Veterinary Bioscience: Cardiovascular System

WEEK 3 – REGULATING FLOW

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INTENDED LEARNING OUTCOMES

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

- Describe the anatomy of the coronary, pulmonary, cutaneous circulations, and the major arteries supplying the brain
- Outline the main factors affecting coronary blood flow
- Describe the differences between systemic and pulmonary blood flow.
- Describe the role of arteriovenous anastomoses in heat loss from the cutaneous circulation
- Understand how arterial anastomoses form the circle of Willis and why brain tissue may be at risk of local ischaemia.

KEYWORDS

Coronary arteries, active hyperaemia, pulmonary arteries, hypoxic vasoconstriction, arteriovenous anastomoses, cutaneous circulation, basilar arteries, circle of Willis, end arteries, collateral circulation, blood-brain barrier

LECTURE 12 OVERVIEW: SPECIAL CIRCULATIONS

1. Coronary circulation

Cardiac myocytes have a very high metabolic rate demanding a very rich blood supply. The coronary circulation accounts for 4-5% of total cardiac output.

The **left and right coronary arteries** are the first branches of the aorta, arising from the root of the aorta at the site of the aortic valve. The Left coronary artery supplies the left side of the heart, and opens from the left aortic sinus. The right coronary artery supplies the right side of the heart, and opens from the right aortic sinus. Since the root of the aorta is situated in the very centre of the heart, the left and right coronary arteries must first pass laterally beneath the left and right auricles respectively to reach the left and right parts of the coronary groove where they divide into circumflex and interventricular arteries.

- The left interventricular groove carries the left interventricular (or paraconal interventricular) artery.
- The right interventricular groove, carries the right interventricular (or subsinuosal interventricular) artery.
- The left and right circumflex arteries lie in the circular coronary groove that encircles the heart.

The left and right coronary arteries and their interventricular and circumflex branches supply the myocardium by three groups of smaller branches, which ultimately supply the dense microcirculation between the cardiac muscle cells. These are the ventricular arteries, septal arteries and atrial arteries. The distribution of regions of the heart supplied by the left and right coronary arteries displays species differences. Within the myocardium the arteries form an exceptionally dense **microcirculation** of arterioles and capillaries. There is at least one capillary for each cardiac muscle cell and many cells are in contact with two or three capillaries.

Most of the venous blood of the coronary circulation drains into the **great coronary vein** and the coronary sinus, which lie in the coronary groove. The coronary sinus opens into the right atrium, ventral to the opening of the caudal vena cava and carries about 75% of total coronary venous flow. The small coronary veins are numerous, and are very small veins that open directly into all four chambers of the heart.

Factors controlling coronary blood flow

The heart has a very high basal *oxygen consumption* and so flow must be tightly coupled to oxygen demand. Whenever cardiac activity and oxygen consumption increases, there is an increase in coronary blood flow (**active hyperemia**) that is nearly proportionate to the increase in oxygen consumption. This coupling between oxygen supply and demand is achieved by the myocardium releasing vasodilator substances proportionally to work rate. *Adenosine* is one important mediator of active hyperemia and autoregulation. It serves as a metabolic coupler between oxygen consumption and coronary blood flow. Nitric oxide is also an important regulator of coronary blood flow.

Activation of sympathetic nerves innervating the coronary vasculature causes only transient vasoconstriction mediated by α-adrenoceptors. This brief (and small) vasoconstrictor response is followed by vasodilation caused by enhanced production of vasodilator metabolites (active hyperemia) due to increased mechanical and metabolic activity of the heart, resulting from β-adrenoceptor activation of the myocardium. Therefore, sympathetic activation to the heart results in coronary vasodilation and increased coronary flow due to increased metabolic activity (increased heart rate, contractility). Parasympathetic stimulation of the heart (i.e., vagal nerve activation) elicits modest coronary vasodilation.

Coronary blood flow also demonstrates how **mechanical compression** of a tissue can reduce blood flow. Although one would expect that coronary blood flow would be highest during ventricular systole (when aortic pressure is highest) and lowest during diastole (when aortic pressure is lowest), coronary blood flow on the left is actually depressed during systole and much higher during diastole. Coronary resistance is high during systole because the contracting ventricular muscle squeezes down on the coronary blood vessels, which increases their resistance to blood flow. Coronary resistance then decreases dramatically during diastole, allowing greatly increased blood flow. Coronary blood flow on the right is not restricted by mechanical compression during systole, because the right ventricle contracts with much less force than the left ventricle. Therefore right coronary blood flow closely follows the changes in arterial pressure – highest during systole and lowest during diastole.

2. Pulmonary circulation

Deoxygenated blood returning from the cranial and caudal vena cava into the right atrium is pumped into the right ventricle through the atrio-ventricular orifice. From the right ventricle, the **pulmonary trunk** is the first part of the pulmonary artery system, and passes blood to the lungs. This trunk arises from the conus arteriosus of the right ventricle, flanked by the left and right auricles. Penetrating the pericardium, it bends caudally over the base of the heart and divides to give rise to 2 main branches: **the left and the right pulmonary arteries.** Each is directed caudo-laterally to the hilus of the corresponding lung. Near its bifurcation the pulmonary trunk is connected onto the aortic arch by a fibrous band known as the ligamentum arteriosum, a remnant of the ductus arteriosus, which is an important arterial shunt present in the foetus.

The subdivision of the pulmonary arteries at the hilus of the lung, usually corresponds to the subdivision of the bronchi. The arteries then mainly follow the course of the bronchi into the substance of the lung. **The pulmonary veins** are the only veins which carry oxygenated blood back to the heart. They have no valves. The right and left groups of veins drain independently into the left atrium; the veins are multiple and the pattern usually corresponds to the number of pulmonary lobes.

Functional features of pulmonary blood flow

The pulmonary arteries are the only arteries that carry deoxygenated blood. The entire cardiac output passes through the lungs, and the **mean arterial pulmonary pressure is very low** (around 13 mmHg in the dog). This is achieved because the pulmonary vascular resistance is less than one tenth of the resistance in the systemic circulation. Pulmonary vessels are quite compliant, and readily distend to accommodate the increase in blood flow observed during exercise. This prevents pulmonary arterial pressure increasing excessively.

Because these vessels are so compliant, gravity has an effect on pulmonary blood flow, increasing the blood pressure in lower parts of the lungs compared to the higher parts. This increased pressure distends the vessels low in the lungs, decreasing their resistance to flow. As gravity has a greater effect on blood flow than on air flow, there may be a slight imbalance between air delivery and blood flow, particularly in large animals – this is called a ventilation-perfusion mismatch. To counteract this, pulmonary blood vessels are sensitive to the local concentration of oxygen, and exhibit a phenomenon called **hypoxic vasoconstriction**. This increases the resistance of blood vessels (and therefore reduces blood perfusion) in regions of lung that are poorly ventilated with air, to achieve an appropriate balance of perfusion with ventilation.

Since pulmonary arterial pressure is much lower than systemic arterial pressure, mechanical compression also has important effects on the pulmonary circulation. If alveolar pressure is too high (this might happen if a patient is intubated and ventilated under anaesthetic), pulmonary blood vessels may be compressed sufficiently to raise the resistance to blood flow through the lungs.

3. Skin blood flow

Terminal branches of the cutaneous arteries give rise to three plexuses: (a) the deep or subcutaneous plexus, which in turn gives off branches to the (b) middle or cutaneous plexus, which provides branches to make up the (c) superficial plexus. The reverse applies for venous return to the cutaneous veins. The superficial plexus provides the capillary loops which extend into the dermal papillae which interdigitate with the epidermis.

Arteriovenous anastomoses directly connect arterioles with muscular venules, hence blood which passes through these bypasses the capillary beds. They are found primarily in the food pads, ears, nose and lips. They have a contractile wall of smooth muscle cells with a sphincter-like action. Regulation of cutaneous circulation occurs primarily through the autonomic nervous system, with wide distribution of sympathetic vasoconstrictor fibres to the skin of the feet and ears.

Role in thermoregulation:
Heat is generated in metabolically active tissues, particularly the muscles, and is transferred around the body by the vascular system to facilitate elimination through the skin and respiratory tract. The skin has many times more blood vessels that would be required purely to provide the skin tissues with nutrients and oxygen. This functional reserve serves to promote heat loss.

Under conditions of heat stress, circulatory transfer of heat to the skin can be increased dramatically by two mechanisms. First, the arterioles of the skin vascular beds dilate, which results in increased capillary blood flow. Second, arteriovenous anastomoses open. These actions greatly enhance the total blood flow to the periphery, and the increased heat delivery increases the temperature of the skin, which facilitates heat loss. Under cold stress, skin vascular beds constrict (particularly in the limbs and other extremities), and A-V shunts close. Blood flow is directed through the deeper vascular beds, and heat is transferred by countercurrent exchange from the warm arterial blood to the cooler venous blood. This results in reduced heat loss from the skin and therefore conservation of body heat

4. Cerebral circulation

The arterial supply to the head is via two main blood vessels on each side: the **left and right common carotid arteries** and the **left and right vertebral arteries**. The common carotid arteries extend up the neck, along the trachea. It terminates at the atlanto-occipital joint where it gives rise to:

- The **internal carotid artery** - together with the vertebral artery, supplies the **intracranial circulation** (to the brain).
- The **external carotid artery** - the larger continuation; gives rise to many branches which supply the **extracranial circulation**.

The vertebral arteries are the first branches of the left and right subclavian arteries. They run on each side craniodorsally under the transverse processes of the 7th cervical vertebrae, then extend cranially through the transverse foramen of the anterior 6 cervical vertebrae. They give off segmental arteries which supply blood to the spinal cord and its meninges and the vertebral bodies. On each side the vertebral artery leaves the foramen of the atlas, fuses with the occipital artery from the external carotid to give rise to the **cerebrospinal arteries** and enters the vertebral canal. Here the left and right cerebrospinal arteries coalesce and continue towards the cranium as the midline **basilar artery** and caudally as the **ventral spinal artery**.

The basilar artery extends along the ventral surface of the spinal canal and at the mid region of the brain it anastomoses with the internal carotid to form a circle like arrangement, called the "**Circle of Willis**". This is a cerebral arterial circle on the ventral surface of the brain, which gives rise to branches which supply the brain. These branches are the cranial and middle cerebral arteries and the cranial and caudal cerebellar arteries. The circle of Willis is an example of an **artery to artery anastomosis.** This is when an artery anastomoses directly with another similar artery, before either of them forms its capillary bed. This protects the vital blood supply to the brain, providing a collateral circulation should one of the major arteries become compromised.

Within the structure of many tissues and organs, having the capacity for a collateral circulation ensures that the tissue is not compromised when one artery becomes blocked or damaged. However this is not the case in all tissues.
True end arteries make no direct anastomotic connections with any other arteries. For example, the central artery of the retina – if occluded, it results in permanent blindness, as there is no alternative blood supply to the retina. Within the tissues of the brain itself, there is little collateral circulation – the blood vessels are termed **functional end arteries.** Although **t**hey do anastomose with some nearby arteries, the anastomoses are too small to be functionally effective and so the artery functions as an end artery. Blockage or damage to a small artery within the brain can result in inadequate blood flow to part of this metabolically active tissue – this is called ischaemia. Transient ischaemia can lead to tissue dysfunction and persistent ischaemia can lead to permanent tissue damage (infarction) or cell death (necrosis).

The brain also has to protect its internal environment from toxins and varying levels of metabolites which may have undesirable effects on brain activity and function. Therefore, the endothelial cells of the brain capillaries have closed intercellular junctions (tight junctions) between them, unlike most other capillaries. They are also surrounded by a layer of 'end feet' extending from supporting astrocytes. This arrangement, along with several specific degradative enzymes, is called the **blood-brain barrier** (BBB). Small lipid soluble compounds can diffuse through, and other nutrients are taken up by carrier-mediated transport mechanisms.

Further Reading

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