Veterinary Bioscience: Cardiovascular System

STRUCTURE AND FUNCTION OF BLOOD VESSELS 1: PRESSURE AND FLOW IN THE VASCULAR TREE

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INTENDED LEARNING OUTCOMES

At the end of this lecture you should be able to:

- Describe the basic components and structure of blood vessels
- Compare the differences in structure between different types of arteries, veins and capillaries
- Describe the differences in blood flow velocity in different parts of the vascular bed, and relate these to their total cross sectional area
- Describe the pressure changes that occur as blood flows through a vascular bed, and relate these to the vascular resistance of the various vascular segments
- Define total peripheral resistance and explain the relationship between TPR and vascular resistance of each systemic organ
- Define vascular compliance and venous capacitance
- Describe the role of arterial compliance in storing energy for blood circulation
- Describe the relationship between arterial pressure, cardiac output and total peripheral resistance
- Explain the factors that contribute to venous return.

KEYWORDS

Vascular endothelium, vascular smooth muscle, conducting arteries, distributing arteries, compliance, pulse pressure, vascular resistance, total peripheral resistance, arteriole, capillary, sinusoid, venule, arteriovenous anastomoses, veins, venous capacitance.

LECTURE OVERVIEW

BASIC BLOOD VESSEL STRUCTURE

The walls of all blood vessels, except the very smallest ones, have three layers:

TUNICA INTIMA

The Tunica intima is a lining of flat endothelial cells, sitting on a basement membrane. The smooth, continuous endothelium confers low frictional resistance to blood flow. Beneath this is a thin layer of sub-endothelial connective tissue and in arteries there is also an internal elastic membrane (or lamina).

TUNICA MEDIA

The Tunica media is the thickest and most variable layer. It is formed by concentric layers of smooth muscle cells and also elastic fibres (particularly in arteries), and an external elastic membrane (or lamina) lies in the media at the boundary with the adventitia in arteries.

TUNICA ADVENTITIA

The Tunica adventitia consists of collagen and elastic fibres that blend imperceptibly with the surrounding connective tissue. In large arteries the adventitia contains small blood vessels supplying the vascular wall (vasa vasorum) and lymphatics.

FUNCTIONAL SIGNIFICANCE OF VESSEL WALL STRUCTURE

The elastic membranes of the tunica intima and tunica media and the elastic fibres in the tunica media provide elasticity during pulsatile pressure changes or distension. The smooth muscle cells in the tunica media make it possible to regulate the internal calibre of the lumen. The collagen fibres in the adventitia, and the collagenous connective tissue in the intima, provide protection against longitudinal and circumferential stresses.

There are several different types of blood vessel, which may be divided according to their structure and function.

ARTERIES

Conducting arteries (elastic arteries). Low-volume high-pressure elastic arteries, arising from the heart. e.g. the aorta, the pulmonary arteries, and the brachiocephalic, subclavian and common carotid arteries. The tunica media of these arteries contains an abundance of elastin, which enables them to be highly distensible. The aorta is the main systemic arterial trunk - distributes oxygenated blood to the various regions of the body.

It arises from the left ventricle, and is divided into 3 main segments:

- Ascending aorta
- Aortic arch
- Descending aorta

DISTRIBUTING ARTERIES (MUSCULAR ARTERIES)

They include the large and small muscular arteries with a contractile capability enabling them to distribute blood selectively to the various components of the body. Most of the arteries of the body, excluding the elastic arteries, belong to this category, e.g: axillary artery, femoral artery.

RESISTANCE VESSELS

Large and small arterioles (metarterioles). These vessels provide a large resistance to flow. The principal role of these vessels is to regulate the total peripheral resistance and hence arterial blood pressure, as well as controlling the flow of blood to capillary beds. Vasodilation and vasoconstriction of these vessels controls local blood flow

THE MICROCIRCULATION

The microcirculation includes the exchange vessels- capillaries, sinusoids and post-capillary venules. The walls of these vessels are so thin (1-2 cells thick) that the terms intima, media and adventitia are no longer meaningful. Exchanges between the blood plasma and the interstitial fluid take place through the walls of these vessels.

The total cross-sectional area of capillary beds is much greater than that of other vessels. Although blood flow (volume / unit time) must remain constant in all segments of the vasculature, local blood flow velocity does vary, and is inversely proportional to the local cross-sectional area. Due to the high cross-sectional area of the capillary beds, blood velocity is lower. This maximises time available for capillary exchange.

CAPILLARIES

The structure of capillaries is reduced to two essential components: a thin endothelial cell and a basement membrane. External to this is a sparse network of connective tissue fibrils. Largely enclosing the outer surface of a capillary, with its slender cell processes, there is often an elongated cell called a pericyte.

Capillaries are classified based on their position in the vascular bed (i.e. whether at the arterial or venous end of the capillary bed) and the nature of the endothelial lining (i.e. whether they are thick, thin, continuous or fenestrated).

SINUSOIDS

These are irregular sized vessels, lined by endothelium, of much greater capacity than the slender capillary.The endothelial lining is discontinuous, with actual spaces between the individual endothelial cells and individual endothelial cells have multiple fenestrations. The basement membrane is either fragmentary or completely absent.

These structural features promote the interchange of fluids and macromolecules, and allow the relatively easy movement of cells across the endothelium. Consequently, these vessels are characteristic of haemopoietic organs, such as the spleen and bone marrow, where there is much movement of cells. They are also found in the liver.

POSTCAPILLARY VENULES

These exchange vessels resemble an outsized capillary - several capillaries drain into one postcapillary venule. Their structure consists of an inner layer of continuous endothelial cells supported by a basement membrane and surrounded by a number of pericytes with some connective tissue externally (no smooth muscle cells). Intercellular clefts promote the migration (diapedesis) of blood cells through the vascular wall. Thus the postcapillary venule is an especially important site for the migration of white blood cells into tissues during an inflammatory response.

Shunt vessels (arteriovenous anastomoses) directly connect arterioles with venules, bypassing capillaries and causing a local diversion of flow.

VEINS

Capacitance (reservoir) vessels.

These are the muscular venules and veins with large volume and low pressure, whose function is to return blood to the heart. Veins are capacitance vessels, serving as blood volume reservoirs. During exercise or hypotensive states, venoconstriction displaces blood to essential organs, and helps to increase blood pressure.

Veins are thinner walled than arteries, with less smooth muscle (blood pressure is lower in the venous side of the circulation). Blood flow in veins is generally not pulsatile.

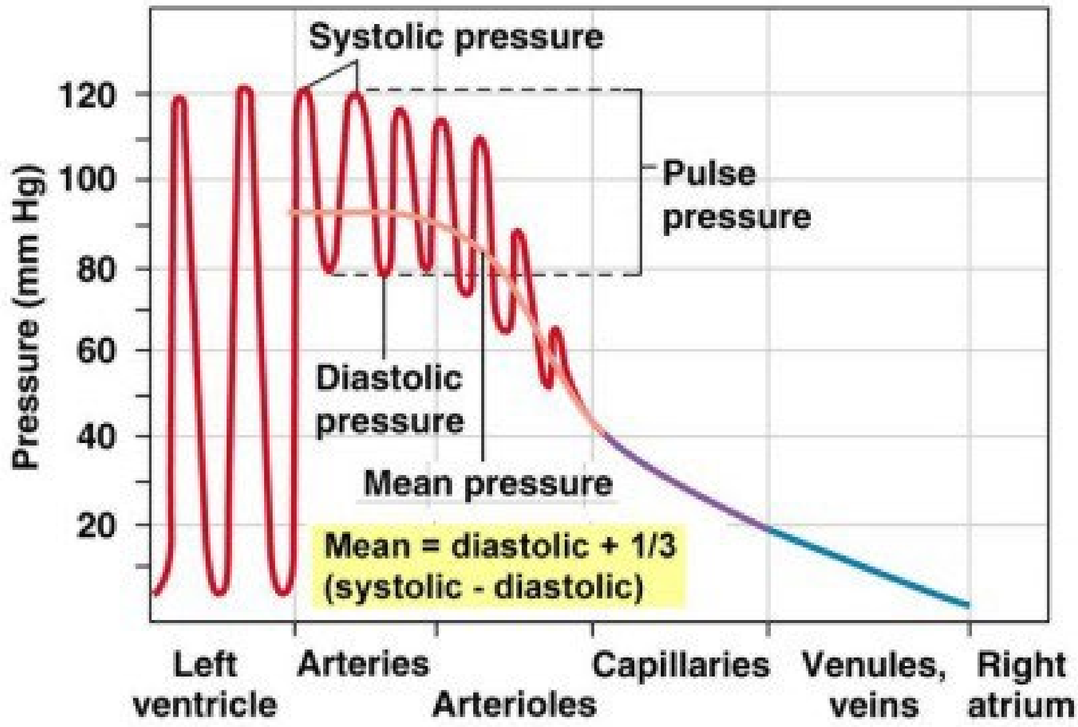
There are several mechanisms to enhance venous return of blood to the heart:

- Sympathetically induced vasoconstriction
- Valves: these are seen in medium sized (>2mm) veins, especially in the limbs. The largest veins, such as the great veins in the abdomen and thorax, have no valves. Each valve is composed of 2 pocket-like semilunar cusps, attached to the interior of the vein, with the opening of the pocket directed towards the heart. In the standing animal, the weight bearing limbs extend well below the level of the heart - the limb veins thus contain long vertical columns of blood and the pressure at the bottom of this continuous column will be high. This would lead to excessive filtration across the capillary bed drained by such a vein. The valves of a vein convert the column into a series of short segments, greatly reducing the hydrostatic pressure.
- Skeletal muscle activity: Contraction of the muscles in the limb, as in walking, applies pressure to the veins. This causes the blood to move towards the heart, since the valves prevent movement away from the heart. This muscular action of the limb is known as the muscle pump. The muscle pump contributes substantially to the venous return to the heart.
- Respiratory activity and ‘cardiac suction’ – these mechanisms also work by increasing the pressure gradient between the veins and the heart.

KEY FUNCTIONAL CONCEPTS

Blood pressure changes across vascular beds

A gradient of blood pressure is the main factor which drives blood flow along the vessels. Arterial pressure is pulsatile because the heart ejects blood intermittently (systole) with rests in between (diastole). There is a large pressure difference between the arteries and the veins, with veins and venules having the lowest pressure.



Compliance is used to describe the elastic property of a vessel, that is how much volume changes in response to a given change in distending pressure. Arterial compliance is important in converting pulsatile flow from the heart into steady flow through peripheral vascular beds. Elastic arteries therefore act as a pressure reservoir – during systole more blood is ejected into them than is drained off into narrow high resistance arterioles. Elastic recoil of arteries during diastole continues driving blood forward when the aortic valves are closed.

The **pulse pressure is the systolic pressure minus diastolic pressure.** Pulse pressure initially increases due to reflection and summation of pressure waves at arterial branch points, but then as blood passes along these arteries, some of the energy of the pressure wave is dissipated, progressively dampening the oscillations in flow and pressure.

Resistance is used to describe the difficulty that blood experiences in passing through a vessel – the opposition to flow. Resistance in large vessels such as larger arteries is low, however arterioles have a much larger resistance, due to their high wall thickness to lumen ratio. Arterioles are normally partially constricted, and their resistance can be reduced by vasodilation. The overall resistance to blood flow in an organ depends on arteriolar resistance. Furthermore, **total peripheral resistance** (the resistance to flow through the entire systemic circulation) is an important determinant of mean arterial blood pressure.

Mean Arterial Pressure (MAP) is very important as it is the average effective pressure that drives blood through organs.

MAP = Cardiac output (CO) x Total peripheral resistance (TPR)

Therefore, all changes in mean arterial pressure result from changes in either cardiac output or total peripheral resistance.

MAP = Diastolic pressure + $\frac{1}{3}$ pulse pressure Pulse pressure = systolic – diastolic pressure

FURTHER READING

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