The cardiac cycle

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Abstract

The heart consists of four chambers that are connected in such a way that contraction of them causes the heart to act as a pump, the right half of the heart passing blood from the venae cavae to the pulmonary circulation for oxygenation and the left half of the heart pumping oxygenated blood from the pulmonary veins into the aorta and systemic circulation. The heart beats rhythmically due to spontaneous firing of cells in the sino-atrial node and passage of the electrical activity throughout the heart via cell-to-cell contacts and specialized conducting tissue. Systole causes the pressure inside the four chambers of the heart to rise which, coupled with the activity of valves, forces blood to move through the heart in one direction. Even though the heart is spontaneously active, its rate of beating can be altered by outputs from the autonomic nervous system. There is a relationship between the length of a cardiac muscle fibre at the end of diastole and its force of contraction (the 'Law of the Heart'), but this can be changed by altered inotropism of the cardiomyocytes due to their sympathetic innervation and circulating catecholamines. Whilst physical exercise promotes an individual's health, there is evidence that extended prolonged exercise can cause transient 'cardiac fatigue'. Recent work has begun to investigate this phenomenon using the technique of echocardiography.

Keywords Contraction; diastole; relaxation: systole

Learning objectives

After reading this article you should be able to:

- describe the structure of the heart and the electrical activity, changes in pressure and volume, and disposition of the heart valves during a cardiac cycle
- describe the relationship between fibre length and force of contraction, the value of this relationship, and how it can be modified in exercise
- outline the concept of cardiac fatigue and how it can be measured

The cardiac cycle describes the mechanical and electrical events that occur in the heart during the course of cardiac contraction (systole) and relaxation (diastole), and which are associated with one heartbeat. In a cardiac cycle, atria and ventricles contract and relax alternately to force the blood from the atria into the ventricles and then into the pulmonary and systemic circuits, and also, during diastole, to allow filling of the chambers in readiness for the next contraction. For each chamber of the heart, the cardiac cycle made up of the four main phases: filling phase; isovolumetric contraction phase; ejection phase and isovolumetric relaxation phase.

The structure of the heart

The heart is a four-chamber cone-shaped organ; the upper two (atria) are receiving chambers (from the venae cavae and pulmonary veins) and the lower two (ventricles) are pumping chambers (to the pulmonary and systemic circuits). The valves of the heart are mechanical devices to restrict blood flow to one direction. The inter-ventricular septum separates the left and right ventricles, and the inter-atrial septum separates the left and right atria. The atrio-ventricular valve is formed by a double fold of endocardium strengthened by some fibrous connective tissue. Between the left ventricle (LV) and atrium (LA) is the mitral valve which has two cusps; between the right ventricle (RV) and atrium (RA) is the tricuspid valve which has three cusps. The pulmonary and aortic valves are formed by three semilunar cusps (Figure 1).

The heart is covered by a pericardial sac that is made of a fibrous pericardium and serous pericardium. The outer fibrous pericardium is a loose-fitting inextensible sac; the serous pericardium contains parietal and visceral layers, adhering to the outer layers of the epicardium. The walls of both the atria and the ventricles have three distinct layers: the endocardium (inner layer), the myocardium (the majority of the contractile cells, cardiomyocytes) and the epicardium (outer layer). The myocardium makes up the bulk of the heart and is mainly responsible for its contractile and pumping action.

Cardiac muscle, like skeletal muscle, contains myosin, actin, tropomyosin and troponin in various isoforms. It also contains titin and dystrophin (Figure 2). Even though cardiac muscle fibres resemble skeletal muscle fibres in that they are striated (the muscle filaments being arranged in the same way), they differ in that they form a functional syncytium, which means that all fibres are electrically connected (through gap junctions). Pacemaker cells of the electrical conduction system can initiate depolarization, and thus contraction, throughout the myocardium without external neuro-hormonal control.

The primary function of the heart is to impart energy to the blood in order to generate and sustain the arterial blood pressure (BP), which is required to move blood through the pulmonary and systemic circulatory systems with a driving force adequate to perfuse the body organs. Cardiac output is the 'key' functional parameter of the LV and is the product of heart rate (HR, the number of cardiac contractions in 1 minute) and stroke volume (SV, the amount of blood pumped out of the LV per beat). SV is the difference between LV end-diastolic volume (LVEDV) and LV end-systolic volume (LVESV). These parameters are under the control of a number of physiological processes (see below).

Heart rate

HR is controlled by a combination of intrinsic (automatic) depolarization and external neuro-hormonal control. The resting HR in adult males and females is around 70 beats/minute, and

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Structure of the heart. (a) Pulmonary circulation and the heart chambers. (b) Systemic circulation

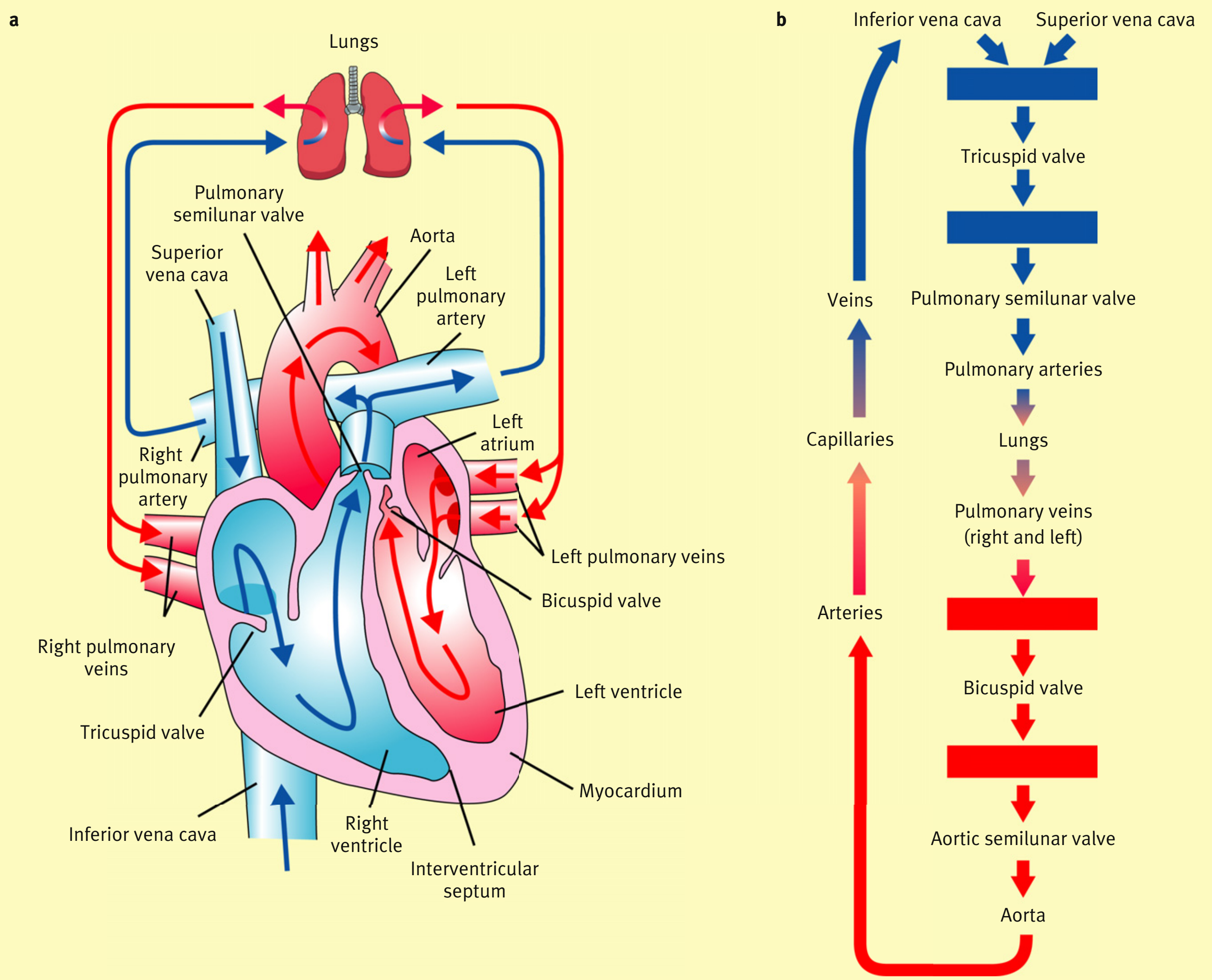

Figure 1

this reflects a basic parasympathetic neural dominance at the sino-atrial (SA) node. If there were no parasympathetic (vagal) tone at rest, the HR would rise to 90 beats/minute. At rest, sympathetic neural activity to the SA node is largely absent but is important for increasing HR in exercise, especially above 100 beats/minute, when parasympathetic tone has been fully withdrawn. The post-ganglionic nerve cells of the sympathetic nervous system (SNS) are located in the grey matter of the lateral horn at levels T1–L4 of the spinal cord. Sympathetic innervation of the heart arises from the cervical and upper thoracic ganglia. The right sympathetic nerves predominantly innervate the SA node and the left sympathetic fibres mainly innervate the atrio-ventricular (AV) node and ventricles, increasing AV conduction, excitability within the His-Purkinje conduction system, cardiac contractility and oxygen consumption.[1] The SNS acts through β_1-adrenergic receptors which act upon potassium channels in the membrane of pacemaker tissue and also promote calcium release during excitation-contraction coupling.

The parasympathetic nervous system (PNS) consists of two parts: the cranial (in the brainstem) and sacral (in the spinal cord at level S2–S4) regions. The PNS innervates the heart via the vagus nerve. The parasympathetic innervation is denser in the SA and AV nodes than in the surrounding myocardium, and the right and left vagal fibres both provide bilateral innervation of the SA and AV nodes.[2] In general, the parasympathetic outflow decreases the rate of firing of the SA node (by slowing closure of the potassium channels in these cells), so decreasing HR. The outflow also hyperpolarizes the AV node (decreasing AV conduction), inhibits atrial and ventricular contractility, and exerts complex effects on cardiac excitability (shortening the refractory period in the atria and prolonging it in the ventricles, Purkinje system, and accessory AV pathways). The actions of the

