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Details of the origin, course, branching patterns, termination and variations of the left coronary artery – a cadaveric study

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SUMMARY

Commonplace cardiac interventional procedures make detailed knowledge of the coronary vascular tree mandatory for accurate interpretation of radiological images. The present cadaveric study was proposed to document the descriptive anatomical details of the left coronary artery. Seventy-five cadaveric hearts of Indian origin were studied. The coronary vessels were injected with coloured cellulose acetate butyrate and dissected. Descriptive analysis of the course of the left coronary artery and its branches is given. Trifurcation of left coronary artery was present in 20% of the cases. Special emphasis is given to the sites of anastomoses seen. There were 4 cases of dual left anterior descending (5%). Two cases belonged to the Type II and two to the Type III. The long unusual course of the SA nodal artery was noted in about 5% (4 cases); in three cases the artery crossed the superior vena cava anteriorly and in one case it partially encircled the superior vena cava. The muscular bridge over the left coronary artery and its branches was present in 26 cases; it was located over left anterior descending in the majority of cases (16) with one each on main left diagonal artery, obtuse artery, posterior ventricular artery and posterior interventricular artery. The width of the majority (81%) of the muscular bridges was from 1-2 inch. The clinical implications of knowledge of the detailed course and anastomotic pattern of all the branches are not only diagnostic, but also therapeutic. This comprehensive description of the vessel will aid in preventing the inadvertent iatrogenic damage.

Key words: Left coronary artery – Myocardial bridges – Anastomosis – Dual left anterior descending artery

INTRODUCTION

Routine use of cardiac vascular interventional procedure makes it mandatory to have detailed knowledge of the coronary vascular tree, despite the availability of radiographic imaging. There are lots of studies describing the left coronary artery (LCA), but most of them are radiology based. The cadaver-based literature describing the LCA is either very old or in the form of case reports (Angelini, 2007; Koşar et al., 2009; de Agustín et al., 2010; Reddy et al., 2012; Yuksel, 2013; Altin et al., 2015; Omerbasic et al., 2015). Radiology-based data have their limitations as regards to the spatial orientation and visualization of small branches, especially with vessels with an unusual course. Most of the radiographic studies, though conducted on a large number of patients, give data regarding the incidence and classification of coronary artery anomalies, but lack the descriptive anatomical details of course, branching and anastomoses present in each vessel. According to Mawson (2002), it cannot be emphasized enough that in order to recognize some of the subtle variations, during angiography or from cross-sectional imaging, physicians needs a good understanding of the

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normal. Clinician's interest in the topography of coronary arteries is driven not only for diagnostic purposes but also for patient management, including catheter based interventions, as coronary arterial anatomy has a profound influence on patient management and outcome (James and Burch, 1958; Loukas et al., 2009). The subject of coronary arteries anomalies is undergoing profound evolutionary changes related to the definition, morphogenesis, clinical presentation, diagnostic workup, prognosis, and treatment of these anomalies (Koşar et al., 2009). Hence there is a need to revisit the coronary artery anatomy with fresh perspective. Injection method is probably the best way for optimal visualization of spatially oriented gross anatomical details of the coronary arterial tree. In the present study, this method was used to examine details of the left coronary artery including its origin, course, branching, anastomoses, termination and variations therein.

MATERIALS AND METHODS

The material for the present study consisted of 75 (55 males, 20 females, 18-75 years age) cadaveric hearts (Origin of LCA was studied in 180 hearts), obtained from cadavers from north-west Indian population, available in the department of anatomy through body donation programme. The approval was granted by the institutional ethics committee.

Adult cadavers of either sex with known medical histories were included in the study, while cadavers with known heart disease, chest trauma, and cardio-thoracic surgery were excluded.

The heart was separated by dividing the aorta and pulmonary trunks 1 cm above the corresponding valves. The remaining vessels were divided near their opening into the heart. The specimens were washed under running tap water and clots removed. Water was drained off almost completely. Exact location of origin of coronary arteries was identified. Warm normal saline was injected into the coronary arteries by means of a Duralock syringe fitted with a cannula, and clots were removed by repeated aspiration with the same syringe fitted with a cannula. When a clear solution was obtained on aspiration, the coronary arteries were considered to have been emptied of small clots. Any water left over in the coronary arteries was removed by repeated aspiration by the syringe. The coronary arteries were then washed with acetone. This prevented immediate solidification of the plastic material when injected. It also helped in removing minute thrombi sticking to the walls of coronary arteries. Acetone was then fully aspirated. A 20% solution of cellulose acetate butyrate, which had been prepared earlier and kept as a stock solution, was injected into coronary arteries by means of a cannula attached to a 10 ml syringe (Gupta et al., 2007). LCA was injected with red solution. Each injected heart was placed in 10% formalin solution for a minimum period of three days at room temperature to allow the plastic material to set in. The left coronary arteries and its branches were dissected manually under a magnoscope with lens magnification of 2.5x (Vaiseshika magnoscope type 7009).

The approval for the study was granted by the institutional ethics review board.

RESULTS

Origin

The left coronary artery arose from the left posterior aortic sinus in 104 (58%) hearts, at the supravalvular ridge in 56 (31%) and above the supravalvular ridge in 20 (11%) hearts. The size of the coronary orifice varied from 2.5-4 mm (3.3±0.32).

Course

After origin from the aorta, LCA extended downwards and to the left in between the pulmonary trunk and left auricular appendage. The length of

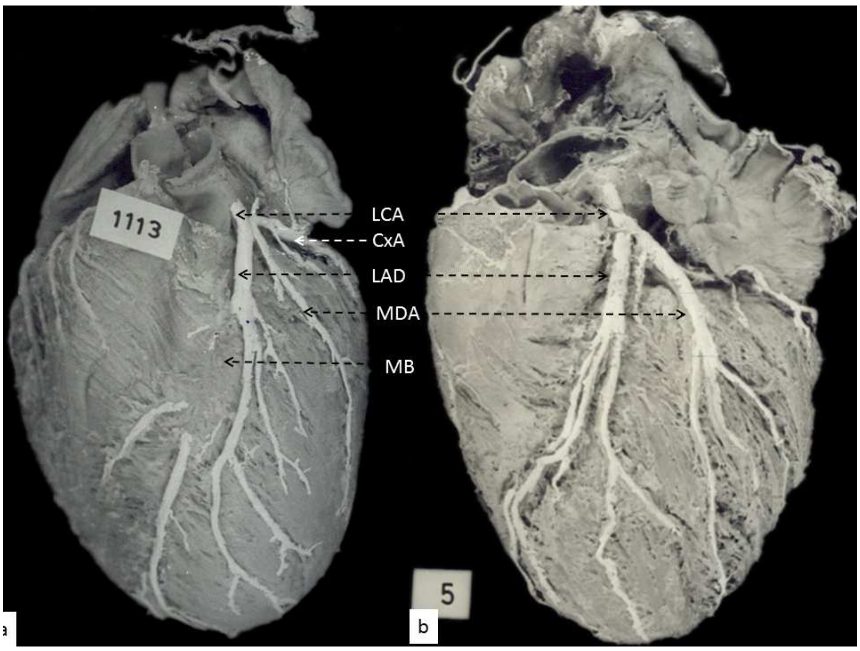

Fig 1. Left oblique view in both the hearts shows trifurcation of the left coronary artery (LCA) in the left anterior descending (LAD), main diagonal artery (MDA) and circumflex artery (CxA). **(a)** Type III dual LAD with myocardial bridge (MB) on the longer LAD is seen. **(b)** Type II dual LAD can be seen. CxA is much thinner.

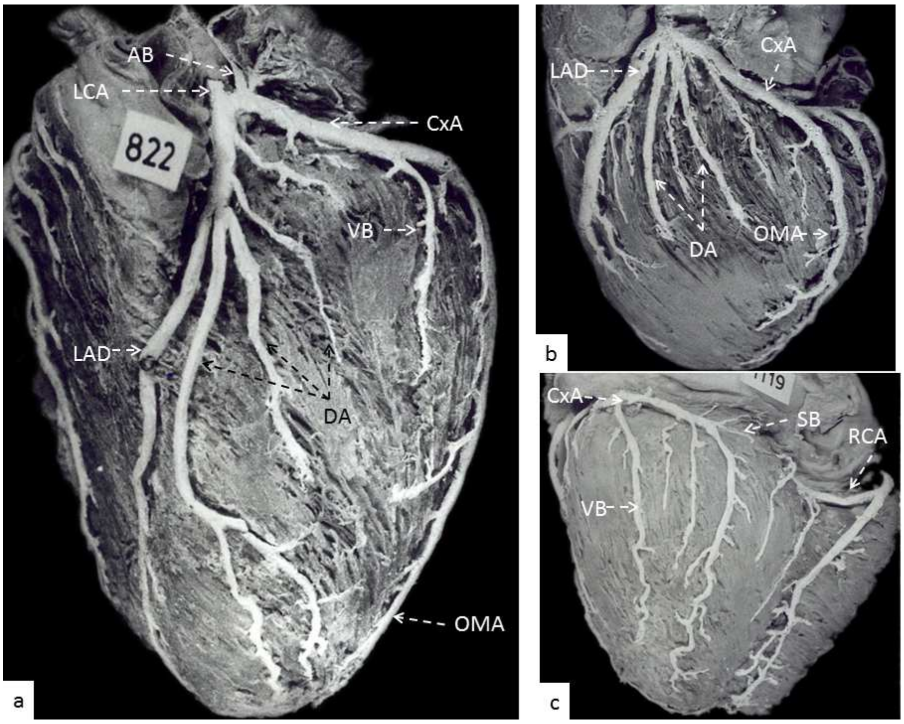

Fig. 2. (a) Left anterior oblique view of the heart showing the diagonal arteries (DA) branching off the left anterior descending (LAD) artery. An atrial branch (AB), two ventricular branches (VB) and the obtuse marginal artery (OMA) of the circumflex artery (CxA) are also visible. LCA – left coronary artery. **(b)** Left oblique view of the heart showing the LAD and CxA and two diagonal branches in between the LAD and Cxa. The right diagonal branch arises from the LCA and the left from the CxA. A very prominent OMA is also seen. **(c)** Posteroinferior view of the heart showing four posterior ventricular branches (VB) and a sulcal branch (SB) of the CxA. The right coronary artery (RCA) is also visible.

LCA from origin to the point of division varied from 2-16 mm (7.11±89mm). No branch arose from the stem of LCA. In 60 (80%) hearts, the LCA divided into two terminal branches, i.e. anterior interventricular or left anterior descending (LAD) artery, circumflex artery (Cx), in the remaining 15(20%) hearts a third branch was also present, i.e. left diagonal artery (LDA) (Fig. 1). In one heart, there was no main LCA and the two branches, LAD and Cx, arose by two separate openings placed one mm apart in the left posterior aortic sinus. The two openings were separated by a ridge.

Anterior interventricular artery or left anterior descending artery (LAD)

After origin, LAD extended forwards, then downwards towards the incisura, where it turned posteriorly to extend in posterior interventricular sulcus for variable distance to anastomose with the terminal part of post interventricular artery (PIVA). In 4 hearts, the LAD was seen to divide into two branches after a course of 10-33 mm into the right and left branches, which extended parallel and adjacent with each other. The right branch extended into the anterior interventricular sulcus, while the left branch extended on the anterior surface of the left ventricle towards the apex of the heart (Fig. 1). Termination of the LAD was seen proximal to incisura (2.7%), at incisura (8%) and posterior to incisura (89.3%). LAD passed under a muscular bridge in 16 hearts. The muscular bridge (MB) was located in upper third of LAD in 9; middle third in 6 and lower third in one case. The width of the muscular bridges ranged from 8-48 mm (Fig. 4).

Branches of LAD

During the course, LAD gave branches from the right and left side. Right branches were conus artery (present in 55 cases) and right anterior ventricular arteries, zero to five in number (number of branches-number of hearts: 0-18; 1-14; 2-26; 3-8; 4-5; 5-4). Anastomosis of right and left conus arteries was found in 43 hearts. Ventricular arteries anastomosed with right diagonal artery in 3 hearts, and with terminal branches of acute marginal artery in 12 hearts. Branches from left side of LAD were 1-9 (number of branches-number of hearts: 1 -2; 2-2; 3-12; 4-16; 5-10; 6-5; 7-5; 8-2; 9-3) ventricular branches (diagonal branches). In one heart there was muscular bridge 23 mm broad on the left diagonal branch of LAD. The LAD gave 5-10 septal branches (perforators) from its deeper aspect (number of branches-number of hearts: 5-10; 6-11; 7-27; 8-20; 9-8; 10-4), which supplied the anterior 2/3rds of the septum. On the posterior surface the LAD gave rise to 1-4 branches from either side (number of branches-number of hearts: 1-9; 2-22; 3-38; 4-6). In 8 hearts LAD gave branches under the MB which pierced the same to come out (Fig. 2).

Anastomoses at termination: In 47 hearts, the LAD anastomosed with the posterior interventricular artery (PIVA).

Left diagonal artery arising from LCA trifurcation (Fig. 1, Fig. 3b)

In 15 (20%) hearts the main left diagonal artery (LDA) originated from LCA. After origin, LDA extended to the obtuse border (OB) of the heart, to divide into two or three branches, which turned around on to the posterior surface of left ventricle. A 23 mm broad MB was present over main LDA in

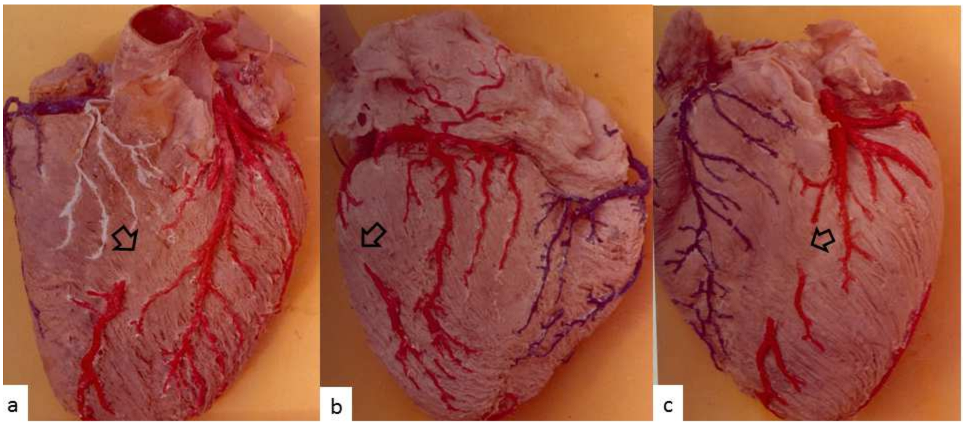

Fig. 3. Myocardial bridge (MB) can be seen on the left anterior descending (LAD) artery in figures **(a,c)**. The obtuse marginal artery (OMA) is passing under the MB in **(b)** and its posterior ventricular branch is sub myocar-

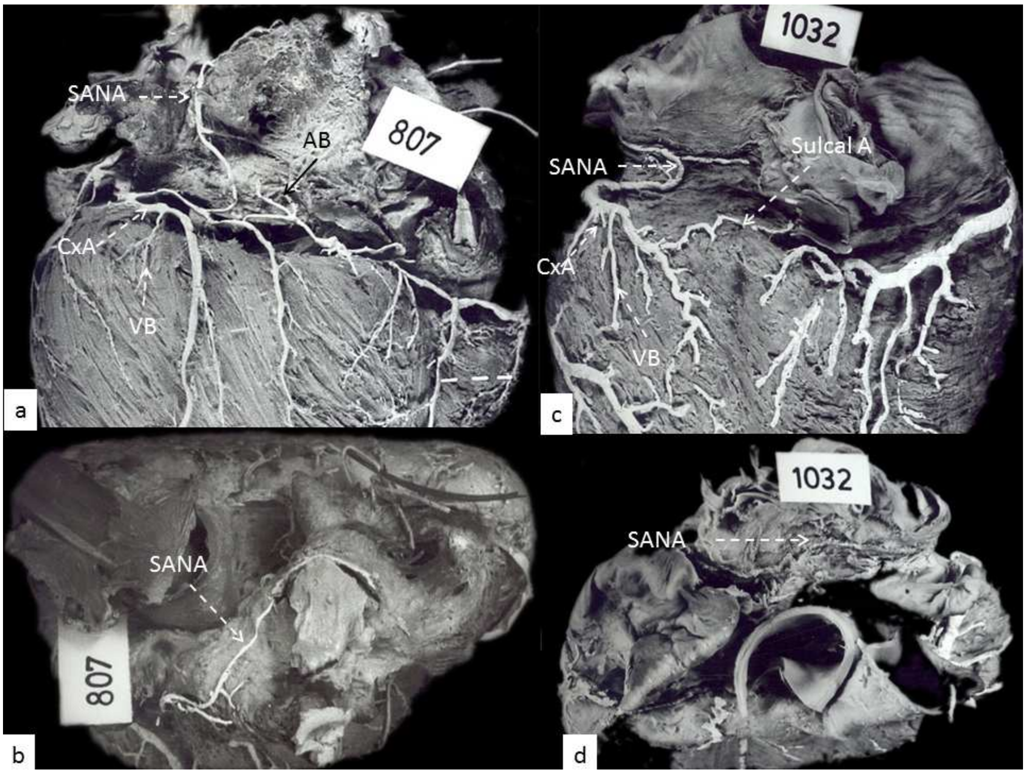

Fig. 4. Unusual origin of the S.A nodal artery (SANA) from the second segment of the circumflex artery (CxA) in two cases. **(a)** The SANA extends upwards in zig-zag manner to reach the upper border of left atrium which it crosses and extends to the right. **(b)** Superior view of the same heart as in figure a, with further course of the SANA. The artery crosses the upper border of left atrium to extend to the right on the anterior surface of the left atrium and the superior vena cava (SVC) to reach the S.A. node. **(c)** The SANA extends slightly upwards and to the right, describing a "U" loop, it extends again to the left on the posterior surface of the left atrium. **(d)** Superior view of the same heart as in figure b, with further course of the SANA. On reaching the left margin of the left atrium the SANA passes on the anterior surface of the left atrium. Then it crosses to the right, passing anterior to the SVC to reach the S.A. node.

one case.

Circumflex artery (CxA) (Fig. 2)

After origin, it turned round the OB to lie in the posterior atrioventricular sulcus for a variable distance going towards the crux of the heart. The point of termination of the CxA was between the OB and the crux in most of the case (n=43, 57%), before the OB in one specimen; at the OB in 16 (21%); at the crux in 13 (17%) and beyond the crux in 2 (3%).

The entire circumflex artery was divided into 3 segments; the artery lying in the left anterior atrioventricular sulcus was called the first segment, the part of the artery lying in the left posterior atrioventricular sulcus was named the second segment. The portion in the posterior interventricular sulcus or right posterior atrioventricular sulcus was called the third segment.

Branches of the circumflex artery from the first segment

S.A. nodal artery and atrial arteries arise from the upper border and ventricular arteries, diagonal branches and obtuse marginal artery arise from the lower border of the CxA.

S.A. nodal artery

The S.A. nodal artery was seen to arise from the circumflex artery in 18 (24%) hearts. It originated from the proximal part of the circumflex artery in 14 cases. In these cases the usual course of the S.A. nodal artery was observed. After origin, it extended upwards, backwards and to the right onto the left atrium, then the right atria to reach the right margin of the superior vena cava to supply the S.A. node. In 4 hearts, the S.A. nodal artery had unusual origin and course (Fig. 4).

Atrial arteries

The atrial arteries arising from the upper border of the first segment of the circumflex artery supplied the anterior surface of the left atrium (Fig. 2). Their number varied from zero to three (0-1; 1-59; 2-12; 3-3).

Ventricular arteries

They originated from the lower border and extended downwards and to the left on the anterior surface of the left ventricle for a variable distance (Fig. 2). Their number as found in the specimens varied from zero to four (0-10; 1-36; 2-19; 3-7; 4-3).

Diagonal branch

A diagonal branch was seen in 18 hearts (Fig. 2b). It gave 1-4 ventricular branches which extended on the anterior or posterior surface of left ventricle. In 3 hearts the diagonal branch anastomosed with the ventricular branches of Cx and LAD.

Obtuse marginal artery

It is a prominent ventricular branch, at the OM, extending towards the apex for a variable distance. It was present in 54 (72%) hearts (Figs. 3a, 3b). In 5 (6.7%) hearts, it was represented by a diagonal-cum-obtuse marginal artery. In 9 (12%) hearts, it was a continuation of the CxA, as the latter terminated at the OM. In 7 (9.3%) hearts, it was absent.

It gave 2-7 ventricular branches. The branches of obtuse marginal artery anastomosed with the left posterior ventricular branches; of the RCA in 4 hearts and the LAD in 15 hearts. The MBs were found in 7 hearts (Fig. 3b).

Branches of the circumflex artery from the second segment

Atrial arteries arise from the upper border while the ventricular branches and A.V. nodal artery arise from the lower border of the CxA.

Atrial arteries

These were small branches (n=1 in 82%) supplying the posterior surface of the left atrium (Fig. 4a). No atrial artery was seen in 29 (38.7%) hearts.

Ventricular branches

They supplied the posterior surface of the left ventricle (Fig. 2c; Fig. 4a, c). Their number – no. of hearts is as follows; 0-26; 1-12; 2- 11; 3- 17; 4-7 and 5-2. In one heart it anastomosed with one of the left ventricular branches of the RCA.

A.V. nodal artery

It arose at the crux in 13 (17.3%) hearts and extended to the right and forwards to supply the A.V. node.

Branches of the circumflex artery from the third segment

Posterior interventricular artery (PIVA)

It was seen in 12 hearts as a continuation of the circumflex artery. In 8 hearts, it anastomosed with the terminal branches of AIVA. In one heart, there was a 8 mm broad MB on its lower part.

Sulcal branch (Fig. 2c, 6c)

This branch was seen in 46 hearts. The sulcal branch anastomosed with the sulcal or terminal branch of the right coronary artery in 23 hearts. In one specimen, it gave two ventricular branches to the posterior surface of the left ventricle, and in another heart it gave one left atrial and 3 left posterior ventricular branches.

DISCUSSION

Ajayi et al. (2013), in their review of 367 coronary angiograms classified the termination patterns of the LCA into 3 categories based on the number of their branches, viz. (a) bifurcation 78.2%, (b) trifurcation 20.4%, and (c) quadrifurcation 1.4%, respectively. Altin et al. (2015), in their retrospective coronary angiographic study of 5,548 patients has found the trifurcation in 11%. In the present study trifurcation of LCA was present in 20% of the cases.

Sub-epicardial anastomoses: Atherosclerosis appears to be more prevalent in the left coronary arterial tree compared to the right according to the radiological and clinical data (Moruzzi et al., 2004). The hemodynamic as well as anatomical differences between the right and left coronary artery might play a key role (Chatzizisis et al., 2007). Collateral circulation is a key factor in the pathophysiology of coronary disease. The location and extent of the collateral circulation is highly variable, and these parameters determine whether or not ischemic symptoms occur and whether left ventricular contractility is abnormal (de Agustín et al., 2010). In our investigations of Indian cadaveric hearts, sub-epicardial anastomoses had been demonstrated at the following sites: - Left conus artery anastomosed with the right conus artery or third coronary artery in 54 (72%) hearts (Fig. 3a, c); right anterior ventricular branches of LAD anastomosed with the right diagonal, ventricular or acute marginal branches in 19 (25%) hearts ; the terminal branches of LAD (Fig. 3b) anastomosed with the branches of PIVA in 47 (63%) hearts and with the posterior branches of RCA in 3 (4%) hearts; the left posterior ventricular branches of RCA anastomosed with the diagonal and obtuse marginal branches of CxA in 5 (6.7%) hearts (Fig. 6c). The posterior ventricular branches of the CxA anastomosed with the left ventricular branches of the PIVA in 1 (1.3%) hearts. The sulcal branch of CxA anastomosed with the sulcal or terminal branch of RCA in 35 (46.7%) hearts (Fig. 2c; Fig. 4a, c).

These biological variations in anastomotic patterns are likely to affect perfusion of tissue. De Agustín et al. (2010) emphasize the importance of always looking for anatomical variants on coronary angiography, especially when occlusion is present in LCA with preserved left ventricular function.

Dual LAD: The presence of a short and long LAD in the anterior interventricular septum (AIVS) is described as a dual LAD. Spindola-Franco et al. (1983) have classified it into four subtypes according to the origin and course of the long LAD. Type I: the long LAD courses in the AIVS, descends on the left ventricular side of the short LAD, and then re-enters at the distal part of the AIVS. Type II: the long LAD courses in the AIVS, descends on the right ventricular side of the short LAD, and then reenters at the distal part of the AIVS. Type III: the long LAD courses intramyocardially, proximally in the ventricular septum, and appears on the epicardial surface in the distal part of the AIVS. Type IV: the long LAD unusually originates from the right coronary artery and then enters the AIVS. In our specimens there were 4 cases of dual LAD (5%). Two cases belonged to the Type II and two to the Type III (Fig. 1). Dual LAD may cause misdiagnosis, and mistreatment when diagnosed. Angelini (2007) in his classification of coronary artery anomaly has labelled the dual LAD as parallel LAD.

S.A. nodal artery: Its anatomy has clinical importance as it affects the clinical expression of ischemic heart disease. Moreover, it might have a bearing on planning of cardiac surgery and catheter-based interventional cardiac procedures (Macduff et al., 2011). In the majority of cases S.A. nodal artery is a branch of RCA, but in 40% -48% of cases it arises from the Circumflex branch of LCA (James and Burch, 1958; Kyriakidis et al., 1988; Sahni and Jit, 1988). According to Nerantzis and Avgoustakis (1980), if the S.A. nodal artery arises from the CxA, then in approximately one-third of cases it adopts a long S-shaped course, designated as S shaped sino-nodal artery (SSNA). The authors have described three possible sites of origins for SSNA. It may arise as a branch of a long CxA, or as an upper division or continuation of a short CxA. The SSNA has three possible terminal routes to the S. A. node. Most commonly it passes posterior to the SVC, but it may also pass anterior to the SVC or terminate in a series of branches which surround the SVC (Rossi et al., 1980).

In the present series, the S. A. nodal artery took origin from the CxA in 24% (n=18) of cases. The long unusual course was noted in about 5% (n=4), out of which, in three cases the artery crossed the SVC anteriorly and in one case it partially encircled the SVC (Fig. 5b, Fig. 4).

As the SSNA is larger and longer in comparison to the usual S. A. nodal artery, it also supplies a large area of the adjacent myocardium along with the S.A. node. Moreover, as it may be the only blood supply to the S. A. node its damage during the cardiac interventions might lead to catastrophic complications (Moruzzi et al., 2004; Sahni and Jit, 1991).

Coronary ostia: Typically, there are two coronary ostia. However, in some cases, three ostia can be detected in the absence of the Left main coronary artery (LMCA). In such a condition, the LAD and CxA originate from different ostia. The absence of the LMCA is a common anomaly that can be detected in 0.4%-0.9% of the population (Ajayi et al., 2013; Altin et al., 2015). In the present study, the incidence of the absence of the LMCA, with two separate ostia, was seen in one case (1.3%).

Myocardial bridge: It is a condition in which a coronary artery tunnels through the myocardium rather than resting on top of it. There is no consensus in literature, regarding the status of the MB; whether they are a pathological anomaly, an anomaly or simply a normal feature of some coronary arteries in humans (Angelini, 2007). Incidence of MBs has been variably reported from 1-85% (Altin et al., 2015; Koşar et al., 2010; Tanigawa et al., 2007; Loukas et al., 2011). There is variable opinion regarding their clinical importance, from clinical insignificance to sudden death because of considerable narrowing of the vessel due to compression from the MB. Ischaemia in MBs is considered to be associated with the severity of systolic compression of the vessel, diastolic filling time and microvascular compression (Altin et al., 2015; Kayrak and Ulgen, 2007; Mollet et al., 2005; Rossi et al., 1980).

In the majority of instances the MB is located on the LAD (Sahni and Jit, 1991; Vanker et al., 2014). In our specimens the incidence of MB over the LCA and its branches was found to be 35%. Out of the 26 total cases of the MB; it was located over the LAD in majority of cases (n=16) with one each on the main left diagonal artery, obtuse artery, posterior ventricular artery and PIVA. The width of the majority (81%) of the MBs was from 1-2 inch (Fig. 3).

The clinical implications of knowledge of the detailed course and termination pattern of all the branches; are not only diagnostic, but also therapeutic as elucidated by Tanigawa et al. (2007) for the conus artery. It is plausible that the propensity of LAD to develop atherosclerosis is related to the branching pattern, as trifurcation of LCA that alters the angle and thus complicating blood flow leading to increased incidence of atherosclerosis in such cases (Furuichi et al., 2007; Rubinstein et al., 2012). Authors opine that knowledge of origin and course of the conus artery is essential as iatrogenic damage can occur during manipulation of infundibulum, especially when it is partially hidden by an intra-myocardial pathway. Moreover, the multidetector computed tomography is now being used to study the coronary disease. By this method it is possible to study the distal beds of the coronary vessels as well as the collateral circulation in patients with coronary occlusion (Mollet et al., 2005). This underlines the need to know the minute anatomical details of coronary artery, provided by this study, for accurate interpretation of images as well as interventions.

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