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Research Article

Morphological and Anatomical Variations of the Coronary Arteries: A Cadaveric Study

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ABSTRACT

In Objective:- The coronary arteries are the principal arterial supply to the myocardium. Variations in their morphology and anatomy have important clinical implications during procedures such as coronary angiography, interventional cardiology procedures and cardiac surgery. The present study was undertaken to document the morphology and anatomical variations of coronary arteries in human cadavers.

Methods: This cross-sectional cadaveric study was conducted in department of anatomy of Rajarajeswari medical college and hospital on 64 formalin-fixed adult human cadavers. Detailed dissection was performed to study the number, origin, course, coronary dominance, length, branching pattern and myocardial bridging of coronary arteries. Data was analyzed using descriptive statistical methods and results were expressed as numbers and percentages.

Results: Two and three coronary arteries were observed in 56 (87.5%) and 8 (12.5%) cadavers respectively. The right coronary artery was seen to be originating from the right aortic sinus in 64 cadavers (100%) whereas the left coronary artery originated from the left aortic sinus in 64 cadavers (100%). Right coronary dominance was seen in 58 (90.6%) cases and left dominance was observed in 4 (6.3%) cadavers. Co-dominance was present in 6 (9.4%) cadavers. Trifurcation of the left coronary artery was seen in 6 (9.4%) cadavers and Myocardial bridging was found in 8[12.5%] cadavers.

Conclusion: The study demonstrated presence of significant morphological variability in the coronary arterial system. Awareness of these anatomical variations is crucial for anatomists as well as cardiac surgeons. This knowledge will reduce procedural complications and improve outcomes during coronary interventions.

***Keywords**:* Coronary Arteries, Anatomical Variation, Coronary Dominance, Cadaveric study.

INTRODUCTION

The coronary arteries represent the terminal branches of the ascending aorta and are responsible for the entire arterial supply of the myocardium. Their unique anatomical architecture—arising from the aortic sinuses and coursing over the surface of the heart before penetrating the myocardium—renders them susceptible to a wide spectrum of morphological variations. These variations range from minor differences in ostial position and vessel calibre to significant anomalies in number, origin, course, and termination.[1]

The clinical importance of coronary arterial anatomy has grown considerably with advances in interventional cardiology and cardiac surgery. Coronary artery anomalies (CAAs) are identified in approximately 0.3–5.6% of patients undergoing coronary angiography, and their accurate delineation is essential before procedures such as percutaneous coronary intervention (PCI), coronary artery bypass grafting (CABG), and transcatheter aortic valve replacement (TAVR).[2]

Coronary dominance—defined by which artery gives rise to the posterior descending artery (PDA) and the atrioventricular nodal branch—determines the extent of myocardial territory at risk during acute coronary syndromes. Right dominance is the most common pattern globally, though its reported prevalence varies between 80% and 93% across different ethnic populations.[3,4]

Myocardial bridging (MB), a phenomenon in which a segment of a coronary artery courses through the myocardium rather than the epicardial fat, has been associated with exercise-induced ischaemia, arrhythmias, and even sudden cardiac death. Its prevalence in cadaveric studies is substantially higher than in angiographic series, owing to the compression of intramural vessels that occurs only during systole.[5,6]

The branching pattern of the left coronary artery (LCA) is particularly variable. While bifurcation into the left anterior descending (LAD) and left circumflex (LCx) arteries is the classic description, trifurcation with the addition of a ramus intermedius (RI) is present in a significant minority and creates an important variant relevant to percutaneous bifurcation treatment.[7,8]

Despite the clinical significance of these variations, there remains a paucity of systematic cadaveric data from the Indian subcontinent. The majority of large-scale studies have been conducted using coronary computed tomographic angiography (CCTA) or conventional angiography in Western or East Asian populations, and findings may not be fully applicable to Indian patients owing to differences in body habitus, cardiac dimensions, and coronary artery disease risk profiles.[9,10]

Regional cadaveric anatomical studies are therefore invaluable. Macroscopic dissection allows direct visualisation and measurement of coronary vessels without the limitations imposed by image resolution, cardiac motion artefact, or contrast medium distribution. Several Indian cadaveric studies have reported unique findings, including higher rates of certain branching patterns, that have not been replicated in imaging-based studies from other populations.[11,12]

The present study was undertaken with the objective of systematically documenting the number, origin, course, dominance pattern, branching morphology, and prevalence of myocardial bridging of coronary arteries in a cohort of formalin-fixed adult human cadavers at a tertiary medical institution in southern India. The findings are compared with published cadaveric and angiographic studies to contextualise the observations within the broader literature.

MATERIALS AND METHODS

This was a cross-sectional observational cadaveric study conducted in the Department of Anatomy, of Rajarajeswari Medical College and Hospital, Bengaluru, Karnataka, India. This cadaveric study was performed over a period of two academic years.

A total of 64 formalin-fixed adult human cadavers were included. Cadavers of indeterminate age, those with prior cardiac surgery, evidence of trauma to the thorax, or advanced autolysis precluding adequate dissection were excluded. Age and sex data were recorded from the cadaver register where available.

A standard anterior thoracotomy was performed. The pericardium was opened and the heart was examined in situ before removal. The aortic root was opened to identify the coronary ostia and the aortic sinuses from which they arose. The coronary arteries were then dissected along their entire epicardial course. Myocardial incisions were made where intramural segments were suspected. Gross measurements of coronary vessels' length and branching points and patterns were recorded using a calibrated digital Vernier calliper.

The following parameters were systematically recorded for each specimen: (i) total number of coronary arteries arising from the aorta; (ii) site of origin of the RCA and LCA relative to the aortic sinuses; (iii) coronary dominance pattern, defined as right, left, or co-dominant based on the origin of the posterior descending artery and posterolateral branches; (iv) branching pattern of the LCA (bifurcation versus trifurcation); (v) presence, location, and length of myocardial bridges; and (vi) notable course variations of the RCA and LAD.

Data was entered into Microsoft Excel and analysed using SPSS version 23.0. Continuous variables were expressed as mean ± standard deviation (SD). Categorical variables were expressed as frequency and percentage. The chi-square test was applied to compare proportions between the present study and published studies. A p-value of < 0.05 was considered statistically significant.

Inclusion Criteria:

- Formalin-fixed adult human cadavers available in the Department of Anatomy
- Cadavers of both sexes (male and female)
- Cadavers with intact thoracic cage allowing adequate dissection
- Cadavers with hearts suitable for macroscopic coronary artery dissection

Exclusion Criteria:

- Cadavers of indeterminate or unknown age
- Cadavers with history of prior cardiac surgery

- Evidence of trauma to the thorax or chest wall
- Advanced autolysis precluding adequate dissection
- Cadavers with gross congenital cardiac defects noted on initial examination
- Cadavers with heavily calcified or fibrosed coronary vessels that prevented accurate dissection

RESULTS

A total of 64 formalin-fixed adult human cadavers were studied. The sample comprised 42 males (65.6%) and 22 females (34.4%), with ages ranging from 35 to 78 years and a mean age of 54.2 ± 11.4 years (Table 1).

Table 1. Demographic characteristics of the cadavers studied (n = 64)

Parameter	n	Percentage (%)
Total cadavers	64	100
Male cadavers	42	65.6
Female cadavers	22	34.4
Age range (years)	35–78	—
Mean age ± SD (years)	54.2 ± 11.4	—

Two coronary arteries were identified in 56 cadavers (87.5%), representing the normal pattern. Three coronary arteries were observed in 8 cadavers (12.5%), where the third vessel represented a separate ostium for the ramus intermedius artery (Table 2).

Table 2. Number of coronary arteries observed (n = 64)

Number of Coronary Arteries	n	Percentage (%)
Two coronary arteries (normal)	56	87.5
Three coronary arteries	8	12.5
Total	**64**	**100**

All 64 cadavers demonstrated a normal origin of the RCA from the right aortic sinus and the LCA from the left aortic sinus. No anomalous ostial origin was identified in any specimen. In 8 cadavers (12.5%) with a third coronary artery, a separate ostium for the ramus intermedius was identified within the left aortic sinus (Table 3).

Table 3. Origin of the coronary arteries from the aortic sinuses (n = 64)

Origin	n	Percentage (%)
RCA from Right Aortic Sinus	64	100
RCA from Left Aortic Sinus (anomalous)	0	0
LCA from Left Aortic Sinus	64	100
LCA from Right Aortic Sinus (anomalous)	0	0
Separate ostia for LAD and LCx	8	12.5

Right coronary dominance was the predominant pattern, observed in 58 cadavers (90.6%). Left dominance was present in 4 cadavers (6.3%) and co-dominance in 6 cadavers (9.4%) (Table 4).

Table 4. Coronary dominance pattern observed in the study (n = 64)

Dominance Type	n	Percentage (%)
Right dominance	58	90.6
Left dominance	4	6.3
Co-dominance	6	9.4
Total	**64**	**100**

Bifurcation of the LCA into LAD and LCx was the most frequent pattern. It was seen in 58 cadavers (90.6%). Trifurcation with a ramus intermedius was observed in 6 cadavers (9.4%). Among RCA branching patterns, a separate conus branch was identified in 18 cadavers (28.1%) and an atrioventricular nodal branch in 44 cadavers (68.8%) (Table 5).

Table 5. Branching pattern of the left and right coronary arteries (n = 64).

Branching Pattern	n	Percentage (%)
LCA bifurcation (LAD + LCx)	58	90.6
LCA trifurcation (LAD + LCx + RI)	6	9.4
RCA: gives PDA (right dominant)	58	90.6
RCA: gives Conus branch separately	18	28.1
RCA: gives AVRN branch	44	68.8

Myocardial bridging was identified in 8 cadavers (12.5%). The LAD was the most commonly involved vessel, affected in 6 cadavers (9.4%), followed by the LCx and RCA, each involved in 1 cadaver (1.6%). The mean length of the intramural segment over the LAD was 18.4 ± 4.2 mm (range: 12–26 mm) (Table 6).

Table 6. Prevalence and distribution of myocardial bridging in the cadavers studied (n = 64)

Parameter	n	Percentage (%)
Myocardial bridging (total)	8	12.5
MB over LAD	6	9.4
MB over LCx	1	1.6
MB over RCA	1	1.6

4. DISCUSSION

The coronary arterial tree exhibits considerable morphological diversity, and accurate knowledge of these variations is fundamental to safe and effective cardiac intervention. The present cadaveric study of 64 specimens from a southern Indian population adds to the growing body of regional data and corroborates several findings from both imaging-based and cadaveric studies published internationally.

The identification of three coronary arteries in 12.5% of cadavers in this study is consistent with the reported prevalence of a separate ramus intermedius ostium in the literature. The third coronary ostium typically represents independent origin of the ramus intermedius from the left aortic sinus and is rarely associated with haemodynamic significance; however, its recognition is important during aortic valve surgery and aortotomy to avoid inadvertent ostial injury. Dhobale MR[13] reported prevalence of third coronary artery to be 32% in a study of 150 cadavers. This prevalence is quite higher as compared to our study.

The universal origin of both the RCA from the right aortic sinus and the LCA from the left aortic sinus in our series (100%) reflects the normal anatomical pattern and is consistent with data from large angiographic registries. Yamanaka and Hobbs[14] analyzed 126,595 patients undergoing coronary arteriography and identified coronary artery anomalies in 1,686 patients (1.3% incidence). Of these, 1,461 (87%) had anomalies of origin and distribution, while 225 (13%) had coronary artery fistulae. The absence of anomalous origins in our sample is likely to be due to the modest sample size rather than a genuine regional difference.

Right coronary dominance in 90.6% of our cadavers is slightly higher than the pooled estimate of approximately 85% in Western literature but is concordant with findings from Indian cadaveric studies. Nerantziz CE et al[15] reported right dominance in 89 % of 200 cadavers, and a large CCTA study by Kosar et al.[16] observed 76 % right dominance in a Turkish population. The modest excess of right dominance in South Asian populations may reflect both genetic predisposition and methodological differences in defining co-dominance, which is a continuum rather than a discrete category. The co-dominance rate of 9.4% in our study deserves comment. Co-dominance is defined variably in the literature, with some authors requiring equal contribution of the RCA and LCx to the crux and posterior interventricular groove while others accept any balanced pattern. This definitional variability partly accounts for the wide reported range of co-dominance patterns. The relatively high co-dominance rate in our series may reflect a liberal definition applied during dissection, and future studies using standardised criteria would be valuable.

Trifurcation of the LCA, with the ramus intermedius interposed between the LAD and LCx, was present in 9.4% of our cadavers. This figure is comparable with the 7–20% prevalence reported in published cadaveric and angiographic series. The ramus intermedius supplies the anterolateral wall of the left ventricle and, when sizeable, represents an important vessel that must be separately protected during coronary artery bypass surgery. In the context of percutaneous coronary intervention, a trifurcation left main stem disease requires a different approach to bifurcation stenting than the standard two-vessel configuration, and pre-procedural imaging is advisable.[17]

Myocardial bridging was identified in 12.5% of our cadavers, with predominant involvement of the LAD (9.4%). This is broadly consistent with cadaveric studies that report MB prevalence of 5–86%, a range that reflects methodological heterogeneity including depth of serial sectioning, definition thresholds, and whether deep or superficial bridges are counted. The prevalence in angiographic series is substantially lower (0.5–5%) because only dynamically obstructive bridges produce the characteristic systolic narrowing.[18]

The mean bridged segment length of 18.4 mm over the LAD in our series is within the range of 10–30 mm reported by Reig and Petit[19] and is clinically significant, as longer bridges are more likely to produce haemodynamically relevant obstruction. Although MB is generally considered a benign incidental finding, it has been associated with exercise-induced ST changes, inappropriate sinus tachycardia, and—in rare cases—acute myocardial infarction. Surgical unroofing or beta-blockade therapy is recommended for symptomatic patients refractory to medical management.

Several limitations of this study merit acknowledgement. First, the sample size of 64 cadavers is relatively modest, which limits the statistical power to detect rare anomalies and the precision of prevalence estimates. Second, formalin fixation alters vessel wall compliance and may obscure subtle dynamic variations. Third, the absence of histological examination means that the depth and completeness of myocardial bridges could not be fully characterised. Fourth, sex-specific analyses were underpowered given the unequal sex distribution. Future studies with larger cadaveric cohorts, standardised dissection protocols, and histological correlation are recommended.

Despite these limitations, this study provides a systematic morphological baseline for the coronary arterial anatomy in an under-represented South Indian population. The findings have direct relevance to the pre-operative planning of cardiac procedures and to undergraduate and postgraduate anatomy education at institutions serving this demographic.

5. CONCLUSION

This cadaveric study of 64 specimens demonstrated significant morphological variability in the coronary arterial system, including a 12.5% prevalence of a third coronary artery, 9.4% co-dominance, 9.4% LCA trifurcation, and 12.5% myocardial bridging. All specimens demonstrated normal ostial origin of both coronary arteries. Right coronary dominance was the predominant pattern (90.6%). These findings are broadly consistent with published cadaveric and angiographic literature and contribute regional anatomical data from southern India. Awareness of coronary anatomical variations is essential for cardiac surgeons, interventional cardiologists, and imaging specialists, and may help reduce procedural complications and improve patient outcomes during coronary interventions.

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