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Computed Tomographic Evaluation of Branching Patterns and Variations of Coronary Arteries.

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KEY WORDS

AV	Atrio-ventricular
CHD	Congenital Heart Disease
CPR	Curved Planar Reformation
CT	Computed Tomography
EBCT	Electron Beam Tomography
IV	Interventricular
IVS	Interventricular septum
LA	Left atrium
LAD	Left anterior descending artery
LCA	Left coronary artery
LCX	Left circumflex artery
lp/cm	Three Line Pairs Per Cm
LPA	Left pulmonary artery
LV	Left ventricle
LV	Left ventricle
MDCT	Multidetector Computed Tomography
MPA	Main Pulmonary Artery
MPA	Main pulmonary artery
MIP	Maximum Intensity Projection
MPR	Multiplanar Reformation
MRI	Magnetic Resonance Imaging
PDA	Posterior Descending Artery
RA	Right atrium
RCA	Right coronary artery
RPA	Right pulmonary artery
S/Sec	Seconds
SA	Sino-atrial
SR	Serial number
TGA	Transposition of great arteries
TOF	Tetralogy of Fallot
VR	Volume Rendering

I. INTRODUCTION:

The human body has special organs to transport and distribute blood so that it is accessible to all the cells in the body. These organs consist of the Heart and the vascular system.

The heart is a hollow muscular organ with four chambers which is responsible for the

circulation of blood. In spite of being in the constant contact with the blood through the various chambers, the heart does not receive the blood directly from its chambers. The arterial supply of the heart is by two arteries which are branches of ascending aorta. These arteries branch in such a way that they occupy the atrioventricular and interventricular groove in the shape of a crown, hence they are called the coronary vessels.

The word coronary is derived from the Latin word 'co-ro-ne', Greek 'ko ro ne' which means anything hooked or curved and coronary means 'encircling in a manner of crown'.

Coronary anomalies are a poorly understood topic in medicine. Clinicians should be aware of such anomalies, chiefly because such anomalies can result in sudden death.

Coronary artery disease is one of the major causes of death in developing countries. In recent times there is increasing use of diagnostic and therapeutic interventional procedures for which knowledge of the coronary artery pattern is a must. Vascular anomalies pose a great challenge to medical community and coronary artery anomalies are one of the most confusing topics in cardiology. Coronary artery anomalies may sometimes be asymptomatic but they may also deteriorate coronary circulation which may also lead to sudden cardiac death.

Although the medical community and general population are increasingly aware that coronary anomalies can be fatal, the reasons for the sudden fatal event and the frequency with which it occurs are mostly unclear. The prevalence of coronary artery anomalies are reported between 0.6–1.3percent in the literature.' Conventional angiography is the golden standard in diagnosing the anomalies; however, it is an invasive procedure.

MRI has good anatomic and functional assessment abilities for major cardiac structures. Moreover, because of its large field of view, it plays an important role in the evaluation of the mediastinal vessels and connections. However, MRI is time consuming and may require prolonged sedation especially in children and uncooperative patients.

The CT has advantages of widespread availability and short acquisition times. The recent development of ECG gated multi-detector row computed tomography angiography with sub-millimeter slice collimation and high temporal resolution has allowed accurate and noninvasive depiction of coronary artery diseases in a single breath hold. Detection, characterization, and quantification of coronary artery disease and elegant delineation of coronary anatomy are possible using 2D multiplanar reformation (MPR), 3D maximum-intensity-projection (MIP), and 3D volume-rendered post-processing techniques. It has an additional capacity of simultaneous evaluation of cardiovascular structures and lung parenchyma.

II. AIMS & OBJECTIVES

Aim

To determine the branching, distribution and dominance pattern of coronary arteries in adult population.

Objectives

This study is undertaken to study following anatomical features of coronary arteries,

1. To study the origin of right and left coronary arteries.
2. To study different branching patterns of the right and left coronary arteries.
3. To know any variations.
4. To differentiate benign and malignant courses of the coronary arteries and its branches.
5. To determine the coronary dominance.
6. To study the distribution of the coronary arteries.

III. METHODS AND MATERIALS

Study design: Non interventional cross sectional observational study design.

Setting: Department of Radiology, Tertiary care teaching hospital.

Approximate subjects: 40 patients referred for coronary angiography over a period of 12 months.

SELECTION CRITERIA:

Patients of any age over 18 years, who were referred for Coronary/Cardiac CT for,

- Evaluation of suspected coronary anomalies.
- Assessment of complex congenital heart diseases including anomalies of coronary circulation, great vessels, cardiac chambers and valves.
- Evaluation of coronary arteries in patients with new onset heart failure to assess etiology.

EXCLUSION CRITERIA:

1. Any patient refusing to give consent for the procedure.
2. Serum creatinine values of more than 1.4 mg/dl
3. Serious allergic reaction to iodinated contrast agent in the past.
4. Pregnancy.
5. Patients of less than 18yrs of age.

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STUDY PROCEDURE:

The Serum creatinine value of the patient was obtained.

Proper informed consent was taken from the patient after explaining to them about the risks and benefits of the examination.

Patient is kept 5hrs NBM before the examination. ECG leads were attached to the patient before the examination began. The heart rate of the patient was monitored. If the heart rate was over 65bpm, patient was given beta blockers to reduce the heart rate, as higher heart rate causes poor visualization of coronary arteries in the examination. After the heart rate stabilized between 55 to 65bpm the study was begun.

All studies were performed on a PHILIPS 64 slice Brilliance Computed Tomography unit. CT data was obtained with the following parameters:

1.25mm collimation and 0.5mm reconstruction interval was used. A weight-based low-dose CT protocol (120 kVp, 1000 mAs) was be used. Scanning was performed from the thoracic inlet level to the L1–2 level in patients with congenital heart disease. In patients referred to rule out atherosclerotic disease in coronary arteries scan was done from tracheal bifurcation up to the diaphragm.

Non-ionic contrast agent (2 ml/kg) was injected along peripheral venous routes via power injector. Contrast injection was followed by saline chaser of 30cc.

ECG gated protocol was selected for every patient. CT was performed in the craniocaudal direction to decrease contrast agent related artifacts and to achieve homogeneous contrast enhancement. The injection rate was 5ml/sec. Scan delay was determined with an automatic bolus tracking system. A threshold level of 120 HU was set for starting the scan.

CT was performed during quiet breathing in patients who could not hold their breath.

After the scan was done patient was observed for 1 hour. No contrast reactions were encountered.

The following post processing techniques were used:

1. Multiplanar Reformation (MPR)
2. Maximum intensity projection (MIP)
3. Volume rendering (VR)
4. Cine imaging

IV. RESULTS

CT coronary angiography was performed on 40 patients who were referred. All the studies were observed for the origin, course and branching patterns of the coronary arteries. Termination of each coronary artery was studied. Origin and course of PDA was also studied to determine the dominance of the coronary arteries. Any variations in the form of origin, branching and course of coronary arteries were noted.

1) NUMBER OF CORONARY ARTERIES

Table No.2: Showing distribution about the number of coronary arteries

No. of coronary arteries	Number	Percentage
2	40	100%
3	0	0%
4	0	0%
Total	**40**	**100%**

Out of the 40 patients studied, all of them had only two coronary arteries (100%). None of them had more than two coronary arteries.

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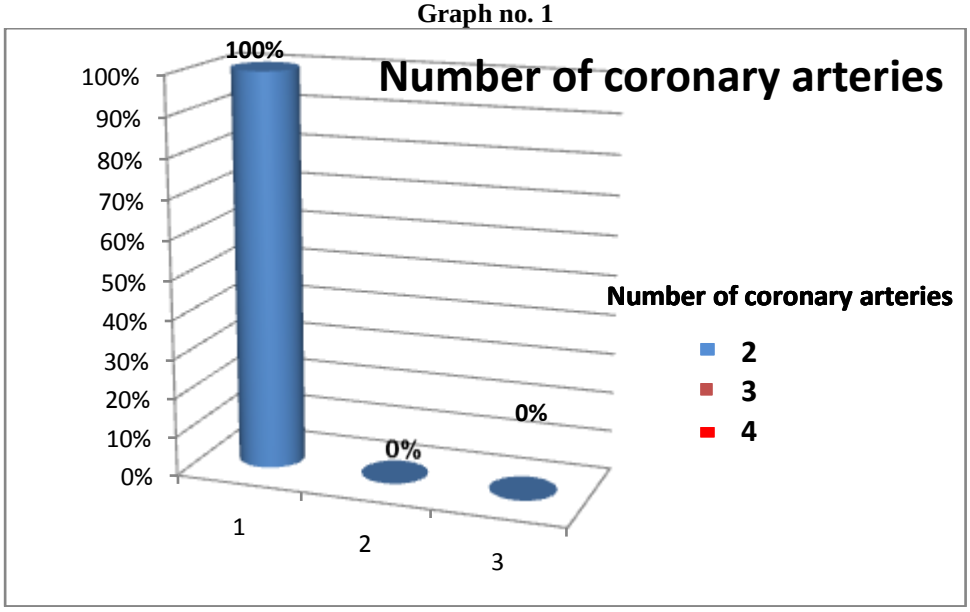
Graph no. 1



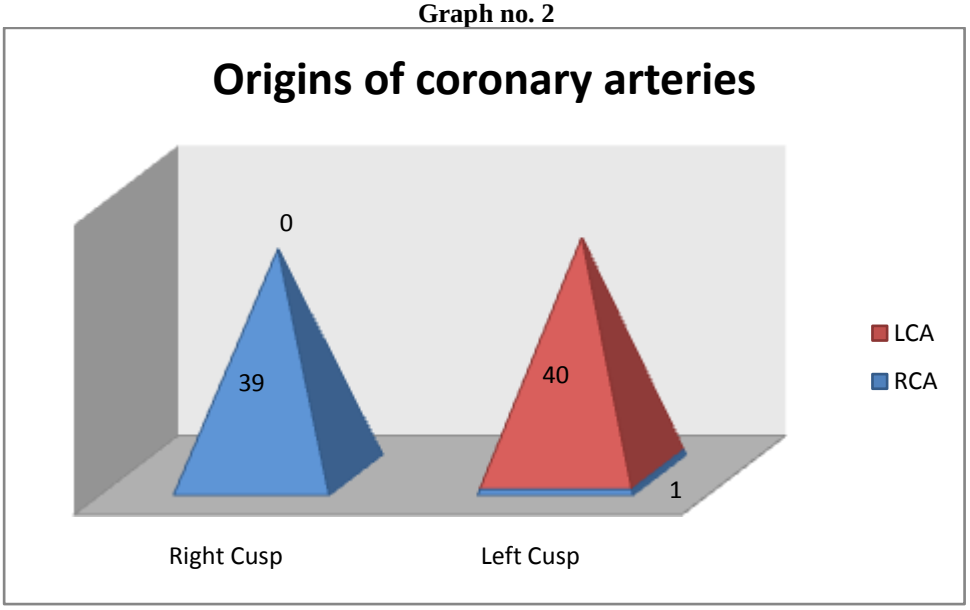
2) ORIGIN OF CORONARY ARTERIES

Table 3 showing distribution about the origin of the coronary arteries

Origin of	Right Cusp	Left Cusp	Percentage (normal origin)
RCA	39	1	97.2%
LCA	0	40	100%

Amongst the 40 subjects, RCA originated from right cusp of the aortic sinus in 39 cases (97.5%) and 1 originated from left cusp of coronary sinus (2.5%). However, in all subjects LCA originated from left cusp of aortic sinus, no abnormal origin of LCA was observed.

Graph no. 2



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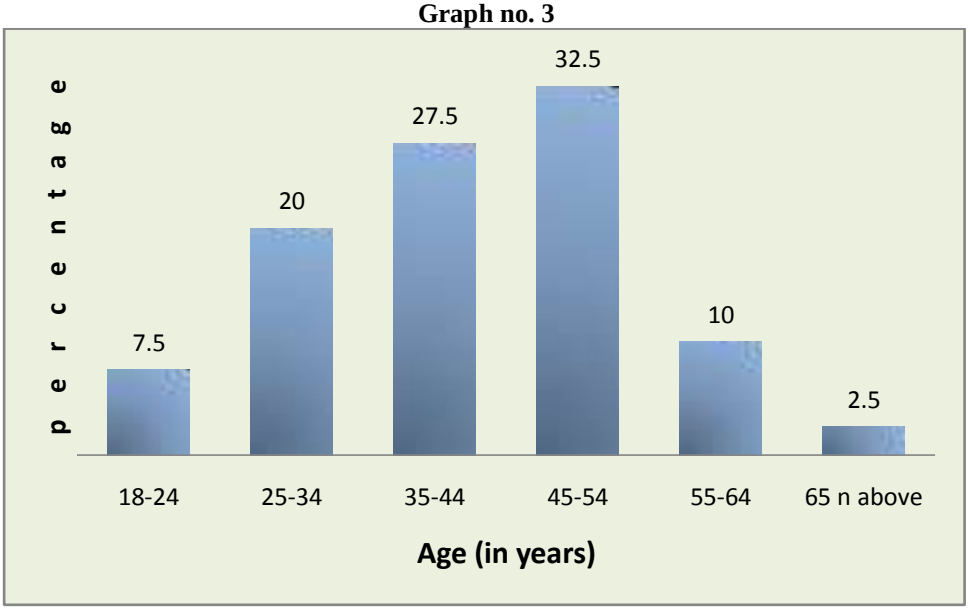
3) Age- Table.4 showing distribution in different age groups

Age (years)	Number	Percentage
18-24	3	7.5 %
25-34	8	20 %
35-44	11	27.5 %
45-54	13	32.5 %
55-64	4	10 %
65 n above	1	2.5 %
Total	**40**	**100 %**

Graph no. 3



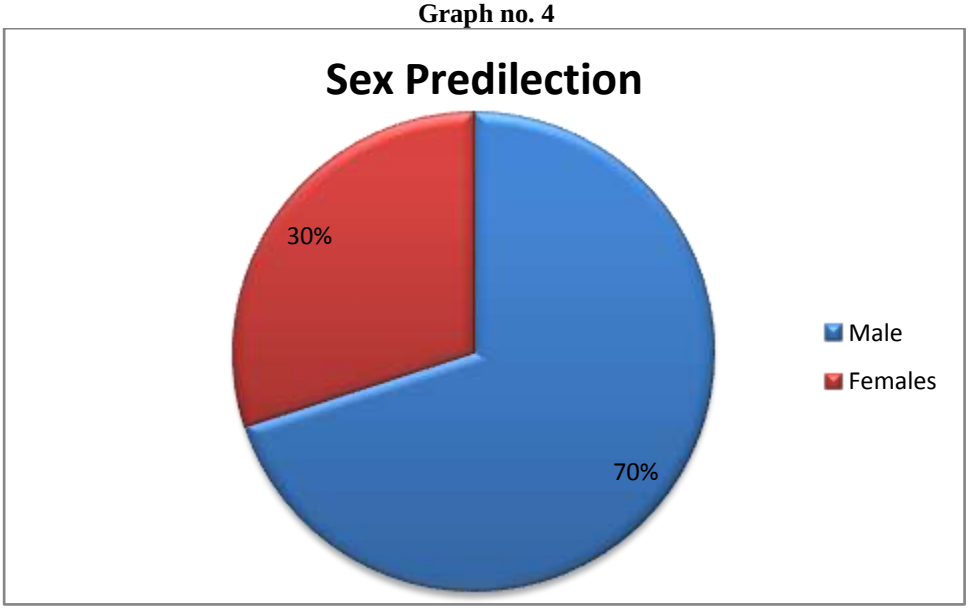
The age of the subjects included in this study was over 18 years (table 4). Among these subjects highest number of subjects was from the age group 45 to 54 years and lowest number of them was from over 65 years.

4) Sex

Table 5. Showing the distribution about different gender.

Gender	Number	Percentage
Male	28	70%
Female	12	30%
Total	**40**	**100%**

Graph no. 4



In present study group, 28 subjects (70%) were males and 12 subjects (30%) were females.

5) LCA Division

Table 6 showing distribution about the division of LCA

Division	**Number**	**Percentage**
Bifurcation	34	85%
Trifurcation	6	15%
Tetrafurcation	0	0
Pentafurcation	0	0
Total	**40**	**100%**

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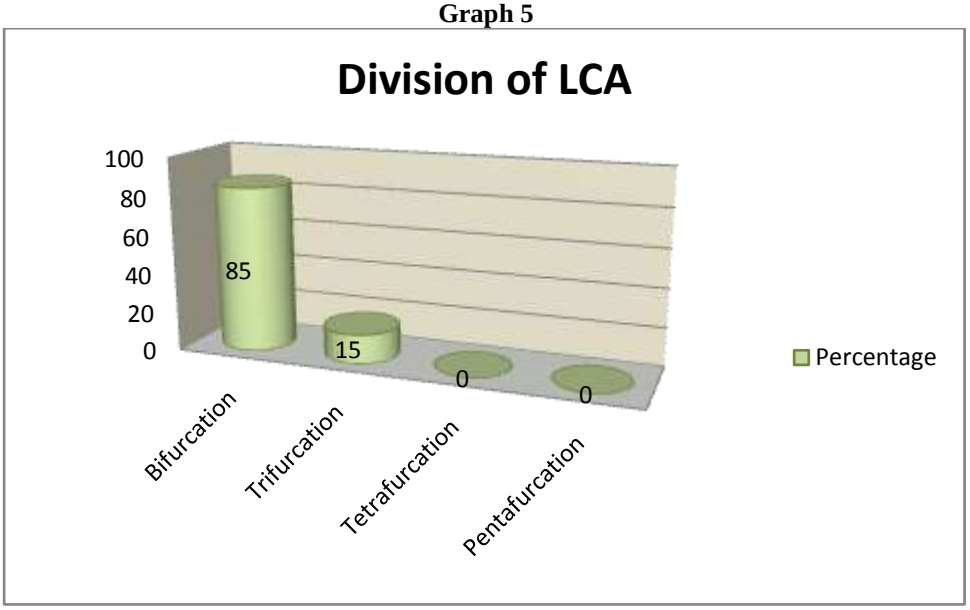
Graph 5



In regards to the branching pattern of the left coronary artery, out of 40 subjects we found bifurcation in 34 (85%) subjects, followed by trifurcation in 6 (15%) subjects. However, no subjects had tetrafurcation or pentafurcaion.

6) RCA Termination:

Table.7 showing distribution about the termination of RCA

RCA Termination	**Number**	**Percentage**
Before right border	2	5
At right border	3	7.5
Before Crux	8	20
At or after crux	27	67.5
Total	**40**	**100%**

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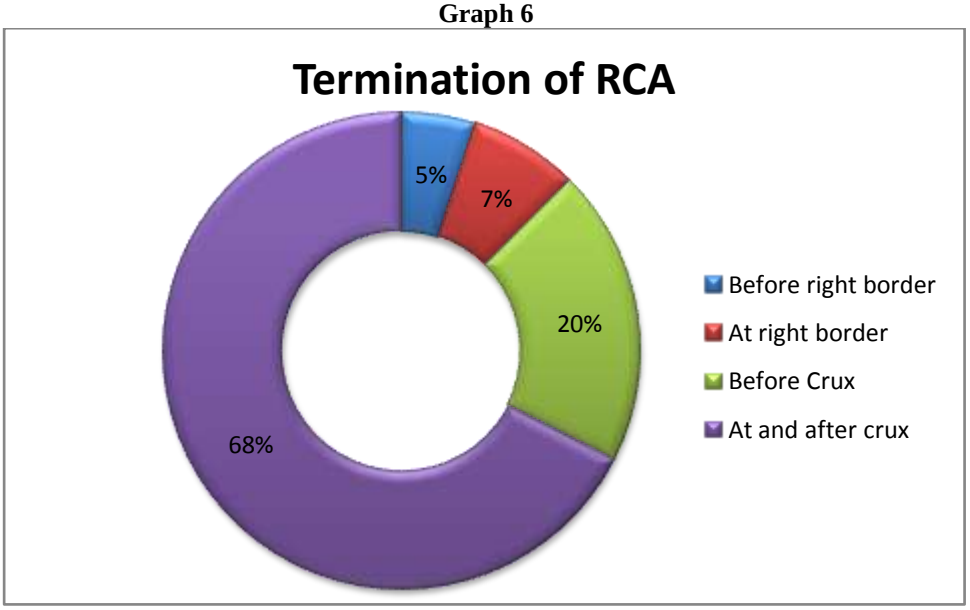
Graph 6



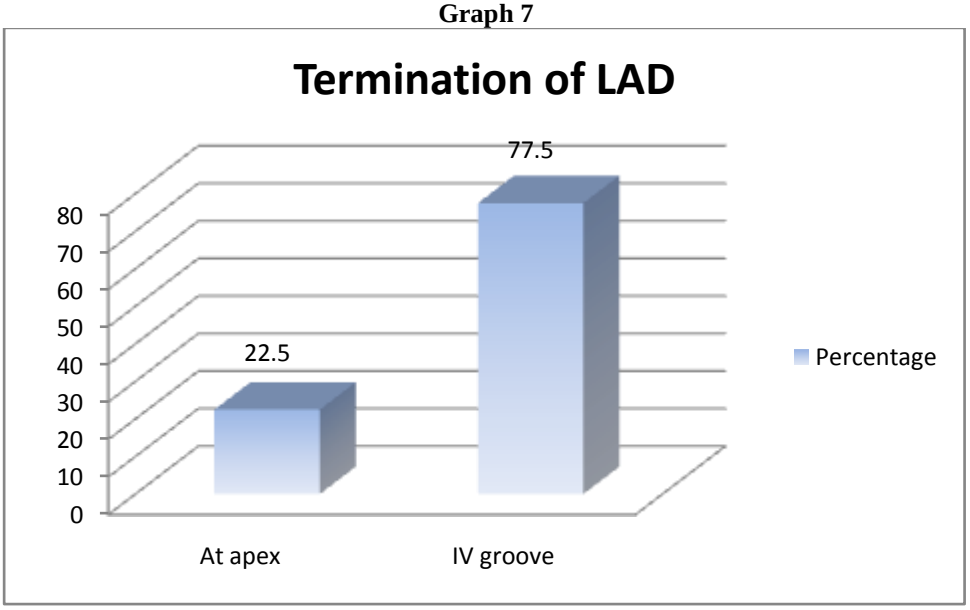
RCA terminates before right border in 2 (5%) out of 40 subjects, at the right border in 3 (7.5%) subjects, turns at right angle to continue in posterior interventricular sulcus and terminates before crux in 8 (20%). Or the RCA terminates at or after crux in 27 (67,5%) subjects.

7) LAD Termination

Table.8 showing distribution about the termination of LAD

LAD Termination	Number	Percentage
At apex	9	22.5
Posterior IV groove	31	77.5
Total	**40**	**100%**

Graph 7



Out of 40 subjects studied, the LAD was observed to reach and terminate at the apex in 9 subjects (22.5%). In remaining 31 (77.5%) subjects the LAD terminated in the posterior interventricular groove.

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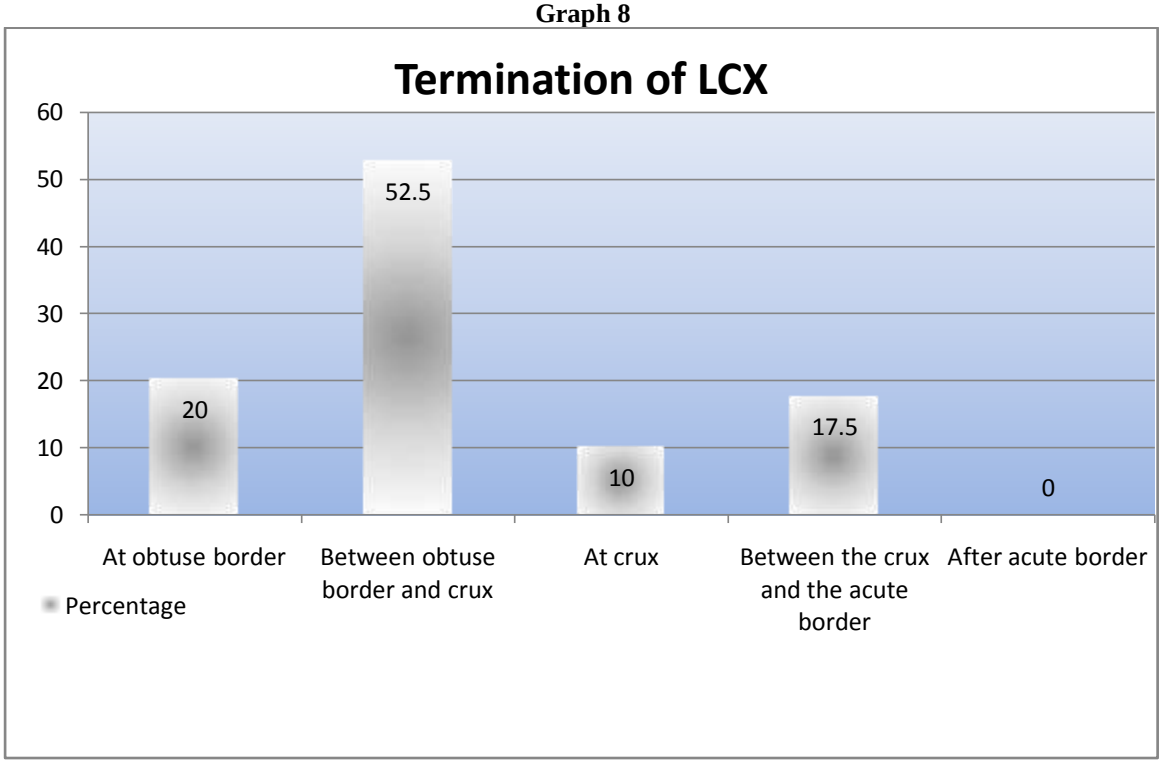
8) LCX termination

Table.9 showing the termination of LCX

LCX termination	Number	Percentage
At obtuse border	8	20 %
Between obtuse border and the crux	21	52.5 %
At the crux	4	10 %
Between the crux and the acute border	7	17.5 %
After acute border	0	0 %
Total	**40**	**100%**

Graph 8



In this study LCX terminates at the obtuse border in 8 (20%) out of 40 specimens, between obtuse border and crux of heart in 21 (52.5%) subjects, terminates at the crux in 4 (10%) subjects, and terminates between crux and acute border in 7 (17.5%) subjects. However, in none of the patients in this study does the LCX terminate after the acute border (0%).

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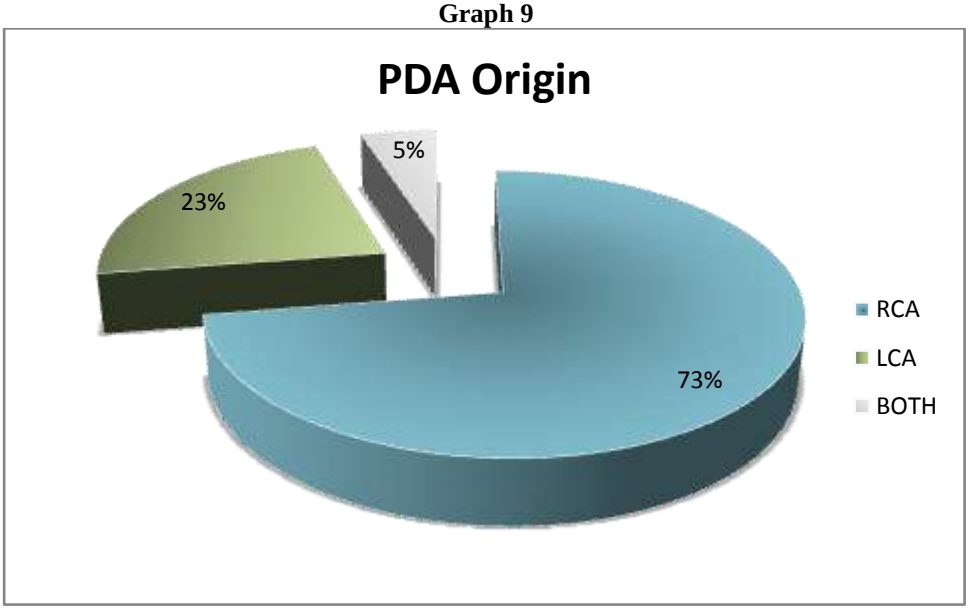
9) Origin of PDA

Table.10 showing distribution about the origin of PDA.

PDA origin	NUMBER	PERCENTAGE
RCA	29	72.5%
LCA	9	22.5%
BOTH	2	5%
Total	40	100%

Graph 9



It is observed that out of 40 subjects studied, the PDA originated from RCA in 29 (72.5%) cases, in 11 (22.5%) cases PDA originated from LCA and in 2 (5%) cases PDA originated from both RCA and LCA.

The origin of PDA also decides the dominance of coronary circulation. Thus, in this study 72.5% subjects had right dominant circulation while 22.5% subjects had left dominant circulation and 5% subjects had balanced circulation.

* Kindly note that percentage of PDA origin from RCA and LCA in this study was observed to be 72.5% and 22.5% respectively; however, due to limitations of the MS Excel software the percentage was rounded off to 72% and 23% respectively.

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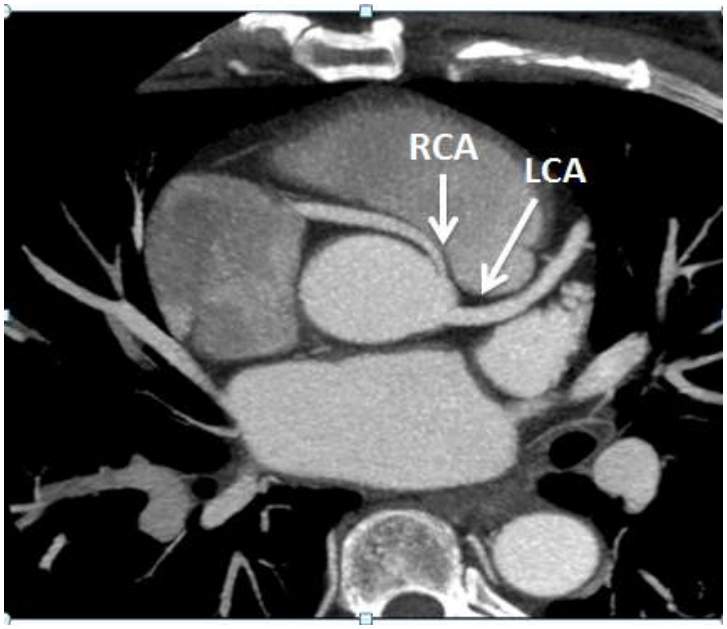

Figure.22 -Anomalous origin of the RCA from left cusp of aortic sinus.

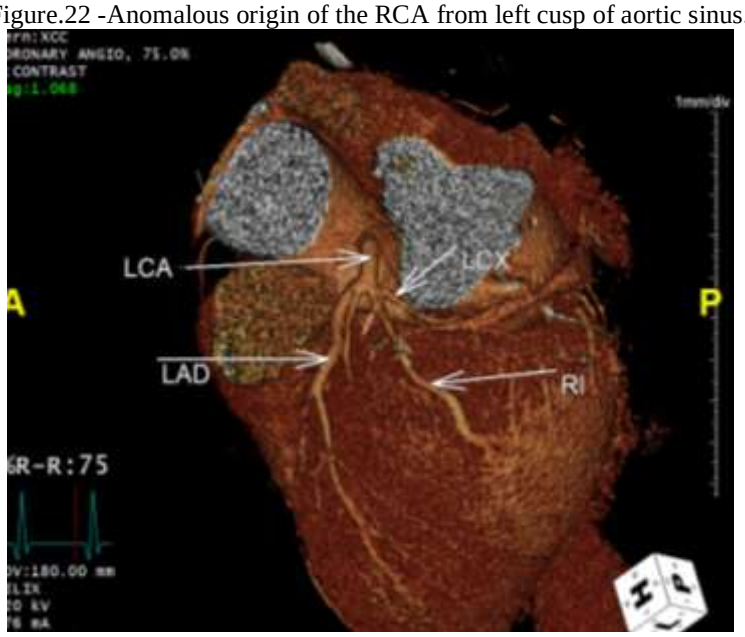

Figure.23 – VR image of Trifurcation of LCA

V. DISCUSSION

The branching pattern and distribution of coronary arteries have been studied by various workers in the past. The present study was taken up with the hope that the data collected in the study may help clinician to interpret properly the findings which will lead on to its remedy.

In this study, the origin, course and branching pattern and termination of the coronary arteries was studied. This study also determines the origin of the PDA which determines the circulatory dominance of the heart.

The location, level and size of ostium are very important in the successful performance of a coronary angiogram.

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Table no.11: Showing distribution about the number of coronary arteries

Author & No of subjects	1 coronary artery	2 coronary arteries	3 coronary arteries	4 coronary arteries
Almira Lijonovic et al n=32	-	64%	32%	4%
Patel MP et al n=210	0.48%	89.52%	10%	-
Present study n=40	-	100%	-	-

In the present study all (100%) cases showed the presence of 2 coronary arteries which was similar to the observations of Almira Lijonovic et al (64%) and Patel M Pet al (89.52%).

The incidence of single coronary artery is 0.48% as observed by Patel M P et al, however in the present case none of the specimen showed the presence of single coronary artery.

In the present study none of the specimens showed the presence of 3 or 4 coronary arteries, whereas Almira Lijonovic et al showed the presence of 3 arteries in 32% of cases and 4 coronary arteries in 4% of cases.

Normally, an individual has two or sometimes three coronary ostia. Often, the conal branch of the RCA may arise separately from the right aortic sinus. The circumflex or LAD on occasion arise directly from the aortic root. Coronary ostia are typically equal to, or larger than, the vessel they supply.[39]

Branches may arise as a common trunk or both arise from the same aortic sinus. The anterior interventricular and terminal branches of the left coronary sometimes arise separately from the aortic sinus.

In a survey of patients undergoing diagnostic coronary angiography the incidence of anomalous origin was 0.64% and the incidence of both coronary arteries arising from a single aortic sinus was 0.2%.[24]

however, in this study incidence of both coronary arteries from a single aortic sinus was 2.5% (Table.3)

Table no. 12: showing comparison of branching pattern of LCA

Authors & no. of subjects	Bifurcation	Trifurcation	Tetrafurcation	Pentafurcation
Das Hirak et al, no=100	60%	35%	5%	0%
Reig et al, n=100	62%	38%	0%	0%
Present study n=40	85%	15%	0%	0%

In majority of cases the common pattern of branching of LCA is bifurcation. The results of bifurcation of our study are consistent with earlier reports of Reig J et al (62%) and Das Hirak et al (60%). The frequency of quadrifurcation of LCA in present study is 0%, which is similar with findings reported by Reig J et al as 0%.

Trifurcation of the LCA is less common and lowest reported in our study (15%) when compared with Reig J et al (38%) and Das Hirak et al (35%).

Table no.13- showing origin of PDA

Authors	From RCA	From LCA	Both
Kalpana R	89%	11%	0%
Charles E. Khan	70%	10%	20%
K.V.Vankkoteshu	68.75%	16.66%	14.58%
Present study	72.5%	22.5%	5%

In present study 72.5% subjects were right dominant and 22.5% were left dominant while 5% showed balanced circulation.

The RCA is dominant in approximately 70% of people. If the circumflex branch of the LCA terminates in the posterior IV groove, left dominance is present. This occurs in about 15% of people. In the remaining posterior septum is vascularized either by descending branches from both the right coronary and left circumflex arteries or by a network of small branches from these two passing obliquely, so that there is no posterior IV branch. In such hearts the circulation is said to be

'balanced', as the posterior IV branch is either bilateral or absent.[16]

When average coronary flows in each of the three arteriographic groups are compared it is observed that right coronary flow is 42% in LCA predominant group, 54% in balanced group and 98% in RCA predominant group.

Table 14 showing termination of RCA

Author	Before right border	At right border	Before crux	At or after crux
Grays	10%	10%	20%	60%
Present study	5%	7.5%	20%	67.5%

In the present study RCA terminated at crux or beyond crux in 67.5%, before crux in 20% and at the right border in 7.5% and before right border in 5%.

In comparison with study undertaken by Grays, that showed 60% subjects showing termination of RCA at or after the crux, 20% showed termination before crux and 10% each showed before and at the right heart border.

Table no.15 showing termination of LAD artery.

Author	At apex	Posterior IV groove
James	40%	60%
Kalpana R.	20%	80%
Present study	22.5%	77.5%

In present study, the LAD terminated at the apex in 22.5% of subjects and in 77.5% of subjects it terminated in posterior IV groove. Comparing it to James et al, that revealed termination of LAD at the apex in 40% of subjects and in posterior IV groove in 60% subjects. Similar findings were put forth by Kalpana R. in 2003, that suggested termination at the apex in 20% and in posterior IV groove in 80% of subjects.

Table no. 16 showing termination of LCX

Termination	Hirak Das et al	Kalpana R	Present study
At the obtuse border	17.14%	13%	20%
Between obtuse border and crux	52.86%	67%	52.5%
At the crux	18.57%	6%	10%
Between crux and acute border	11.4%	11%	17.5%
After acute border	0%	0%	0%

In all the above mentioned studies majority of subjects showed termination of LCX between obtuse border and crux, 52.86% in Hirak Das et al, 67% in Kalpana R. and 52.5% in present study. However, almost similar distribution is seen about termination of the LCX at obtuse border, at the crux and between the crux and acute border. While none of the subjects showed termination of LCX after the acute border.

VI. SUMMARY AND CONCLUSION

Coronary CT has become an important adjunct and alternative to invasive conventional angiography in the evaluation of the coronary arteries.

In this study all the subjects show origin of the LCA from left cusp of the aortic sinus; however one subject showed origin of RCA from left cusp of aortic sinus.

This study also reveals higher number of male subjects than females. (approximately M:F=2:1)

Most of the subjects show bifurcation of the LCA (85%) and few (15%) show trifurcation of LCA. None of the subjects show tetrafurcation or pentafurcation of LCA.

Majority of the subjects show termination of the RCA at or after the crux (67.5%) while very few subjects show termination of RCA before the right border (5%).

The LAD is seen to terminate in the posterior IV groove in most of the cases (77.5%) while remainder show termination at the apex (22.5%).

Maximum number of subjects show termination of LCX between obtuse border and the crux.

Right dominance is seen in higher number of subjects. PDA originates from RCA in most of the cases.

CT coronary angiography is a valuable tool for depicting the cardiac anatomy. It has good spatial resolution and gives good visualization of coronary arteries and also cardiac anatomy. It has become particularly useful in the study of origin, course and anomalies of coronary arteries.

However, the visualization of coronary arteries may be difficult if the scan is non-gated. For example when the patient had high heart rate and had to undergo non-gated scans, which did not give good imaging quality and thus did not serve purpose for which CT was done.

CT has an added advantage of providing important information about the visualized lung fields, mediastinum, bronchial tree, anomalies of aorta and origins of great vessels of the neck.

Hence, the information provided by cardiac CT imaging is useful for treatment planning. In many cases, it may reduce the need for potentially harmful cardiac catheterization.

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