Original Article

Coronary artery anatomy in peri-crux cordis area on computed coronary tomography angiography

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Background: The peri-crux area is an anatomical structure of the heart. Unfortunately, important information on this area mainly derives from autopsy heart with a small, under-representative sample size, resulting in limited clinical applications. Furthermore, little has been done to standardize the definition of the peri-crux area on coronary computed tomography angiography (CCTA) images or to investigate coronary artery anatomy wherein potential values are attracting experienced inventional cardiologists in terms of the revascularization strategies. The current study aimed to identify the peri-crux cordis area and to observe coronary artery anatomical distributions in this area on CCTA.

Methods: A total of 1,006 consecutive patients undergoing CCTA exams were enrolled. We delineated the peri-crux cordis area based on the posterior interatrial sulcus, posterior interventricular sulcus (PIS), left and right posterior atrioventricular groove on the diaphragmatic surface of the heart. Then we observed the coronary artery distributions in the peri-crux cordis area in different sexes.

Results: We have defined the peri-crux cordis area according to the anatomical landmarks on the diaphragmatic surface of the heart on CCTA images. We have observed 8 coronary artery distributions in the peri-crux cordis area. Right dominance has 4 types (types 1–4); left, 1 type (type 0) and balanced, 3 types (types 5–7). Out of the 1,006 cases, the type 1 is commonest with 834 cases (82.9%). There are no statistically significant differences in terms of coronary dominances and coronary artery distributions in the peri-crux cordis area between sexes ($P>0.05$).

Conclusions: We have defined the peri-crux cordis area utilizing the anatomical landmarks of the heart on CCTA images, where 8 types of coronary artery distributions have been identified. The current study may provide interventional cardiologists with useful information on recognition of coronary artery dominance, use of collateral channels for revascularization of chronic total occluded lesions, and evaluation of prognosis in patients with coronary artery disease (CAD).

Keywords: Peri-crux cordis area; coronary computed tomography angiography (CCTA); coronary dominance; coronary artery distributions

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Introduction

The peri-crux cordis area, located on the diaphragmatic surface of the heart, is a 3-dimentional structure. It has been likened to a toppled pyramid, with the apex of the pyramid at the central fibrous body and its base at the epicardial reflection covering the fat pad at the crux of the heart (1). The pyramid-like structures exist because of the difference in the thickness of the walls of the atria and ventricles (2). The peri-crux area is an anatomical structure of the heart, where important blood vessels [e.g., atrial-ventricular nodal artery and posterior descending artery (PDA)], conduction bundles, and nerves distribute wherein (3). Electrophysiologists have long paid attention to the distribution of the conduction system in this area in the radiofrequency ablation procedure (4-6). Unfortunately, important information on this area mainly derives from autopsy heart with a small, under-representative sample size, resulting in limited clinical applications (3,7,8). Furthermore, little has been done to standardize the definition of the peri-crux area on coronary computed tomography angiography (CCTA) images or to investigate coronary artery anatomy wherein for potential values of the revascularization procedures or operations. A study on coronary artery distribution in the peri-crux area will be helpful to recognize coronary artery dominance, to identify the PDA and left or right posterolateral vessels (PLVs), and to retrograde recanalize the chronic total occluded lesions via the collateral channels.

With the improvement of image quality and diagnostic accuracy, CCTA has been widely used in the diagnosis of coronary artery disease (CAD) as the most accurate non-invasive cardiovascular examination (9-13). One of the strengths of CCTA lies in its ability to provide a three-dimensional visualization of the epicardial vessels (14). Thus, it provides us with a good method to study the coronary artery anatomic variation. We can clearly see the characteristics of coronary artery distribution in the peri-crux area and evaluate its dominance (15). Compared with studies using the autopsy heart, we easily get a relatively large sample size undergoing coronary CTA with a more stable and reliable result. The purpose of our study was to identify the peri-crux cordis area and the distribution types of coronary artery circulation in this area on the diaphragmatic surface of the heart on CCTA.

Methods

Study subjects

Study subjects included all the persons undergoing the CCTA exams visiting the Outpatients of Chest Pain of The First Affiliated Hospital of Soochow University between Jun 1st, 2015 and Nov 20th, 2015. The indications of CCTA included chest discomfort, abnormal electrocardiogram or echocardiogram for ruling out suspected CAD or known CAD for further diagnostic and therapeutic assessments. Exclusion criteria included loss of image data, incomplete image reconstruction, presence of occluded CAD, and history of coronary artery bypass surgery. All patient medical records were anonymized and de-identified. The institutional Review Board waived the need for informed consent before analysis as the nature of these data was retrospective. The current study conforms to the principles outlined in the Declaration of Helsinki (the ethical approval number is No. 2016SZYYLL00601).

CT acquisition

All the CCTA examinations were performed using 64-detecter scanners (SOMATOM Definition Flash, Siemens Healthcare, Forchheim, Germany). Data were acquired using the following parameters: 120 kV tube voltage, 350–450 mA tube current, 128×0.6 mm collimator width, pitch of 0.20–0.33 adapted to the heart rate, and 0.28 s gantry rotation time. A bolus of 55–60 mL contrast agents Visipaque 320 followed by injection of 40ml saline into the median antecubital vein at a flow rate of 5.0 mL/s using an automated power injector. A beta-blocker 25–50 mg was taken orally to control heart rate less than 65 if the heart rates were >70 beats per minute. In the absence of contraindications, nitroglycerin 0.5 mg was given sublingually before the CCTA. Contrast agent administration was controlled by a bolus tracking technique. A circular region of interest was selected in the descending aorta at the level of primary tracheal bifurcation. It scanned automatically if the threshold (100 HU) was reached and images acquisition started 6 s after reaching the threshold. CCTA images were reconstructed using filtered back projection at 0.75 mm slices in 0.5 mm intervals. Images were reconstructed at 40–80% of the cardiac cycle in increments of 5% and the radiation dose was 3.7–11.9 mSv.

All images were analyzed by two experienced radiologists on a three-dimensional work station (EBW) using multiplanar-reformatting (MPR), volume-rendering (VR), maximum intensity projection (MIP) and curved surface reconstruction (CPR) images.

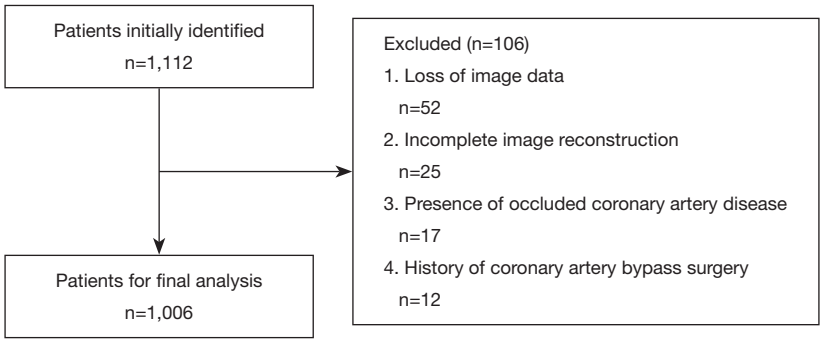

Figure 1 Flow diagram of patient enrollment.

Determination of coronary dominance

The coronary dominance was determined according to the origin of PDA regardless of the origin of the PLVs (16-18). The circulation was named right dominant if the PDA only arose from right coronary artery (RCA) while it was named left dominant if the PDA only arose from the left circumflex artery (LCX). If both LCX and RCA gave off PDAs, it was named balanced circulation.

Statistical analysis

We used frequency and percentage to describe categorical data. The different coronary dominance and coronary artery distributions in the peri-crux area between men and women were tested by χ^2 and Fisher's exact test. Statistical analyses were completed with STATA 13.0. Two-tailed $P<0.05$ was considered to be statistically significant.

Results

Study subjects

There were totally 1,112 consecutive patients undergoing the CCTA examinations, among whom, 106 were excluded according to the exclusion criteria. Thus, 1,006 patients, aged 58±12 years old, made up our study population with 590 males and 416 females. See the flow diagram in *Figure 1*.

Definition of peri-crux cordis area

We obtained 4 lines according to the anatomical marks on CCTA images: line 1 is the extension line of the upper boundary of the left atrioventricular groove towards the right atrium; line 2 is the extension line of lower boundary of the right atrioventricular groove towards the left ventricle; line 3 is the extension line of the left boundary of the posterior interatrial sulcus towards the left ventricle; and line 4 is the extension line of the right boundary of the posterior interventricular sulcus (PIS) towards the right atrium. These 4 lines intersect at 4 points (A, B, C, D) and form a quadrilateral region (*Figure 2*). The quadrilateral region in combination with the crux cordis pointing cephalad makes up a tetrahedron, which is referred to as the peri-crux cordis area defined in the current study.

Coronary dominance

In our study, the circulation was right dominant in 918 (91.25%), left dominant in 60 (5.96%), and the balanced dominant in 28 (2.78%). There were no statistically significant differences in different coronary dominances between sexes (*Table 1*).

Coronary artery distributions in peri-crux cordis area

We have observed 8 types of distributions of coronary artery circulation in the peri-crux cordis area on the diaphragmatic surface of the heart.

(I) In the left coronary artery dominance, only type of coronary artery distribution has been found in the peri-crux cordis area on the diaphragmatic surface of the heart (*Table 2*):
- ❖ Type 0: LCX courses in the left atrioventricular groove of the diaphragmatic surface of the heart, turns anteriorly in the peri-crux cordis area, and finally enters diagonally the PIS, usually without major branches crossing the PIS (*Figure 3*).

(II) In the RCA dominance, there were 4 types of coronary artery distribution in the peri-crux cordis

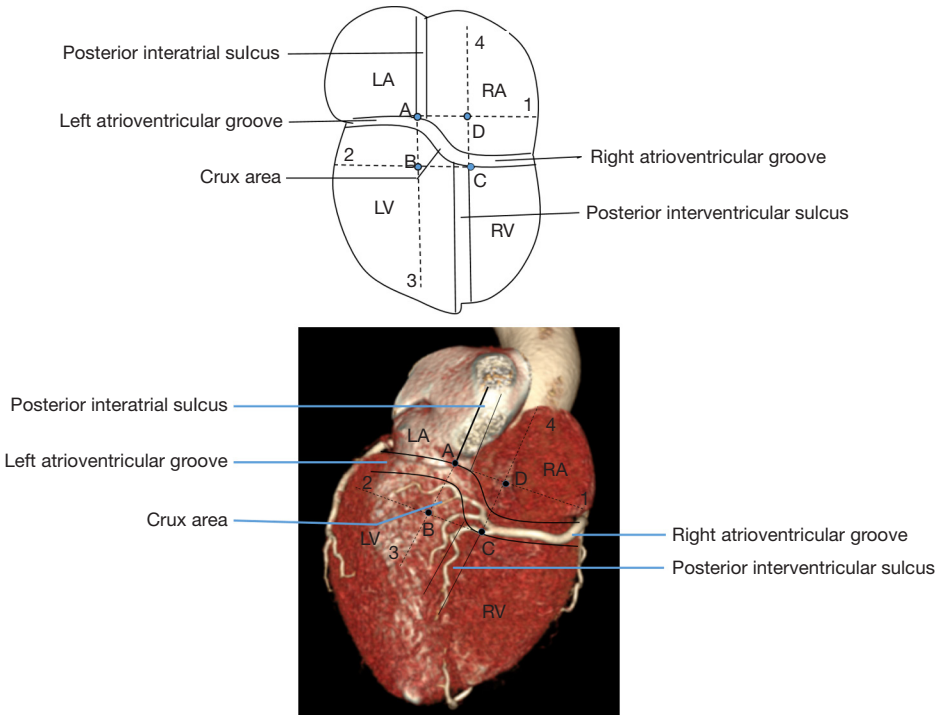

Figure 2 Definition of the peri-crux cordis area. LA, left atrium; RA, right atrium; LV, left ventricle; RV, right ventricle.

Table 1 Distribution of coronary artery dominance in sexes

Sex	Coronary artery dominance			
	Balanced	Left	Right	Total
Men, n (%)	21 (3.56)	37 (6.27)	532 (90.17)	590 [100]
Women, n (%)	7 (1.68)	23 (5.53)	386 (92.79)	416 [100]
Total, n (%)	28 (2.78)	60 (5.96)	918 (91.25)	1,006 [100]
P value	0.075	0.624	0.148	–

P values indicated comparisons of the same coronary artery dominance between different sexes.

Table 2 Coronary artery anatomy distributions in the peri-crux area in different dominances

Dominance	Coronary artery distributions								
	Type 0	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Total
Balanced, n (%)	0 (0)	0	0	0	0	22 (78.57)	5 (17.86)	1 (3.57)	28 [100]
Left, n (%)	60 (100.00)	0	0	0	0	0	0	0	60 [100]
Right, n (%)	0 (0)	834 (90.85)	62 (6.75)	21 (2.29)	1 (0.11)	0	0	0	918 [100]
Total, n (%)	60 (5.96)	834 (82.90)	62 (6.16)	21 (2.09)	1 (0.10)	22 (2.19)	5 (0.50)	1 (0.10)	1,006 [100]

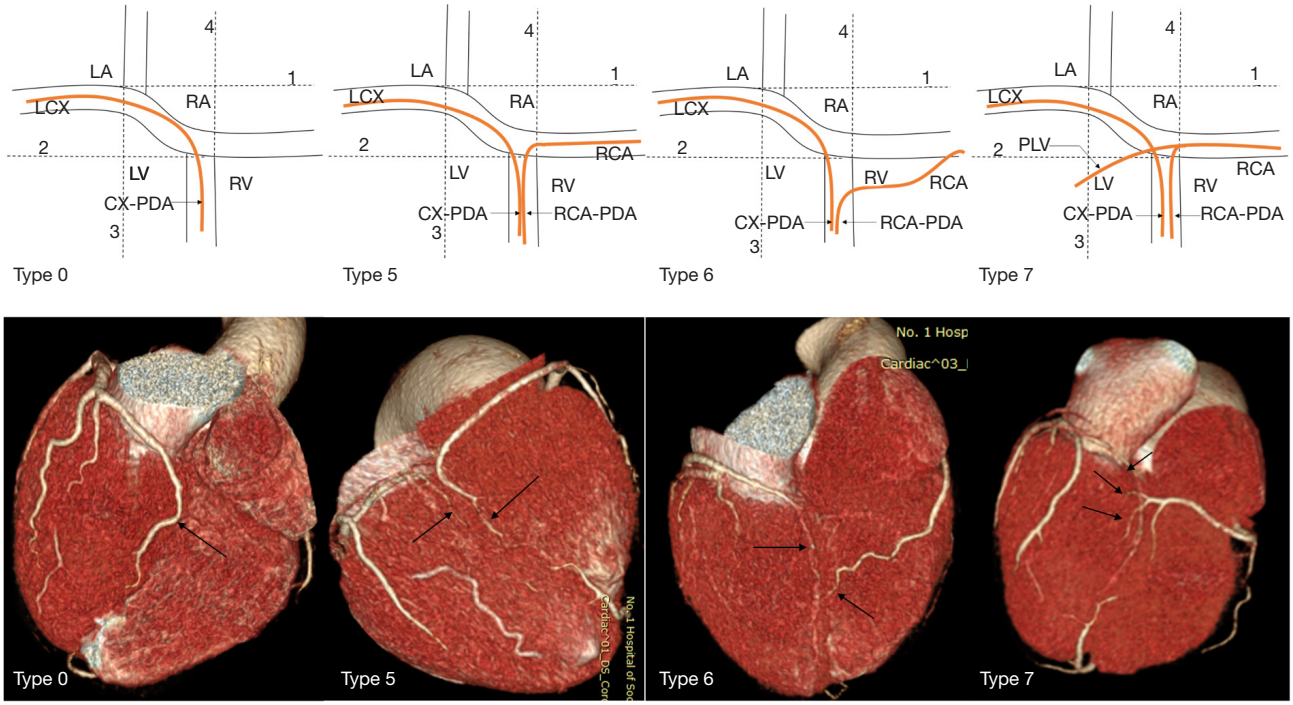

Figure 3 Coronary artery anatomy distributions in the peri-crux cordis area in the left or balanced dominant circulations. The sketch maps (upper row) and their corresponding coronary artery distributions in peri-crux cordis area on volume-rendered CCTA images (lower row). Blood vessels indicated by black arrows on the CCTA images correspond to those in the sketch maps (brown). CCTA, coronary computed tomography angiography; LA, left atrium; RA, right atrium; LV, left ventricle; RV, right ventricle; LCX, left circumflex artery; RCA, right coronary artery; PLV, posterolateral vessels; CX-PDA, posterior descending artery from left circumflex artery; RCA-PDA, posterior descending artery from right coronary artery.

area of the diaphragmatic surface of the heart (*Table 2*):

- Type 1: RCA courses in the right atrioventricular groove of the diaphragmatic surface of the heart, turns cephalad and/or towards left atrium in the peri-crux cordis area, where branches off the RCA either run in the left atrioventricular groove or on the left diaphragmatic surface of the heart after crossing the PIS, and the distal RCA finally runs in the PIS (*Figure 4*).
- Type 2: RCA courses along the right atrioventricular groove of the diaphragmatic surface of the heart to the peri-crux cordis area, where the RCA, without turning cephalad and/or towards left atrium or the turning trend, runs in the PIS with one or more branch(es) running on the left diaphragmatic surface of the heart after crossing the PIS (*Figure 4*).
- Type 3: RCA courses in the right atrioventricular groove of the diaphragmatic surface of the heart, turns anteriorly at the crux level and finally runs in the PIS, usually without major branches crossing the PIS (*Figure 4*).
- Type 4: RCA neither courses in the right atrioventricular groove of the diaphragmatic surface of the heart nor reaches the peri-crux area. This artery, however, turns around the acute margin and runs on the diaphragmatic surface of the heart, and finally courses in the PIS, usually without major branches crossing the PIS (*Figure 4*).

(III) In the balanced-dominance, there were 3 types of coronary artery distribution in the peri-crux cordis area of the diaphragmatic surface of the heart (*Table 2*):

- Type 5: LCX courses in the left atrioventricular groove of the diaphragmatic surface of the heart, turns anteriorly in the peri-crux area, and finally runs in the PIS. Correspondingly, RCA courses in the right atrioventricular groove of the diaphragmatic surface of the

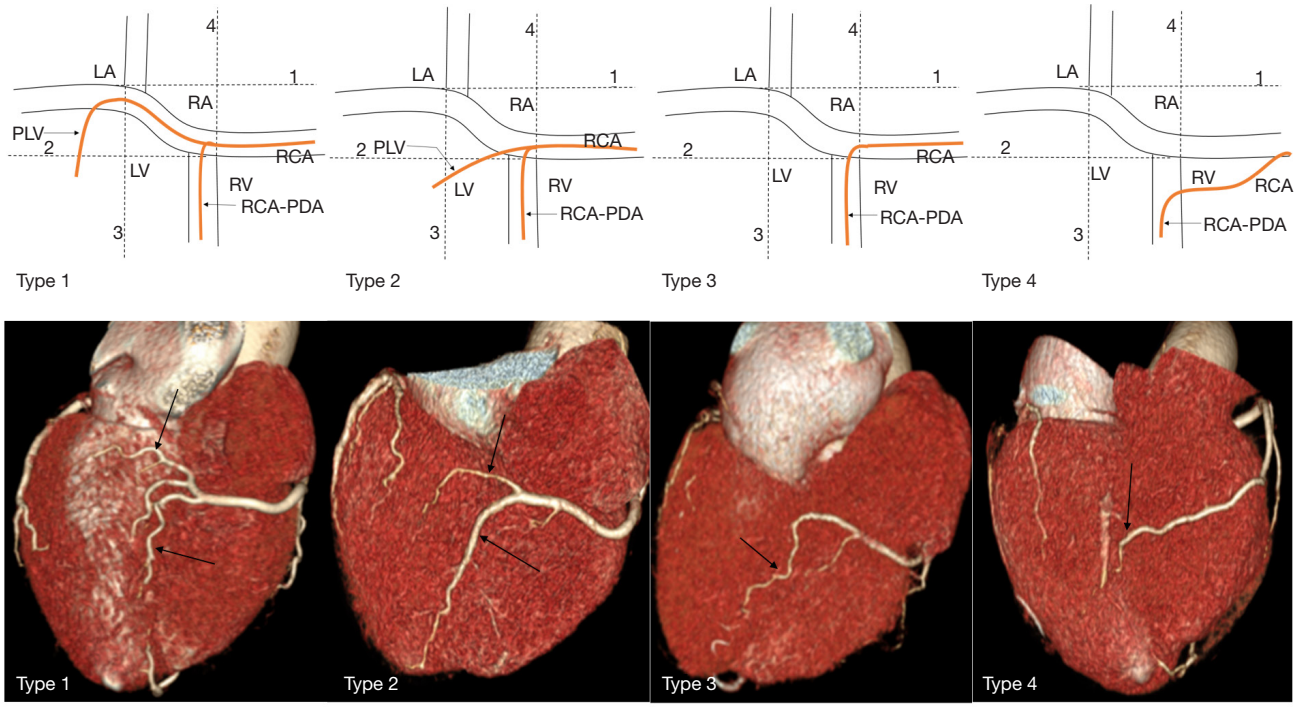

Figure 4 Coronary artery anatomy distributions in the peri-crux area in the right dominant circulation. Blood vessels indicated by black arrows on the CCTA images correspond to those in the sketch maps (brown). CCTA, coronary computed tomography angiography; LA, left atrium; RA, right atrium; LV, left ventricle; RV, right ventricle; RCA, right coronary artery; PLV, posterolateral vessels; RCA-PDA, posterior descending artery from right coronary artery.

heart, turns anteriorly in the per-crux area and finally runs in the PIS (*Figure 3*).

- Type 6: LCX courses in the left atrioventricular groove of the diaphragmatic surface of the heart, turns anteriorly in the peri-crux area, and finally runs in the PIS. RCA, however, neither courses in the right atrioventricular groove of the diaphragmatic surface of the heart nor enters the peri-crux area. This artery turns around the acute margin, runs on the diaphragmatic surface of the heart, and finally courses in the PIS (*Figure 3*).
- Type 7: LCX courses in the left atrioventricular groove of the diaphragmatic surface of the heart, turns anteriorly in the peri-crux area, and finally runs in the PIS, usually without major branches crossing the PIS. RCA courses in the right atrioventricular groove of the diaphragmatic surface of the heart, turns anteriorly in the per-crux area and finally runs in the PIS, with definite branches crossing the PIS (*Figure 3*).

Coronary artery distributions in the peri-crux cordis area in men and women

According to the different sexes, we recorded the frequencies of coronary artery distributions and calculated the percentages. There were 590 men and 416 women in total 1,006 cases. Type 1, the most frequent one, accounted for 83.22% in men, and for 82.45% in women. We did not detect statistically significant differences in terms of 8 types of coronary artery distribution in men and women (*Table 3*).

Discussion

The current study has defined the peri-crux cordis area on CCTA images, where 8 types of coronary artery distribution have been revealed. There have been no significant differences in terms of 8 types of coronary artery distribution in the peri-crux cordis area regarding sexes.

The peri-crux cordis area

The nomenclature on the crux area has been inconsistent

Table 3 Coronary artery anatomy distributions in the peri-crux area in different sexes

Sex	Coronary artery distributions								
	Type 0	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Total
Women, n (%)	23 (5.53)	343 (82.45)	33 (7.93)	9 (2.16)	1 (0.24)	5 (1.2)	2 (0.48)	0 (0)	416 [100]
Men, n (%)	37 (6.72)	491 (83.22)	29 (4.92)	12 (2.03)	0 (0)	17 (2.88)	3 (0.51)	1 (0.17)	590 [100]
Total, n (%)	60 (5.96)	834 (82.90)	62 (6.16)	21 (2.09)	1 (0.10)	22 (2.19)	5 (0.50)	1 (0.10)	1,006 [100]
P value	0.642	0.750	0.062	0.887	0.414	0.073	0.659	0.586	–

P values indicated comparisons of the same distribution of coronary artery anatomy between different sexes.

till now. Some scholars have named it Koch triangle while others, posterior septal space or atrioventricular groove crux area (19-21). Previous studies have proposed that the upper boundary of the crux area is the Eustachian ridge or sinus septum, the lower boundary is the septal leaflets of tricuspid valve, the basal is the orifice of coronary sinus, and the apex is the right fiber triangle (22). These nomenclatures on the crux area are based on the anatomical structures recognized on the autopsy heart. Limited sample size and clinical applicability have to be reconsidered. In this study, we proposed a new method identifying the crux area based on the different levels between the left and the right atrioventricular groove, and between the PIS and the posterior interatrial groove, in which these anatomical landmarks were easily recognized on CCTA images. This definition of the crux area proposed is simple and easy to operate, and can be easily applied to clinical research.

Coronary artery dominance

Different criteria for the classification of coronary artery dominance result in different results. Schlesinger first proposed the coronary circulation dominance according to both the origin of the PDA and PLVs (23). However, another study pointed out that it did not include all the coronary artery distributions (24). We thus in the current study determined the coronary artery dominance only according to the origin of the PDA (24-26). In our study, right dominance is with 918 cases (91.2%); left, with 60 (6.0%); and the balanced, with 28 (2.8%), which are consistent with a previous study conducted using the same classification criterion (right dominance with 87.1%, left, with 9.5%, and balanced, with 3.4%) (26). However, Schlesinger revealed a far different finding from ours with the right dominance of 48%; the left, 18%; and the balanced, 34% (23).

Coronary artery distributions in the peri-crux cordis area

In the current study, we recorded 8 types of coronary artery distribution in the peri-crux cordis area.

In the left dominance, there has been only type (type 0) of coronary artery distribution in the peri-crux cordis area. LCX, after giving off the PDA, usually no longer gives off a major branch to supply right ventricle. The distal LCX, also the largest one, running in the PIS, is almost definitely the PDA. These findings have suggested unilateral coronary angiography (CAG) (e.g., CAG conducted on a daily basis) could identify the PDA, and further identify the peri-crux cordis area and the PIS in the left dominance.

In the right dominance, there have been 4 types of coronary artery distribution in the peri-crux cordis area, among which, the type 1 is commonest with 834 cases, accounting for 91%. In the type 1, RCA relatively consistently turns cephalad and/or towards left atrium in the peri-crux cordis area in an overwhelming majority of individuals. It is in accordance with the anatomical description of the peri-crux cordis area on volume-rendered CTA images, which is a tetrahedron with 4 boundaries and the crux cordis pointing cephalad defined in the current study. Type 2 is with 62 cases, accounting for 6.75%. Although there are obviously visible branches in this type supplying the left diaphragmatic surface of the heart after crossing the PIS, they are small in size relative to the large PDA consistently originating from the peri-crux cordis area. Type 3 is with 21 cases, accounting for 2.29%, in which, RCA only consistently gives off one large PDA, with no obvious branches running in left diaphragmatic surface of the heart any more. Type 4 is extremely rarely seen, with only 1 case in the current study. The difference between this type and other 3 types in right dominance is that RCA runs on the right diaphragmatic surface of the heart rather than in the right atrioventricular groove and turns around and runs in the PIS. Actually, type 4 is similar to type 3

in terms of the coronary artery distribution except the coursing of the RCA in the right heart. Therefore, we think type 4 is most likely to be as a result of cardiac geometry changes or vascular distortions caused by a long-term overload. Whether it is reasonable to treat the type 4 as an independent one warrants further studies conducted with a larger sample size. These findings have suggested that the peri-crux cordis area and PDA are easily recognized on unilateral CAG in right dominance.

In the balanced dominance, there have been 3 types of coronary artery distribution in the peri-crux cordis area, among which the type 5 is most common with 22 cases (2.19%). What they have in common in the balanced dominance is the PIS has been supplied by both RCA and LCX (double PDAs). The coursing of the PDA off RCA is similar to the type 3 while the coursing of the PDA off LCX is similar to the type 0. In the type 6, the PDA off RCA runs on the right diaphragmatic surface of the heart rather than in the right atrioventricular groove while the PDA off LCX runs similarly as in the type 0. In the current study, we reported 5 cases of type 6. These both types of coronary artery distributions (type 5 and type 6) in the peri-crux cordis area were easily identified on the CCTA images. However, based on the characteristics of the RCA coursing, the crux cordis and PIS were only recognized on unilateral CAG in the type 5, but not in the type 6. Unfortunately, whether or when LCX enters the PIS is unrecognizable in both type 5 and type 6. The type 7 is also a type of balanced dominance and its coronary artery distribution in the peri-crux cordis area is similar to that of the type 5. The uniqueness of the type 7 is major branches off RCA, after crossing the PIS, supplying blood flow for the left diaphragmatic surface of the heart, namely, overlapping blood supply for one heart territory by RCA and LCX. The type 7 is rarely seen with only 1 case. Repeat reconstruction of the CCTA images by another experienced radiologist for this type confirmed the presence of the overlapping blood supply without technical problems. We think the type 7 may be a variant, and its physiological and pathological significances remain unclear, which warrants further studies. In the type 7, the peri-crux cordis area and the PIS could be easily recognized on the unilateral CAG as RCA usually gives rise to the PDA in the peri-crux cordis area, but whether or when the LCX enters the PIS remains unknown.

In sum, coronary artery distribution in the peri-crux area is relatively constant despite of its great variability in the whole heart surface.

Limitations

The current study focused on the southern Chinese, and we should be cautious when we extrapolated our findings to other ethnic population. Whether the characteristics of coronary artery anatomy over the peri-crux area differed in different ethnics warrants further study.

Conclusions

In the current study, we have delineated the peri-crux cordis area taking advantage of anatomical landmarks of the heart on CCTA images, where 8 types of coronary artery distribution have been identified. Our study provides a definition of the peri-crux cordis area on CCTA images, which may standardize clinical studies on CCTA images and facilitate comparison among different studies. In addition, our study also provides interventional cardiologists with useful information on recognition of coronary artery dominance, use of collateral channels for revascularization of chronic total occluded lesions, and evaluation of prognosis in patients with CAD.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

Ethical Statement: The current study conforms to the principles outlined in the Declaration of Helsinki (No. 2016SZYYLL00601). The institutional Review Board waived the need for informed consent before analysis as the nature of these data was retrospective.

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