A systematic review on normal and abnormal anatomy of coronary arteries

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SUMMARY

Coronary artery (CA) disorders are among the major causes of morbidity and mortality in humans. We attempt to explain CA anatomy and its variations in a simple, concise, and understandable way to help clinicians deal with the various disorders. There are two main arteries: right coronary artery (RCA) and left CA. The left bifurcates into two terminal branches: left anterior descending artery (LAD) and left circumflex artery (LCX). The commonest anatomical variant is trifurcation of left main coronary artery (LMCA) with presence of ramus intermedius artery (RIM), abnormal origin of LCX from RCA or right sinus of Valsalva, abnormal CA origin from unusual aortic sinus in-between aorta and pulmonary trunk, myocardial bridging, CA fistula and aneurysm. The RCA may arise abnormally from the left sinus of Valsalva rather than the usual origin from the right sinus. Furthermore, most cases of abnormal CA fistulas affect the RCA where the artery opens into the right heart chambers, pulmonary trunk, or coronary sinus. Although their incidence is relatively rare, coronary abnormalities are of critical importance in medical practice. Identification of normal and abnormal anatomy of CA is essential because not knowing one of the differences can lead to loss of a person's life.

Key words: Right coronary artery – Left coronary artery – Anterior interventricular artery – Left circumflex artery – Coronary variations

ABBREVIATIONS

CA: Coronary artery; CAD: Coronary artery disease; LAD: Left anterior descending artery; LCX: Left circumflex artery; LDL: Low-density lipoproteins; LMCA: Left main coronary artery; LV: Left ventricle; MB: Myocardial bridging; PDA: Posterior descending artery; RA: Right atrium; RCA: Right coronary artery; RIM: Ramus intermedius artery; RV: Right ventricle; SA: Sinoatrial.

INTRODUCTION

Coronary artery disease (CAD) is one of the leading causes of sudden death. This has been attributed to the resulting acute coronary syndrome, or fatal arrhythmia, due to subsequent fibrosis and/or scarring of the myocardium. While CAD is more common among the elderly, it has also been identified as a cause of sudden cardiac death in younger adults (Vahatalo et al., 2021).

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Determining the normal anatomy and its variations is essential for physicians and surgeons for the accurate diagnosis and proper management of any clinical disorder (Hegazy, 2019; Hegazy and Hegazy, 2021). Due to the significant increase in interventional procedures, awareness of the normal and abnormal anatomy of the coronary arteries has become a mandatory factor for cardiologists, radiologists, and other clinicians. This is because the incorrect interpretation or misdiagnosis of such variants or anomalies might lead to technical difficulties during coronary catheterization and interventional procedures or cause major complications at coronary surgery (Cademartiri et al., 2008). Good anatomical knowledge is also important to correctly interpret coronary computed tomography (CT) and angiography images (Kini et al., 2007). Moreover, defining the normal anatomical variation facilitates stent design and selection of optimal treatment strategy (Medrano-Gracia et al., 2016).

The CA anomalies should not be considered just rare findings as they might be associated with serious clinical consequences (Becker, 1995). In a study including 16,573 patients, CA anomalies were noticed in about 0.3% of cases (Yuksel et al., 2013). Despite the relatively uncommon prevalence, CA variants and anomalies represent the second most common cause of death among young athletes. They may go unnoticed and discovered incidentally through routine investigations or in postmortem analysis of cases of sudden death. However, some patients with CA abnormalities may present with angina pectoris, syncope, myocardial infarction, and heart failure (Kastellanos et al., 2018). Therefore, clinicians must be familiar with the normal anatomy of the coronary arteries as well as anatomical differences and abnormalities in order to accurately diagnose and manage coronary lesions.

NORMAL ANATOMY OF CORONARY ARTERIES

There are two CAs; each supplies the corresponding half of the heart although there is an overlap in blood supply particularly found in the interventricular septum (Iaizzo, 2015). The two coronary arteries arise at the root of the aorta from the two of the three aortic sinuses of Valsalva following the aortic semilunar valve. The right coronary artery (RCA) originates from the right "anteriorly located" sinus, while the left coronary artery arises from the left posterior sinus (Hegazy, 2018). Hence, there is a sinus with no CA origin, and called noncoronary sinus (Iaizzo, 2015) (Figs. 1-4). The distribution of arterial blood supply to the myocardium is variable. However, the RCA mostly supply the right ventricle (RV), while the left coronary artery supplies the anterior wall of the left ventricle (LV) and anterior part of interventricular septum. The supply of the remainder of LV depends on arterial dominance of coronaries (Kini et al., 2007). Kini et al. (2007) classified the coronary arteries into 4 arteries as follows: RCA and LMCA, and they added the two terminal branches of LMCA named the anterior interventricular artery "left anterior descending artery" (LAD) and the left circumflex artery (LCX) as another two main arteries. They described the arterial supply of the heart as a ring and half-loop; the circle is formed by RCA and LCX, while LAD and PDA (posterior descending artery) form the half-loop. However, we may add the LMCA to the ring to be formed of RCA, LMCA and LCX (Fig. 3).

1. Anatomy of RCA

Its origin from the right aortic sinus lies slightly below the level of the left coronary artery (Kini et al., 2007). It passes to the right side behind the pulmonary trunk between it and the right auricle to run in the coronary sulcus (anterior atrioventricular groove) till reaching the lower part of the right margin of the heart, where it curves posteriorly (Hegazy, 2018). At the crux of the heart, it bends to form the PDA, also called posterior interventricular artery (Iaizzo, 2015). The RCA ends by anastomosing with the continuation of LCX. The crux is the point at the posterior surface of the heart where the coronary sulcus meets the line of the interatrial and interventricular groove, forming a cross (O'Brien et al., 2007).

Near its beginning, it gives off two branches. The first is the conus artery in 50% of population passing anteriorly to supply the conus arteriosus "its pulmonary outflow". In the other part of the population, the CA arises as a separate branch

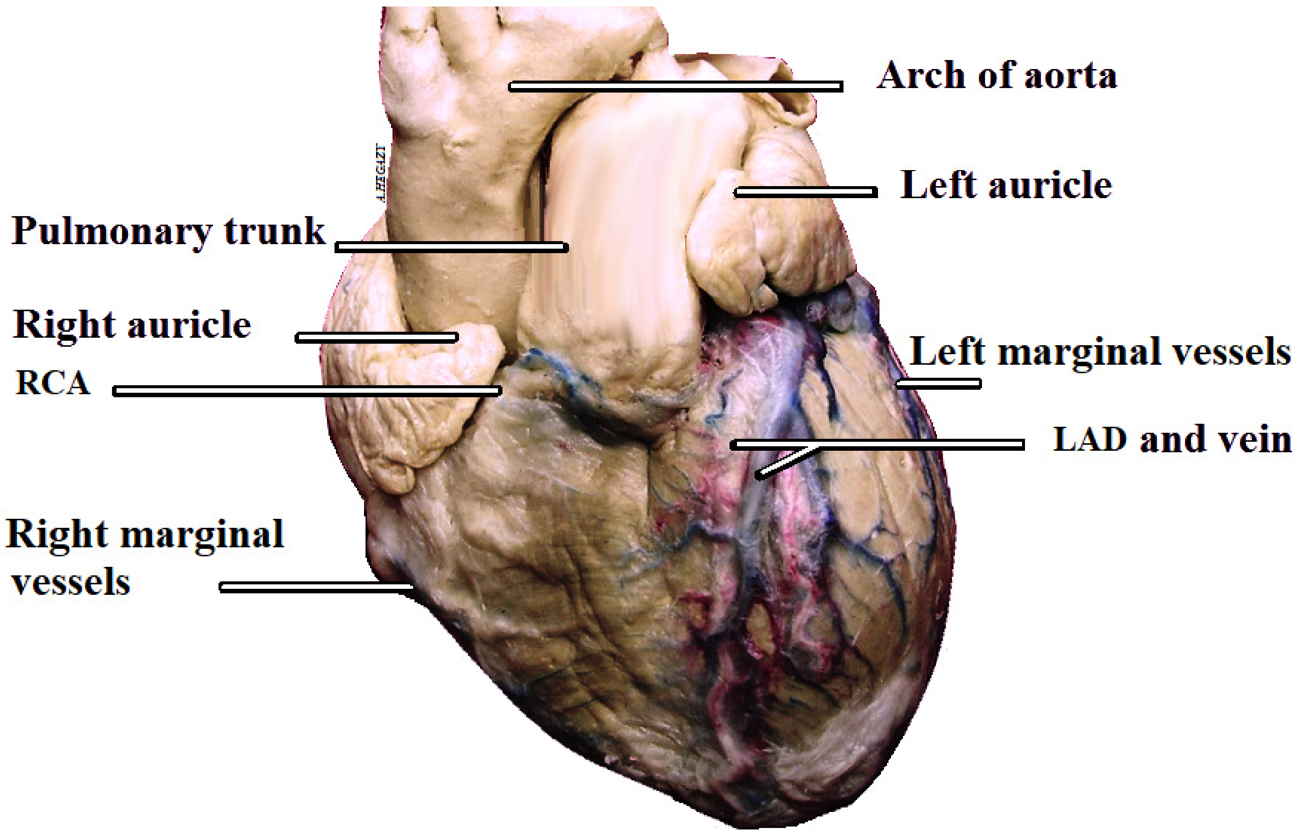

Fig. 1.- Photograph showing the sternocostal surface of heart and coronary vessels (from Hegazy, 2018).

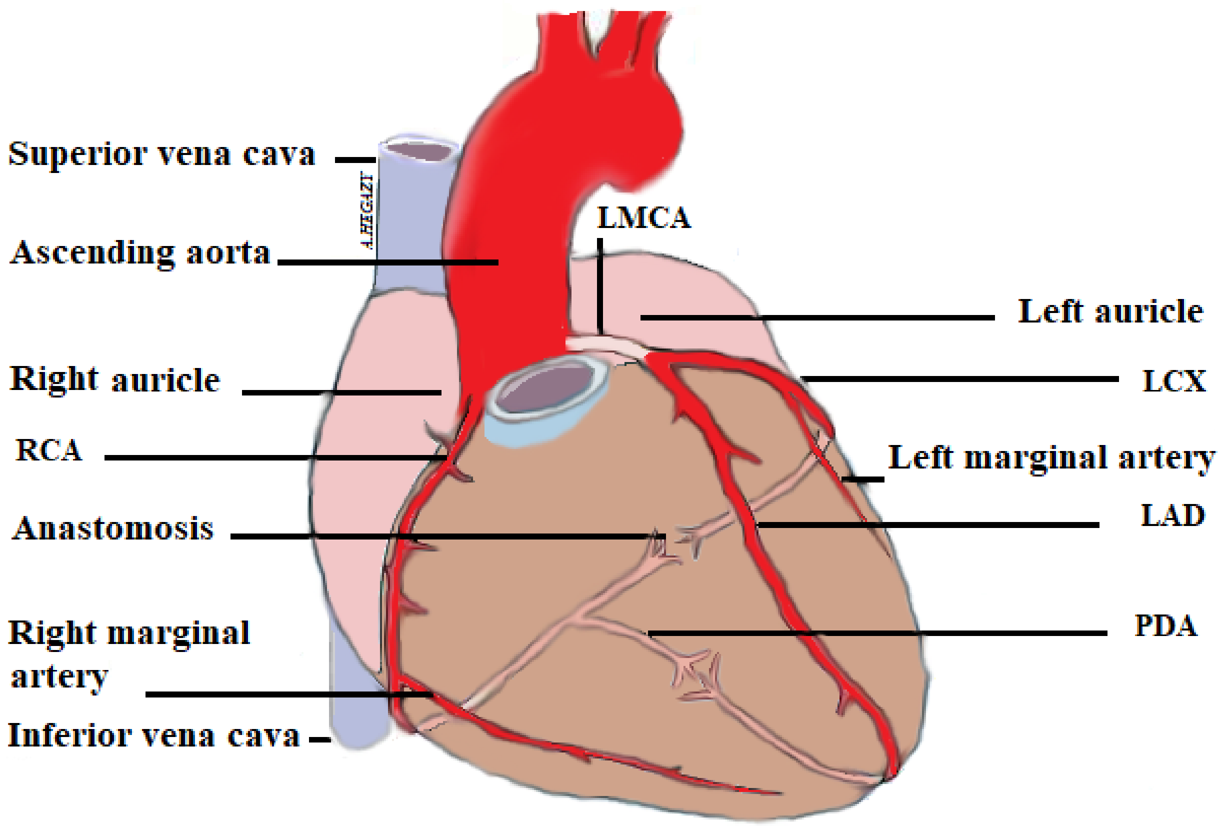

Fig. 2.- Diagram showing the arrangement of coronary arteries supplying heart.

from the aorta. The second branch is the sinoatrial (SA) nodal artery arising from RCA in 55% of cases to supply the right atrium (RA) at the inflow of the superior vena cava, and also gives SA nodal branch to SA node. In the remaining cases, this artery arises from the proximal part of left circumflex artery (Kini et al., 2007; Iaizzo, 2015). Other authors stated that conus branch arises mostly from RCA by an incidence of about 86% and from the aorta in only about 12% of cases (Cademartiri et al., 2008). They added that SA nodal originates from the RCA in about 65% and from left coronary artery in about 17%, It might arise from aorta or pulmonary trunk in rare cases (0.2%).

Before coursing to the diaphragmatic surface, the RCA gives off many small branches to supply the anterior aspect of the RA and RV; the most prominent of them is called RV marginalis or right marginal artery. Such branch supplies the part of RV coursing along it (Kini et al., 2007; Iaizzo, 2015).

At the posterior aspect of the heart, the RCA ends by giving 2 or 3 branches. The first branch is PDA passing towards the apex of the heart through the posterior interventricular sulcus. It supplies the posterior free part of RV, as well as the posterior one-third of interventricular septum in about 85% of cases (Fig. 5). The second one is the AV nodal

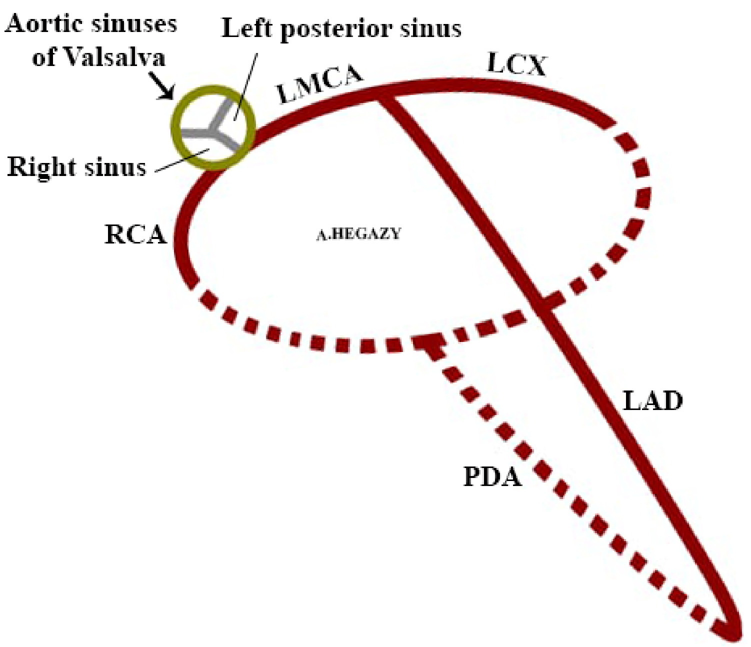

Fig. 3.- Diagram showing arrangement of the main coronary arteries.

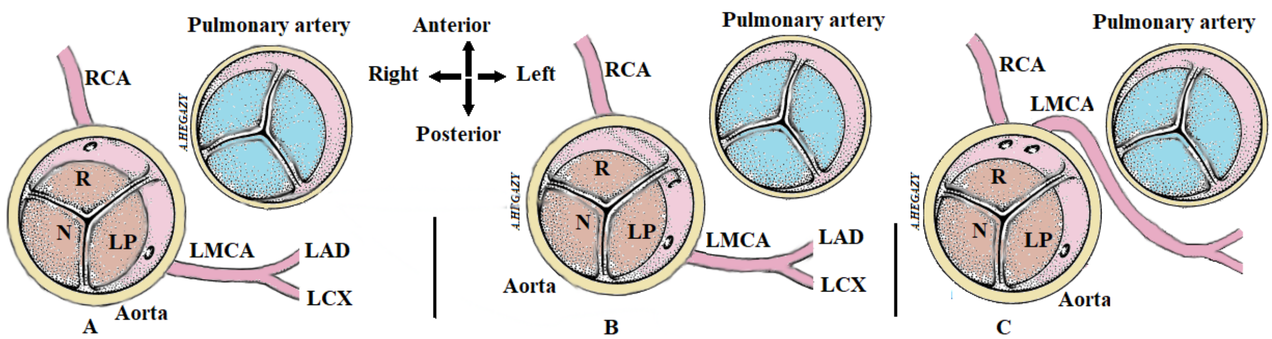

Fig. 4.- Diagrams showing origin of coronary arteries: **A)** RCA arising from right sinus of Valsalva (R), LMCA from left posterior sinus (LP) and none arising from the right posterior sinus (N). **B)** RCA arising from LP with part passing intramural "within wall of aorta". **C)** LMCA arising from R and coursing in-between aorta and pulmonary trunk.

artery. It arises from RCA at the crux of the heart, passing anteriorly along the base of interatrial septum to supply the AV node in about 55% of cases, bundle of Hiss and parts of interventricular septum surrounding it. A third artery arises from RCA at the crux of the heart, passing to the left side of AV sulcus to supply the diaphragmatic surface of LV (El-Maasarany and Aboul-Enein, 2009; Iaizzo, 2015).

Another (Kugel) artery has been described by Kugel in 1927, arising from left circumflex artery (Kugel, 1927). Other authors did not accept the presence of Kugel artery; and instead, they described small collateral connections arising from both LCX and RCA, or from one of them connecting the anterior and posterior arteries (McAlpin, 1975). However, another study found such artery in only 6% of cases originating from LCX or RCA (Nerantzis et al., 2004).

2. Anatomy of left coronary artery

The left coronary artery emerges from the posterior left the sinus of Valsalva. It passes to the left side behind the pulmonary trunk in-between it and the left auricle. It runs in the anterior part of the atrioventricular sulcus (Hegazy, 2018). This part, from its origin to bifurcation into LCX and LAD, is called the left main coronary artery (LMCA). Its length is about 5-10 mm. Sometimes the LMCA trifurcates into LCX, LAD and RIM. The presence of RIM represents the most common variation of left coronary artery; its incidence ranges from 15 to 30% of populations (O'Brien et al., 2007; Kosar et al., 2009). It is situated intermediate in a position between the two branches in case of bifurcation, namely LCX and LAD, so it is called ramus intermedius. It is also named left diagonal artery.

3. Left anterior descending artery (LAD)

It represents the largest branch arising from LMCA and carries almost 50% of blood from coronary circulation (Rehman et al., 2021). It turns around the left aspect of the pulmonary trunk to descend into the anterior interventricular sulcus towards the apex of heart. At the lower margin of the heart, it turns posteriorly to run shortly in the posterior interventricular sulcus, where it anastomoses with termination of PDA (Hegazy, 2018). Myocardium is often seen on CT to bridge over the LAD. Most cases of myocardial bridging (MB) are asymptomatic. It rarely could lead to ischemia, which might result from compression of the part of the artery by crossing myocardium at the systole (Berry et al., 2002). Branches arising from LAD include diagonals and septal perforators. Septal branches pass through the interventricular septum to supply its anterior two-thirds. On the other hand, diagonal arteries pass laterally to supply the myocardium of anterior aspect and free wall of LV (Kini et al., 2007; O'Brien et al., 2007). The

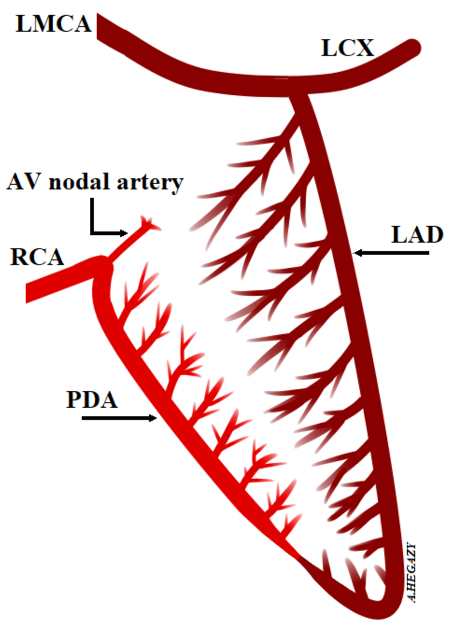

Fig. 5.- Diagram showing distribution of arterial blood supply of interventricular septum in most of cases.

first diagonal branch arising from LAD represents the main diagonal artery and is mainly responsible for supplying arterial blood to the anterolateral aspect of LV. The diagonal arteries vary in number ranging from 2-9 (Medrano-Gracia et al., 2016). The term "diagonal" is given to these arteries, because they arise from their parent artery at an acute angle. The acute angle take-off of the branches makes them more prone to possible occlusion and subsequent of sudden death (Yuan, 2014). Loss of diagonal blood flow in patients with anterior ST-segment elevation myocardial infarction is independently associated with higher incidence of major adverse cardiac events, and all-cause death (Zhang et al., 2020). In addition to origin of CA with acute angle, the anatomic features that could be associated with sudden cardiac death might also include the slit-like orifice and intramural course (Agarwal et al., 2017).

The LAD is divided for description into 3 parts: proximal, middle and distal parts. There is more than one definition to describe LAD parts. The first is based on septal branches. The proximal part extends from its origin to the origin of its first main branch (the significant diagonal or first septal perforator) (Kini et al., 2007; Zhang et al., 2020). The middle portion is extending from origin of its first branch to the point where the artery forms an acute angle coinciding with the origin of the second septal branch. If such acute angle is not marked, the middle and distal portions are marked from each other by a point mid-way between the first septal artery and apex of heart. The distal portion is the segment distal to the apex of the heart (Kini et al., 2007; O'Brien et al., 2007). Another possibility of defining parts of LAD is depending on diagonal branches: Proximal LAD is before 1^{st} diagonal, Mid LAD between 1^{st} and 2^{nd} diagonals and distal LAD after the 2^{nd} diagonal branch (Sundaram et al., 2009).

4. Left circumflex artery (LCX)

It is the smallest branch of LMCA, but appears as the direct continuation of left CA. It continues in the coronary sulcus to pass in its posterior, where its terminal branches might form an anastomosis with the RCA coming from the opposite side (Hegazy, 2018). It gives the left marginal artery, passing on the left side of the heart to supply myocardium of LV. It also gives small branches to supply the anterior and inferior aspects of LV. The LCX could be divided for description into two: "proximal and distal" parts. The parts are marked by the common branch arising from LCX, called left marginal artery (O'Brien et al., 2007).

5. Ramus intermedius artery (RIM)

It represents the most common variation in the anatomy of the left coronary artery, where it terminates by trifurcation instead of the common bifurcation. It arises and passes in-between the LAD and LCX. When present, it usually passes towards the LV free margin; and it might replace some branches of these two arteries in supplying the anterolateral aspect of LV (O'Brien et al., 2007; Kultida et al., 2018). Its course might be similar to that of the diagonal branches of LAD (O'Brien et al., 2007).

DOMINANCE OF CORONARY ARTERIES

Although each CA supplies the corresponding side of the myocardium, there is some overlap between the Cas, especially in the interventricular septum (Pappano and Wier, 2013). This could be represented as a CA dominance. This dominance depends on the supply of the posterior "inferior" one third of the interventricular septum. As previously mentioned, this part is supplied by the RCA in most (about 85%) hearts. In this case, the RCA is the dominant artery, a condition called right dominance. In the less common cases, the posterior part of the septum is supplied by branches of left CA, where the LCX crosses to the posterior interventricular groove, supplying the posterior part of interventricular septum in about 7.5% of cases, a condition named left dominance. In the remaining 7.5% of cases, the posterior "inferior" interventricular septum is perfused by branches from both RCA and LCX: this case is called codominance (Reagan et al., 1994; Kim et al., 2006). In other reports, the range of dominance were as follows: RCA: 50% - 91.4%; left CA: 7.2% - 20% and codominance: 1.4% - 30% (Table 1). However, all of them agreed regarding the dominance of RCA.

Table 1. Incidence of CA dominance.

Study	RCA dominance %	Left CA dominance %	Codominance %
Angelini et al., 2002	89.1	8.4	2.5
Pappano and Wier, 2013	50	20	30
Michalowska et al., 2016	84.1%	11.9%	4%
Kultida et al., 2018	91.4	7.2	1.4
Rafiq et al., 2020	75.8	19.8	4.8

Although considered part of normal contrast, determination of coronary dominance is very important for diagnostic imaging, prognosis, and planning for surgical treatment of myocardial ischemia or infarction (Waziri et al., 2016; Selcuk et al., 2020). It has been shown that left CA is frequently associated with poor prognosis in patients with CAD and percutaneous interventions; therefore, its evaluation should be an integral part of outpatient follow-up after elective coronary artery bypass grafting (Selcuk et al., 2020).

CORONARY ANASTOMOSES

The small terminal branches of the coronary arteries anastomose together, but the anastomosis is insufficient to give an adequate arterial blood supply if one of them is occluded. This case is called functional end-arteries (Wineski, 2019). Such anastomosis is present in fetal life and diminishes postnatally. However, it could be re-established if the atheroma development is a gradual event giving a chance for the anastomosis to proliferate. Development of atheromatous is initiated by the presence of low-density lipoproteins (LDL) carrying cholesterol in blood. Other factors that can be risk factors include smoking, hypertension, diabetes mellitus, inflammation and clonal hematopoiesis (Libby et al., 2019; Hegazy et al., 2022). Type 2 diabetes is not only a risk factor for the development of atheroma, but also hinders the development of collateral coronary vessels that might occur through different mechanisms including angiogenesis and arteriogenesis (Shen et al., 2018). It has been suggested that high-density lipoproteins can rescue impaired angiogenesis of diabetes mellitus by modulating the metabolic reprogramming of endothelial cells (Primer et al., 2020). The risk factors also include the sedentary life commonly associated with hyperlipidemia (Yusuf et al., 2004). Furthermore, excessive alcohol consumption could be a precipitating factor for atheromatous development (Ilic et al., 2018).

Seiler et al. (2013) added that the coronaries have extensive collateral anastomoses, being able to prevent myocardial ischemia during a brief occlusion in about 25% of individuals. Coronary atheromatous block is considered a chronic type if it has persisted for at least 3 months. It affects the main coronary arteries, but differ in their incidence. RCA is affected in 43%-55%, LAD in 24% and finally LCX is affected in 17%-20% of cases of chronic coronary occlusion (Mohammed and Khan, 2022). Development of well-developed collaterals is associated with improved patient survival (Elias et al., 2017). Furthermore, Wustmann et al. (2003) reported in their study of 100 patients that about one-fifth to one-fourth of the population have collaterals to accommodate blood flow in the event of short vascular occlusion.

The anastomoses include three main sites. The first is found in the interventricular septum between the septal branches of LAD and PDA. The second site is located in the posterior interventricular sulcus between the terminal branches of LAD and PDA. The third anastomosis could be found in the posterior aspect of coronary sulcus between the terminations of LCX and RCA (Figs. 2, 6) (Hegazy, 2018). Moreover, the LAD gives anastomosing branch that joins the branch of RCA named conus artery to form a collateral anastomosis. Such anastomosis is called Vieussens' circle (Iaizzo, 2015). However, growth of collateral vessels "arteriogenesis" and formation of new capillaries "angiogenesis" may occur as a life-saving adaptive mechanism in response to arterial occlusion and subsequent ischemia (Schaper and Scholz, 2003).

Well-developed coronary anastomoses form an alternative pathway for blood supply to a part of myocardium that is at risk from ischemia. Therapeutic promotion of the anastomotic collaterals could have clinical value in some patients with CAD who do not benefit from CA by-pass or percutaneous CA intervention (Seiler et al., 2013). This might be achieved through endurance exercise training (Zbinden et al., 2004), external counterpulsation (Gloekler et al., 2010) and therapeutic management using granulocyte-colony-stimulating factor (Meier et al., 2009; Seiler et al., 2013). It has been suggested that exercise programs can enhance coronary collateral growth even for stenosed arteries subject to PCI (Zbinden et al., 2007; Laughlin et al., 2012).

NORMAL CALIBER OF CORONARY ARTERIES

Knowing the normal lumen diameter of the coronaries at a given location is the first step to diagnose condition of blood flow and estimation of severity of coronary diseases. It is considered to be more informative than the traditional method for estimating the percent stenosis that is based on the ratio of a focal diameter to the nearby normal finding (Dodge et al., 1992).

Divia Paul et al (2018) agreed that the CA calibers in males are greater than those found in females. They added that the calibers decrease with increase in body-mass index. Normal caliber of coronary arteries and their major branches have been estimated using catheter angiography. The average range in males is about 4 mm while it is 3 mm in females. It also varies from one artery to another, ranging from a mean of 5 mm in LMCA in males to 2 mm in PDA in females (O'Brien et al., 2007). Dodge et al. (1992) stated that the normal diameter of LMCA is 4.5±0.5 mm; LAD is 3.7+0.4 mm at its proximal part and 1.9+0.4 mm at its distal part; and LCX is ranging from 3.4±0.5 and 4.2±0.6 mm. For RCA, the diameter in proximal part ranges from 3.9±0.6 to 2.8±0.5 mm. Another study showed that the mean values of LMCA are 3.5±0.8 mm diameter and 10.5±5.3 mm length. Its angulation is 75±23° in cases of bifurcation and increased to about 89±21° in presences of RIM, cases called trifurcation (Medrano-Gracia et al., 2016). Regarding diagonal arteries arising from LAD, vessel of a diameter more than 2 mm is regarded as the main one (Zhang et al., 2020). The caliber of the main CA might assist in identifying the dominant artery. In case of left dominance, the caliber of the LCX and LAD is larger than that of RCA. At the same time, the proximal RCA

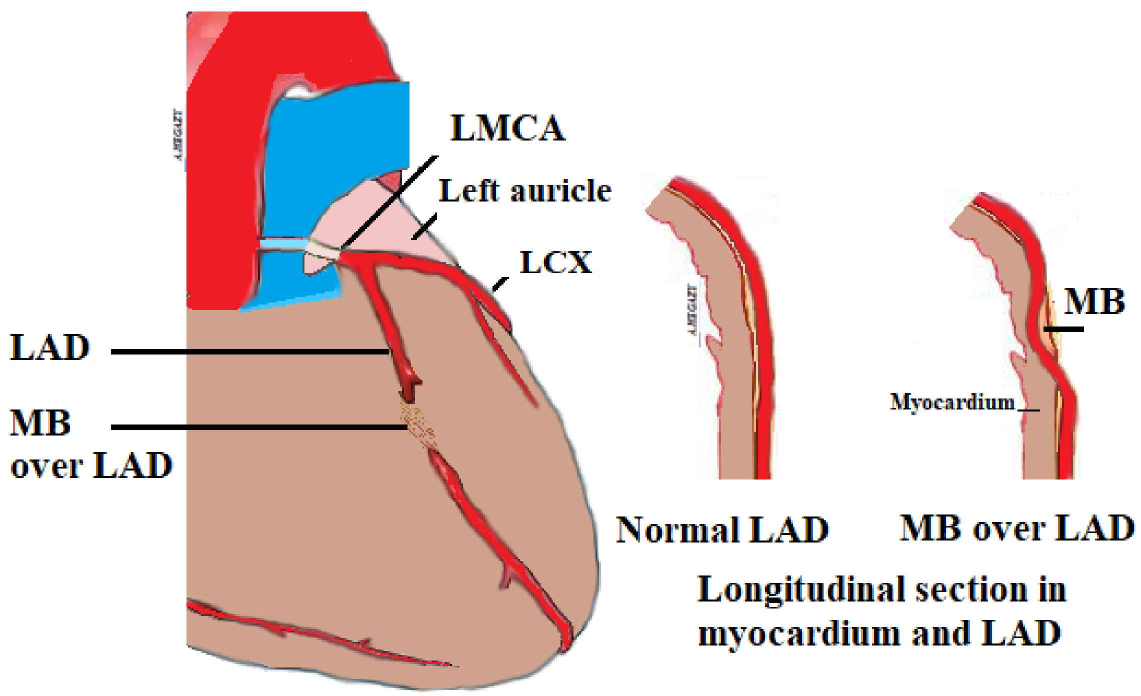

Fig. 6.- Diagrams showing myocardial bridging over a segment of LAD.

diameter is larger than the two terminal branches of LMCA in case of right CA dominance. Detection of small caliber of CA is suggested as an indicator of hypoperfusion in absence of signs of myocardial ischemia. Its evaluation can also reduce false results in the case of ischemia (Pilz et al., 2011).

CORONARY ARTERY ANOMALIES

Coronary artery anomaly is a rare condition. In general, the anomalies of coronaries have been reported to be about 0.3% to 1.3% of healthy population; and discovered incidentally at routine investigations (Angelini et al., 2002; Yildiz et al., 2010). Its incidence has been noticed to be about 0.17% in autopsy investigations (Alexander and Griffith, 1956), 1.2% in angiographically investigated cases (Engel et al., 1975) and 2.33% of population evaluated with multidetector-row computed tomography (Graidis et al., 2015). However, Cademartiri et al. (2008) reported a relatively higher incidence in multi-ethnic Dutch population reaching about 18.4%. Despite the general rare incidence, about one-fifth of such cases could produce life-threatening clinical manifestations such as syncope, arrythmias, myocardial infarction, or even sudden death in young athletes (Maron, 2003; Datta et al., 2005). There is a significant difference in incidence of CA anomalies between both genders. However, the authors reporting gender differences have disagreed regarding who is affected more. Aydar et al. (2011) stated that females are more affected than males. However, others reported the reverse; most of investigated cases of CA anomalies are males (Graidis et al., 2015; Yousif et al., 2019).

Anomalies in origin of main coronary arteries

Despite the uncommon incidence, awareness of the variations in origin of coronaries is important to be remembered and should be put into consideration at CT angiographic investigations to avoid misinterpretations (Kini et al., 2007). The unusual variations of main coronary arteries' origin were found in a percentage of about 0.3% to 0.6% in patients referred to coronary catheterization (Yamanaka and Hobbs, 1990; Harikrishnan et al., 2002; Angelini et al., 2002).

The anomaly of RCA origin is typically from the left sinus of Valsalva (Kini et al., 2007). On the other hand, left CA might arise from the right sinus just above the origin of RCA (Barth and Roberts, 1986; Paolillo et al., 2006). In this case, the LMCA passes anomalously between the two main arteries named the aorta and pulmonary trunk (Fig. 4). This interarterial course of LMCA could be associated with exertional angina and episodes of syncope (Barth and Roberts, 1986). The origin of CA from the unusual aortic sinus with coursing in-between aorta and pulmonary trunk might be responsible for causing sudden death among young athletes with incidence up to about 20% (Basso et al., 2000; Angelini et al., 2002). The CA originating from the opposite sinus might be also intramural "inside wall of aorta", transseptal (or subpulmonic), prepulmonic and retroaortic in its course to reach its dependent area of myocardium (Agarwal et al., 2017). Symptomatic patients undergoing abnormal origin of CA from opposite side might be managed with conservative medical treatment, stent deployment for coronary angioplasty or repair by surgical interference (Angelini, 2007).

Paolillo et al. (2006) also described an origin for RIM early from LMCA before its bifurcation and runs in an unusual course, where it passes to the left side beneath the middle LAD, and emerges epicardially to reach the left free aspect of heart.

However, there are other reported anomalies. In their study of 16,573 patients, the authors stated that the most common abnormality accounting for 0.17% of the total cases and more than 50% of the abnormalities encountered was the abnormal origin of LCX from RCA or the right sinus of Valsalva (Yuksel et al., 2013). Furthermore, the anomalies include a rare case where RCA and other 3 arteries, LCX, LAD and RIM, arise from the right sinus with four separate ostia (Bartorelli et al., 1994; Asciutto et al., 2016; Choudhary et al., 2019). Ludhwani and Woo (2019) reported a case with single RCA arising from right sinus and giving rise to LMCA that passes in a pre- pulmonic course and terminates by trifurcation. Choudhary et al., 2019 stated that none of them pass between the pulmonary trunk and aorta. They found that LCX passes behind aorta, and LAD and RIM run in an anterior course without causing significant obstructive lesion. However, the course of LAD in-between pulmonary trunk and aorta has been noticed to be associated with increased risk of myocardial ischemia and sudden death (Bartorelli et al., 1994; Asciutto et al., 2016).

On the other hand, some authors reported a case of CAs arising from abnormal single trunk (Barendra et al., 1995). They reported a case of single CA originating from the left sinus of Valsalva. The RCA arises from its proximal portion; while its distal part trifurcates into LAD, RIM and LCX. Similarly, Abdulshakour et al. (2019) recorded a single CA but arising from the right sinus of Valsalva. They added that cases of single CA might represent a difficulty in performing coronary catheterization as all coronaries arise from a single sinus.

Rarely, the coronary arteries might originate from the pulmonary artery. The incidence of CA origin from pulmonary artery instead of the normal arising from aorta is up to 1% of population. The anomalous origins of LMCA and RCA are about 0.25 to 0.5% and 0.002% of all congenital heart anomalies, respectively (Vergara-Uzcategui et al., 2020). In addition to the anomalous origins of LMCA and RCA, this case might occur with LAD or LCX. However, LMCA is the most common of these rare cases. It could lead to death in 90% of cases within the first year of life if not treated (Wesselhoeft et al., 1968; Agarwal et al., 2017).

High take-off CAs is another rare cardiac abnormality with a prevalence of about 0.2%, of cases. In this case, the CA arises above the sinutubular junction with a distance up to 5 cm. High take-off RCA is the most common condition in this category of abnormalities, forming about 85% of total cases (Loukas et al., 2016). Cases of a distance of ≥ one cm are clinically relevant (Loukas et al., 2009). The main clinical concern in high take-off CA is the decreased perfusion that occurs with physical exertion leading to myocardial ischemia. The high take-off CA has been reported to be a cause of sudden cardiac death. Moreover, it is necessary to identify such anomalies to avoid clamping or occluding the CA in interventional therapy or surgery (Deng et al., 2017).

MYOCARDIAL BRIDGING

Myocardial bridging (MB) was first described in the year 1737. It has been defined as one or more segments of epicardial CA that pass through the myocardium “having intramyocardial course” (Mohlenkamp et al., 2002). Although it is frequently silent, it might form a risk factor for coronary artery disease (CAD). This is because the overlying part of the myocardium is prone to compression at the cardiac systole. Its incidence is higher in cases of CADs reaching about 7.4% vs 2.8% in others (Cademartiri et al., 2008). The authors found its prevalence to be 10.9% in their study using computed tomography coronary angiography. On average, the MB affects about one-third of adult populations. The most common site for MB is found in the middle segment of LAD (Fig. 6). It commonly investigated angiographically in LAD at a depth of 1-10 mm with an average length about 10 to 30 mm. The MB also might comprise the marginal and diagonal arteries with an incidence of 40% and 18%, respectively (Mohlenkamp et al., 2002).

CA ANEURYSMS

Local dilatation of an artery to more than 1.5 times diameter of its adjacent part is considered an abnormal finding called aneurysm. If such dilatation is diffuse, it defined as ectasia (O’Brien et al., 2007).

CA aneurysm is a rare anomaly, found in 0.3%–4.9 % of cases undergoing angiography (Swaye et al., 1983; Sheikh et al., 2019). The presence of coronary aneurysm or ectasia is commonly associated with poor outcome irrespective presence of coronary atherosclerosis or not (Warisawa et al., 2015; Doi et al., 2017). Individuals with aneurysms are at risk of developing myocardial ischemia (O’Brien et al., 2007).

The most frequent CA to be affected is the proximal and middle portions of RCA (68%), followed by the proximal segment of LAD (60%) and LCX) (50%). CA aneurysm of the LMCA is rare and occurs in only 0.1% of cases (Swaye et al., 1983; Sheikh et al., 2019).

It might be congenita,l but atherosclerosis is the commonest factor in its incidence in adults.

Cases related to atherosclerosis usually appear at later stages of life than those with congenital or inflammatory etiology (ElGuindy and ElGuindy, 2017). The pathogenesis of CA aneurysm is not clearly understood. However, the sequence might be similar to that occurring in large arteries of other parts of body where there may be weakness of segment of arterial wall either congenital or acquired followed by its progressive dilatation (Sheikh et al., 2019).

CONGENITAL CORONARY ARTERIAL FISTULAS

These are rare abnormal communications between coronary arteries and cardiac chambers or other structures like veins without intervening capillaries (Yun et al., 2018). These cases account about 0.08% to 0.4% of congenital heart anomalies, and 0.3% to 0.8% of indications for catheterization cases (Gowda et al., 2006; Butt et al., 2019).

The majority of cases of coronary fistulas are congenital. However, they might occur following cardiac surgery (Qureshi, 2006). It has been reported that about 90% of cases of fistulas could occur in RCA that joins the RA (Sharland et al., 2016). However, other authors mentioned that the fistulas in the left coronary artery amounted to about 50% of all cases of fistulas, while RCA cases are about 38%, and the remaining 12% occurred in both left coronary artery and RCA. Both RCA and LMCA fistulas mostly drain into the right side of the heart, such as the RA, RV (Fig. 7), pulmonary trunk and coronary sinus (Agarwal et al., 2017).

They are usually asymptomatic in the first two decades, particularly when small. Later on, the incidence of complaints and complications increases. Such complications include coronary steal phenomenon, thrombosis and embolism, atrial fibrillation, rupture, heart failure, endocarditis and arrhythmias. Spontaneous rupture of aneurysmal fistula might occur causing haemopericardium (Skimming and Walls, 1993; Qureshi, 2006). There is often a continuous murmur, and this is highly suggestive of presence of CA fistulas. Its differential diagnosis includes pulmonary or arteriovenous fistulas, persistent ductus arteriosus and ruptured aneurysm of sinus of Valsalva. Its diagnosis depends mainly on coronary angiography but concomitant cardiac catheterization also could help in precise anatomy delineation and assessment of hemodynamics. Treatment of symptomatic patients include surgical repair and transcatheter embolization (Gowda et al., 2006).

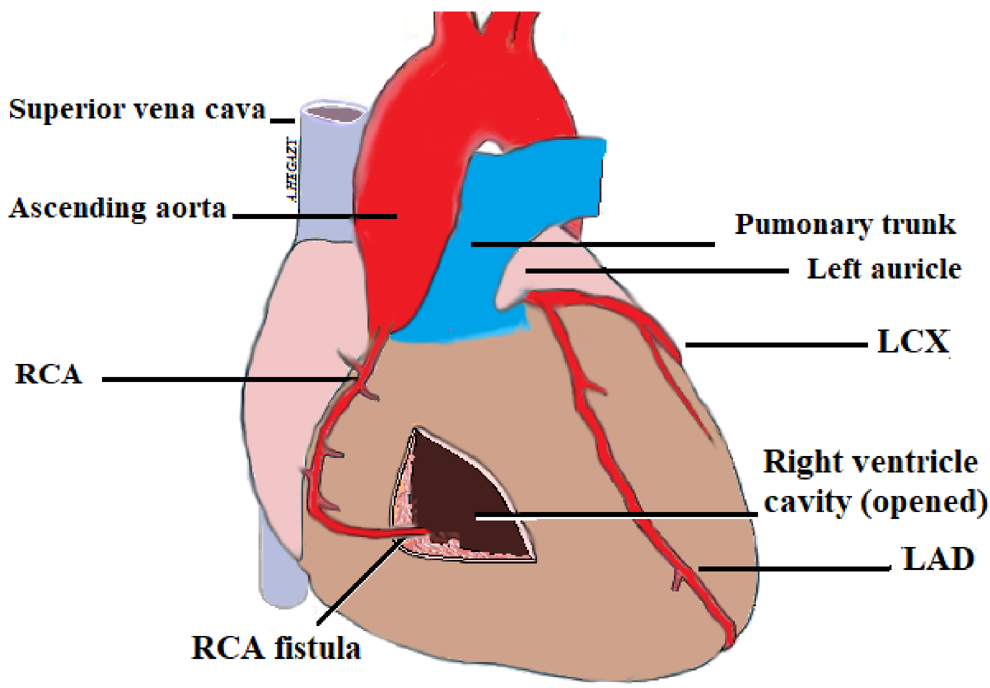

Fig. 7.- Diagram showing RCA fistula into cavity of right ventricle.

CONCLUSIONS

Knowledge of CA anatomy and its differences is critical to the proper diagnosis and treatment of CAD. Although there is an anatomical anastomosis between the terminal branches of the coronary arteries, it lacks the function. Therefore, coronaries are considered functional end-arteries; occlusion in any branch is not compensated by the anastomosis, resulting in the death of the corresponding part of the myocardium. The arteries form an epicardial horizontal ring with a half- loop extending downwards from the ring. The ring is formed by RCA, LMCA and LCX, while the loop comprises the LAD and PDA. Each CA supplies the corresponding side of the heart. In addition, RCA artery gives blood supply to SA node and AV node; and left coronary artery supplies the anterior two-thirds of interventricular septum. The posterior third of interventricular septum is supplied according to the dominance. It is supplied by the RCA in most (about 85%) of populations, a case is called right dominance. On the other hand, the remaining 15% include left dominance where this part is supplied by left coronary artery and codominance supplied by both coronary arteries. The most common variant encountered in this context is trifurcation of LMCA with an additional branch called RIM found to originate in the angle between LAD and LCX. Significant anomalies also include unusual CA origin, myocardial bridging, CA fistula and aneurysm.

Identification of anatomy of CA is recommended before any CA therapeutic intervention. Misinterpretation or misdiagnosis of such variants or anomalies may lead to technical difficulties during coronary angioplasty and interventional procedures or cause significant complications in CA surgery. Furthermore, identification of normal anatomical asymmetry facilitates stent design and selection of the optimal treatment strategy, hence the importance of defining normal and abnormal coronary anatomy.

AUTHORS' CONTRIBUTIONS

All authors share in all steps of the article.

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