Introduction

I became inspired to write this article when I realized that so many people, even those you exercise regularly and participate in endurance sports, did not fully understand the basics of cardiovascular exercise physiology. My goal here is to keep it simple, yet establish a foundation so when I write about the acute and chronic effect that endurance exercise has on the cardiovascular system, you will have a better understanding of how and why the body reacts in the way it does. Also, you will be in a better position to optimize your training to meet your goals.

The study of the cardiovascular exercise physiology is one of the significant disciplines of exercise physiology. It examines how oxygen and other nutrients are transported by cardiovascular system and used by the muscles during exercise.

The primary purpose of the system is to deliver nutrients to and remove metabolic waste products from tissues. It performs the following functions [1]:

- Transports deoxygenated blood from the heart to the lungs and oxygenated blood from the lungs to the heart
- Transports oxygenated blood from the heart to tissues and deoxygenated blood from the tissues to the heart
- Distributes nutrients to cells (e.g. glucose)
- Removes metabolic wastes (e.g. lactate)
- Regulates pH to control acidosis and alkalosis
- Transports hormones and enzymes to regulate physiological function
- Maintains fluid balance to prevent dehydration
- Maintains body temperature by absorbing and redistributing heat

Anatomy of the Heart

The heart is a muscular organ that has two interconnected but separate pumps. Each pump has two chambers – an atrium (upper) and a ventricle (lower). The right side of the heart pumps collects deoxygenated blood from the periphery and pumps it through the lungs (pulmonary circuit). The left side collects blood from the lungs and pumps it throughout the body (systemic circuit).

The sulci, the external deep grooves of the heart, define the four chambers - right atrium (RA), left atrium (LA), right ventricle (RV), and left ventricle (LV) [2]. The coronary sulcus separates the atria from the ventricles. The interventricular sulcus separates the right ventricle and the left ventricle.

The heart has a base and an apex. The base consists mainly of the LA and RA, and parts of the proximal portion of the large veins. It is located above and close to the right sternal border at the level of the second and third ribs. The apex of the heart is located below the base at the level of the fifth intercostal space.
The heart is covered by a double-walled loose-sitting membrane called the pericardium. The interior lining of the heart is called the epicardium. The cardiac muscle, the thickest layer of tissue in the heart, is called the myocardium. The myocardium contains a network of connective tissue fibers called the fibrous skeleton which separates the atria from the ventricles and provides support for the myocardium and the valves of the hearts.

Chambers, Values, and Blood Flow within the Heart

As I stated earlier, the heart has four chambers – right atrium (RA), left atrium (LA), right ventricle (RV), and left ventricle (LV). The RA and LA function primarily as blood reservoirs, delivering blood into the RV and LV, respectively. The RV supplies the main force for moving blood through the pulmonary circuit. The left LV supplies the main force for moving blood through the systemic circuit.

The heart has four valves whose function is to keep the blood flowing in one direction. The atrioventricular (AV) valves separate the atria from the ventricles. The right AV valve has three cusps and is called the tricuspid valve. It controls the blood flow from the RA to the RV. The left AV has two cusps and is called the mitral or bicuspid valve. The mitral value controls blood flow between the LA and LV.

There are two semilunar valves – pulmonic and aorta. The pulmonic valve lies between the RV and the pulmonary artery. The aortic valve lies between the LV and the aorta. They separate the ventricles from the pulmonary artery and aorta, respectively. Both semilunar valves prevent the backflow of blood to the ventricles.

Blood flow through the heart is accomplished by the following sequence of events starting with the return of blood from the body.

1. Deoxygenated blood flows into the RA through the superior and inferior vena cavae, the coronary sinus, and anterior cardiac veins
2. RA contracts, and blood moves through the tricuspid value into the RV
3. The RV contracts, the tricuspid closes, and blood flows through the pulmonic value into the pulmonary arteries
4. Blood enters the alveolar capillaries where oxygen is absorbed and carbon dioxide is removed
5. Blood flows back to the LA through the pulmonary veins
6. The LA contracts, and blood flows through the mitral valve and into the LV
7. The LV contracts, the mitral value closes, the blood flows through though the aortic value into the aorta where it's then distributed to the coronary circulation and the systemic circulation[3]

Figure 1 depicts the heart's anatomy including the blood flow. Please excuse my drawing as you can see, illustrations is not my strong point. I hope you at least get the idea.

The Heart's Electrical Conduction System

Cardiac muscle has unique properties that allow it to contract without an external nervous system. The electrical stimulus for the mechanical contraction is provided by a specialized electrical conduction system. This system consists of the sinoatrial (SA) node, atrioventrical (AV) node, AV bundle, right and left branches, and the Purkinje fibers.

Going into the detail of how this system functions is outside the scope of this article. For now just know that the SA node normally controls the rhythm of the electrical stimulation of the heart and ultimately the heart's contraction patterns; and that this is influenced by the brain's cardiovascular center (medulla) that transits signals to the heart through two components of the autonomic nervous system - the sympathetic nervous system and the parasympathetic nervous system. Stimulation of the sympathetic nerves accelerates firing of the SA node, causing the heart to beat faster. Simulation of the parasympathetic nervous system slows the rate that the SA node fires, thus slowing the heart rate. In another article I'll explain the effect that exercise and stress has on these nervous systems and thus heart rate.

Cardiac Function

The topics of heart rate, stroke volume, and cardiac output are important as they are key elements when I discuss the effects of endurance exercise on the cardiac function in other articles.

Heart Rate

Heart rate (HR) is number of heart beats per minute. The average normal resting HR is between 60 and 80 beats per minute (bpm). Resting HR in women is usually 10 bpm higher then men. Children have higher heart rates than adults; elderly people have lower heart rates; and fit people in the same age group and gender have lower resting HR than unfit people.

Stroke Volume

Stroke volume (SV) is the amount of blood ejected from the left ventricle (LV) in a single contraction measured in milliliters (mL). At rest, SV is usually 70mL, and is calculated by taking the difference between end-diastolic volume (EDV) and end-systolic volume (ESV) (SV = EDV − ESV). EDV is the volume of blood available to be pumped by each ventricle at the end of the filling or resting
phase (diastole). At rest, at normal EDV is about 125mL. ESV is the volume of blood remaining in each ventricle following its contraction phase (systole). At rest, ESV is about 55mL. SV increases when you are in the prone (supine) position. In an upright position, SV is lower in untrained than trained individuals. SV in men is usually greater than that in women as men have larger hearts.

Another measurement is the ejection fraction (EF). It is the ratio of stroke volume to end-diastolic volume. The formula is EF = SV/EDV. In healthy adults it can range between 50% and 75%.

**Cardiac Output**

Cardiac output (Q) is the volume of blood pumped from the heart per minute and is calculated by multiplying HR by SV (Q = HR x SV). Resting Q for adults are approximately the same for both trained and untrained adults, about 4 to 5 liters per minute. However, the maximal Q is higher in trained than untrained adults.

Let's look an example of a healthy male who has a resting HR 72 bpm and SV at 70 mL/beat. His Q is therefore 5mL/min.

**The Blood Vessels and Circulation (The Vasculature)**

Another important topic that I will elaborate on in subsequent articles is the effect that exercise has on the vascular system. But first let's understand the function of some of its main components.

After the blood flows from the heart, it enters the vascular system, which is composed of numerous blood vessels. The blood vessels deliver blood to the tissues, help promote the exchange of nutrients, metabolic wastes, hormones, and other substances with cells and return blood to the heart.

The circulation of the heart and lungs (central circulation) and the rest of the body (peripheral circulation) form a single closed system with two components – an arterial system and a venous system. The arterial system carries blood from the heart and the venous system returns blood to the heart.

**Arteries and Arterioles**

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**Capillaries**

Capillaries form dense networks that branch throughout all tissues. The capillary walls are very thin, averaging about 1 mm in length and .01 mm in diameter. This is just large enough for a single red blood cell to pass through [4]. The main function of capillaries is to exchange oxygen, fluid, nutrients, electrolytes, hormones, and other substances between the blood and the various tissues of the body.

**Venules and Veins**

Blood moves back to the heart through the venous part of the circulation system. Capillaries converge into small venules, which converge to veins. Because the pressure in the venous system is low, the venous walls are thin. The muscles tissue surrounding them allows them to constrict or dilate greatly, thus allowing the venous circulation to act as a reservoir for blood in either small or large amounts [5, 6]. Some veins, such as those of the legs, contain one-way values that help prevent the blood from flowing away from the heart.

**Blood Pressure**

Blood pressure is the force exerted by the blood on the walls of the vessel as it flows through the vessel. The pressure is greatest in the aorta and arteries and greatly reduced as blood flows through the capillaries. There is no pressure as blood moves through the venules and veins.

The two main blood pressure measurements are the systolic blood pressure (SBP) and the diastolic blood pressure (DBP). SBP is the pressure exerted on arterial walls during the contraction of the left ventricle. At rest, a healthy individual's normal systolic pressure is about 120 mm Hg. Resting numbers above 140 mm Hg indicate hypertension. Diastolic blood pressure is the pressure exerted on arterial walls during the resting phase between beats. This value reflects peripheral resistance and health of the vasculature. In healthy individuals, normal diastolic pressure when resting is about 80 mm Hg. Resting numbers above 90 mm Hg indicate hypertension.

Since I enjoy number crunching, it's probably worth mentioning a few other pressure calculations - pulse pressure (PP), mean...
arterial pressure (MAP), and rate-pressure product (RPP). PP is the difference between the systolic and diastolic pressures. MAP is the average pressure exerted throughout the entire cardiac cycle. It reflects the average force driving blood into the tissue. The formula is MAP = DBP +1/3(SBP – DBP). The RPP, also called the double product, is an estimate of workload of the left ventricle. The formula for RPP is RPP = SBP x HR.

Let's look an example of a healthy male whose resting SBP is 120 mm Hg and his DBP is 80 mm Hg, sometimes referred to as having a blood pressure of 120 over 80. His resting HR is 72 bpm. Based on these values his:

\[ PP = 40 \text{ mm Hg} (120 \text{ mm Hg} - 80 \text{ mm Hg}) \]
\[ MAP = 93 \text{ (80 mm Hg + 1/3(120 mm Hg – 80 mm Hg))} \]
\[ RPP = 8,640 \text{ (120 mm Hg x 72 bpm)} \]

**Formula Recap (Blood Pressure, Stroke Volume and Cardiac Output)**

Just to recap, listed below are formulas related to Blood Pressure, Stroke Volume and Cardiac Output:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Formula</th>
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</thead>
<tbody>
<tr>
<td>Pulse Pressure (PP)</td>
<td>( PP = SBP - DBP )</td>
</tr>
<tr>
<td>Mean Arterial Pressure (MAP)</td>
<td>( MAP = DBP +1/3(SBP – DBP) )</td>
</tr>
<tr>
<td>Rate-Pressure Product (RPP)</td>
<td>( RPP = SBP \times HR )</td>
</tr>
<tr>
<td>Stroke volume (SV)</td>
<td>( SV = EDV – EDV )</td>
</tr>
<tr>
<td>Ejection Fraction (EF)</td>
<td>( EF = SV/EDV )</td>
</tr>
<tr>
<td>Cardiac output (Q)</td>
<td>( Q = HR \times SV )</td>
</tr>
</tbody>
</table>

**References**