Physiology

Regulation of Venous Pressure: Combination of Cardiac and Vascular Function Curves

See online here

The heart pumps the blood to the aorta, which divides into arteries to supply the various organs of the body. Inside an organ, the main artery is divided into smaller arterioles, which further divide into capillaries at the tissue level. As the wall of the capillary is only one-celled thick, rapid diffusion of gases and nutrients takes place. The capillaries combine to form venules, which drain into larger veins. Finally, all the veins of the body drain either into superior vena cava or inferior vena cava.

Venous Pressure
Venous pressure refers to the average blood pressure in the venous compartment. The **central venous pressure (CVP)** is the blood pressure in the thoracic part of the vena cava near the heart and thus the pressure correlates with that in the right atrial chamber of the heart. It is often measured to approximate the pressure in the right atrium and the amount of blood returning to the heart, which is known as the venous return/preload of the right ventricle. The pressure can be estimated radiologically, and it has thus found its way into clinical application.

The walls of veins have less smooth muscle as compared to arteries. The **myogenic tone** in veins is therefore less. Also, veins have more collagen fibers and less elastic fibers in their outer layers. They are therefore more distensible compared to the arteries. Veins have a large diameter so the resistance to the blood flow is less.

They serve as the **reservoir vessels** because of their increased capacitance. Whenever the body requires less amount of blood such as in resting state, the extra blood is stored in the veins. Many of the capillary beds are closed and more blood sweeps into the venous system.

When venous capacity decreases due to any external or internal factors, the venous pressure increases and more blood returns to the heart.

VSMCs are tethered at one end to collagen filaments. At low filling pressures, collagen is
folded. The increase in filling pressure causes the vein to expand and collages unfold. Sympathetic stimulation causes smooth muscle to contract. Capacity is reduced. Collagen is pulled taut but limits the extent to which internal diameter is reduced.

Regulation of Venous Pressure and Venous Return

Right atrial pressure

As blood moves away from the heart, the resistance to blood flow decreases and so does the blood pressure. The blood pressure in the veins is reduced to an average value of 17 mmHg. Although this is a very low pressure, it is still greater than the right atrial pressure. Blood, therefore, travels from higher pressure region to lower pressure area i.e., from the veins into the right atrium.

Sympathetic activity

The smooth muscle layer of the veins is abundantly supplied with sympathetic nerve fibers. In the case of sympathetic stimulation of these muscles, contraction occurs leading to vasoconstriction. A decrease in the diameter of the veins causes a decrease in the capacitance and an increase in the venous pressure and also the peripheral resistance. This increases the pressure gradient and therefore increases the venous return to the heart.

Cardiac output
The sympathetic stimulation not only causes vasoconstriction but also increases the force of cardiac contractility and the heart rate. As the ventricles pump the blood with greater force, the stroke volume increases. This, in turn, decreases the pressure in the right atrium. The blood, therefore, moves down the pressure gradient and venous return increases. It is often referred to as the "suction effect".

If the cardiac output is reduced, it increases the atrial pressure. This causes backflow of blood into the vena cava causing an increase in the central venous pressure. The pressure gradient in this case decreases.

**Blood volume**

An increase in the total blood volume such as in renal failure or in case of activation of the renin-angiotensin-aldosterone system increases the average venous pressure.

CVP is measured by a change in the blood volume ($\Delta V$) divided by the compliance ($C_v$) of the thoracic veins.

$$CVP = \frac{\Delta V}{C_v}$$

If the volume of blood is greater, it will increase the CVP. However, if the thoracic veins are distensible, they will have more compliance, which will keep the CVP within limits. But the thoracic veins more so the vena cava do not undergo large changes in compliance thus the CVP is almost always increased with an increase in blood volume.

**Skeletal muscle activity**

Many of the large veins of the lower limb lie between the bulky skeletal muscles. When a person performs some physical activity, the calf muscles contract. This puts external pressure on the veins, which decreases the capacitance and increases the venous pressure. Blood again moves down the concentration gradient i.e., towards the heart.

The pressure effect caused by muscles contraction also opens the venous valves present in the lower limb, above the level of the muscles. The valves lying below the skeletal muscles remain closed due to the lower pressure of blood in that region.

*The gastrocnemius* is a powerful calf muscle, which effectively increases the venous
return during physical activity. It is therefore also referred to as the 'second heart'.

Venous valves

Large veins of the body are equipped with one-way valves at a distance of every 3-4 cm. When pressure is applied at the center of a vein, the blood is displaced in both directions.

However, due to the presence of the valves, the blood does not start flowing in either direction. The valve lying above the pressure point opens due to increased blood pressure. This leads to a flow of blood in one direction, i.e., towards the right atrium. The valve lying below the pressure point closes. The structure of the valve is such that if the pressure is applied from above, the valve leaflets close.

Respiratory activity

When a person inspires, the ribcage moves upwards and outwards while the diaphragm moves downward. This decreases the intra-thoracic pressure and increases intra-abdominal pressure.

The portion of the vena cava lying above the diaphragm experiences low pressure from outside and so the venous blood pressure is also low. On the other hand, the portion of vena cava lying sub-diaphragmatically experiences a compression effect which reduces the venous compliance. The venous pressure increases.

As a result of this, a pressure gradient is created, which allows the blood to move towards the thorax. This facilitates the venous return and the mechanism is known as the 'respiratory pump'.

Gravity

When a person is sitting or in a lying posture, the effect of gravity on the column of blood in vessels is minimal. However, when he stands from the sitting posture, the blood in the veins of the lower limbs becomes stagnant and accumulates in them. The blood
capacitance increases, which reduces the central venous pressure and the venous return. To counteract the effect of low venous pressure and venous return, the sympathetic nervous system is activated. This causes vasoconstriction and increased venous return as already explained. The phenomenon is known as reflex venous vasoconstriction.

As the person stands up, the calf muscles contract causing an increase in blood pressure in the specified venous column. This also creates a pressure gradient, causing blood to return to the heart.

Clinical Applied Physiology

As mentioned earlier, CVP is an estimation of the blood in the right atrium. It may be raised in the right heart failure or volume overload.

Jugular venous pressure (JVP) is the clinical measurement of the pressure of blood in the internal jugular vein. It is raised in right heart failure. JVP measurement is easier and requires less technique as compared to the CVP.

Portal venous pressure is the pressure in the portal vein. It is measured by ultrasonography. It is raised in conditions like liver cirrhosis and Budd-Chiari syndrome. Increased pressure in the portal vein results in extravasation of fluid into the peritoneal cavity, a condition known as ascites.

References


Sherwood, L. Human physiology. 7th ed; 2010.


Legal Note: Unless otherwise stated, all rights reserved by Lecturio GmbH. For further legal regulations see our legal information page.