Effects of Vasodilation and Arterial Resistance on Cardiac Output
Aliya Siddiqui

Abstract
Heart is one of the most important organs present in human body which pumps blood throughout the body using blood vessels. With each heartbeat, blood is sent throughout the body, carrying oxygen and nutrients to all the cells in the body. The cardiac cycle is the sequence of events that occurs when the heart beats. Blood pressure is maximum during systole, when the heart is pushing and minimum during diastole, when the heart is relaxed. Vasodilation caused by relaxation of smooth muscle cells in arteries causes an increase in blood flow. When blood vessels dilate, the blood flow is increased due to a decrease in vascular resistance. Therefore, dilation of arteries and arterioles leads to an immediate decrease in arterial blood pressure and heart rate. Cardiac output is the amount of blood ejected by the left ventricle in one minute. Cardiac output (CO) is the volume of blood being pumped by the heart, by left ventricle in the time interval of one minute. The effects of vasodilation, how the blood quantity increases and decreases along with the blood flow and the arterial blood flow and resistance on cardiac output is discussed in this review Article.

Keywords: Heart; Cardiac cycle; Arteries; Blood flow; Vasodilation; Arterial Resistance; Cardiac output

Introduction
The circulatory system is composed of the heart and blood vessels, including arteries, veins, and capillaries [1,2]. Arteries and Veins play an important role in blood circulation along with heart [3]. The heart is the key organ in the circulatory system [4]. As a hollow, muscular pump, its main function is to propel blood throughout the body. It usually beats from 60 to 100 times per minute, but can go much faster when necessary. It beats about 100,000 times a day, more than 30 million times per year, and about 2.5 billion times in a 70-year lifetime. With each heartbeat, blood is sent throughout our bodies, carrying oxygen and nutrients to every cell. Each day, 2,000 gallons of blood travel many times through about 60,000 miles of blood vessels that branch and cross, linking the cells of our organs and body parts. Heart collects the deoxygenated blood from the body and pushes it to the lungs where it becomes oxygenated, and then heart pumps the oxygen rich blood to the body. Normal functioning of heart is very important to lead a healthy life [5]. Vasodilation is widening of blood vessels caused by relaxation of smooth muscle cells in the vessel walls particularly in the large arteries, smaller arterioles and large veins thus causing an increase in blood flow [6]. Arterial dilation leads to an immediate decrease in arterial blood pressure and heart rate [7]. The relationship between mean arterial pressure, cardiac output and total peripheral resistance (TPR) gets affected by Vasodilation. Cardiac output is the amount of blood that is pumped by the heart per unit time, measured in liters per minute (l/min). The amount of blood that is put out by the left ventricle of the heart in one contraction is called the stroke volume. The stroke volume multiplied by the heart rate is the "cardiac output". Numerous cardiovascular afflictions are currently known to be associated with heart including aortic root dilation, aortic regurgitation, mitral regurgitation, myocardiitis, heart failure, pericarditis, pericardial effusion [8,9,10]. Sudden deaths due to cardiac arrest, cardiac stroke, atriocentral conduction block, and heart failure are reported worldwide [11,12,13]. Various animals like mouse were used to detect the heart disease [14]. Cardiovascular disease is one of the most frequent causes of death in women in the world [15,16,17]. Stroke is the major healthcare problem with higher mortality and morbidity rates [18]. Women are more affected with Atherosclerosis [19]. At times increase in blood pressure may lead to various kinds of health problems [20,21]. Heart failure patients are at increased risk of sudden death due to ventricular problems [22,23,24]. Diabetes Mellitus (DM) is also a main risk factor for heart failure [25,26,27]. Most of the cardiovascular emergencies are caused by coronary artery disease [28,29]. Echocardiography is the modality of choice for investigation of suspected congenital or acquired heart disease [30,31,32]. Suspected heart disorders and related heart diseases can be investigated using Echocardiogram [33,34,35].

Cardiac cycle
The sequence of events that occurs when the heart beats, is known as "cardiac cycle". The frequency of the cardiac cycle is described by the heart rate [36]. There are two phases of the cardiac cycle. The heart ventricles are relaxed and the heart fills with blood in diastole phase [37]. The ventricles contract and pump blood to the arteries in systole phase [38]. When the heart fills with blood and the blood is pumped out of the heart one cardiac cycle gets complete. The events of the cardiac cycle explains how the blood enters the heart, is pumped to the lungs, again travels back to the heart and is pumped out to the rest of the body [39]. The important thing to be observed is that the events that occur in the first and second diastole and systole phases actually happen at the same time [40].

Cardiac Cycle: 1st Diastolic Phase: During this first diastole phase, the atrioventricular valves are open and the atria and ventricles are relaxed. From the superior and inferior venae cavae the de-oxygenated blood flows in to the right atrium. The atrioventricular valves which are opened allow the blood to pass through to the ventricles [41]. The Sino Atrial (SA) node contracts and also triggers the atria to contract. The contents of the right atrium get emptied into the right ventricle. The back flow of blood into the right atrium is prevented by "Tricuspid valve".

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Vasodilators include carbon dioxide (CO₂) and Nitric oxide (NO) are the factors that result in vasodilation. Some of the examples of veins [58]. The process is the opposite of vasodilation. “Vasodilators” wall of the vessels, particularly the large arteries, small arterioles and narrowing of blood vessels resulting from contraction of the muscular rate were recorded while surgeries [57]. “Vasoconstriction” is the (due to hormones or the nervous system). The frequencies and heart intrinsic (due to local processes in the surrounding tissue) or extrinsic [55]. At times leads to respiratory problems [56]. The response may be to treat heart failure, systemic and pulmonary hypertension, and angina (due to a decrease in vascular resistance [54]. Therefore, dilation of arteries and arterioles leads to an immediate decrease in arterial blood due to a decrease in vascular resistance [54]. TPR depends on certain factors, like the length of the vessel, the viscosity of blood (determined by hematocrit) and the diameter of the blood vessel. Vasodilation works to decrease TPR and blood pressure through relaxation of smooth muscle cells in the tunica media layer of large arteries and smaller arterioles [65,66]. A rise in the mean arterial pressure is seen when either of these physiological components (cardiac output or TPR) gets increased [67]. Vasodilation occurs in superficial blood vessels of warm-blooded animals when their ambient environment is hot; this diverts the flow of heated blood to the skin of the animal [68], where heat can be more easily released into the atmosphere [69]. Vasoconstriction is opposite physiological process. These processes are naturally modulated by local paracrine agents from endothelial cells like nitricoxide [70], bradykinin, potassium ions and adenosine etc, as well as an organism’s autonomic nervous system and adrenal glands, both of which secrete catecholamines such as epinephrine and norepinephrine respectively [71].

Vascular Resistance

The resistance to flow that must be overcome to push blood through the circulatory system is known as “Vascular resistance”. Systemic vascular resistance (SVR) is the resistance offered by the peripheral circulation [72], while the resistance offered by the vasculature of the lungs is known as the pulmonary vascular resistance (PVR) [73]. The systemic vascular resistance may also be referred as the “Total Peripheral Resistance” (TPR). Vasodilation (increase in diameter) decreases SVR, where as Vasoconstriction (i.e., decrease in blood vessel diameter) increases SVR [74]. The Units for measuring vascular resistance are dyn.s.cm⁻⁵, pascal seconds per cubic metre (Pa.s/m³) or, deriving it by viscosity of blood (determined by hematocrit) and the diameter of the arterial pressure is seen when either of these physiological components [64,65]. TPR depends on certain factors, like the length of the vessel, the viscosity of blood (determined by hematocrit) and the diameter of the blood vessel. Vasodilation works to decrease TPR and blood pressure through relaxation of smooth muscle cells in the tunica media layer of large arteries and smaller arterioles [65,66]. A rise in the mean arterial pressure is seen when either of these physiological components (cardiac output or TPR) gets increased [67]. Vasodilation occurs in superficial blood vessels of warm-blooded animals when their ambient environment is hot; this diverts the flow of heated blood to the skin of the animal [68], where heat can be more easily released into the atmosphere [69]. Vasoconstriction is opposite physiological process. These processes are naturally modulated by local paracrine agents from endothelial cells like nitricoxide [70], bradykinin, potassium ions and adenosine etc, as well as an organism’s autonomic nervous system and adrenal glands, both of which secrete catecholamines such as epinephrine and norepinephrine respectively [71].

Vasodilation and Arterial Resistance

The relationship between mean arterial pressure, cardiac output and total peripheral resistance (TPR) gets affected by Vasodilation. Vasodilation occurs in the time phase of cardiac systole while vasoconstriction follows in the opposite time phase of cardiac diastole [63]. Cardiac output (blood flow measured in volume per unit time) is computed by multiplying the heart rate (in beats per minute) and the stroke volume (the volume of blood ejected during ventricular systole) [64]. TPR depends on certain factors, like the length of the vessel, the viscosity of blood (determined by hematocrit) and the diameter of the blood vessel. Vasodilation works to decrease TPR and blood pressure through relaxation of smooth muscle cells in the tunica media layer of large arteries and smaller arterioles [65,66]. A rise in the mean arterial pressure is seen when either of these physiological components (cardiac output or TPR) gets increased [67]. Vasodilation occurs in superficial blood vessels of warm-blooded animals when their ambient environment is hot; this diverts the flow of heated blood to the skin of the animal [68], where heat can be more easily released into the atmosphere [69]. Vasoconstriction is opposite physiological process. These processes are naturally modulated by local paracrine agents from endothelial cells like nitricoxide [70], bradykinin, potassium ions and adenosine etc, as well as an organism’s autonomic nervous system and adrenal glands, both of which secrete catecholamines such as epinephrine and norepinephrine respectively [71].

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Calculation of Resistance can be done by using these following formulae:

Calculating resistance is that flow is equal to driving pressure divided by resistance. The systemic vascular resistance can therefore be calculated in units of dyn.s.cm⁻⁵ as

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\frac{\text{Mean arterial pressure – mean right atrial pressure}}{\text{Cardiac output}}
\]

Where Mean Arterial pressure is 2/3 of diastolic blood pressure plus 1/3 of systolic blood pressure.

The basic tenet of calculating resistance is that flow is equal to driving pressure divided by resistance.

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Control of Stroke Volume: The heart does not fill to its maximum capacity, under rest conditions. If the heart were to fill more per beat then it could pump out more blood per beat, thus increasing stroke volume. During systole, the heart ventricles empty only about 50% of their volume. The heart could pump out more blood per beat if the heart were to contract more strongly [88]; in other words, a stronger contraction would lead to a larger stroke volume. During the exercise time or exercise periods, the stroke volume increases because of these mechanisms; the heart contracts more strongly and the heart fills up with more blood [89].

The Stroke volume is increased by 2 mechanisms:

- Increase in end-diastolic volume and
- Increase in sympathetic system activity

End-diastolic volume: volume of blood in the ventricles at the end of diastole, called 'end-diastolic volume'. A larger end-diastolic volume will stretch the heart [90]. Stretching of the heart muscles optimizes the length and strength relationship of the cardiac muscle fibers, which results in stronger contractility and greater stroke volume [91].

Increase in sympathetic system activity increases the Stroke Volume: Release of norepinephrine by sympathetic nerve fibers causes an increase in the strength of myocardial contraction, thus increasing the stroke volume [92]. Epinephrine, like norepinephrine will stimulate an increase in the strength of myocardial contraction and thus increase stroke volume.

Conclusion

Heart is a major organ and plays a key role in circulatory system of body. The main function of heart is to pump the blood to all parts of the body through various blood vessels. The force exerted by the blood against the vessel wall is referred to as “Blood pressure”. Every blood vessel in the circulatory system has its own blood pressure, which changes continually. Arterial blood pressure rises and falls in a pattern corresponding to the phases of the cycles of the heart, the cardiac cycle. Flow through a blood vessel is determined by two factors: the force that pushes the blood through the vessel, and the resistance of the vessel to the blood flow. Usually the rate of blood flow is measured in milliliters or liters per minute (ml/min or l/min). Vasodilation causes increase in blood flow due to decrease in vascular resistance. The resistance produced mainly in the arterioles is known as the systemic vascular resistance (SVR) or the peripheral vascular resistance (PVR). Cardiac output is a function of heart rate and stroke volume. If the pressure in a vessel increases then the blood flow will increase. However, if the resistance in a vessel increases then the blood flow will decrease. Vasodilation, flow of blood and arterial pressure can be examined and resistance to arterial pressure on cardiac output can be studied, determined and controlled.

References


