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A morphometric anatomical study of the right coronary artery in Vietnamese

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SUMMARY

Coronary artery disease (CAD) is a major cause of death and disability in developed countries, and incidence of CAD is increasing annually in the underdeveloped world. Today, percutaneous coronary intervention plays a major role both in diagnosis and treatment of CAD. As a result, an understanding of the anatomy of the coronary artery system is vital cardiologists. Yet, studies are lacking that focus on Vietnamese hearts. The objective of this study was to examine the morphometric anatomical variation of the right coronary artery (RCA) in Vietnamese cadavers. The hearts from 125 cadavers were used in the study. In all hearts, the RCA originated from the right aortic sinus, had a right marginal branch, and gave rise to one to three right posterior ventricular (RPV) branches. In 96.8% of hearts, the posterior interventricular branch (PIV) originated from the RCA; in 3.2% from the left circumflex artery (LCX), and the mean diameter was 2.09 mm ± 0.62 mm. The RCA had a mean diameter and length of 4.21 mm ± 0.64 mm and 122.5 mm ± 17.8 mm, respectively, and terminated between the crux and left border (72%) and at the crux (14.4%). The origin of the sinoatrial node artery was 81.6% from the RCA, 16.8% from the LCX, and 1.6% from both the RCA and LCX. There were one to four right atrial branches observed across the hearts studied; a maximum of 32% (one branch) and a minimum of 12.8% (four branches). In 68.8% of hearts the conus artery originated from the RCA. In 8.8%, it arose from the right aortic sinus at the same site as the RCA, but in 22.4% away from this site of origin. The RCA gave rise to one to eight right anterior ventricular (RAV) branches (i.e., because they are at the anterior surface of the right ventricular); with the highest incidence of 3 branches in 37.6% of hearts. The RCA gave rise to one to seven left posterior ventricular branches; the majority of cases, 28.8% gave rise to 4 branches. The rare incidence of myocardial bridging in the right coronary system occurred in 7.2% of hearts, and each case involved the posterior interventricular branch. Anatomical variations of the RCA system can cause difficulties in imaging interpretation and interventional procedures. This study is the first to document these variations of the RCA system in Vietnamese hearts, contributing knowledge that is essential for physicians.

Key words: Right Coronary artery – Circumflex artery – Anterior Interventricular artery – Intermediate branch – Conus artery – Crux

Abbreviations:
Atrioventricular (AV)
Cardiovascular Disease (CVD)

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Coronary Artery Disease (CAD)
Left Anterior Descending (Left Anterior Interventricular) Artery (LAD)
Left Circumflex Artery (LCX)
Left posterior interventricular (LPV)
Left ventricle (LV)
Myocardial bridge or Myocardial bridges (MB or MBs)
Percutaneous Coronary Intervention (PCI)
Posterior interventricular (PIV)
Posterior interventricular sulcus (PIS)
Right anterior ventricular (RAV)
Right Coronary Artery (RCA)
Right marginal (RM)
Right posterior ventricular (RPV)
Right ventricle (RV)
Sinoatrial (SA)
Standard Deviation (SD)

INTRODUCTON

The left coronary artery (LCA) originates from the left aortic sinus and bifurcates into the left anterior descending artery (LAD) and the left circumflex (LCX) (James, 1961; Patel, 2008; Guglielmo and Guttadauro, 1954; Tuncer, et al., 2006). The LAD lies within the anterior interventricular sulcus, and supplies blood to the anterior wall of the left ventricle and the interventricular septum. The LCX travels along the left coronary sulcus, supplies blood to left wall and diaphragmatic wall of the left ventricle. In some occasions, the LCX reaches the crux to supply the atrioventricular (AV) node and the posterior interventricular (PIV) artery.

The right coronary artery (RCA) originates from the right aortic sinus, and as it emerges from its ostium it lies deep in the epicardial fat between the pulmonary conus and the right atrium. Covered by fat, the RCA travels deep in the right AV sulcus (or right coronary sulcus). According to Angelini et al. (1989), Patel (2008) and James (1961; 1965), the RCA follows a course along the right coronary sulcus to reach the right border of the heart at the minimum.

From a strict perspective, the anatomical morphology of the RCA is divided into three segments: (1) the proximal segment that begins at the origin and ends at the right border of the heart; (2) the middle segment that continues from the right border of the heart and ends at the crux; and (3) the distal segment that begins at the crux and ends at the termination point of the RCA, and including the segment that passes through the intersection (Gatzoulis, 2008; James, 1961; James, 1965; Kaku et al., 1996). However, clinicians accurately describe lesion (i.e., plaque) location, differently by dividing the RCA into (1) proximal (Prox RCA) that extends from the right coronary ostium up to and including the first (anterior) right ventricular (RV) branch; (2) mid (Med RCA) that courses from the anterior RV branch to and including the origin of the acute marginal branch; and (3) distal (Dist RCA) that begins at the level of the acute marginal branch and extends through the bifurcation of the posterior descending artery to the distal RCA continuation (Fiss, 2007; Austen et al., 1975). In order from proximal to distal, the branches of the RCA are the conus artery, right atrial branches, right ventricular branches, posterior interventricular branch, AV node branches, and left ventricular branches. The posterior interventricular branch will give rise to septal branches.

The conus artery (infundibular artery, adipose artery, third coronary artery, arteria of Vieussens), when present, takes a semicircular course away from the RCA on the epicardial anterior surface of the right ventricle at the level of the pulmonary valve (Fiss, 2007; Morgan, 2012; Suminoto et al., 1992). It terminates in multiple, small twig-like branches near the superior aspect of the anterior interventricular sulcus, but does not reach the right border of the heart; giving branches to the anterior wall of the right ventricle (Angelini, 1989).

Right atrial branches vary in number, size, and location (Fiss, 2007; Patel, 2008; Guglielmo and Guttadauro, 1954). Right atrial branches are named according to their origin from the RCA as it travels downward in the atrioventricular sulcus (anterior, marginal/intermediate, or posterior) and are usually small in caliber (Baptista et al., 1987). The main atrial branch (or artery) is usually the atrial branch that terminates in the sinoatrial (SA) node, known as the SA node artery. During its course, it gives off branches to both atria and penetrates into the interatrial septum. The artery terminates by partially or completely encircling the lower portion of the superior vena cava, giving off branches called the ramus cristae terminalis, which terminate in the SA node (Anderson, et al., 1979).

The right ventricular branches of the RCA take a looping course as they emerge from the AV sulcus at nearly right angles from the RCA and course over the anterior, marginal, and posterior surface of the right ventricle. The anterior and marginal right ventricular branches usually run a parallel course over the right ventricular surface. The posterior right ventricular branches are usually small and vary in number.

The inferior aspect of the interventricular septum is supplied by the posterior descending artery (James, 1961; Fiss, 2007; Patel, 2008). This artery usually arises as a branch or continuation of the RCA, where the AV sulcus meets the interventricular sulcus (the crux) on the posterior surface of the heart. The posterior descending artery courses along the posterior aspect of the interventricular sulcus toward the apex. Arising from the posterior descending artery, a variable number of branches penetrate upward into the inferior portion of the interventricular septum.

The artery to the AV node usually arises from the

RCA and less frequently from the LCX, depending on which artery crosses the crux. The RCA (or LCX), as it courses in the AV sulcus, makes a U-shaped bend at the crux around the posterior interventricular vein by penetrating within the myocardium and emerging again on the other side of the vein. The AV nodal artery arises from the apex of the U-turn and takes a straight course 2 or 3 cm cephalad, terminating in right angle branches to the AV node.

The left ventricular branches of the RCA are known as the posterolateral branches. These branches extend to the adjacent portion of the left ventricle and arise at right angles from the posterior descending artery. These branches traverse the interventricular septum and supply the inferior wall of the left ventricle.

Coronary artery disease (CAD) is a major cause of death and disability in developed countries (Roger, 2007; Nguyen and Talarico, 2018). CAD is the most common type of heart disease, and is the leading cause of death in the United States in both men and women (Medline Plus, 2017). Further, these trends are now documented in westernized cultures and other Third-World Countries including Vietnam (Sanchis-Gomar et al., 2016; Anbumani et al., 2016; Priyadharshini et al., 2016; Nguyen et al., 2012; 2014; Dang et al., 2011; VNHA, 2017). According to the Vietnam National Heart Association, 20% of the Vietnamese population suffers from coronary vascular disease (VHNA, 2017), and 16.3% of North Vietnamese suffer from CAD (VHNA, 2017; Dang, 2016). Decreased physical inactivity; obesity; nicotine abuse; bad nutrition practices and loss of traditional diet habits in new-industrial cultures, as well as social inequalities, are suggested as factors leading to an increase of prevalence in most countries (Sanchis-Gomar et al., 2016; Nguyen and Talarico, 2018).

Diagnostic technique and treatment for CAD also develop quite rapidly, and thus, specific features of the coronary artery (i.e., diameter, length, branching pattern, etc.) are vital in diagnosis and treatment of CAD, especially in percutaneous coronary intervention (PCI). Aside from one prior investigation (Nguyen and Talarico, 2018) that examined the size, distribution and branching patterns of the LCA in Vietnamese patients, there are no research data focused on the anatomical morphology of the RCA in Vietnamese. The present work eliminates this lack of information by investigating the morphometric features of the RCA in Vietnamese patients and comparing these data to the results in other studies of non-Vietnamese peoples in the published literature.

MATERIALS AND METHODS

Anatomical Donors and Preservation

This study was conducted on the hearts of 125 Vietnamese cadavers including 91 males and 34 females. These anatomical donors had been prepared for use in the formal course in human gross anatomy in the Department of Anatomy at the University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam. The age range of subjects in this cohort was 38 to 91 years with the average age of 65.1-years-old. Hearts were excluded from this cohort if the subject had previous heart disease or PCI. All guidelines were followed regarding the use and care of cadaveric materials, as well as all regulations set forth by the Vietnamese Anatomical Education Program. The embalming procedure was done as previously described (Nguyen and Talarico, 2018).

Dissection

Briefly, the pectoralis muscles were reflected, and the sternocleidomastoid muscle was detached from the superior margin of the sternum. Using a Striker saw, cuts were made bilateral at the midpoint of the clavicles and across the xiphisternal joint (at approximately the 5th intercostal space). Cuts were carried through the costal margin following the cure of the margin inferolateraly; then along the midaxillary line; gradually coursing superoanterioly through rib 1. Then, the anterior thoracic wall was lifted. The pericardium was open using two parallel transverse cuts, one just superior to the origin of the great vessels, and one near the diaphragm. Transverse cuts were connected by a midline, vertical incision, and the pericardium was reflected to expose the heart. The aorta, pulmonary artery, pulmonary veins, superior vena cava and inferior vena cava were cut 5 cm from the origin of the vessels, and the heart was removed and cleaned. Adipose tissue and any remnants of the pericardial sac were carefully dissected away to expose the coronary arteries and their branches. Following clear visualization and identification of all the coronary arteries and their branches, the heart was then washed with clean water.

Measurements

The origin and termination points, embranchment, and myocardial bridge(s) of the RCA system were observed. Using a caliper with a center distance attachment, measurements of the RCA circulation were taken, and the data was saved and evaluated using MircoSoft® Excel 2007. The following data were recorded: (1) size (length and diameter) of the RCA; (2) division of the RCA; (3) size of the branches of the RCA, and (4) the length and diameter of the right marginal (RM) and PIV branches. The length of myocardial bridges was also measured. In cases where vessels were curled, vessel length was measured by using a thread placed on the vessel running along its length, and then the thread was straightened and its length measured. Results were expressed as mean length (or diameter) in millimeters (mm) ± mm standard deviation (SD).

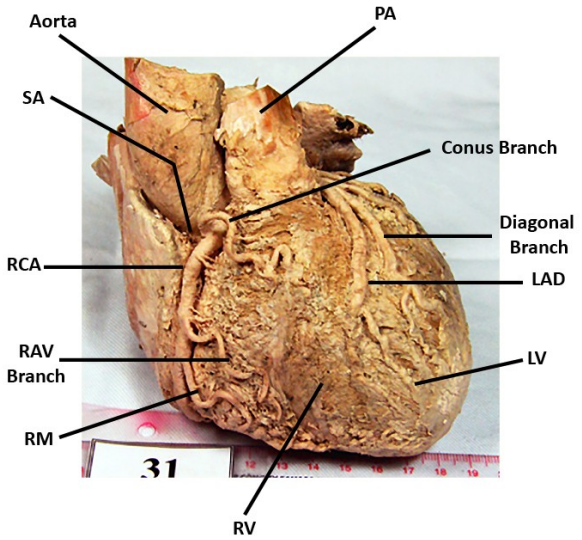

Fig 1. Branches of the Right Coronary Artery System. This cadaveric specimen, representative of Vietnamese hearts used in this study, shows the branches of the right coronary artery (RCA) system. The branching pattern of the RCA includes: the sinoatrial node artery; conus branch, right atrioventricular branch and the right marginal branch. The aorta, pulmonary artery, left anterior descending branch, and the left and right ventricles are also seen in this view. [Abbreviations: left anterior descending LAD); left ventricle (LV); pulmonary artery (PA); right atrioventricular (RAV); right coronary artery (RCA); right marginal (RM); right ventricle (RV); sino-atrial (SA)].

Photography

Digital photography of the external features of the right coronary circulation was done using a NIKON D7000 with a NIKKOR 18-105 mm/F3.5-5.6 optical lens (B&H Foto & Electronic Corporation, NY).

RESULTS

Origin of RCA

Of the 125 hearts examined in this study, all originated directly from the right aortic sinus.

Termination Point of the RCA

In this investigation, three landmarks were identified to describe the termination of the RCA. These landmarks are: (1) the right border of the heart, (2) the crux, and (3) the left border of the heart. Variation of termination point was documented being at these borders and adjoining regions with a maximum incidence of 72% between crux and left border; a second highest incidence of 14.4% at the crux, and a minimum incidence of 1.6% at the right border. These results are summarized in Table 1.

Size of the RCA: Diameter and Length

The diameter of the RCA measured at the origin ranged from 1.94 mm to 5.61 mm, with a mean of 4.21 mm ± 0.64 mm. More specifically, the mean diameter was 4.28 mm ± 0.60 mm in males and 4.03 mm ± 0.69 mm in females. There was a statistically significant difference of the mean diameter in males and females with a $p = 0.046$.

The length of the RCA was measured from the origin to the endpoint of the RCA in the coronary sulcus. The length ranged from 57.5 mm to 174 mm, with a mean of 122.5 mm ± 17.8 mm.

The RCA originates from the right coronary sinus and is divided into proximal (ostium to the right border), mid (the right border to crux), and distal (from the crux to the termination point of RCA) segments. In the present study, the size of these three segments varied. Of the 125 specimens examined, 102 specimens (81.6%) had all three segments; 21 specimens (16.8%) had the proximal and the middle segments; and 2 specimens (1.6%) only had the proximal segment as the RCA terminated at the right border of the heart. The diameter and length of these segments are summarized in Table 2.

Embranchment of the RCA

The branching pattern of arteries arising from the RCA was observed to be complex, and included variation in the (1) sinoatrial (SA) nodal artery; (2) right atrial branch; (3) conus branch; right anterior ventricular (RAV) branches; (4) right marginal (RM) branch; (5) right posterior ventricular (RPV) branches; (6) PIV branch; and (7) left posterior ventricular (LPV) branches (Fig. 1).

With respect to the anatomical origin of the SA node artery, 102 specimens (81.6%) had the SA nodal artery branching from the RCA (Fig. 1). In 21 specimens (16.8%), the SA node artery branched from the LCX. There were two specimens (1.6%) that had two SA node arteries in which one branched from the RCA and one branched from the LCX.

There were one to four right atrial branches observed across the 125 specimens studied. There

Table 1. Variation in the Termination Point of the Right Coronary Artery (RCA).

	Termination point of RCA					
	Right border	Between right border and crux	Crux	Between crux and Left border	Left border	Total
No. of Cases	2	3	18	90	12	125
Incidence (%)	1.6%	2.4%	14.4%	72%	9.6%	100%

Table 2. Diameter and Length of the Three Segments of the Right Coronary Artery (RCA).

Size	RCA Segment		
	Proximal Segment	Medial Segment	Distal Segment
Mean Diameter (Min - Max)	4.21 mm ± 0.64 mm (1.94 – 5.61)	3.36 mm ± 0.57 mm (0.97 – 5.29)	2.37 mm ± 0.53 mm (1.04 – 4.35)
Mean Length (Min - Max)	64.41 mm ± 14.62 mm (32 – 127.8)	36.68 mm ± 11.68 mm (11 – 68.8)	25.19 mm ± 9.75 mm (2.9 – 56.7)

were 40 hearts (32%), 66 hearts (52.8%), 16 hearts (12.8%), and 3 hearts (2.4%) that had one right atrial branch, two right atrial branches, had three right atrial branches, and four right atrial branches, respectively.

The conus branch may originate from RCA or directly from the right aortic sinus. In the present study, 86 specimens (68.8%) had the conus branch originating from the RCA (Fig. 1). There were 11 specimens (8.8%) in which the conus branch originated directly from the right aortic sinus and at the same location with the origin of the RCA, whereas 28 specimens (22.4%) had the conus branch originating directly from the right aortic sinus and at a location different from that of the RCA.

The RCA gave rise to one to eight RAV branches (Fig. 1). In one rare occasion (0.8%), the RCA did not have any RAV branches. The majority of cases (37.6%) had 3 RAV branches, with the second-highest incidence of 27.2% having 4 RAV branches. The number of right anterior ventricular branches and incidence are summarized in Table 3.

The RM branch is also called acute marginal branch (Fig. 1). All 125 specimens had the RM branch. In 121 specimens (96.8%), the RM branch started branching out before the RCA reached the right heart border. In 4 specimens (3.2%), the RM branch started branching out at the right border of the heart. The diameter of the RM branch was from 0.79 mm to 2.8 mm, with a mean of 1.60 mm ± 0.42 mm.

Table 3. Right Anterior Ventricular (RAV) Branches Arising from the Right Coronary Artery.

Number of RAV Branches	0	1	2	3	4	5	6	7	8
Cases	1	5	20	47	34	11	4	1	2
Incidence (%)	0.8	4	16	37.6	27.2	8.8	3.2	0.8	1.6

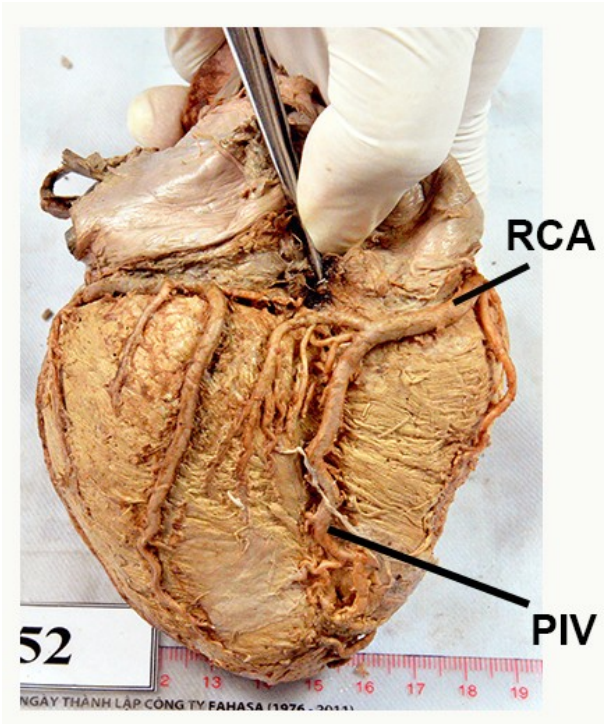

Fig 2. Posterior Interventricular Branch. In this posterior view of the heart, the right coronary artery gives rise to the posterior interventricular branch that course through the posterior interventricular sulcus and septum. [Abbreviations: posterior interventricular (PIV); right coronary artery (RCA)].

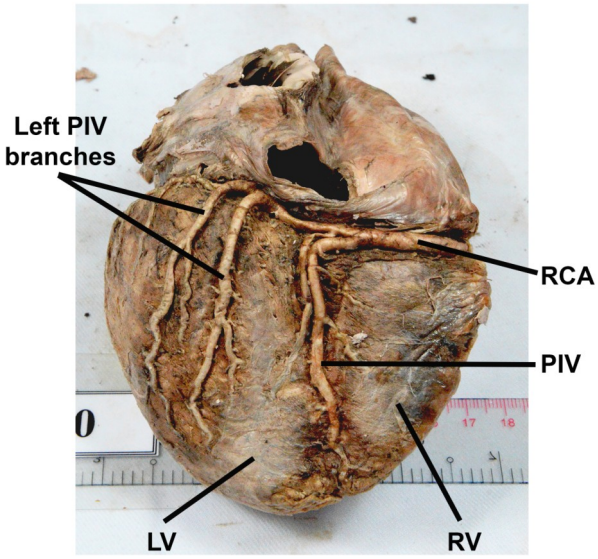

Fig 3. Left Posterior Ventricular Branches of the Right Coronary Artery System. In this posterior view of the heart, the right coronary artery gives rise to the posterior interventricular branch, and then terminates in multiple left posterior interventricular branches. The posterior interventricular artery (showing right-side dominance), and the left and right ventricles are also observed. [Abbreviations: left posterior ventricular (LPV); left ventricle (LV); posterior interventricular (PIV); right coronary artery (RCA); right ventricle (RV)].

Table 4. Variation in number of Right Posterior Ventricular (RPV) Branches from the Right Coronary Artery.

Number of RPV Branches	1	2	3	4
Cases	11	67	37	10
Incidence (%)	8.8	53.6	29.6	0.8

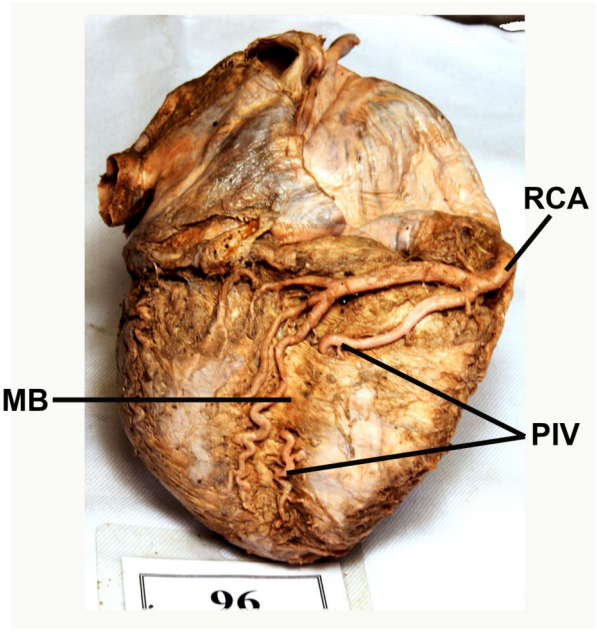

Fig 4. Myocardial Bridging in the Right Coronary Arterial System. This is a posterior view of a Vietnamese heart specimen showing a myocardial bridge of the posterior interventricular artery. Myocardial bridging is a congenital condition where a segment of epicardial coronary artery courses intramurally through the myocardium. The muscle overlying the intramyocardial segment of the artery is referred to as a myocardial bridge, and the artery coursing within the myocardium is called the tunneled artery. [Abbreviations: myocardial bridge (MB); posterior interventricular (PIV)].

In all 125 specimens, the RCA gave rise to one to four RPV branches (Fig. 2). A single RPV branch occurred in 11 cases (8.8%), two branches in 67 cases (53.6%), 3 branches in 37 cases (29.6%), and 4 branches in 10 cases (0.8%). These data are shown in Table 4.

In 121 specimens (96.8%), the PIV branch originated from the RCA (Fig. 4). In 4 specimens (3.2%), the PIV branch originated from the LCX. The diameter of the PIV branch ranged from 0.9 mm to 5.82 mm, with a mean of 2.09 mm ± 0.62 mm. In 11 specimens (8.8%), the termination point of the PIV branch was in the proximal one-third of the PIV sulcus. In 54 specimens (43.2%), the termination point of the PIV branch was in the middle one-third of the PIV sulcus. In 60 specimens (49.6%), the termination point of the PIV branch was in the distal one third of the PIV sulcus.

The LPV branches are also called posterolateral branches. In all 125 specimens, the RCA gave rise to one to seven LPV branches (Fig. 3). The number of LPV branches is shown in Table 5. The majority of cases, 36 (28.8%) and 34 (27.2%) gave rise to 4 and 3 LPV branches, respectively.

Table 5. Variation in number of Left Posterior Ventricular (LPV) Branches from the Right Coronary Artery.

Number of LPV Branches	1	2	3	4	5	6	7
Cases	8	11	34	36	25	7	4
Incidence (%)	6.4	8.8	27.2	28.8	20	5.6	3.2

Myocardial Bridges

In the RCA system, the overall incidence of myocardial bridges (MBs) in this study is 7.2% or 9 specimens of the 125 hearts that were examined (Fig. 4). In each case, the myocardial bridge (MB) was at the PIV branch. The mean length was determined to be 19.26 mm ± 9.28 mm (minimum length: 3 mm; maximum length: 33.3 mm). The depth of MBs was not measured in this study.

DISCUSSION

Along the path, the RCA gives rises to right atrial branch, SA node artery, conus branch, right anterior ventricular branches, RM branch (also called acute marginal branch), RPV branches, PIV branch and LPV branches. The SA node branch may originate from the LCX (James, 1961, 1965). The conus branch can originate directly from the right aortic sinus instead of the RCA, and in this instance it is sometimes referred to as the third coronary artery (Bhimalli et al., 2011; Edwards et al., 1981). The PIV branch usually originates from the RCA and terminates at the crux (James, 1961, 1965; Gugliemo and Guttadauro, 1954; Adams and Treasure, 1985). The LPV branches travel along the diaphragmatic wall, and they are also known as posterolateral branches (Angelini, 1989, 2007; Fiss, 2007).

Increasingly, diagnostic and interventional procedures such as coronary angiography; MRI and 3-dimentional computed tomography; angioplasty and stent placement, are done to assess, diagnose and treat CAD (Fazliogullari et al., 2010; Hamdan et al., 2011; Roy et al., 2014; Anbumani et al., 2016; Nguyen et al., 2012). For a successful coronary angiogram, correct interpretation of other diagnostic tests, and for therapeutic and/or interventional or surgical procedures to have positive outcomes, a thorough knowledge of the normal architecture and anatomical variants of the coronary arterial system is essential. This investigation addressed this issue by examining the anatomy of the right coronary vasculature in Vietnamese cadavers; and thus, filling a gap in current scientific reports.

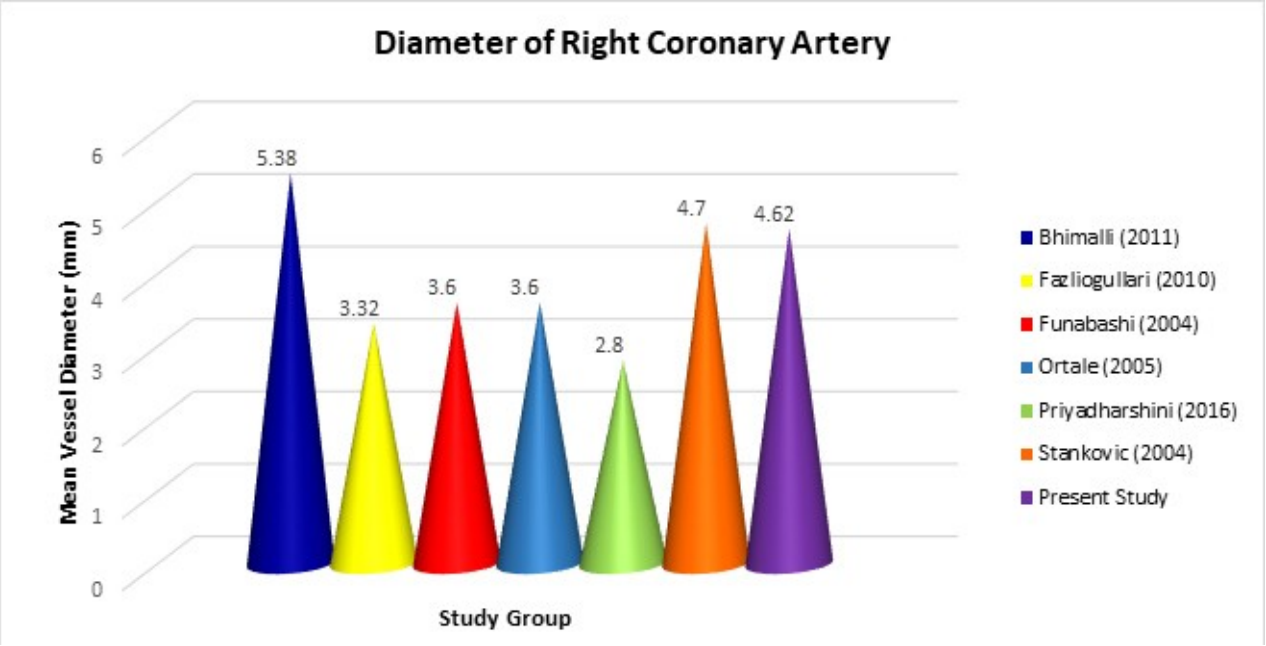

Fig 5. Diameter of the Right Coronary Artery. This diagram is a graphical comparison of the mean diameter of the right main coronary artery found in Vietnamese cadaveric specimens (purple) in the current investigation with the results of other studies.

In dissecting 125 hearts, the diameter of the RCA at its origin was measured to be 4.21 mm ± 0.64 mm. The maximum and minimum diameters were found to be 8.74 mm and 3.32 mm, respectively. These data are reasonable when compared to the results of studies done in other geographic and ethnic groups (Fig. 5) (Bhimalli et al., 2011; Fazliogullari et al., 2010; Funabashi et al., 2004; Ortale et al., 2005; Priyandharshini et al., 2016; and Stankovic and Jesic, 2004).

The length of the RCA was measure from the origin to the endpoint of the RCA in the coronary sulcus, and ranged from 57.5 mm to 174 mm, with a mean of 122.5 mm ± 17.8 mm.

The termination of the RCA determines the main blood supply to the heart and the coronary arterial dominance (James 1961, 1965; Das et al., 2010). When the RCA does not reach the crux, the diaphragmatic wall of the left ventricle and the AV node are supplied by the LCX and the heart is left-dominant. On the other hand, when the RCA reaches the crux or surpasses it, the RCA supplies the SA and AV nodes and the heart is right-dominant or balanced.

In this investigation, the landmarks identified to describe the termination of the RCA were the right border of the heart, the crux, and the left border of the heart. Variation of termination point was documented being at these borders and adjoining regions (i.e., right border, between right border and crux, the crux, between the crux and the left border, and at the left border). In this study, the termination of the RCA was at the right border in 2 cases (1.6%); between the right border and the crux in 3 cases (2.4%); at the crux in 18 cases (or 14.4%), and at the left border in 12 cases (or 9.6%). The highest incidence of termination was between the crux and the left border in 90 cases (72%). These results show no significant difference from prior studies from non-Vietnamese peoples (James, 1961; Baptista et al., 1987; Kalpana, 2003; Das et al., 2010; Bhimalli et al., 2011) (Fig. 6). However, there are some differences when the present and prior studies are compared to results from Ballesteros, et al. (2011) (Fig. 6). Similar to the present study, the highest incidence of RCA termination was between the crux and left border, and next at the crux. However, out of 221 hearts examined by Ballesteros et al. (2011), none had a termination of the RCA at the right border, and only 5 cases (2.2%) had a termination at the left border. The reason(s) for these differences in the Ballesteros study as compared the present work and the work of others (Fig. 6) is unclear.

There is normal anatomic variation with respect to the conus branch such that its origin may be the RCA or the aortic sinus. Critically, the conus branch is anastomosed to one branch of the LAD. As a result, the conus branch serves as an important connecting bridge between the RCA and the LCA (Edwards et al., 1981; Morgan, 2012). In 86 (68.8%) of 125 Vietnamese hearts examined, the conus branch originated from the RCA (Fig. 1 and Fig. 7). These data are comparable to those of other investigators (Fig. 7). However, the present work found variation in the site of origin of the conus branch away from the RCA. Specifically, in 11 (8.8%) Vietnamese hearts the conus branch originated from the right aortic sinus and at the same location as the ostium of the RCA. In contrast, for

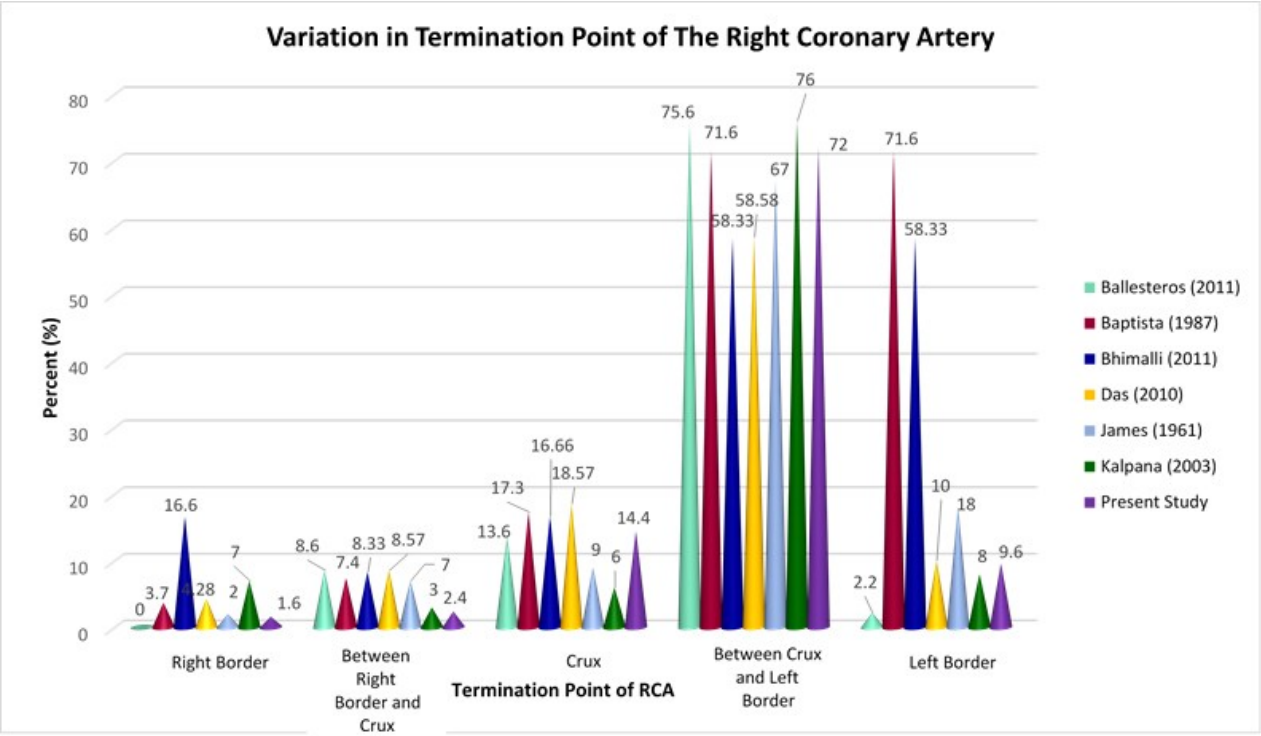

Fig 6. Variation in the Termination Point of Right Coronary Artery. There are five known anatomical variants for the terminus of the right coronary artery (RCA). These are: (1) the right border; (2) between the right border and the crux; (3) the crux; (4) between the crux and left boarder; (5) the left border. This graphical presentation shows a comparison of these termination points in the present study (i.e., percent of specimens with specific RCA termination points; purple) with those revealed by other investigators.

28 hearts (22.4%) the conus branch originated directly from the right aortic sinus, but at a different location from that of the ostium of the RCA. Thus, in the present study, 31.2% of the hearts examined showed an origin of the conus branch from the aorta (Fig. 7). These results are comparable to other studies, but there seems to be greater variation in the percentage of cases where the origin is from the aorta (Fig. 7), with the highest incidence of 64% (Fazliogulari et al., 2010) and the lowest of

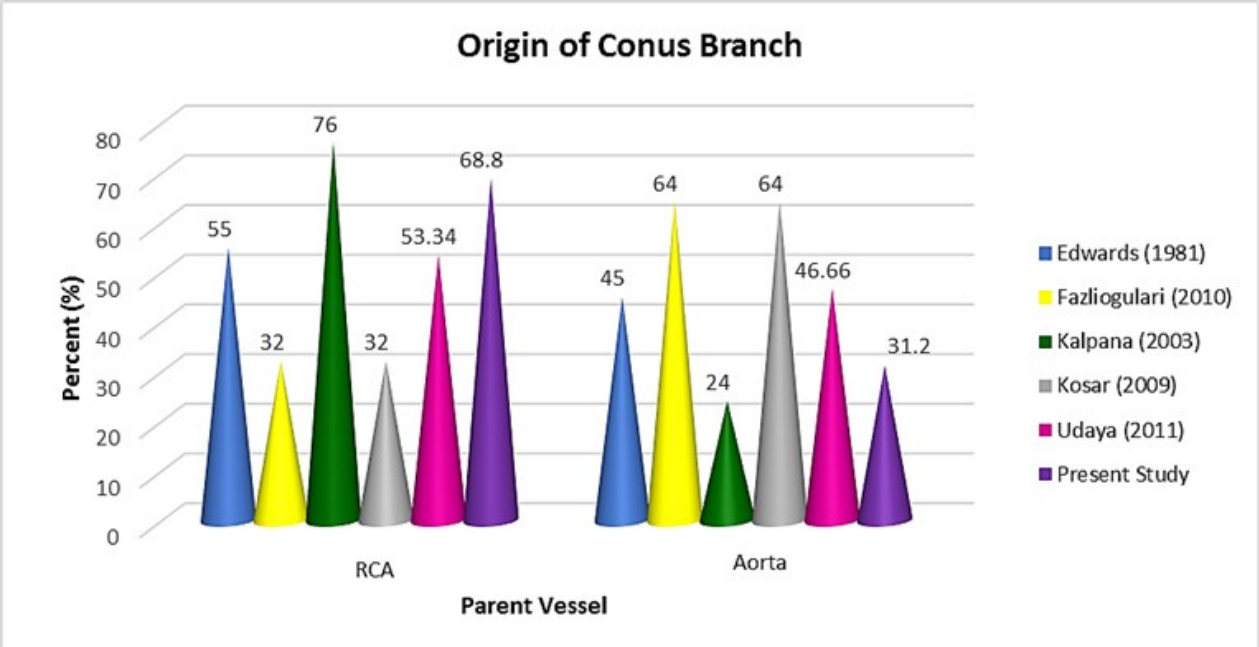

Fig 7. Variable Origin of Conus Branch. The conus branch is an essential anastomosis between the right and left coronary arteries. The origin of the conus branch may be the right coronary artery or the aorta (i.e., right aortic sinus at the same location of the right coronary artery ostium or at a distance away from the ostium). Here, the present results (purple) are shown in comparison to other investigators. [Abbreviations: right coronary artery (RCA)].

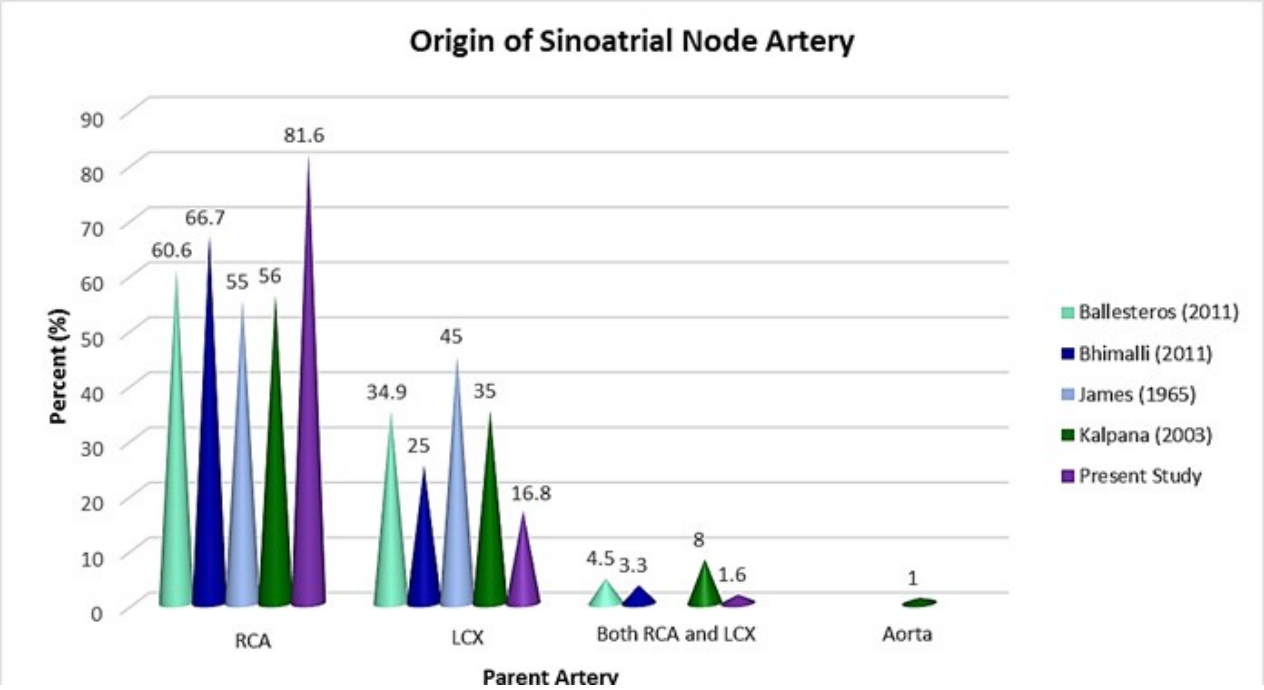

Fig 8. Origin of the Sinoatrial Node Artery. The sinoatrial nodal artery supplies the "pacemaker" of the heart. This critical blood supply has a variable origin of (1) the right coronary artery; (2) the left circumflex artery; (3) both the right coronary and left circumflex arteries; and (4) the aorta. This graphical presentation shows a comparison of these origination points in the present study (purple) with those revealed by other investigators. [Abbreviations: left circumflex artery (LCX); right coronary artery (RCA].

22% (Kosar et al., 2009). In these cases, the conus branch is called the third coronary artery.

The SA node artery can originate from the RCA or the LCX or both (i.e., in cases where there are two SA node arteries). However, the SA node artery, as well as the AV node artery, usually originates from the RCA because right-dominant heart is more common (James, 1961; Das et al., 2010). As a result, blockage of the RCA affects the blood supply to these two nodal arteries and has a high tendency to cause arrhythmia. Due to the fact that the origin of the SA node artery is close to the origin of the RCA, blockage at the proximal segment affects blood supply of the two nodal arteries and blockage at the medial or distal segments only affects the blood supply to the AV node artery. In this study, Vietnamese hearts showed the highest incidence (81.6%) of arising directly from the RCA (Fig. 1 and Fig. 8). In the 125 hearts dissected, there were no cases where the SA node artery originated from the aorta. In only 1.6% of hearts, the SA node artery arose from both the RCA and LCX. These data are comparable to those of other investigators (Fig. 8). However, it should be noted that Vietnamese hearts demonstrate at 15-27% increased incidence of the SA node artery arising from the RCA than those hearts examined in prior studies (James, 1965; Kalpana et al., 2003; Ballesteros et al., 2011; Bhimalli et al., 2011) (Fig. 8). Further work is needed to determine if this is significant and the clinical impact in patients that suffer from CAD.

The RM branch is one of the large branches of the RCA supplying blood to the right ventricle. This research shows that only 3.2% of the RM branches originated at the right border of the heart, and that 96.8% started branching off earlier, before the RCA reaches the right border of the heart. This is an important factor in clinical practice when an interventional cardiologist is attempting to find the origin of this branch and/or to thread guide wires or catheters. According to one prior study (Gatzoulis et al., 2008), 93% of the RM branches terminate at the apex of the heart. However, in this study of Vietnamese hearts, the results show that only 11% of the RM branches terminated at the apex of the heart and the remaining 88.8% terminated before that.

In the present study, the PIV branch originated from the LCX in only 3.2% of the specimens. This number is lower than results of other ethnic groups reported from other investigator (Kalpana et al., 2003; Ortale et al., 2004; Das et al., 2010; Fazliogullari et al., 2010; Ballesteros et al., 2011) (Fig. 9). The origin of the PIV branch carries anatomical and clinical significance in the connection of the RCA and the LCA in the interventricular sulcus or septum (Fig. 2). The anterior two-thirds of the interventricular septum is supplied by the anterior septal branches from the LAD. The posterior one-third of the interventricular septum is supplied by the posterior septal branches from the PIV artery. The anterior septal branches connect to the posterior septal branches inside the interventricular sep-

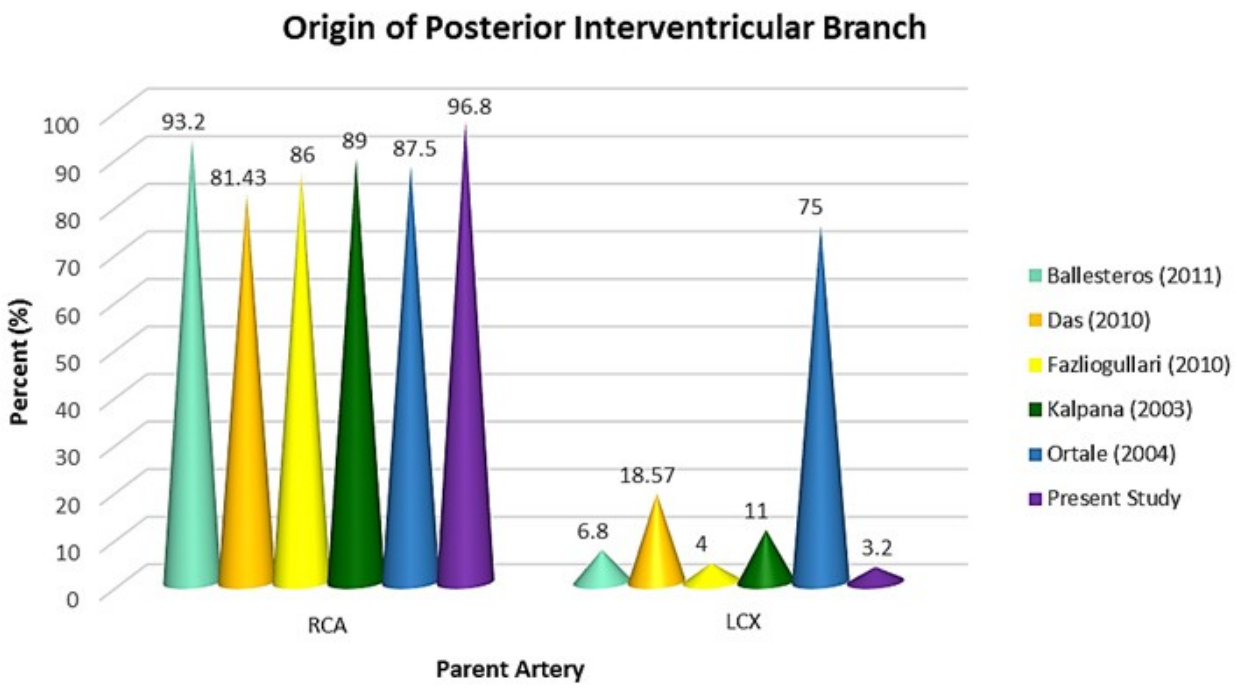

Fig 9. Origin of the Posterior Interventricular Branch. The origin of the posterior interventricular branch can be the right coronary artery or the left circumflex artery. This graphical presentation shows a comparison of these origination points in the present study (purple) with those revealed by other investigators. The lowest incidence of origin at the left circumflex artery is seen in the present work. In contrast, the results for the left circumflex by Ortale (2004) being highest as compared to other studies remains unclear. [Abbreviations: left circumflex artery (LCX); right coronary artery (RCA].

tum. When the PIV artery originates from the RCA, the connection between RCA and LCA exists. In contrast, when the PIV branch originates from the LCX, there is no connection between the RCA and the LCA. This can prove dangerous in situations where the LCA is completely blocked (Skandalakis, 2004).

Different from the LAD, the PIV branch is short and usually does not reach the end of the posterior interventricular sulcus (PIS). Fig. 10 shows the termination point of the PIV artery in the Vietnamese hearts examined in the present study and compares this to published data in Colombian people (Ballesteros et al., 2011). The results in Vietnamese hearts shows that in the majority of specimens the PIV artery terminated at the middle one-third or the distal one-third of the PIS, or 43.2% and 48%, respectively. This is comparable to the Colombian study. However, none of the specimens in the present work had the PIV artery travelling to the anterior interventricular sulcus as reported in Colombian research. This may be clinically significant, due to the fact that when the PIV artery does not travel to the end of the PIS, part of apex on the diaphragmatic side must be supplied by the LAD.

Myocardial bridging is a congenital condition where a segment of epicardial coronary artery courses intramurally through the myocardium. This coronary artery may dive into the myocardium for varying depths and lengths, and then reappear on the myocardial surface. The muscle overlying the intramyocardial segment of the artery is referred to as a myocardial bridge (MB), and the artery coursing within the myocardium is called the tunneled artery. While there are many reports of MB of the LCA (Angelini, 2007; Angelini et al., 1983; Saidi et al., 2002; 2010; Loukas et al., 2006; Hwange et al., 2010; Nguyen and Talarico, 2018), incidence of MB for the RCA are rarer (Chen et al., 2010; Zhang et al., 2016; Nguyen and Talarico, 2018). Still further, it has been documented that the presence of bridges appeared to be related to coronary dominance, especially in the left coronary circulation, where 66.6% of the hearts with bridges were left dominant vs. 24.6% that were right dominant (Loukas et al., 2006). Nguyen, et al. (2007) reported a single case of MB of the RCA in an 81-year-old woman that presented with chest pain of four hours' duration. Numerous manifestations for MB have been described including angina, myocardial infarction, arrhythmias and sudden death (Nguyen et al., 2007; Chen et al., 2010; Liu et al., 2010; Alegria, et al., 2005; Zhang, et al., 2016). The overall incidence of MBs in this study is 7.2%, or 9 specimens, of the 125 hearts, and in each case, the MB was at the PIV branch (Fig. 4). This may suggest a higher incidence of MB in the RCA system in the general population than these isolated, rare cases indicate, or a higher incidence specific

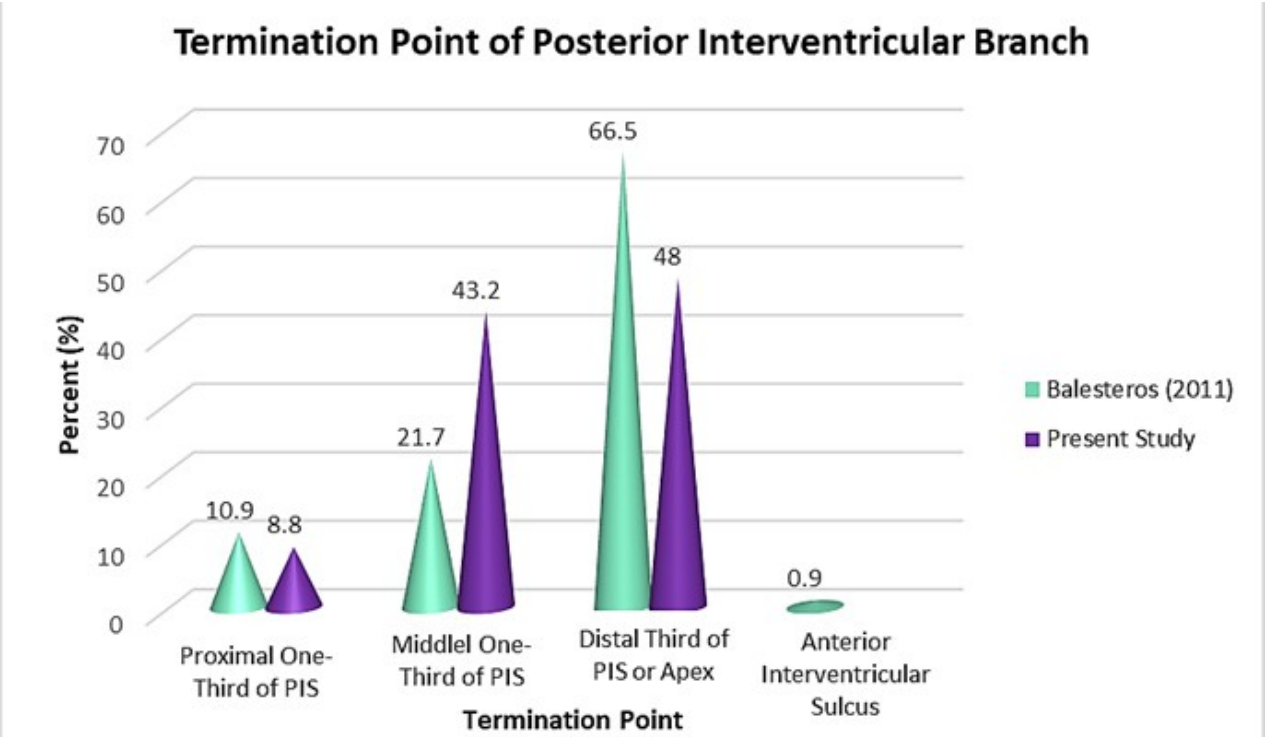

Fig 10. Termination Point of the Posterior Interventricular Branch. This graphical presentation shows a comparison of the termination points of the posterior interventricular branch in the present study (purple) with those of Ballesteros et al. (2011). The anatomic variation in termination point is: (1) the proximal one-third of the posterior interventricular sulcus (PIS); (2) the middle one-third of the PIS; (3) the distal third of the PIS or Apex; and (4) the anterior interventricular sulcus.

to Vietnamese. It is reasonable to suggest that further investigation into coronary vasospasm my reveal a higher incidence of bridging as a proximate cause (Liu et al., 2010).

CONCLUSION

This investigation addressed a deficiency in the scientific literature, namely a lack of data documenting morphometric variation of the RCA system in Vietnamese cadavers. The RCA originates from the right aortic sinus and gives rises to many branches supplying right atrium, right ventricle including SA node artery, conus branch, right anterior ventricular artery, RM branch, RPV branches, PIV branch and LPV branches. However, significant anatomical variation exists in the number of branches supplying the right and left ventricles. Even further, the present study found variation in the site of origin of the conus branch (i.e., the RCA or the aorta); and with a higher incidence of cases with origin from the aorta. Interestingly, this study also showed that Vietnamese hearts have a higher incidence of the SA node artery originating from the RCA than recorded by other investigators in studies focused on other populations. No Vietnamese hearts that were examined had the PIV artery travelling to the anterior interventricular sulcus as reported in other non-Asian populations. Finally, this research study suggests that Vietnamese hearts have a higher incidence of myocardial bridging in the RCA system, whereas only rare cases are reported in non-Vietnamese populations. These anatomical variations of the RCA system can cause confusion and difficulties in imaging interpretation (i.e., cardiac CT, ECG-gated cardiac MSCT, or coronary angiogram, etc.), and in interventional procedures such as PCI. Interventional cardiologists, radiologists and anatomy educators must have knowledge of individual and racial/ population variations in coronary arteries that is essential for the accurate diagnosis and the best treatment of CAD patients.

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