CHAPTER 1
NORMAL VENOUS CIRCULATION

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Introduction

The circulatory system is responsible for circulating (moving) blood throughout the body. The heart and the blood vessels are the most important parts of the circulatory system. The heart is a central organ in the circulatory system. With each beat it forces blood into the blood vessels which transport or carry oxygen and nutrients to all of the tissues and organs (the arteries) of the body and then blood returns back to the heart through the veins.

There are three different types of blood vessels which play different roles within the circulatory system. The two main blood vessels are the **arteries** and the **veins**. The arteries carry the blood loaded with oxygen and nutrients away from the heart and the veins return the "used" blood, which has had the oxygen and nutrients removed, back to the heart. The **lymphatic vessels** are the third component. Briefly, they act as a "clean-up" system to pick up fluid, protein, and other debris left behind by the veins. They filter and clean the fluid before returning it to the heart.

Physiology/Hemodynamics

In normal circulation, the oxygenated blood leaves the left side of the heart through very large arteries. It flows through smaller and smaller **arteries** and even smaller **arterioles** and **capillaries** until it reaches the tissues and organs where the blood vessels are very small usually requiring a microscope to see them. This is called the "**capillary bed**". This is where the end of the arterial system connects to the beginning of the venous system. The blood vessels in the "**capillary bed**" are very tiny, thin walled vessels. This allows for easy release of oxygen and nutrients (sugars, fats, etc.) into the tissues **(Figure 1)**. Blood must then return through the **veins** to the right side of the heart where it can enter the lungs and pick up more oxygen. The venous system has **deep** and **superficial veins**. The **deep veins** are the major veins which return the blood. These lie within the muscles of the arms and legs. The **superficial veins** collect blood from the skin and are intended to take blood through the **communicating veins** back into the deep system. This is assisted by a series of one-way **valves**.

The regulation of **blood flow** through the blood vessels and to the tissues is under fairly complex control of the brain and nervous system as well as local chemicals which may be released by the tissues. Through out the course of the blood vessels there is a complex network of nerves that help regulate the flow through the arteries and veins. This allows tissues to have more blood flow when they are active or exercising and less flow when they are quiet or relaxed. For example, the blood vessels within the skin play a major role in maintaining body temperature. When it is cold they constrict or shut down and move blood away from the skin to the center of the body to preserve heat and when it is hot, they shunt more blood towards the skin to increase heat loss. Local injury or

trauma causes release of chemicals which may create either increased or decreased flow. Increased flow may be seen as localized swelling such as in the case of a burn or an ankle sprain.

The **veins** are fairly thin walled and are able to change their shape depending on the volume or amount of blood within the vein. The volume of blood is proportional or related to the pressure in the veins. When the amount of blood (or pressure) in the vein is low, the veins are flat like an empty balloon. As the volume (or pressure) increases, the vein expands, similar to an inflated balloon. If the pressures are elevated in the venous system and the veins are too full this may cause leaking into the tissues which is reflected as **swelling** or **edema**.

To normally circulate blood through the body there are 4 requirements **(Figure 2, a and b).**
(1) A pump – the **heart**
(2) A **pressure difference** or areas of high pressure and areas of low pressure
(3) A "**venous pump**" – the muscles
(4) A normal vein with intact **valves**

(1) The **heart** serves as the main pump in the circulatory system. Blood moves through the arterial system propelled by the force of the heart. Even at the level of the ankle the arterial blood pressure can be recorded with a blood pressure cuff. When the heart is not pumping well, as in heart failure, this will frequently cause **swelling**.

(2) A **pressure difference** exists between the legs and the right side of the heart where bloods returns to as it goes through the body. At the end of the capillary bed and moving into the venous system there is very little pressure in the veins and at the level of the heart there is even less venous pressure. This pressure difference helps move blood back to the heart. When you lay flat the blood can flow from the higher pressure in the legs to the lower pressure at the heart fairly easily. If there are higher pressures on the right side of the heart, from heart disease or lung disease, the normal pressure difference between the legs and the heart is changed and this may cause swelling.

(3) A **"venous pump**" - normal venous return requires a "pump", similar to the heart, to return blood from the legs to the heart. There are two muscular "pumps" in the legs. The main pump of the legs, responsible for generating most of the venous return (blood pushed back toward the heart), is the calf muscle. In the foot there is a network of veins which serve as a minor or secondary pump to "prime" the calf muscle pump of the legs. With each step the foot and calf muscles contract (squeeze) and forces blood up through the venous system against gravity on the way back to the right side of the heart. Loss of the normal **calf muscle pump** because of not walking normally (shuffling) or loss of normal ankle movement in a cast or splint or after a stroke will result in swelling of the leg because of a decrease in venous return. Some adults as they age their gait may change and they can develop a "shuffling" gait – this may cause swelling because of loss of the calf muscle pump.

(4) A **normal vein** with intact **valves** is required to control "one-way" flow in the veins. A normal vein with intact valves is also required for **normal venous return**. When the **calf muscle pump** contracts it lifts a column of blood up against gravity through the venous system. The venous valves act like steps on a ladder – supporting the column of blood until it reaches the right side of the heart and the pressure difference can pull the blood back to the heart **(Figure 2, a and b)**. A normal vein

is clean on the inside like a soda straw. If there has been **injury from a blood clot** and the inside of the vein is scarred or rough this will inhibit normal venous return. If the valves are not working properly, either because of prior injury or because they have worn out (are incompetent), they will not support the column of blood and cause more pressure in the veins this is called **reflux**. The weight of the blood pushing down in the veins causes increased pressure and can push fluid out of the veins into the tissues. This is one cause of **swelling** or **edema**, a main symptom of **abnormal venous function**.

If any of the above mechanisms of **venous return** are impaired for a short time – **swelling** or leaking of fluid into the tissues may be noted. This is commonly noted after a long flight or with short-term immobilization. When these mechanisms are chronically impaired and pressures are chronically or persistently elevated we can begin to see the effects reflected in the skin and tissues of the legs as long-standing swelling, **darkening** and **thickening of the skin**, and occasionally even **ulceration** or wound formation.

Conclusion

The **heart** pumps the blood to other parts of the body through tubes, **blood vessels**, called **arteries**. This arterial blood supplies blood rich in oxygen and food to very small blood vessel called **capillaries** that are in direct contact with your cells that need this nourishment. The used blood is taken back to the heart and lungs by **veins**. The veins must use the force of the heart, the force of the muscles in the leg and special one way **valves** to move the blood up the leg (especially when standing) and against gravity to make the return of blood to happen. The veins must be widely open to allow good movement of blood as well. When any part of this process fails; leg swelling, skin **damage** and **discoloration** and even skin breakdown (**ulcers**) can happen.

Commonly asked questions

Why do my legs swell?

Leg swelling may occur for many reasons. When it is related to **venous disease** it may be because of increased pressure in the **veins** from heart or lung disease or because the **veins** are not working properly because the **valves** are worn out or incompetent and there is **reflux** or backflow in the veins. Other **causes of swelling** may include liver disease, kidney disease, medications, problems with water balance, or mechanical loss of the “calf muscle pump”. Your doctor can do laboratory testing and vascular testing to determine what conditions you may have.

What if my swelling is only in one leg?

Swelling that affects only one leg may be more likely to be a problem with outflow or **obstruction of the vein**. You need to seek medical attention to make sure there is not an acute **deep vein thrombosis (DVT)** or other important cause.

What causes the veins to not work well?

In many cases, **veins** may wear out because of an inherited (related to the family) or genetic (your own gene make up) predisposition. If you have a family history of **varicose veins**, this may not be avoidable. **Trauma or injury to the vein** is another cause for the veins to not work well this is the case after a blood clot or **deep vein thrombosis**. **Increased pressure in the veins** from obesity may also contribute to the veins not working well.

What can I do about my swelling?

Once your doctors determine the cause, they can provide therapy to help with this problem. In many cases, **elevating the foot of the bed** to provide drainage of the leg at night and using **compression stockings** may be very helpful. Of course, if there is a problem with your heart or other organs your physician will need to address these concerns also.

Figure 1. Blood leaves the heart by large arteries (red) until it reaches the legs and arms and other organs by way of the peripheral arteries. The blood then goes through smaller and smaller blood vessels until it reaches the smallest arterioles. These are the smallest blood vessels used by the heart to pump oxygen and food to where it is needed. At the levels of the skin and other end organs, oxygen and food is given to the cells at the level of the capillaries (purple). After the oxygen and food is delivered blood returns to the heart through the veins (blue).

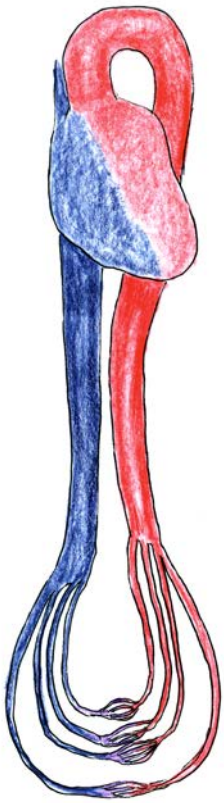
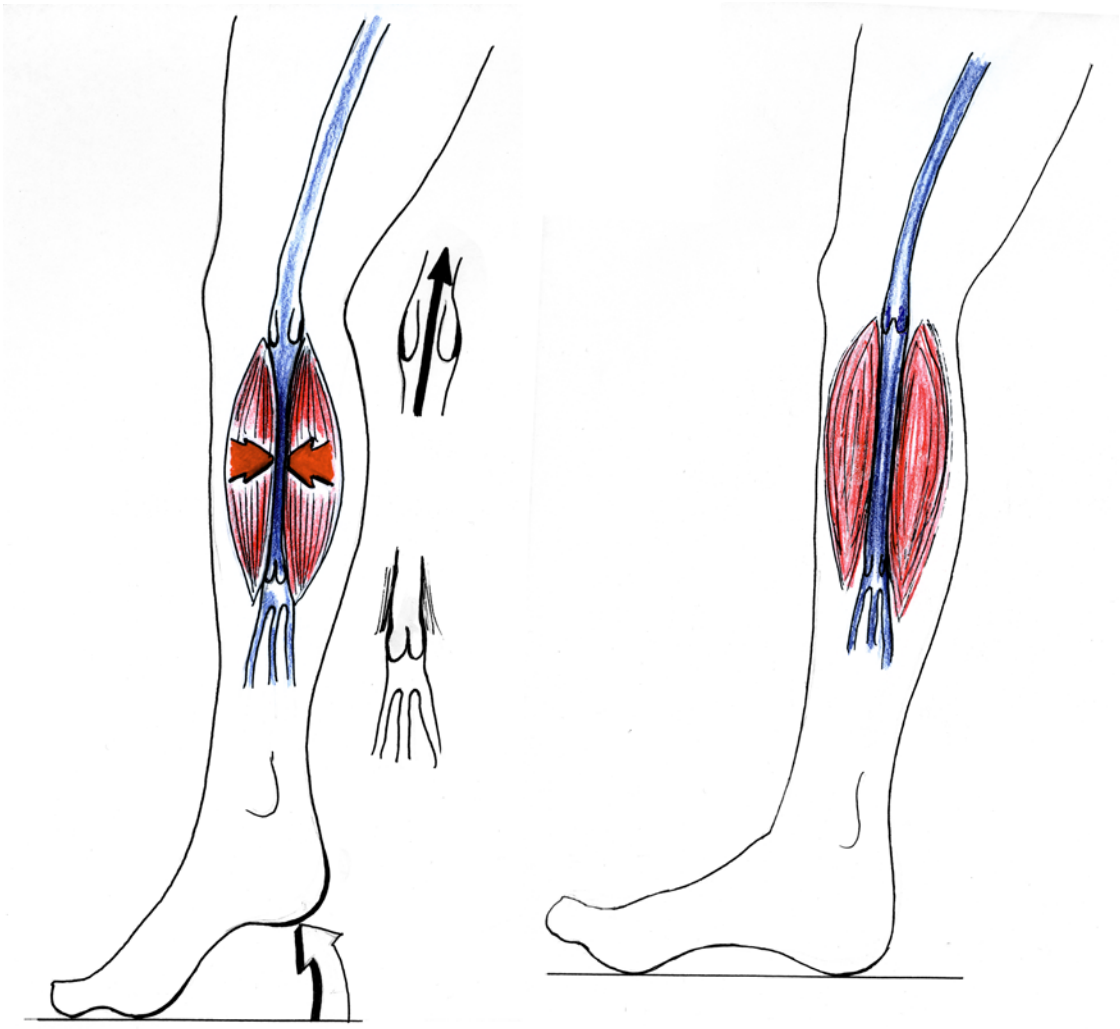


Figure 2. This artist's drawing shows how the normal calf muscle pump works to push the blood out of the leg and back to the heart and lungs. Venous flow is pulled from the superficial system (skin and fat under the skin) to the deep system (veins lying in the muscles) through a series of one-way valves. **(a)** When the calf muscle contracts this squeezing action forces blood forward against gravity and back towards the heart. **(b)** When the calf muscle relaxes the one-way valves closer to the heart close, preventing back-flow of venous blood.



(a) **(b)**