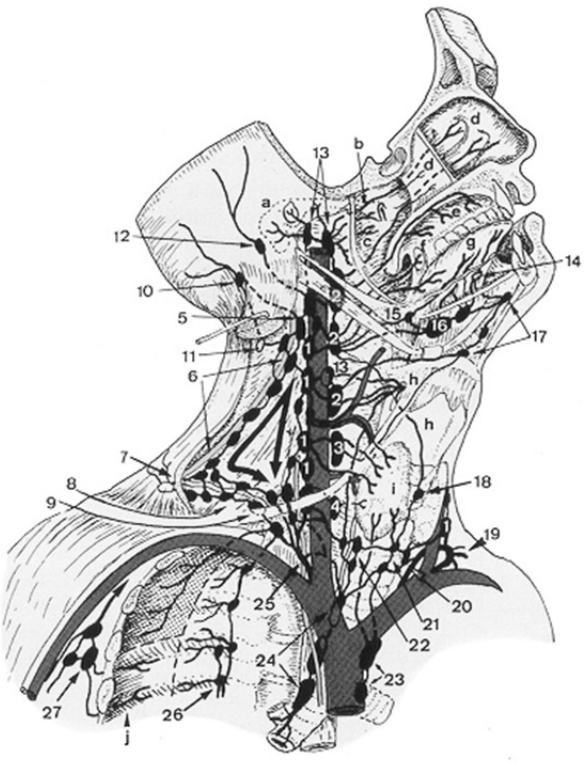

Deep Cervical Lymph Nodes

Fig. 20 Deep cervical lymph nodes.

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

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Axillary & Parasternal Lymph Nodes

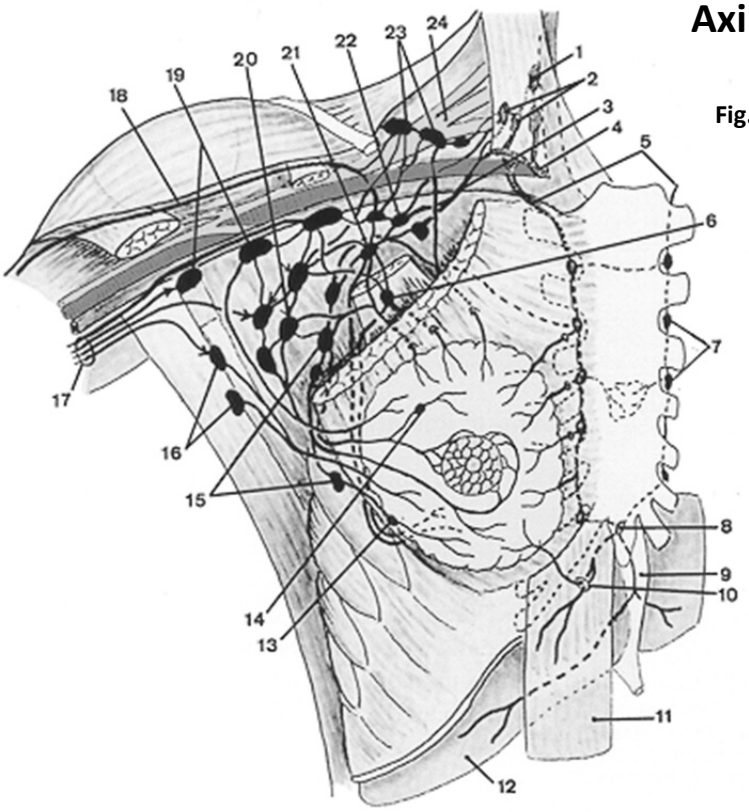

Fig. 21 Axillary lymph nodes.

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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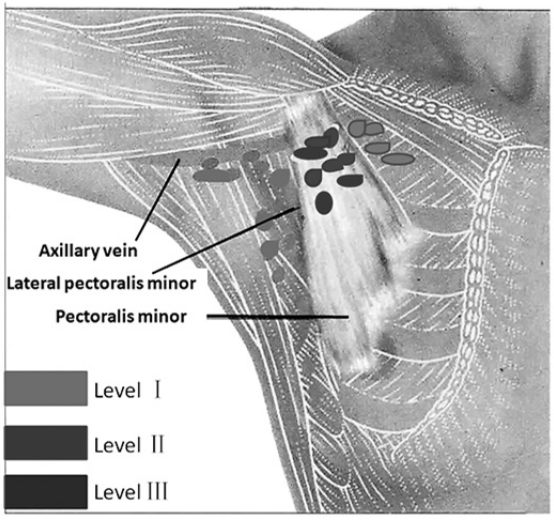

Level 1-3 Axillary Lymph Nodes

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

Intercostal Lymph Nodes and Collectors

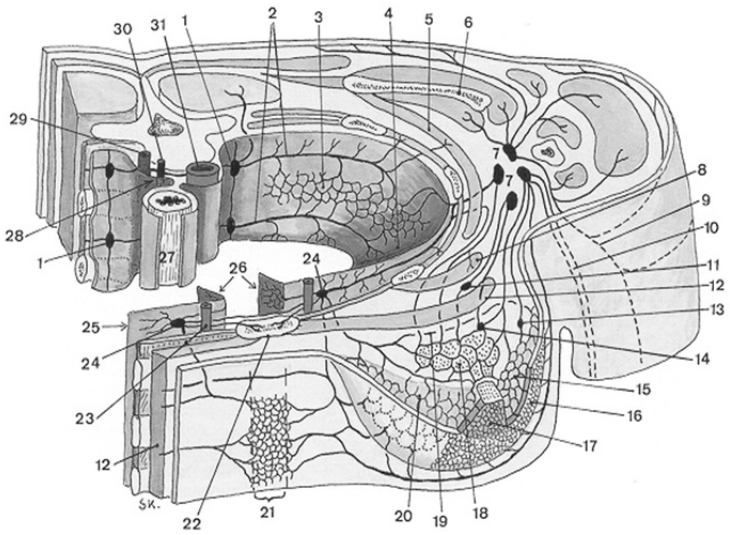

Fig. 23 Intercostal lymph nodes and collectors

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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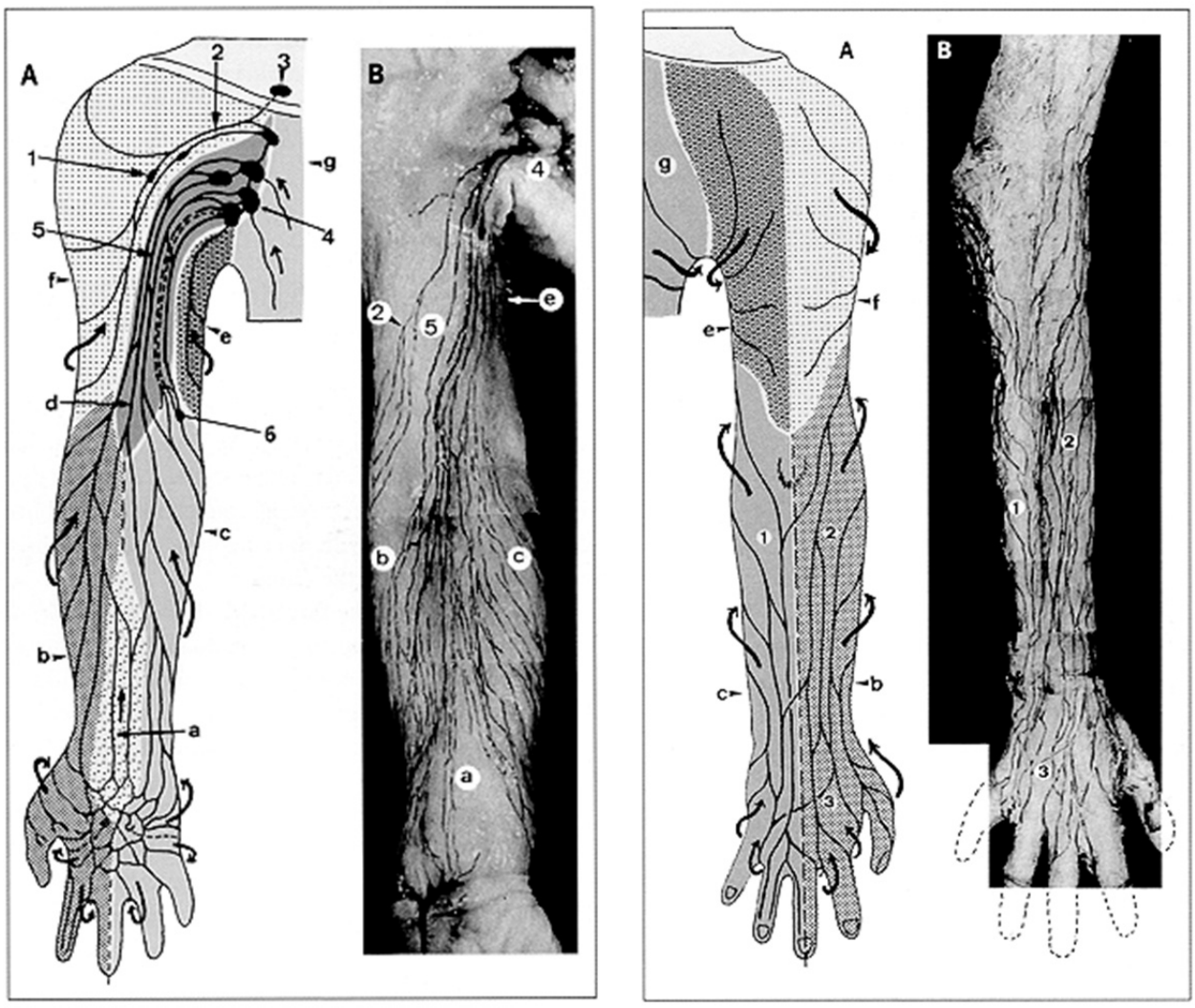

Lymph Vessels and Drainage Areas of the Upper Extremity

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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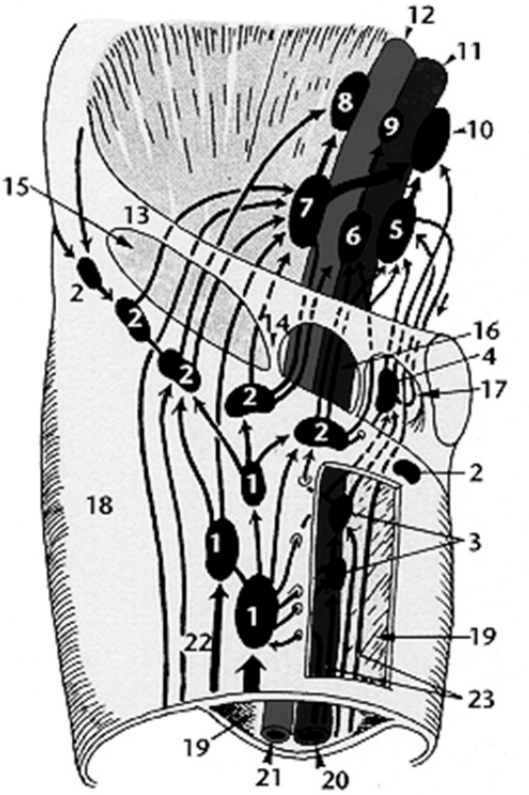
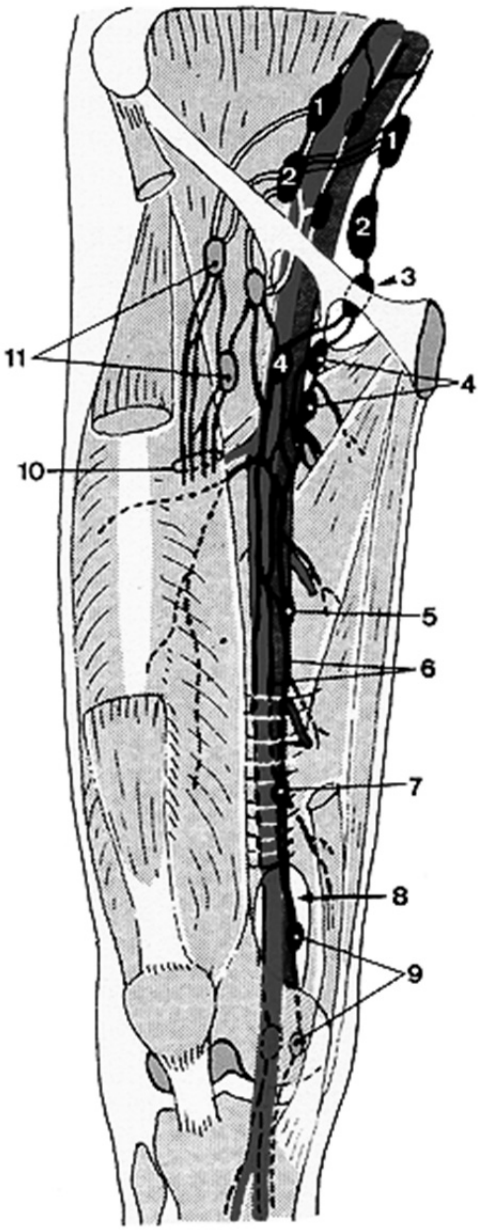
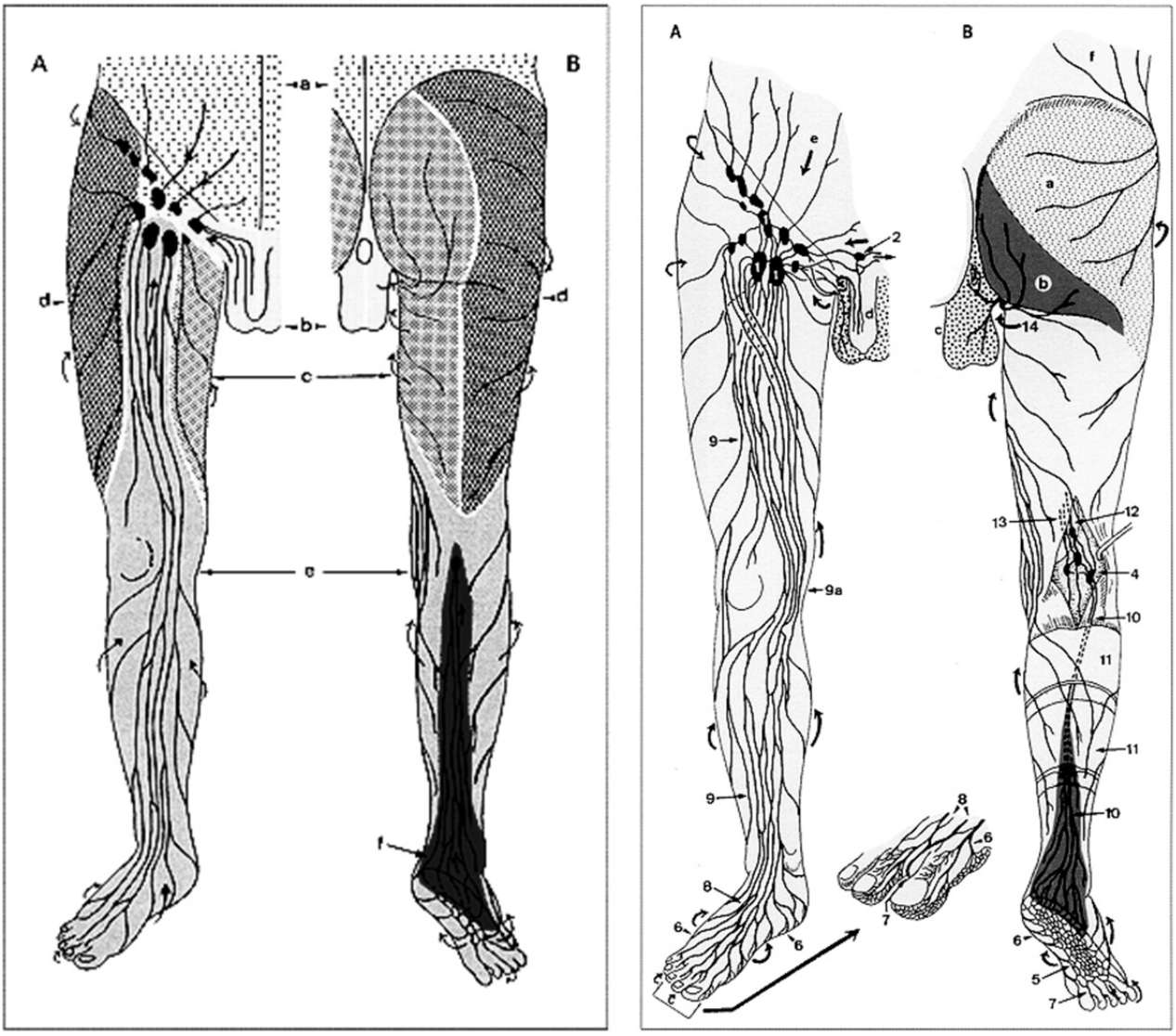




Inguinal Lymph Nodes

Fig. 26 and 27 Inguinal lymph nodes.
1-2. Superficial inguinal nodes
3. Deep inguinal nodes
4. Rosenmueller's node
5-10. Iliac (pelvic) nodes
Foeldi's Texbook of Lymphology



Lymph Vessels and Drainage Areas of the Lower Extremity

Fig. 28 and 29 Lymph vessels and drainage areas of the lower extremity.
Foeldi's Textbook of Lymphology

Bonus Pictures

Fig. 30 and 31 Lymph collectors of the lower extremity in a cadaver.
Anatomy Department of the University of Zurich, Switzerland

Fig. 32 and 33 Lymphanigiogram of the lower extremity. Healthy lymph collectors (left) and dilated lymph collectors in patient with primary lymphedema (right).
N. Browse, Reducing Operations for Lymphoedema of Lower Limb

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Physiology and Pathophysiology 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 (tissue spaces) back into the systemic circulation, thus preventing fluid accumulation (edema) in the tissues (Fig. 1). Most important is the removal of protein molecules from the tissue spaces 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.

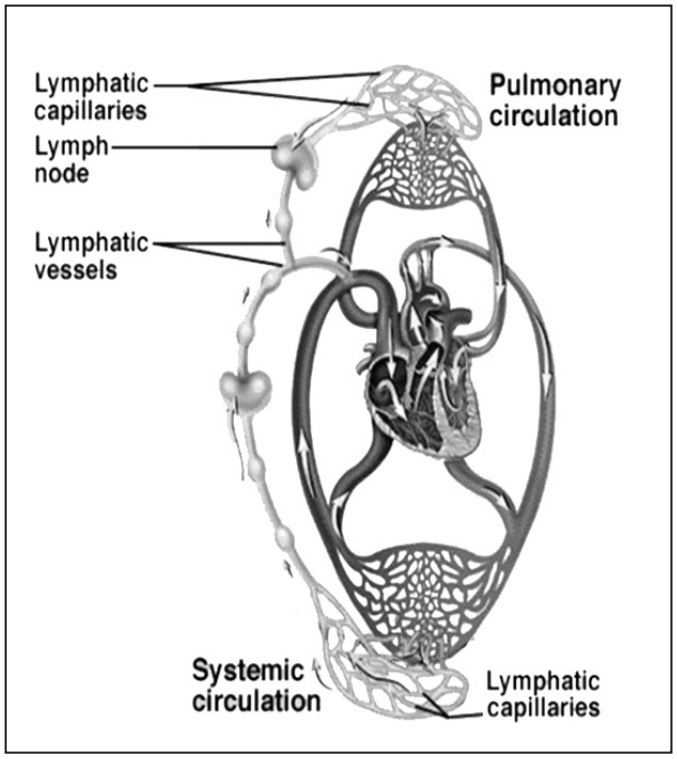

Fig. 1 Diagram of the relationship between the blood circulatory and lymphatic systems.

Lymphatic Load [4,5]

Lymphatic load (LL) is the term used to describe the substances that are moved through the lymphatic system. The main components of LL are protein, water, cells and fat.

Lymph Time Volume and Transport Capacity [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. The lymph time volume of the thoracic duct is estimated to be up to 4 l/day in humans. The normal lymph time volume equals about 10% of the maximum possible transport in a healthy lymphatic system. (Fig. 2)

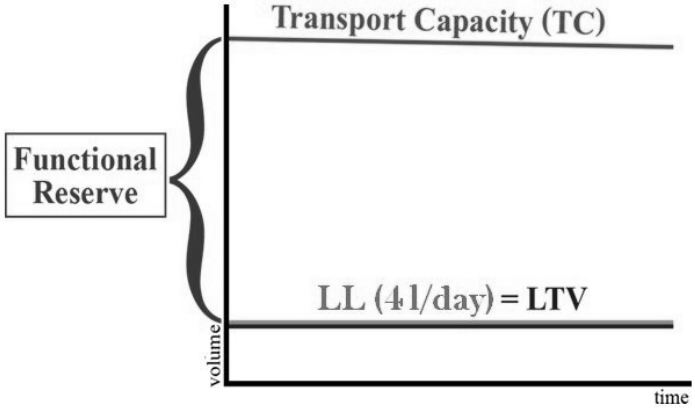

Fig. 2 Diagram showing the relationship between the normal lymph load and the transport capacity. Because the lymph time volume is only about 10% of the maximum transport capacity, the lymphatic system has a large functional reserve.

Safety Function of the Lymphatic System [4,5]

If necessary, the lymphatic system is able to activate its safety function/safety-valve function and respond to an increase in lymphatic load by increasing its lymph time volume (Fig. 3). 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. The transport capacity is equal to the *maximum* lymph time volume.

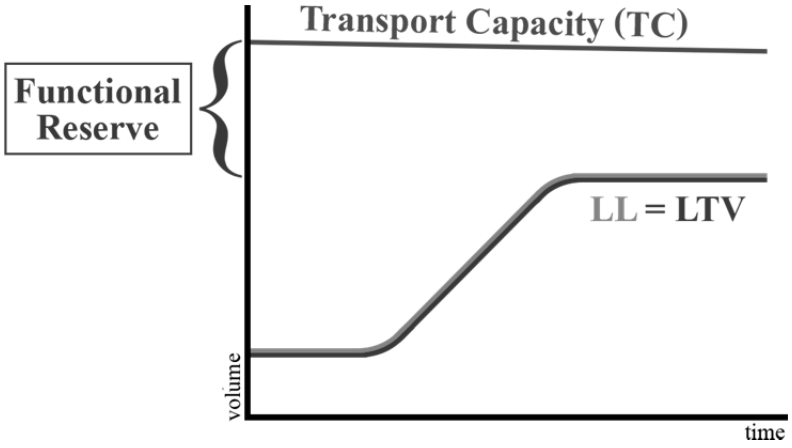

Fig. 3 Diagram showing how the lymphatic system responds to an increase of interstitial fluid (water and/or protein load) with an increase in lymph capillary uptake and activation of the motor function of the lymph vessels.

Interstitium [3]

Approximately 1/6 of the human body consists of interstitium which is made up of proteoglycan filaments, collagen fiber bundles, and fluid. This gelatinous substance is the "glue" that keeps our cells together. Proteoglycan filaments are extremely thin, coiled and create a mat of reticular fibers. Interstitial fluid becomes entrapped in that mat which limits the ability of large numbers of its molecules to flow at once. Instead, individual molecules diffuse through the gel. (Fig. 4)

Blood capillaries release water and proteins into the interstitium. Because protein molecules have difficulty passing the basement membrane of the blood capillaries, the protein concentration in interstitial fluid is much lower than in plasma.

The interstitium is also composed of "free fluid" which is <1% of normal tissue. Free fluid lacks proteoglycan filaments so has the ability to flow. In edematous tissue, small streams (rivulets) of free fluid can expand and more fluid becomes free flowing.

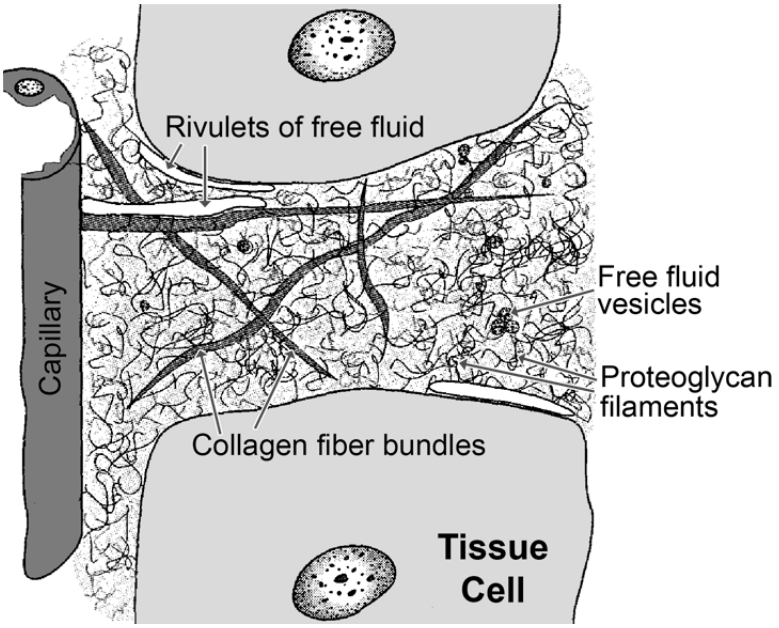

Fig. 4 Structure of the interstitium. Proteoglycan filaments are everywhere in the spaces between the collagen fiber bundles. Free fluid vesicles and small amounts of free fluid in the form of rivulets occasionally also occur.

To help you and your patients 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.

Fluid Exchange at the Blood Capillary [2,3,4]

DIFFUSION

Diffusion is the most important process for the nourishment of the tissues! Diffusion is the tendency of molecules of a substance (gaseous or liquid) to move from a region of higher concentration to one of lower concentration. Diffusion is caused by the tendency of the molecules to establish equilibrium.

This movement of the molecules depends on the size of molecules, the difference in concentration, distance, the total cross-sectional surface and temperature.

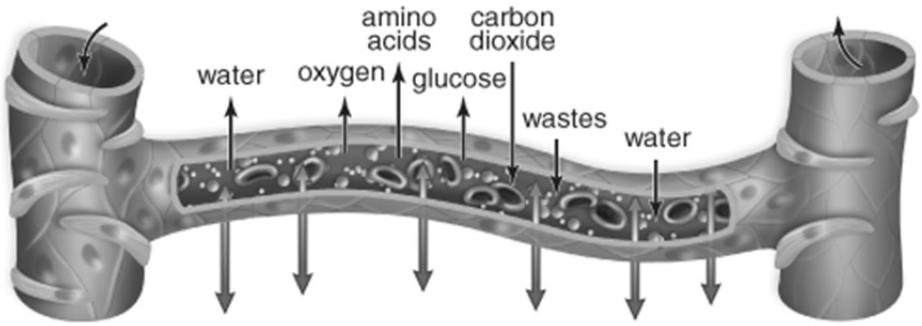

Fig. 5 Diffusion occurs continually in the human body, e.g. the wall of the blood capillaries is permeable for plasma and small organic and small inorganic molecules. The entire exchange of oxygen and carbon dioxide happens through diffusion.

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.

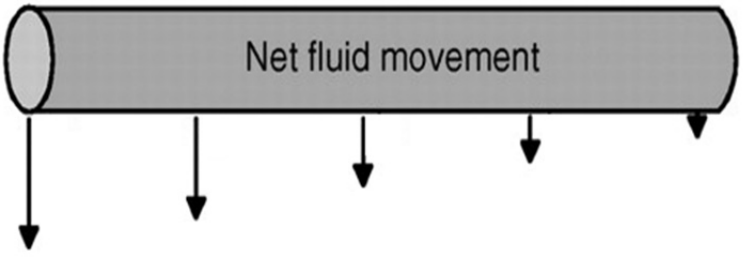

Fig. 6 Fluid movement though filtration. The entire filtrate will become lymphatic water load which needs to be removed from the interstitium by the lymphatic system.
Modified from http://cnx.org/content/col11496/1.6/

Blood Capillary Pressure

Active and Passive Hyperemia[4]

The average blood pressure in the aorta is 100 mmHg; at the vena cava, it's only 2–4 mmHg. The blood pressure undergoes a steep drop at the small arteries and **arterioles**. Together, they account for about 50% of the total peripheral resistance (Fig. 7).

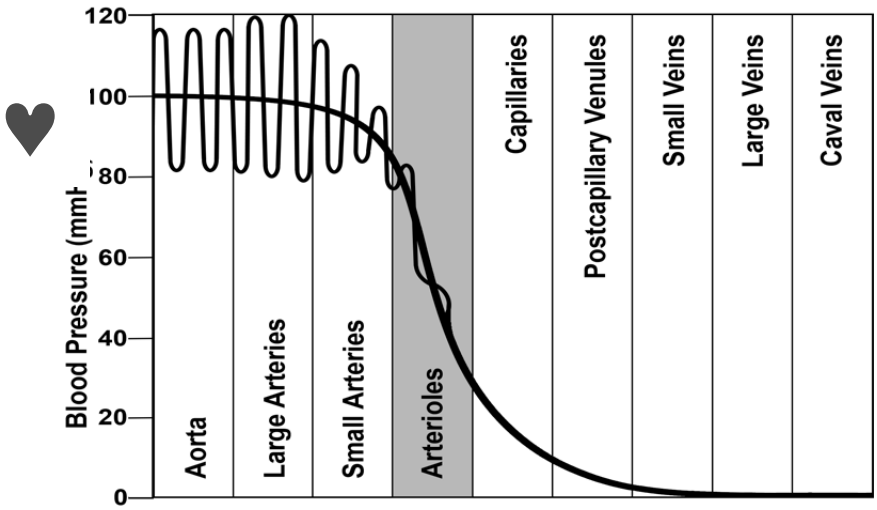

Fig. 7 Diagram showing the average blood pressure in different parts of the systemic circulation.

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.

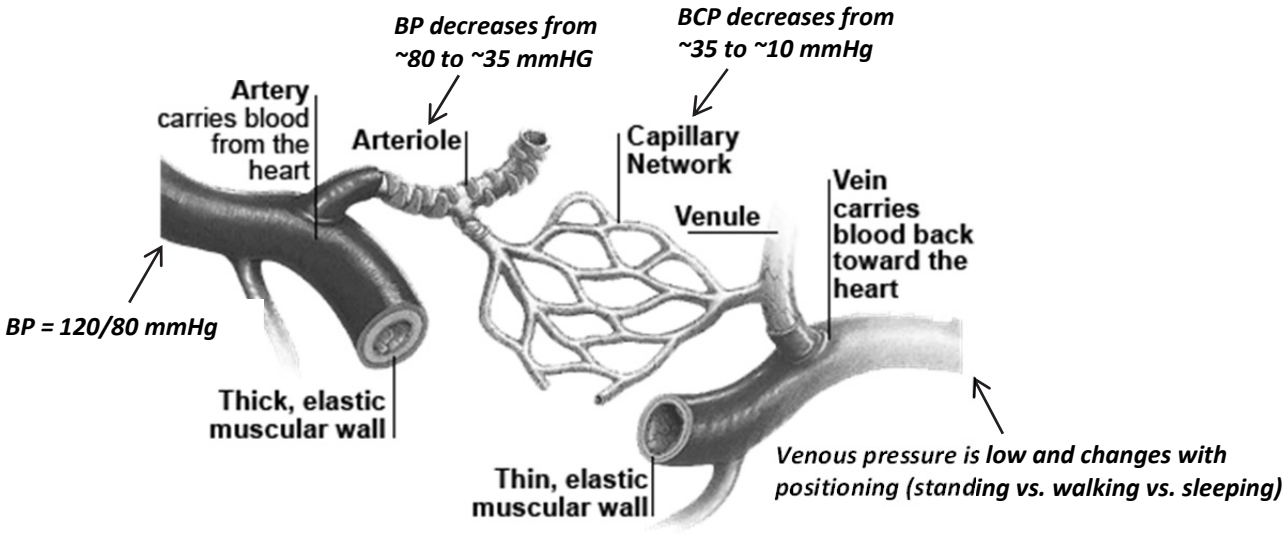

Fig. 8 Precapillary arterioles are rich in smooth muscle fibers. Postcapillary venules have much less muscle tissue in their walls. *Emaze.com*

If the sympathetic nervous system is activated, the number of impulses reaching the periphery increases, the muscle tone increases, the arteriole contracts, and the blood capillary pressure and the blood flow decreases.

A decrease in muscle tone results in the opposite response. The precapillary arterioles dilate and blood flow increases. This leads to increased blood volume in the capillaries and increased blood capillary pressure, a state called **active hyperemia**. As a consequence of active hyperemia, BCP increases leading to increased filtration – lymphatic load increases! (Fig. 9) Active hyperemia can be caused by:

- Inflammation (Fig. 10)
- Massage
- Application of heat (Fig. 11)
- Exercise

Fig. 9 Comparison of normal capillary perfusion (left) and increased capillary volume in *active* hyperemia (right).

Fig. 10 Patient with BLE lymphedema and cellulitis of the LLE.

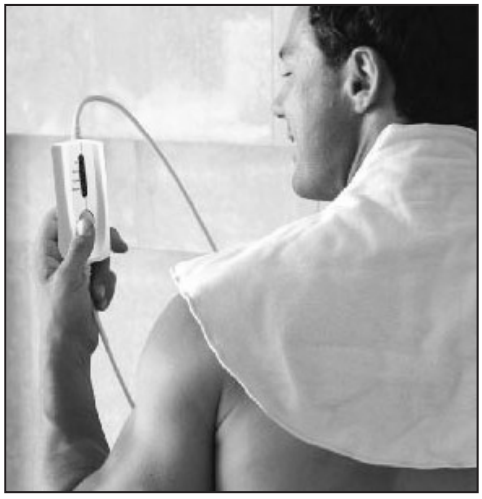

Fig. 11 Use of a heating pad may result in active hyperemia.

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. 12) Passive hyperemia can be caused by:

- Congestive heart failure (Fig. 13)
- Deep venous thrombosis (Fig. 14)
- Tumor growth
- Chronic venous insufficiency

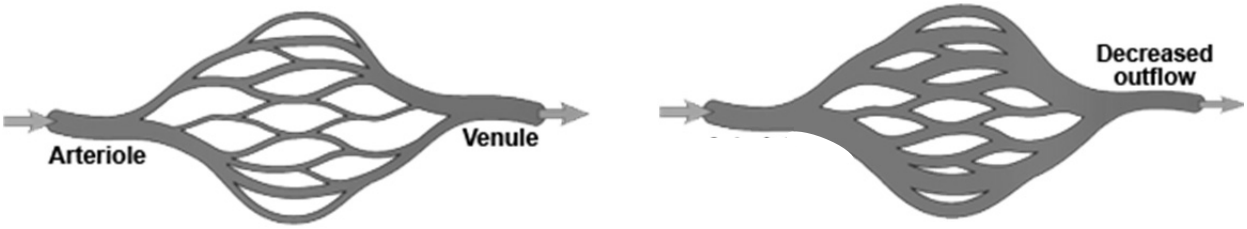

Fig. 12 Comparison of normal capillary perfusion (left) and increased capillary volume through *passive* hyperemia (right).

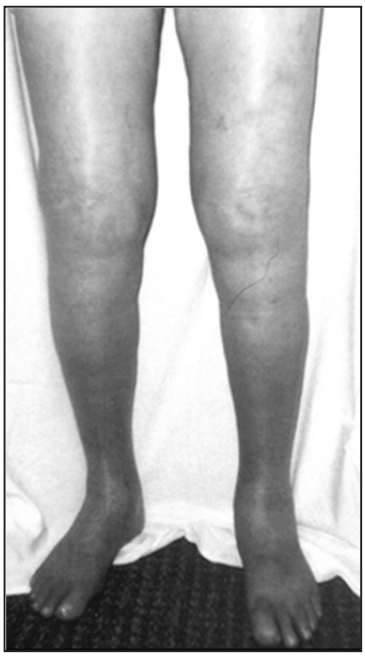

Fig. 13a Patient with BLE edema from congestive heart failure.

Fig. 13b Same patient after diuretic treatment.

Fig. 14 Patient with LUE lymphedema exacerbated by DVT in the left subclavian vein.

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
- Malabsorption
- Liver disease
- Nephrotic syndrome (kidney disease)
- Protein-losing enteropathy (intestinal disorder)

Fig. 15 Patient with BLE edema as a result of malnutrition.

The following conditions can potentially increase lymphatic load and subsequently cause edema:

Active Hyperemia (dilation of the precapillary arterioles)

Passive Hyperemia (venous obstruction or decreased venous return)

Hypoproteinemia (decreased plasma protein concentration)

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. 16)

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.

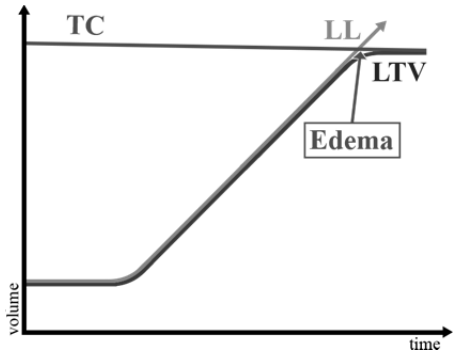

Fig. 16 Edema arises when the increased lymphatic load (LL) exceeds the transport capacity (TC) of a healthy lymphatic system. The lymph time volume cannot exceed the transport capacity of a healthy lymphatic system.

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. 17)

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.

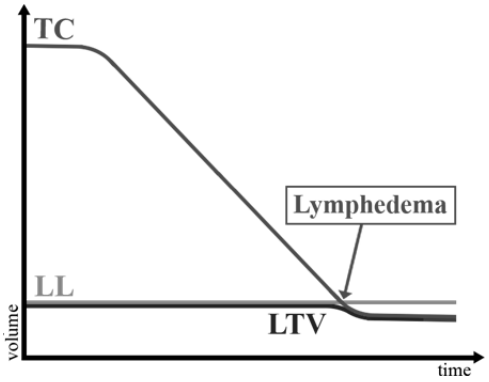

Fig. 17 In low output failure, the transport capacity drops below the physiological level of lymph load which leads to lymphedema.

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. 18)

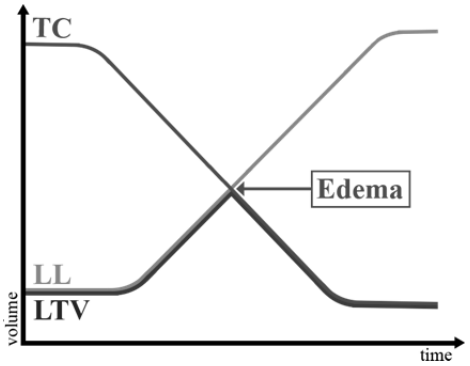

Fig. 18 Combined lymphatic insufficiency. Combination of high and low output failure.

Here are two examples of combined lymphatic insufficiency:

1. 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.
2. If a patient with primary lymphedema of the lower extremity develops 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

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

1. Increased capillary hydrostatic pressure
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

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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