Using sympathomimetic drugs to manage hypotension 1: the cardiovascular system

This article outlines background on the cardiovascular system, and how its components affect blood pressure and common factors that lead to hypotension.

INTRODUCTION
The cardiovascular system (CVS) pumps blood around the body. Blood contains important physiological elements, such as oxygen, carbon dioxide, nutrients and hormones (Aron, 2004).

Without oxygen, the body would not be able to perform many of its vital functions and the energy needed for homeostasis could not be manufactured. All cells need oxygen and many cannot survive for long without it. For oxygen to reach the body’s cells it must make its way from the atmosphere (outside) to the inside. The respiratory system’s primary role is to deliver oxygen from air to inside the body. The lungs allow oxygen to pass from the respiratory system into the blood.

Once oxygen has made its way through the respiratory system, it is carried via the cardiovascular system to cells and tissues. Similarly, the body’s main waste product (carbon dioxide) needs to be transported through the body to the lungs to be expelled (Tortora and Derrickson, 2006). Carbon dioxide is transported via the CVS, being formed from cells and expelled by the respiratory system. There is, therefore, an essential relationship between the respiratory system and the CVS.

CARDIOVASCULAR SYSTEM
The CVS – sometimes referred to as the circulatory system – moves blood containing oxygen, carbon dioxide, waste products, hormones, nutrients, blood cells, any injected drugs and metabolised ingested drugs to and from the body’s cells. It consists of the heart, which is a muscular pumping device, and a closed system of vessels – arteries, capillaries and veins.

The blood contained in the CVS is pumped by the heart around a closed circuit of vessels as it passes again and again through the various ‘circulations’ of the body (for example, the systemic, venous, pulmonary, coronary and capillary circulations). Blood moving from the heart delivers oxygen and nutrients to all the body’s cells. Blood pumped back to the heart carries carbon dioxide and other waste products for removal. Put simply, the CVS can be said to move blood.

The heart
A muscular pump that provides the force to circulate blood to all the body’s tissues, its principal function is to pump blood around the CVS continuously. While blood is in the transport medium, the heart is the organ that keeps blood moving through the vessels (Klabunde, 2004).

Blood pressure
An adult heart will contract (beat) around 70 times a minute. The strength and frequency of the beat is controlled by the autonomic nervous system – specifically, the parasympathetic and sympathetic branches of this system innervate the heart and control the heart rate (HR).

The normal adult heart pumps about 70ml of blood each time it contracts (one cardiac cycle). The volume of blood ejected in every contraction is referred to as the stroke volume (SV). Over one minute, the heart pumps approximately 5L of blood, known as the cardiac output (CO). Thus, CO can be expressed as: CO = SV x HR.

During ventricular systole, the left ventricle pushes blood into the aorta and out into the systemic circulation. The pressure that the left ventricle has to push against to eject blood into the aorta is called ‘afterload’. Afterload can be thought of as the ‘load’ that the heart must eject blood against (Klabunde, 2004). Increases in afterload can affect SV; if afterload increases, SV decreases. Ultimately, this can adversely affect CO and blood pressure (BP).

Another important concept is ‘preload’. This can be applied to the ventricles or atria, but is usually used in relation to the left ventricle.

When the heart’s ventricles are in diastole they are filling with blood, which causes them to stretch. The amount of blood in the left ventricle just before the ventricles contract is referred to as the left ventricular end-diastolic volume, and is related to the term preload. Preload can be defined as the initial stretching of cardiac cells (myocytes) before contraction.

Changes in ventricular preload dramatically affect ventricular stroke volume via the
Frank-Starling mechanism (Klabunde, 2004). This states that the greater the volume of blood entering the left ventricle during diastole, the greater the volume of blood ejected by the left ventricle during systolic contraction. If, for example, venous return increases, this will increase preload, which in turn will increase SV and, ultimately, BP.

Systemic vascular resistance (SVR) is also an important factor in BP regulation. Commonly referred to as total peripheral resistance (TPR), it is the resistance to blood flow by the blood vessels of the systemic vasculature (Guyton and Hall, 2005). The blood vessels’ diameter affects resistance to blood flow. If these dilate then SVR falls, if they constrict it increases.

The HR, SV, CO and vascular resistance (VR) influence BP, which is about 120/80mmHg. The relationship between these variables is what provides BP, which can be expressed as: CO x VR. Fig 1 highlights the component factors affecting BP.

Factors affecting HR include: intravascular blood volume; nervous system stimulation; and hormones such as adrenaline. Those affecting SV include: intravascular blood volume; changes to preload and afterload volumes; and the heart’s ability to contract. Changes to HR or SV affect CO and BP.

### Hypotension and Cellular Hypoxia

Because BP can vary between people, it is best assessed in terms of how well the body’s tissues are supplied with blood.

| TABLE 1. FACTORS AFFECTING HEART RATE, STROKE VOLUME AND VASCULAR RESISTANCE |
|---------------------------------------------------|----------------------------------|----------------------------------|
| FACTORS THAT DECREASE HEART RATE                  | FACTORS THAT DECREASE STROKE VOLUME | FACTORS THAT DECREASE VASCULAR RESISTANCE |
| Heart disease (such as coronary plaque, sick sinus syndrome) | Loss of intravascular blood volume (caused by, for example, traumatic shock, burns) | Vasodilation due to hypoxia |
| Systolic/diastolic heart failure                   | Systolic/diastolic heart failure | Vasodilation due to hypercapnia |
| Drug overdose                                      | Reduced venous return            | Neural factors and hormones such as atrial natriuretic peptide |
| Metabolic and endocrine disorders                  | Cardiac tamponade                | Nitric oxide – produced by vascular endothelium |
| Electrolyte imbalance (changes to, for example, sodium, calcium, potassium levels) | Chest trauma                        | Vasoactive drugs (such as glyceryl trinitrate) |
| Sinoatrial and atrioventricular node associated bradycardias | Myocardial ischaemia             | Sepsis leading to multiple organ failure |

Many clinical conditions can affect BP, leading to hypotension. If BP falls, then cells can be deprived of oxygen. If this happens they quickly become ischaemic and switch to anaerobic cellular metabolism. Prolonged cellular ischaemia can lead to cell death (Bersten and Soni, 2008). Common factors leading to hypotension include loss of intravascular blood volume (shock), neurologically induced peripheral vasodilatation and heart disease (Boon et al, 2006). Table 1 outlines factors that affect SV, HR and VR.

### Compensatory mechanisms

If hypotension occurs, the body uses physiological mechanisms to restore adequate BP. The body’s compensatory mechanisms can be divided into neural, hormonal and chemical ones. These occur simultaneously to restore BP and tissue oxygenation (Bersten and Soni, 2008).

- **Neural compensation:** a decrease in BP will stimulate sympathetic nervous system activation, leading to a series of neurological responses. Neural mechanisms cause both the HR and the rate and depth of breathing to increase and the blood vessels to constrict.

- **Hormonal compensation:** antidiuretic hormone, secreted from the posterior pituitary gland, acts to prevent the production of dilute urine, thus helping to maintain intravascular volume. Aldosterone from the adrenal glands causes the kidneys’ tubules to retain sodium and water, again helping to maintain intravascular volume and restoring BP. In addition, adrenaline and noradrenaline are secreted from the adrenal medulla, resulting in vasoconstriction and increased HR.

**Chemical compensation:** decreased BP means a decrease in blood flow to the lungs, which affects gaseous exchange. Hypoperfusion of the lungs results in a high ventilation-to-perfusion ratio (ventilation with low perfusion). This increases physiological dead space (part of the respiratory system that does not participate in gaseous exchange), resulting in decreased arterial oxygen levels. The hypoxia stimulates chemoceptors, resulting in increased rate and depth of respirations.

Most of the body’s blood vessels dilate during episodes of hypoxia. Although this will not help to raise BP, the widening of the blood vessels allows for greater blood perfusion and oxygen delivery to the tissues.

**Managing hypotension**

If a patient’s BP falls, clinical staff can manipulate venous return, SV, CO and vasoconstriction, thus mimicking the body’s natural physiological responses to hypotension. Decreases in intravascular volume can be dealt with by administering IV fluids. Depending on the nature and causes of hypotension, fluids such as crystalloid and/or colloid solutions can be administered to increase BP.

Vasoactive drugs can also be administered to manipulate HR and VR. Drugs such as adrenaline/noradrenaline, which mimic the sympathomimetics released from the sympathetic division of the autonomic nervous system, can be administered to increase BP.

- Part 2 of this unit, to be published in next week’s issue, examines the use of sympathomimetic drugs.

### References