# Introduction

Myocardial revascularization has been an established mainstay in the treatment of coronary artery disease for almost over half a century. Coronary artery bypass grafting (CABG), used in clinical practice since the 1960s and is arguably the most intensively studied surgical procedure ever taken ***(Kolh et al., 2010).***

Though undergoing open heart surgery in general and CABG in specific carries various risks, possible morbidities and mortality following coronary artery bypass grafting (CABG), some are generally related to undergoing any surgery, while others are particularly related to undergoing myocardial revascularization ***(Shahian et al., 2007)***.

Patients referred for cardiac surgery are increasingly, at high risk of perioperative mortality and morbidity because of advanced age, comorbidities, poor left ventricular (LV) function, and extensive coronary disease. Several therapeutic options are available to support failing heart during the perioperative period. These include inotropes, vasopressors, Intra-aortic balloon pump (IABP), and assist devices ***(Dyub et al., 2008)***.

Several clinical trials as well as a recent meta-analysis have failed to demonstrate the benefit of IABP therapy on left-ventricular (LV) function or survival ***(Lauten et al., 2013*).**

New percutaneous LV assist devices (pLVAD) have been developed for mechanical circulatory support. These devices unload the left ventricle and partially replace myocardial function, thus, potentially promoting myocardial recovery ***(Lauten et al., 2013*)**.

Extracorporeal membrane oxygenation (ECMO) is a treatment modality for providing prolonged but temporary cardiac or respiratory support in the critically ill patient. The initial results of ECMO with adult respiratory distress syndrome showed poor outcome, However several subsequent studies have reported the successful use of ECMO for temporary circulatory support in patients with cardiopulmonary failure ***(Doll et al., 2004)***.

Patients undergoing cardiac surgery are generally able to resume spontaneous ventilation as soon as they have recovered from the anesthesia. However, approximately 2.6% to 22.7% of them require prolonged mechanical ventilation (MV) ***(Trouillet et al., 2009).***

Pulmonary injury after cardiopulmonary bypass (CPB) is a common complication which can continue for several days, leading to prolonged mechanical ventilation. Inflammatory response to CPB and ischemic damage of the lungs have been considered as major causes of respiratory failure after cardiac surgery **(*Imura et al., 2009).***

A number of studies have examined the risk factors for prolonged mechanical ventilation (PMV) after CABG. These include age, smoking, left ventricular dysfunction, congestive heart failure, renal failure, and angina. However, patients continue to require mechanical ventilation for a variety of reasons, including hematologic, respiratory and neurological ***(Yende et al., 2002).***

# Aim of The Work

The aim of the work is to shed the light on different modalities for the mechanical support of CABG patients as a category of critically ill patients in order to decrease morbidity and mortality after cardiac surgery.

# Chapter I

# Anatomy of the coronaries and indication of coronary artery bypass surgery

## Anatomy of the coronaries:

Although the heart is filled with blood, it provides very little nourishment and oxygen to the tissues of the heart. The walls of the heart are too thick to be supplied by diffusion alone. Instead, the tissues of the heart are supplied by a separate vascular supply committed only to the heart. The arterial supply of the heart in the vast majority of people is the two main coronary arteries, right and left (running in the coronary sulcus) which arise from separate ostia in the aorta. The venous drainage is via cardiac veins that return deoxygenated blood to the right atrium (Fig.1) ***(Weinhaus and Roberts, 2009).***

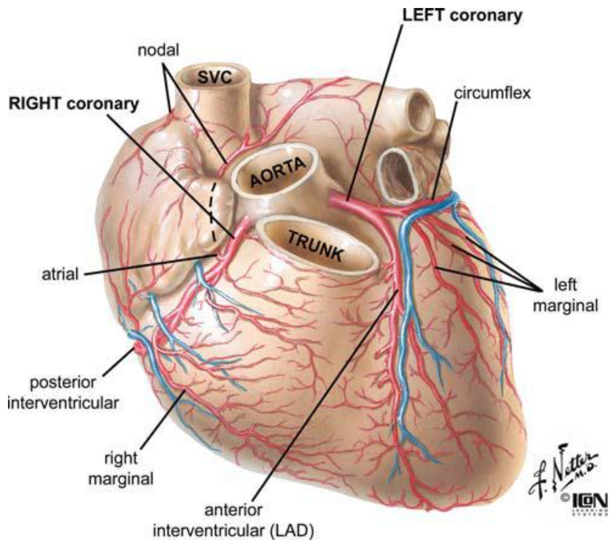


**Fig (1):** Vascular supply to the heart. Arterial supply to the heart occurs via the right and left coronary arteries and their branches. Venous drainage occurs via cardiac veins ***(Weinhaus and Roberts, 2009).***

## Anatomy of the Coronary Arteries:

There are many variations of “normal” that are not considered “anomalous. As a result, the concept of dominance has been adopted into the clinical vernacular to describe which artery gives rise to the posterior descending artery (PDA), the posterolateral artery (PLA), and the atrioventricular (AV) nodal artery, which, in turn, supply the inferior aspect of the interventricular septum, the inferior aspect of the left ventricle, and the AV node, respectively. If these arteries originate from the right coronary artery (RCA), the circulation can be classified as “right-dominant” (Fig. 2).Alternatively, if supplied by the left circumflex artery (LCx), the circulation can be classified as “left dominant” (Fig. 3) ***(Fiss, 2007).***

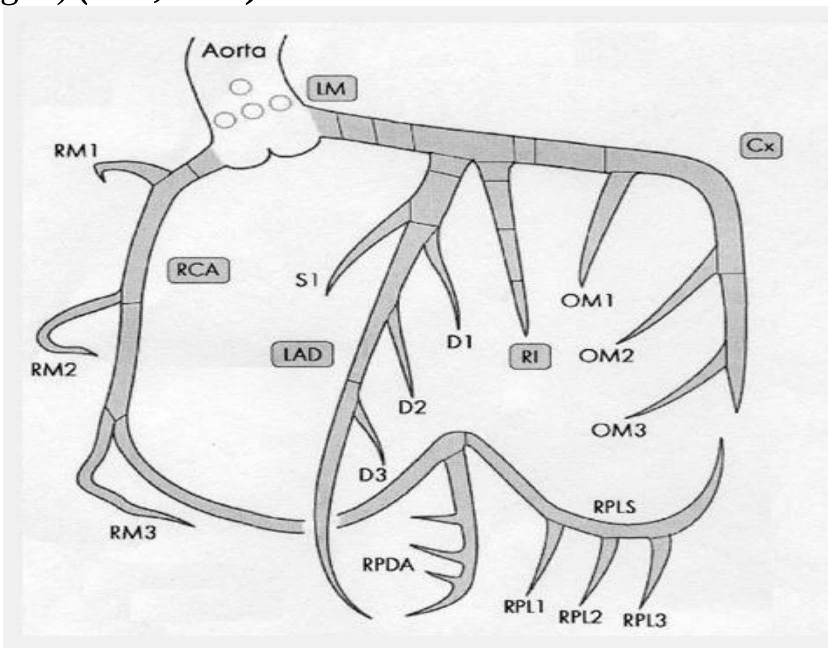


**Fig (2):** Right-dominant circulation.[LM = left main artery; LAD = left anterior descending artery; Cx = circumflex; RCA = right coronary artery; S = septal; D = diagonal; OM = obtuse marginal; RM = right marginal; RPDA = right posterior descending artery; RPL = right posterolateral; RI = ramus intermediate] ***(Fiss, 2007).***

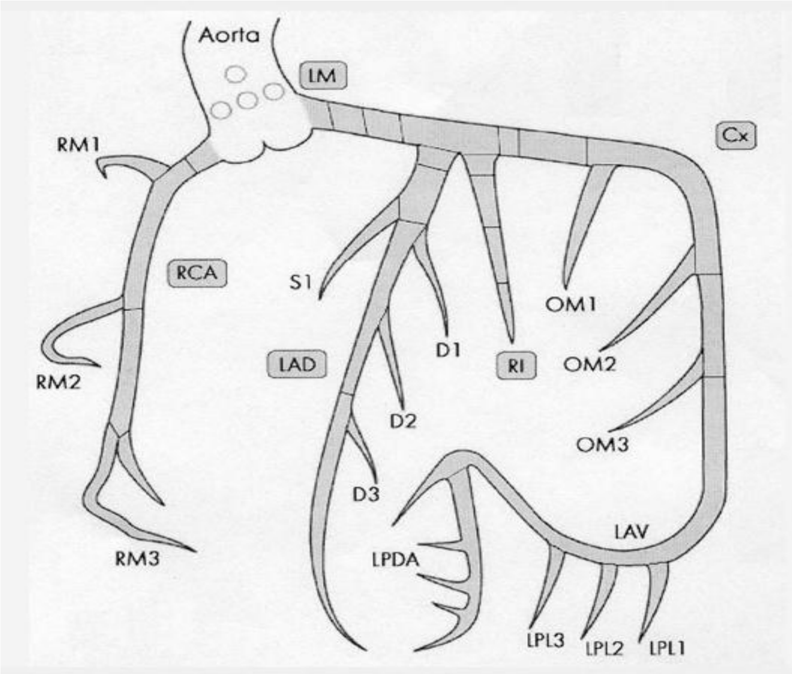


**Fig (3):** Left-dominant circulation, [LM = left main artery; LAD = left anterior descending artery; Cx = circumflex artery; RCA = right coronary artery; S = septal; D = diagonal; OM = obtuse marginal; RM = right marginal; lPDA = left posterior descending artery; lPL = left posterolateral; RI = ramus intermediate] ***(Fiss, 2007).***

In such patients, the right coronary artery is quite small and supplies only the right atrium and right ventricle. In the case of "co-dominant" circulation, the right coronary artery supplies the PDA and terminates. The left circumflex artery supplies the PLA with an occasional parallel posterior descending branch that supplies the inferior interventricular septum. Approximately 85% of the general population is right-dominant, 8% are left-dominant, and 7% are co-dominant ***(Fiss, 2007).***

The coronary ostia are usually located below the sinotubular ridge, within the sinus of Valsalva, centrally located between the commissural attachments of the aortic cusps (Fig. 4) ***(Fiss, 2007).***

The ostium of each coronary artery tends to form a slight funnel, with the diameter of the left main coronary artery at its ostium slightly larger than that of the right coronary artery (mean 4.0 versus 3.2 mm) ***(Fiss, 2007).***

The main left coronary artery lies in epicardial fat between the body of the left atrium and the pulmonary artery, and curves anteriorly toward the anterior interventricular sulcus After a usual length of 1 to 2cm. it divides into two or more branches. The branch that enters the left atrio-ventricular sulcus originates at a right or greater angle and becomes the left circumflex artery (LCX). The branch that enters the anterior interventricular sulcus, virtually as a continuation of the main left coronary artery, becomes the left anterior descending artery (LAD*)* ***(JAMES, 1965)***

Branches of the left anterior descending artery (LAD), anterior septal perforating arteries, enter the septal myocardium to supply the anterior two-thirds of the interventricular septum (in about 90% of hearts) (Fig. 4). Other branches extend laterally through the epicardium to supply adjacent right and left ventricular free walls ***(Weinhaus and Roberts, 2009).***

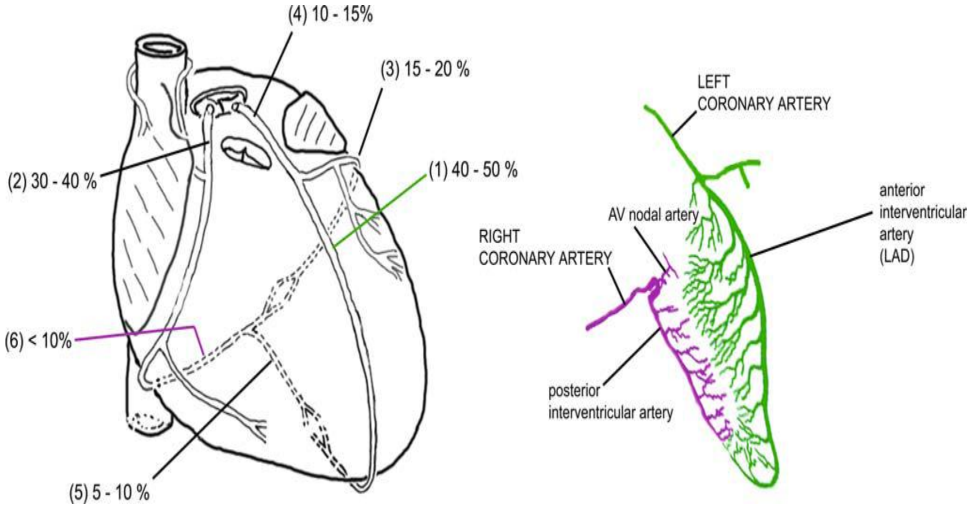


**Fig (4):** Arterial supply to the interventricular septum. Left: Sites of coronary artery occlusion, in order of frequency and percentage of occlusions involving each artery. Right: The right coronary artery supplies the posterior one-third of the interventricular septum, and the left coronary supplies the anterior two-thirds. The artery to the atrioventricular node commonly branches off of the posterior interventricular artery. Occlusions occur most frequently in the anterior interventricular artery, which is the primary blood supply to the interventricular septum (and bundle branches within).AV=atrioventricular ***(Weinhaus and Roberts, 2009).***

The LAD artery also sends a branch to meet the conus artery from the right coronary to form an important collateral anastomosis called the circle of Vieussens, as well as branches to the anterior free wall of the left ventricle called diagonal arteries. These are numbered according to their sequence of origin as first, second, etc. diagonal arteries. The mostdistal continuation of the LAD artery curves around the apex and travels superiorly in the posterior interventricular sulcus to anastomose with the posterior descending from the right coronary artery ***(Weinhaus and Roberts, 2009)***.

The circumflex artery branches of the left coronary artery and supplies most of the left atrium, the posterior and lateral free walls of the left ventricle and (with the LAD artery) the anterior papillary muscle of the bicuspid valve. The circumflex artery may give off a variable number of left marginal branches to supply the left ventricle. More likely, the circumflex artery may continue through the AV sulcus to supply the posterior wall of the left ventricle and (with the right coronary artery) the posterior papillary muscle of the bicuspid valve ***(Weinhaus and Roberts, 2009)***.

In 40–50% of hearts the circumflex artery supplies the artery to the SA node. The LAD is the most commonly occluded of the coronary arteries (Fig. 4). It is the major blood supply to the interventricular septum and the bundle branches of the conducting system, branches of the right coronary artery supply both the SA and AV node in at least 50% of hearts. An occlusion in this artery could result in necrosis of the SA or AV nodes, thus preventing or interrupting the conduction of electrical activity across the heart ***(Weinhaus and Roberts, 2009)***.

The right coronary artery emerges from the aorta into the AV groove. It descends through the groove, then curves posteriorly, and makes a bend at the crux of the heart and continues downward in the posterior interventricular sulcus. Within millimeters after emerging from the aorta, the right coronary artery gives off two branches (Fig.1). The conus (arteriosus) artery runs to the conus arteriosus (right ventricular outflow tract), and the atrial branch to the right atrium. This atrial branch gives off the SA nodal artery (in 50–73% of hearts, according to various reports), which runs along the anterior right atrium to the superior vena cava, encircling it in a clock wise or counterclockwise direction before reaching the SA node. The SA nodal artery supplies the SA node, Bachman's bundle, crista terminalis, and the left and right atrial free walls ***(Weinhaus and Roberts, 2009)***.

The right coronary artery continues in the AV groove and gives off a variable number of branches to the right atrium and right ventricle. The most prominent of these is the right marginal branch which runs down the right margin of the heart supplying this part of the right ventricle. As the right coronary curves posteriorly and descends downward on the posterior surface of the heart, it gives off two to three branches. One is the posterior interventricular (posterior descending) artery (PDA) that runs in the posterior interventricular sulcus. It is directed toward the apex of the heart to supply the posterior free wall of the right ventricle ***(Weinhaus and Roberts, 2009)***.

In 85–90% of hearts, branches of this artery (posterior septal arteries) supply the posterior one-third of the interventricular septum (Fig. 4). The second artery is the AV nodal artery which branches from the right coronary artery at the crux of the heart and passes anteriorly along the base of the atrial septum to supply the AV node (in 50–60% of hearts), proximal parts of the bundles (branches) of His, and the parts of the posterior interventricular septum that surround the bundle branches. Another artery crosses the crux into the left AV groove to supply the diaphragmatic surface of the left ventricle and the posterior papillary muscle of the bicuspid valve ***(Weinhaus and Roberts, 2009)***.

The right coronary artery also serves as an important collateral supply to the anterior side of the heart, left ventricle, and anterior two thirds of the interventricular septum via the conus artery and communicating arteries in the interventricular septum (Fig.4). Kugel's artery, which originates from either the right or left coronary artery, runs from anterior to posterior through the atrial septum. This artery serves as an important collateral connection from anterior arteries to the AV node and posterior arteries ***(Weinhaus and Roberts, 2009)***.

## Anatomical Concepts of Coronary Circulation :

Although acute and chronic ischemic syndromes are commonly due to coronary flow limiting atherosclerotic plaques in epicardial coronary arteries, 10 to 20% of patients undergoing cardiac catheterization are found to have normal coronary angiograms ***(Escudero, 2001).***

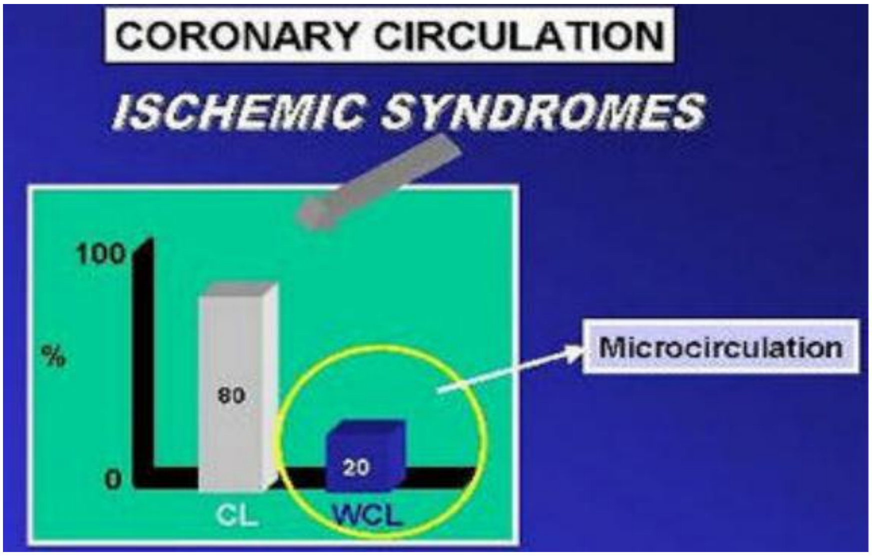


**Fig (5):** 10 to 20% of patients with ischemic syndromes undergoing cardiac catheterization are found to have normal coronary angiograms ***(Escudero, 2001).***

The coronary circulation can be thought of as a system of interconnecting pathways with conduit arteries, distribution vessels (arterioles), exchanged vessels (capillaries) and reception vessels (venules and veins) with two anatomical compartment: conduit (epicardial arteries) and mixing chambers (microcirculation) as shown in Fig (6) ***(Escudero, 2001).***

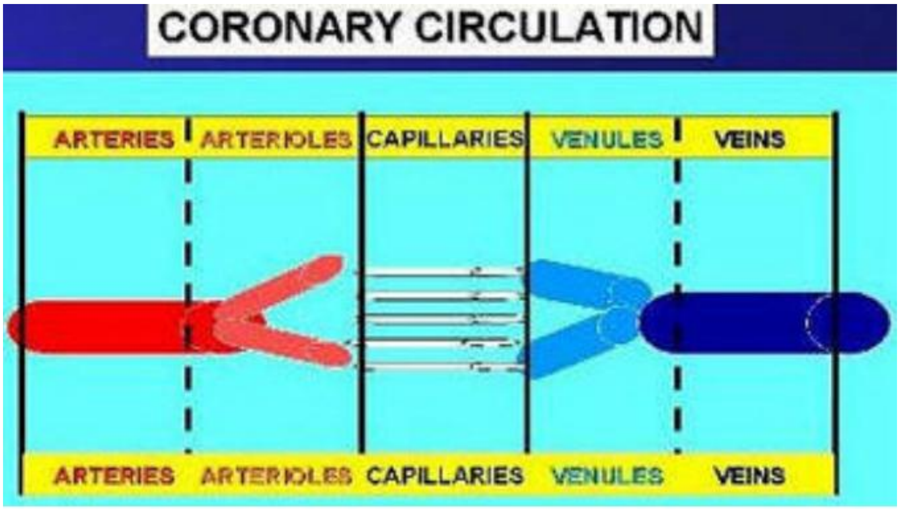


**Fig (6):** Schematic of coronary flow system. Coronary circulation consisted of interconnecting pathways with conduit arteries, distribution vessels (arterioles), exchanged vessels (capillaries) and reception vessels (venules and veins) ***(Escudero, 2001).***

Anatomically and functionally distinct categories of myocardial vessels segregated in discrete areas have called vascular microdomains because they are reminiscent of the protein microdomains that provide for specialization of functions. In the pig, with similar coronary morphology of humans without coronary artery disease, the entire coronary system (epicardial conduit arteries, arterioles, capillaries, venules and veins) contains 12 ml of blood / 100g LV mass -1. This volume is distributed in the arterial, capillaries and venous compartments as 3.5, 3.8 and 4.9 ml / 100g LV mass -1 respectively. The blood present in the LV myocardial vessels (myocardial blood volume) is 4.5 ml / 100g LV mass -1 and resides primarily (> 90%) in microvessels (principally capillaries) ***(Escudero, 2001).***

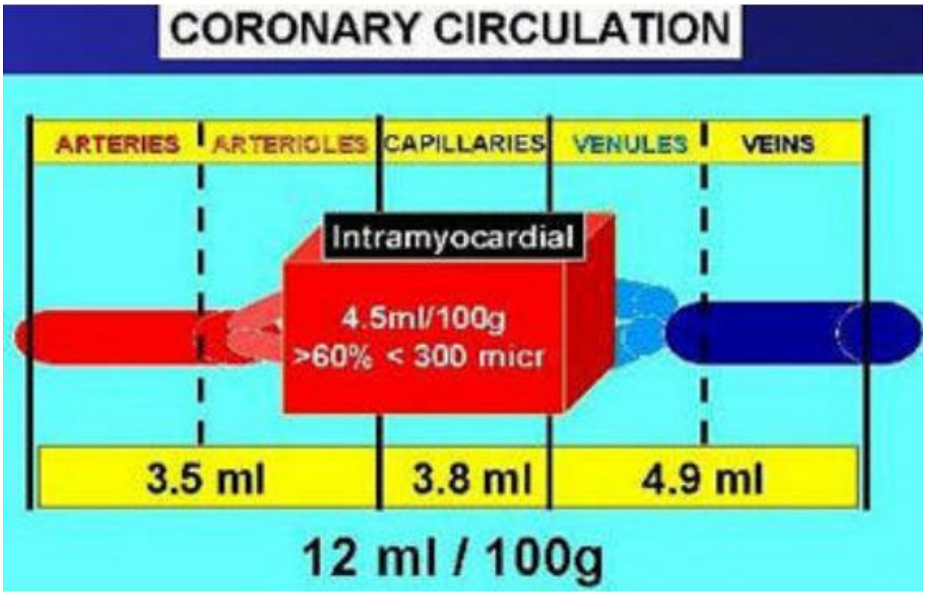


**Fig (7):** Blood volume distribution in pig's coronary circulation (**Escudero, 2001).**

## Integrative Physiology of Coronary Circulation:

Mechanoenergetic interaction between coronary vessels and myocardium is tightly coupled because the high oxygen consumption and flow rate of the myocardium. Such interaction is not uniform transmurally: the mechanical effect of cardiac contraction on the myocardial vessels is greater in deeper myocardial layers than in the superficial myocardial layers despite its greater metabolic demand in deeper myocardium. Therefore, in order to match the oxygen supply to myocardial metabolic requirement, locally and highly organized vascular regulations are required ***(Escudero, 2001).***

The coronary vessels are expected not only to connect the entrance of the coronary artery with the capillary vessels near each cardiac myocyte by increasing the number of vascular segments, but also to provide integrated regulatory systems so as to produce the required flow rate at each path in the vascular tree. This integrative mechanisms is founded in multiple signals (physical, nervous, humoral, molecular) that are involved linking between longitudinal and parallel vascular segments and also between coronary vessels and the myocytes. Traditionally, the close matching of coronary blood flow to myocardial oxygen consumption has been attributed to metabolic mechanisms, although the precise mediators have eluded discovery ***(Escudero, 2001).***

Myocardial oxygen delivery occurs at the capillary level. When myocardial oxygen consumption increases, the coronary circulation compensates by increasing myocardial blood flow through dilatation of coronary microvessels. Studies indicate that myogenic and endothelial mechanisms strongly influence diameters of coronary microvessels through the transudation of intravascular pressure (stretch) and flow (shear stress) ***(Escudero, 2001).***

Myogenic dilatation and constriction are potentially autoregulatory and a fall in arteriolar pressure, during either coronary occlusion or metabolic vasodilatation would be expected to reduce coronary vascular resistance through this mechanisms. Longitudinal gradients for pressure -and flow -dependent responses can be integrated into a hypothetical system that could match coronary blood flow to myocardial metabolic demands as shown in Fig (8):

1. The smallest arterioles (< 30 microns), apparently the most sensitive to metabolic stimuli, dilate during increase metabolic demand, lowering microvascular resistance and increasing myocardial perfusion.

2. As the upstream arteriolar pressure falls, myogenic dilatation of slightly larger arterioles (30 - 60 microns) as consequence of the decrease of tensile-stress, with a further decrease in resistance occur.

3. Increased flow in large arterioles (120-150 microns) upstream stimulates flow dependent dilatation and further reducing network resistance ***(Escudero, 2001).***

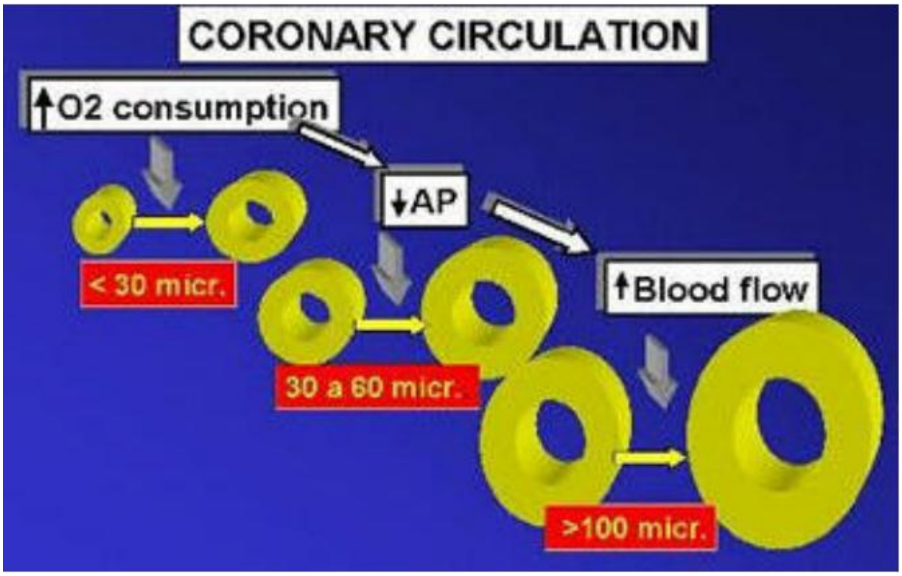


**Fig (8):** Longitudinal integration of regulation mechanisms into a hypothetical system that could match coronary blood flow to myocardial metabolic demands ***(Escudero, 2001).***

## Pathophysiology of coronary circulation : its implications in detection of coronary artery disease with stress Echo and myocardial perfusion"

Despite the presence of coronary stenosis, resting myocardial blood flow is normal in the majority of stable patients with coronary artery disease (CAD) who have not had previous myocardial infarction. Blood flow is maintained distal to a stenosis by autoregulation. As the severity increase, arterioles in microcirculation (< 300 microns) distal to obstruction dilate in order to maintain resting blood flow as close to normal as possible. When autoregulation is exhausted (usually at > 85% luminal narrowing) resting flow