C 5. Control of circulation

a. Describe the role of the vasomotor centre and the autonomic nervous system in the regulation of cardiac output and venous return.

The peripheral vasculature is innervated by the sympathetic nervous system, from fibres of the coeliac plexus in the abdominal viscera and from fibres from the sympathetic chain in the somatic circulation. Sympathetic activity also causes the release of systemic adrenaline and noradrenaline which act on the circulation as circulating factors. Parasympathetic innervation is significant only in the vagal innervation of the heart, where stimulation produces a reduction in rate, transmission and contractility.

Integration of the autonomic control of circulation takes place in the vasomotor centre in the medulla and lower third of the pons. Within the vasomotor centre lies the vasoconstrictor centre, anterolateral in the upper medulla, which stimulates sympathetic vasoconstrictor fibres via noradrenergic transmission. The vasodilator area lies anterolaterally in the lower medulla and acts to inhibit the vasoconstrictor area. A sensory area lies posterolaterally in the medulla and receives projections from the vagus and glossopharyngeal nerves. It projects to the vasoconstrictor and vasodilator areas and produces the baroreceptor reflex.

In the resting state there is a baseline discharge throughout the sympathetic vasoconstrictor fibres, producing vasomotor tone which is partially responsible for maintaining arterial pressure. There is also baseline tone in the sympathetic and parasympathetic innervation of the heart. Many higher centres affect activity of the vasomotor centre, especially the hypothalamus.

The vasomotor centre acts to compensate rapidly for changes in blood pressure. A fall in blood pressure, increased motor activity or a fright generates a rapid response inhibiting parasympathetic outflow, increasing sympathetic vasoconstrictor tone and releasing adrenal hormones. This produces a rise in heart rate and contractility, arteriolar constriction which increases blood pressure, and increased venous tone which increases venous return and EDV. These effects can double arterial pressure within 5 to 10 seconds. The reverse effects are produced by reducing sympathetic tone (as in spinal anaesthesia).

b. Describe the functions of baroreceptors and relate this knowledge to clinical situations.

Baroreceptors are pressure-sensitive nerve endings in the major arteries of the neck and thorax. They are particularly prominent in the carotid sinus and the aortic arch. Signals from the carotid sinuses are transmitted via Hering’s nerve and IX to the tractus solitarius in the medulla. Signals from the arch of the aorta go via X to the same projection.

The firing rate from baroreceptors is extremely responsive to arterial pressure in the normal range, varying markedly from diastole to systole. They respond to both arterial pressure and the rate of rise in arterial pressure. They accommodate rapidly to changes in the baseline blood pressure. Baroreceptor firing has a strong inhibitory effect on the vasoconstrictor centre, so any sudden fall in arterial pressure (for example, from standing up), results immediately in an autonomic response to increase CO and TPR. The carotid sinus receptors have a stronger influence on the vasoconstrictor centre than those of the aortic arch.

Baroreceptors are required for the reflex responses to short-term changes in blood pressure. This is required for normal response to changes in posture and in theatre for normal response to hypotension resulting from hypovolaemia. They adapt rapidly to sustained changes in blood pressure and become less sensitive due to reduced vessel wall compliance in long-standing hypertension.

External pressure on the carotid sinus particularly can cause a marked fall in blood pressure and heart rate. This is used clinically in cases of SVT or rapid AF and is also described as causing syncope in some individuals with tight collars.
The cardiopulmonary baroreceptors are found in the atria, ventricles and pulmonary vessels. The atrial receptors are divided into A-receptors which respond to atrial tension during systole and B-receptors which respond to wall tension during atrial filling. Stimulation of these receptors results in secretion of ANF and decreased sympathetic outflow to the kidneys, increasing RBF and urine output as well as decreased sympathetic tone to the heart. ANF inhibits the release of ADH, renin and aldosterone. These effects are important in the regulation of plasma volume and blood pressure over hours to days.

c. Explain the role of the autonomic nervous system in controlling systemic vascular resistance and redistribution of blood volume.

Sympathetic innervation of the blood vessels and the adrenals plays a major role in the regulation of TPR and volume distribution. Baseline tone in sympathetic outflow from the vasoconstrictor centre maintains arteriolar and venous tone which maintain systemic blood pressure.

An increase in sympathetic tone, as a result of stimulation of the vasoconstrictor centre, results in increased arteriolar tone, increasing TPR and blood pressure and also in increased venous tone, reducing venous capacitance, rapidly increasing venous return and EDV in the short term, thus boosting CO.

Circulating noradrenaline from the adrenals acts on α receptors in vessels to produce vasoconstriction. Adrenaline at low concentrations acts on β receptors in skeletal muscle, producing vasodilatation, but at higher concentrations, its α effects predominate.

The vascular beds which are most responsive to changes in sympathetic tone are skeletal muscle and skin. Skeletal muscle overall constitutes the largest vascular bed and plays a major role in determining TPR. The splanchnic and renal circulations are less responsive to sympathetic tone and the cardiac and cerebral hardly at all.

d. Explain the neural and humoral regulation of blood volume.

Effective blood volume is affected by the compliance of the venous side of the circulation. This is reduced with an increase in sympathetic tone or by circulating α agonists resulting in increased filling pressure and increased cardiac output.

True blood volume is determined by net loss or gain from the intravascular compartment. Volume gain can result from oral fluid intake, intravenous infusion and to a minor extent from products of metabolism. Volume loss can result from bleeding, evaporative loss in expired air, secretion as sweat and enteric losses from malabsorption. Redistribution between intravascular and interstitial spaces can result from changes in hydrostatic or osmotic pressures detailed above.

Circulating volume is maintained within narrow bounds by renal loss or retention of fluid and to some extent by the hypothalamic stimulus of thirst.

Renal blood flow and consequently GFR is determined by the afferent and efferent arteriolar tone at the glomerulus, given an adequate systemic blood pressure. The main external control of renal arteriolar tone is via sympathetic innervation. An increase in stimulation of atrial baroreceptors results in a reduction in renal sympathetic tone, causing increased RBF and GFR.

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e. Explain the integrated cardiovascular responses to exercise.

The response to exercise consists of central, local and baroreceptor responses. The central response starts in anticipation of exercise with inhibition of vagal output and increased sympathetic tone resulting in an increase in heart rate and contractility before exercise begins. Increased sympathetic tone also causes vasoconstriction of skin, splanchnic and renal vascular beds.

Local responses in muscle are due to local contraction and metabolites stimulating mechanoreceptors and chemoreceptors which are carried to the medulla in
type III and IV nerve fibres and result in increased sympathetic tone. The local effects of metabolites and the myogenic response are also important in increasing blood flow to working muscle. Myocardial blood flow also increases with cardiac output in response to local control of coronary vessel tone.

The baroreceptor response helps maintain sympathetic-mediated vasoconstriction of inactive beds and cardiac sympathetic outflow to maintain blood pressure. The arterial chemoreceptors play no role in exercise as arterial gases and pH are usually unchanged.

With prolonged exercise, body temperature rises and so skin vessels dilate to maintain temperature homeostasis. Local metabolites become the major determinant of active muscle vasodilation and muscle blood flow rises to a maximum of 15 to 20 times resting flow. There is still some vasoconstrictor effect from sympathetic innervation even in active muscle. Vasodilation increases capillary hydrostatic pressure and causes increased fluid movement into active tissues and increased lymphatic return. Acidosis, increased temperature and increased O₂ demand and CO₂ production in muscle move the Hb-O₂ dissociation curve to the right, enhancing O₂ extraction and lowering mixed venous PO₂. Oxygen consumption rises to 60 times resting values.

The cardiac response to exercise is an almost linear rise in CO with workload. This is achieved mainly through a rise in heart rate to a maximum of about 180/min, accompanied by a smaller increase in stroke volume of 10%-35% depending on the level of training. The rise in CO is to a maximum of between four and six times resting output and is the limiting factor in heavy exercise.

Venous return in enhanced by the skeletal muscle pump, by reduced venous compliance with higher sympathetic tone and by the increase in respiratory effort. Blood volume is usually slightly reduced because of fluid losses into tissue, as sweat and in exhaled air. This is opposed to some extent by the increased osmotic effect of metabolites and the rise in tissue hydrostatic pressure. Renal blood flow and urine output is reduced.

There is usually a small rise in blood pressure and pulse pressure as the rise in CO is usually greater than the fall in TPR.

At the extreme of exercise, stroke volume and blood pressure fall, sympathetic tone causes cutaneous vasoconstriction resulting in a rise in temperature and blood pH begins to fall and PCO₂ to rise. These changes usually cause sufficient distress to limit exercise, but if it continues, the rise in body temperature can cause rhabdomyolysis and renal failure.

After exercise, sympathetic outflow falls abruptly, resulting in a fall in CO and BP as TPR remains low due to accumulated metabolites. This is corrected by the baroreceptor reflex.

f. Explain the integrated cardiovascular responses to pregnancy.

g. Explain the integrated cardiovascular responses to anaesthesia and regional anaesthesia/analgesia.