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Klose Training
MLD Certification

Physiology

of the Lymphatic System

Manual Lymph Drainage Certification

Klose Training
MLD Certification

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PHYSIOLOGY OF THE LYMPHATIC SYSTEM

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.

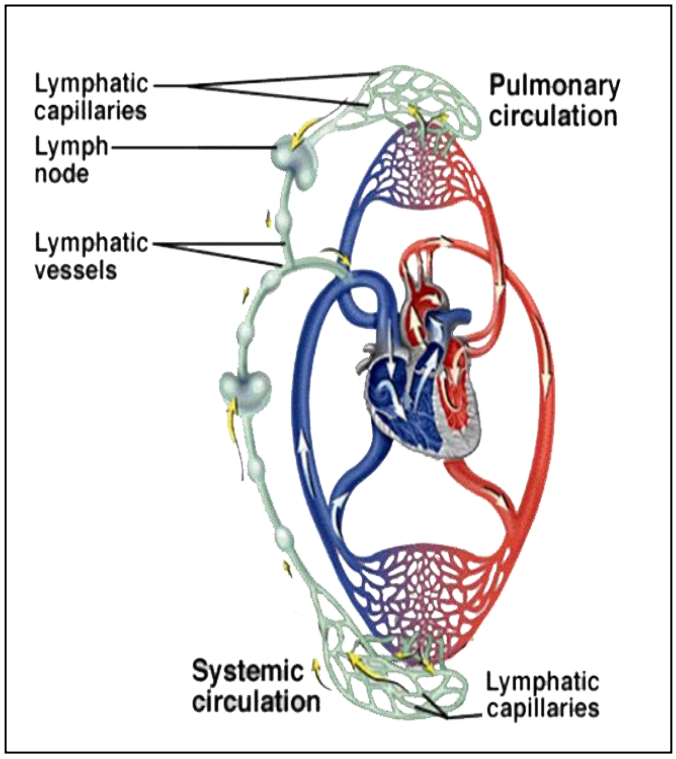

Fig. 1 Diagram of the relationship between the blood circulatory and lymphatic systems.

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)

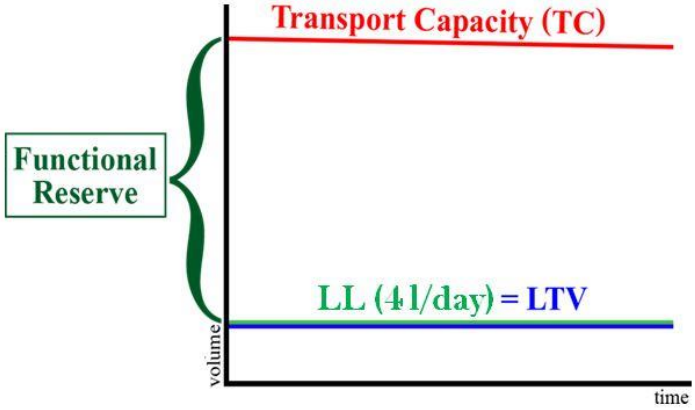

Fig. 2 Diagram showing the relationship between the normal lymph load and the transport capacity. Because the lymph time volume is only about 10% of the maximum transport capacity, the lymphatic system has a large functional reserve.

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.

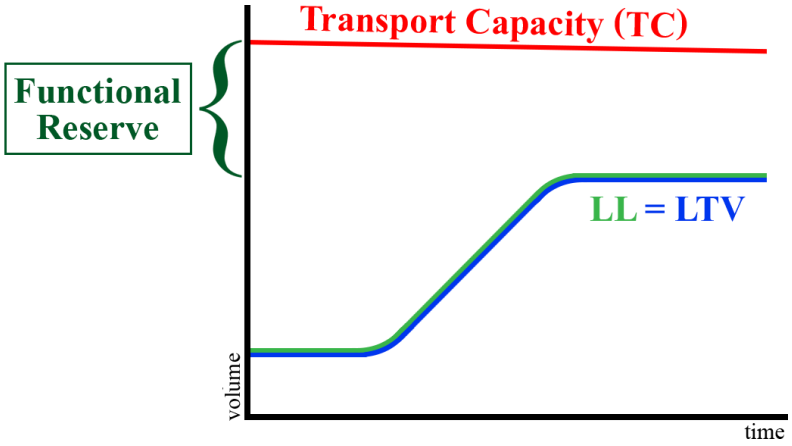

Fig. 3 Diagram showing how the lymphatic system responds to an increase of interstitial fluid (water and/or protein load) with an increase in lymph capillary uptake and activation of the motor function of the lymph vessels.

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.

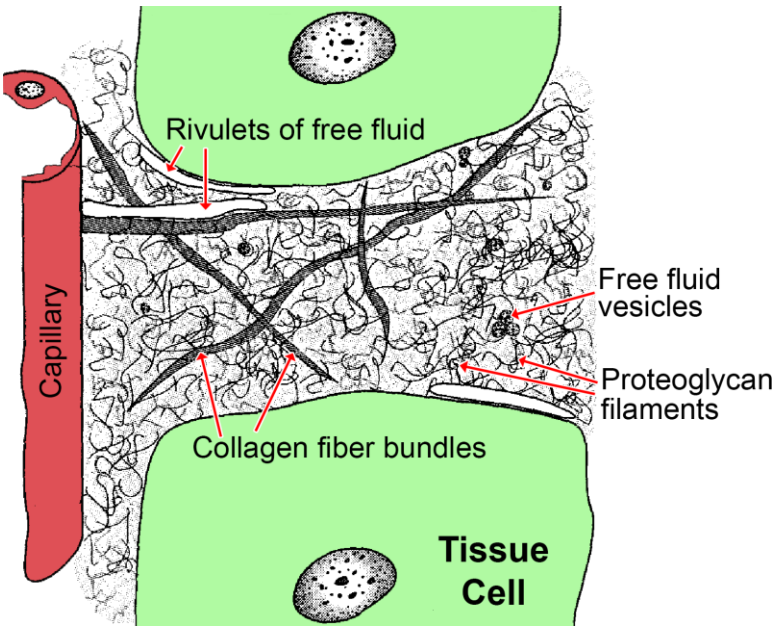

Fig. 4 Structure of the interstitium. Proteoglycan filaments are everywhere in the spaces between the collagen fiber bundles. Free fluid vesicles and small amounts of free fluid in the form of rivulets occasionally also occur.

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.

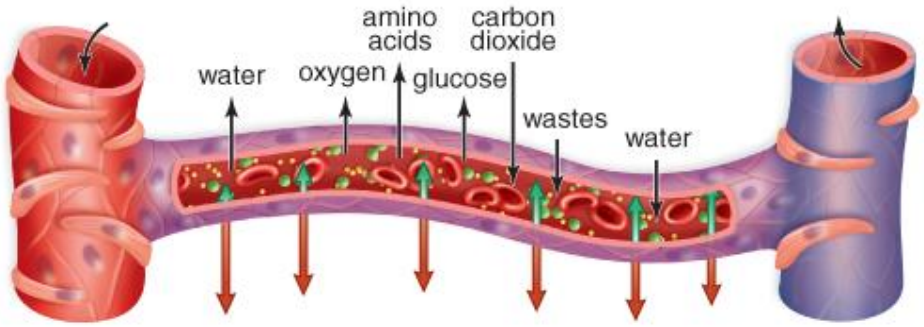

Fig. 5 Diffusion occurs continually in the human body, e.g. the wall of the blood capillaries is permeable for plasma and small organic and small inorganic molecules. The entire exchange of oxygen and carbon dioxide happens through diffusion.

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.

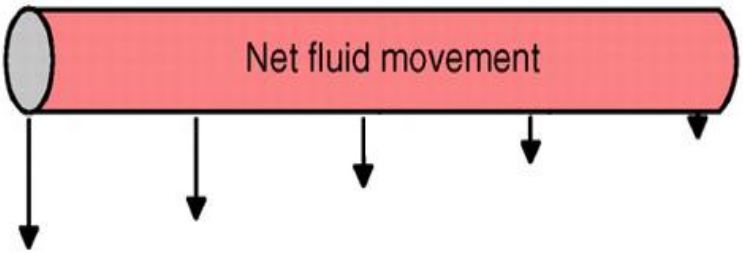

Fig. 6 Fluid movement though filtration. The entire filtrate will become lymphatic water load which needs to be removed from the interstitium by the lymphatic system.
Modified from http://cnx.org/content/col11496/1.6/

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).

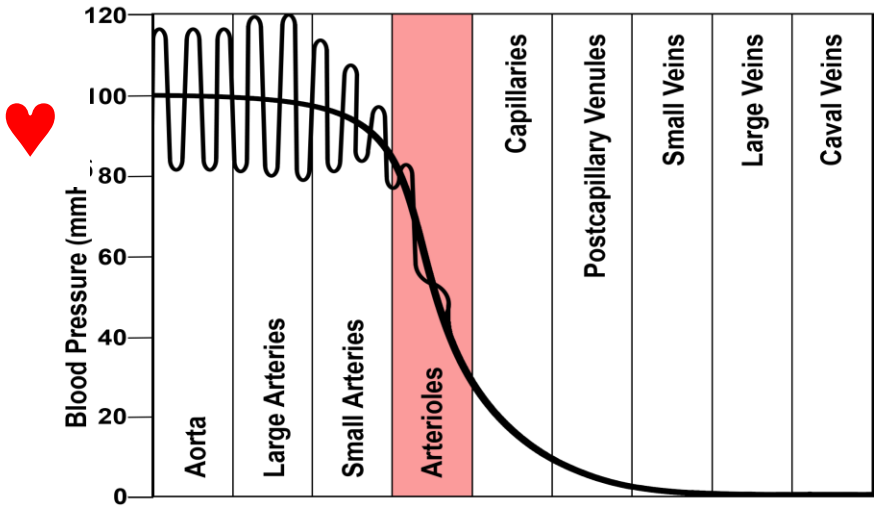

Fig. 7 Diagram showing the average blood pressure in different parts of the systemic circulation.

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.

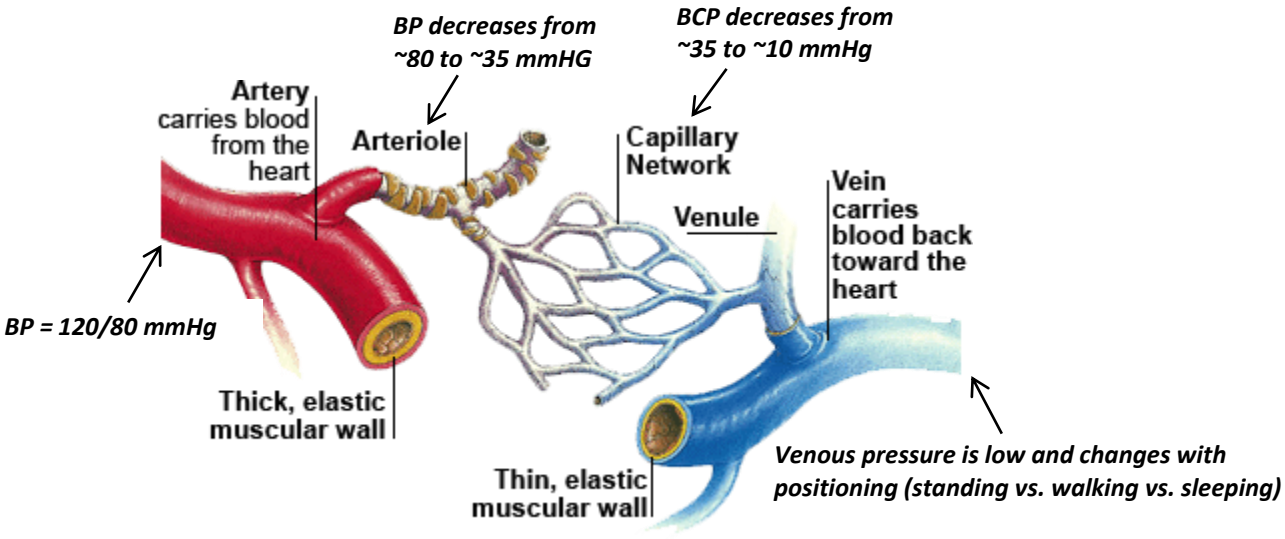

Fig. 8 Precapillary arterioles are rich in smooth muscle fibers. Postcapillary venules have much less muscle tissue in their walls. *Emaze.com*

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

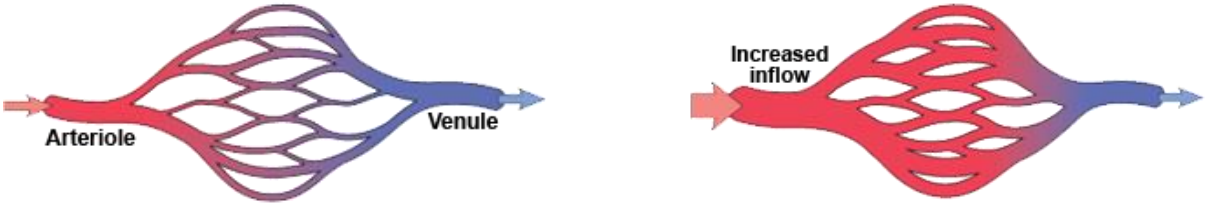

Fig. 9 Comparison of normal capillary perfusion (left) and increased capillary volume in *active* hyperemia (right).

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

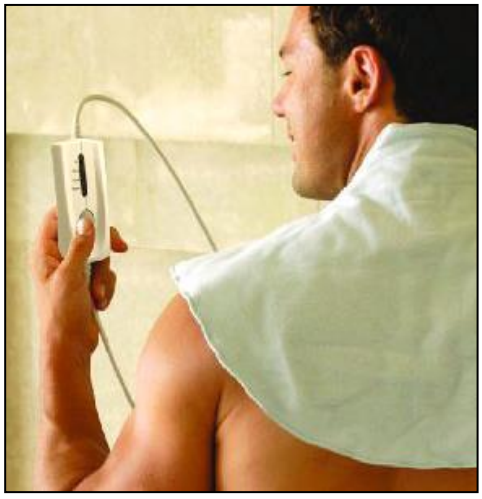

Fig. 11 Use of a heating pad may result in active hyperemia.

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

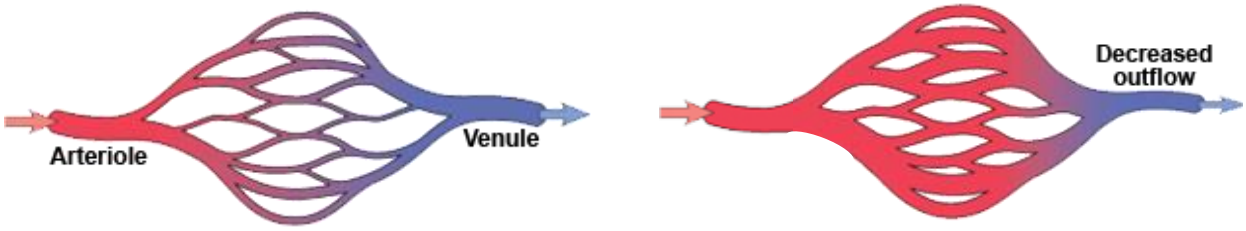

Fig. 12 Comparison of normal capillary perfusion (left) and increased capillary volume through *passive* hyperemia (right).

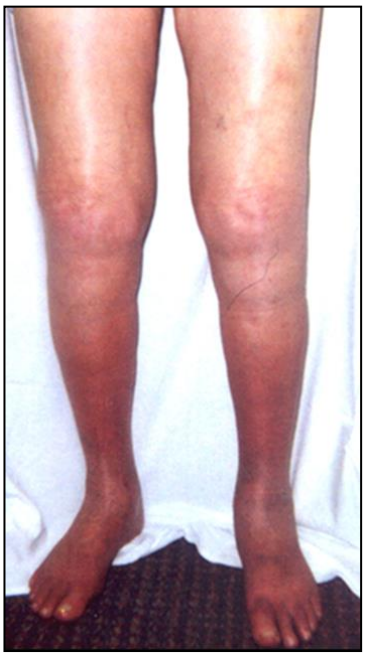

Fig. 13a Patient with BLE edema from congestive heart failure.

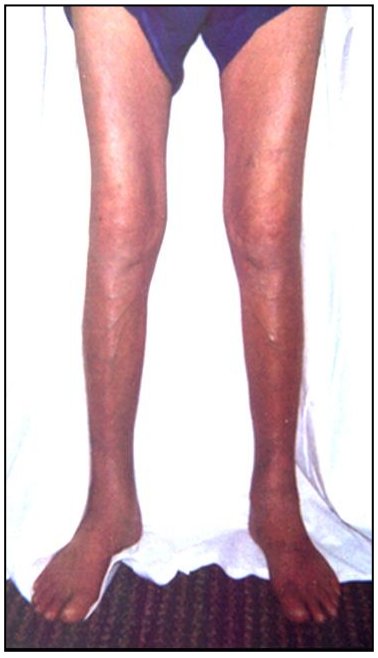

Fig. 13b Same patient after diuretic treatment.

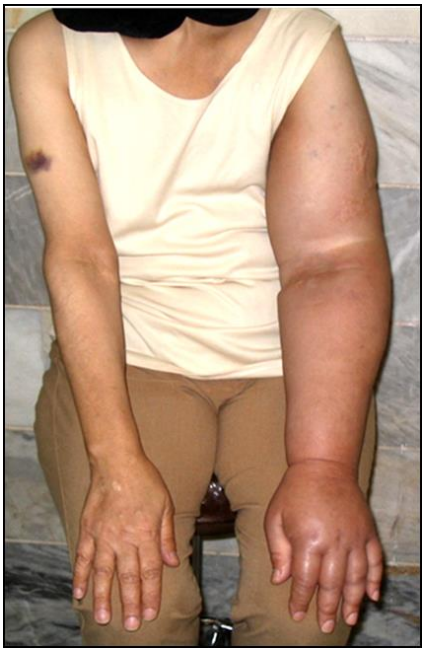

Fig. 14 Patient with LUE lymphedema exacerbated by DVT in the left subclavian vein.

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)

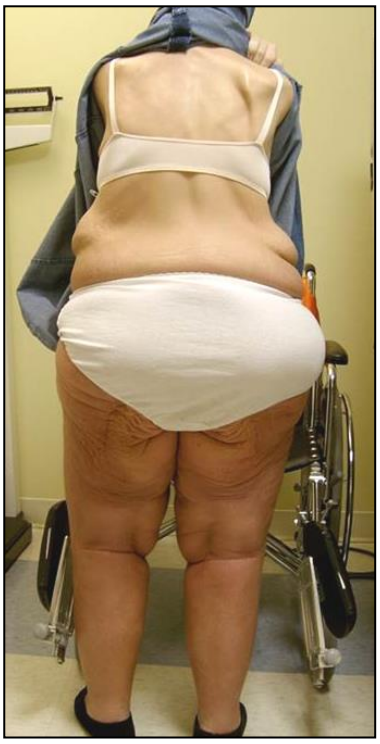

Fig. 15 Patient with BLE edema as a result of malnutrition.

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.

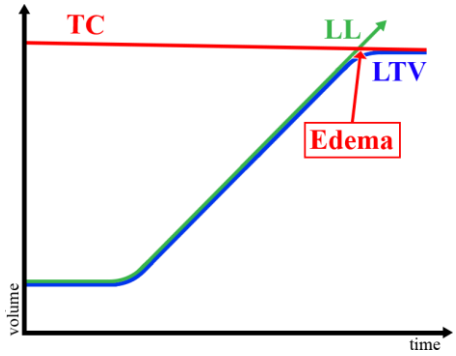

Fig. 16 Edema arises when the increased lymphatic load (LL) exceeds the transport capacity (TC) of a healthy lymphatic system. The lymph time volume cannot exceed the transport capacity of a healthy lymphatic system.

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.

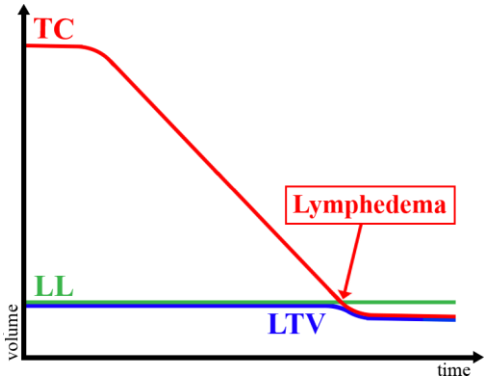

Fig. 17 In low output failure, the transport capacity drops below the physiological level of lymph load which leads to lymphedema.

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)

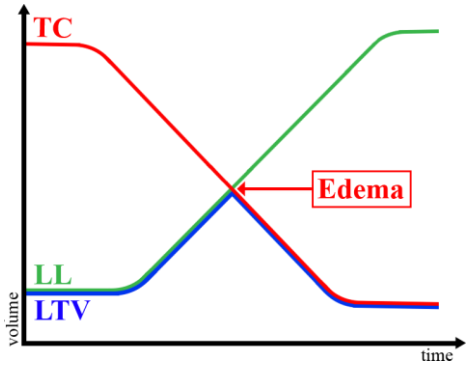

Fig. 18 Combined lymphatic insufficiency. Combination of high and low output failure.

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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