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# A coronary computed tomography angiography study on anatomical characteristics of the diagonal branch of anterior interventricular artery

D.-Q. Zhang[1, 2], Y.-F. Xu[2], Y.-P. Dong[2], S.-J. Yu[1, 2]

[1]*Hebei Medical University, Shijiazhuang, China*
[2]*Department of Diagnostic CT, Cangzhou Central Hospital, Cangzhou, China*

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*Background:* *This study investigated the anatomical characteristics of the ramus intermedius (RI) and its correlation with the proximal diameter of the branch vessels of the left coronary artery (LCA) using coronary computed tomography angiography (CCTA).*

*Materials and methods:* *We screened patients who underwent CCTA from January to September 2021 and randomly enrolled 267 with RI (RI group) and 134 without RI (control group). We evaluated the anatomical features of RI (distribution, proximal diameter, length). We measured the proximal diameter of the anterior interventricular branch of the left coronary artery (LAD) and the circumflex branch of the left coronary artery (LCX). We compared the differences between groups in the proximal diameter of LAD and LCX and the correlation between gender and each parameter of the LCA (LAD, LCX, RI) within the RI group. In addition, we compared the correlation between the distribution characteristics of RI and the proximal diameter of LAD and LCX within the RI group.*

*Results:* *The LAD and LCX proximal diameters in the RI group were significantly smaller than those in the control group ($p < 0.05$). Comparisons within the RI group showed the following results: the RI distribution, RI diameter and length, and the LCX proximal diameter were not significantly different between male and female patients ($p > 0.05$), and the LAD proximal diameter was significantly larger in male than in female patients ($p < 0.05$). There were statistically significant differences in the LAD and LCX proximal diameters between the different RI distribution groups ($p < 0.05$). Based on the pairwise comparison, there were significant differences in the LAD (LCX) proximal diameter between the RI-beside--the-LAD (LCX) group and the RI-middle group, as well as between the RI-beside--the-LAD (LCX) group and the RI-beside-the-LCX (LAD) group ($p < 0.05$).*

*Conclusions:* *A CCTA accurately evaluated the anatomical characteristics of an RI, which has an impact on the proximal diameter of the branch vessels of the LCA (i.e. LAD and LCX), the degree of influence of which is correlated with the RI distribution.* (Folia Morphol 2023; 82, 4: 822–829)

**Key words: ramus intermedius, bifurcation angle, coronary computed tomography angiography**

Address for correspondence: S.-J. Yu, BM, Department of Diagnostic CT, Cangzhou Central Hospital, No.16 of Xinhua West Road, Canal District, Cangzhou 061000, China, tel: +86 18531705788, e-mail: 20204202@stu.hebmu.edu.cn

## INTRODUCTION

The anatomical structure of the left main bifurcation area is an important factor impacting the haemodynamics of this condition, atherosclerosis, collateral damage, choice of interventional therapy, and clinical prognosis [4, 6, 12, 16]. Studies have shown that the size of the anterior interventricular branch of the left coronary artery (LAD)-circumflex branch of the left coronary artery (LCX) bifurcation angle is positively correlated with arteriosclerosis in the bifurcation area [2, 14]. The occurrence and development of coronary heart disease are subject to the proximal vessel diameter of the bifurcation part of the left coronary artery (LCA), and scholars have conducted the following corresponding mathematical modelling [8]. Liu et al. [11] measured the proximal diameter of left bifurcation in patients with a predominant right coronary artery and no ramus intermedius (RI). The results showed that the proximal diameter of the LAD was 3.48 ± 0.77 mm, and the proximal diameter of the LCX was 3.21 ± 1.07 mm. The RI is a coronary artery branch originating from the end of the left main coronary artery (LM) between the LAD and LCX. The emergence of an RI will change the anatomical structure of the original left main bifurcation area, splitting the bifurcation angle into two parts and dividing the LCA blood flow into three parts, which may cause changes in the diameter of the LAD and LCX and cause abnormal haemodynamics. No specific studies on RI were found as part of the current study's literature review. The purpose of this study was to explore the anatomical characteristics of an RI, and the correlation of its presence and location with the proximal diameter of the branch vessel of LCA using coronary computed tomography angiography (CCTA), and then provide guidance for the study of the influencing factors of atherosclerosis in the left main bifurcation area and the decision of interventional treatment.

## MATERIALS AND METHODS

### Participants

A total of 4,866 patients who underwent CCTA examinations in Cangzhou Central Hospital from January 1, 2021, to September 1, 2021, were selected as the study participants. Among them, 1,202 patients were identified as having an RI from the Picture Archiving and Communication System (PACS). After calculating the detection rate, 267 patients were included according to the exclusion criteria (outlined later in this section). These included 138 males with an average age of 54.05 ± 0.97 years and 129 females with an average age of 56.98 ± 0.87 years. In addition, 500 participants were randomly selected from the 3,664 patients without an RI using a computerized random number generator, and, among them, 134 patients were added to the control group according to the exclusion criteria (so that the sample size met the statistical requirements). This included 69 males with an average age of 50.14 ± 11.54 years and 69 females with an average age of 55.06 ± 9.67 years. The inclusion criteria comprised patients who underwent a CCTA examination in the authors' hospital and had complete clinical and imaging data. The exclusion criteria were as follows: 1) patients with metal implants (i.e. a stent or pacemaker); 2) patients with a history of coronary artery bypass surgery; 3) patients with organic heart disease (including heart valve implantations); 4) patients with a coronary artery anomaly (such as the abnormal origin of a coronary artery [coronary arteriovenous fistula]); 5) patients with poor CCTA image quality, or a missing image; 6) patients with a mural coronary artery (LAD, LCX, RI ≥ 1); 7) patients without a predominant right coronary artery; 8) patients with non-single RIs (excluding those without an RI); 9) patients with at least one diffuse plaque at the bifurcation part of the LCA.

### Examination methods

All patients fasted for more than 4 h before the examination and were treated with an intravenous indwelling needle. All patients had their heart rate measured via an electrocardiogram and took part in breath-hold respiratory training; those with a higher heart rate were given beta-blockers to stabilise and control the heart rate within 74 bpm.

A Toshiba Aquiline ONE 320-slice computed tomography scanner was used to image and post-process all of the participants. Each patient was placed in a supine position with their feet entering the scanner first, and with their arms extended straight over their head. Three leads were placed at the bilateral subclavian region of the left ribs and lower margins to monitor heart rate changes in real-time. Scanning was performed on the patient in a single end-inspiratory hold.

The scanning range was determined to range from the lower tracheal bifurcation to the diaphragm according to anteroposterior and lateral images, which included the entire heart with a range of 140–160 mm. A non-ionic contrast medium (Iohexol, 60–65 mL)

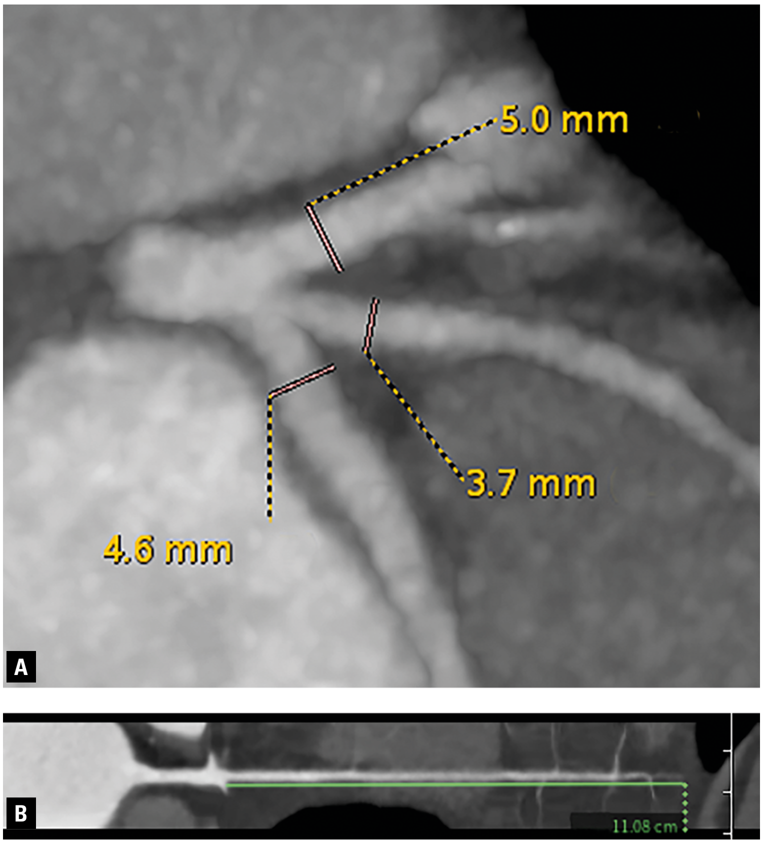


**Figure 1. A.** Diameter measurement; **B.** Ramus intermedius length measurement.

was injected at a flow rate of 4.5–5.0 mL/s with a Mallinckrodt dual-chamber high-pressure syringe, and the flow rate and volume were adjusted according to the body weight and vascular condition of the patient. Then, 40 mL of normal saline was injected at the same flow rate. Monitoring began 10 s after the injection of the contrast medium to observe the time-density curve.

The left ventricle was selected as the monitoring area for manual triggering with a trigger threshold of 150 Hounsfield Unit (HU). The scanning parameters were a tube voltage of 120 kV, a scanning slice thickness and incremental increase of 0.5 mm, and a scanning speed of 0.35 s. All the scans were performed in an intracardiac tube current using autoregulation mode to reduce the radiation dose.

### Image post-processing and measurement

The optimal diastolic images were selected and uploaded to the Shukun CCTA image vascular stenosis analysis software and a General Electric AW4.6 workstation for post-processing to generate the two-dimensional (2D) and three-dimensional (3D) reconstruction images. The maximum diameters (including the tube wall) of the proximal LAD, LCX, and RI (1 cm from the bifurcation) were measured on the 2D oblique map (window level = 40 HU, window width = 400 HU, Fig. 1A). The 2D curved planar reconstruction was selected for length measurement (Fig. 1B), with the length of the RI measured from the initial part of the RI to the visible end.

The distribution judgment of the RI was conducted based on the 3D volume rendering (Fig. 2). The RI distribution was divided into three types according to the boundary of the line from the initial part to the cardiac apex: 1) the beside-the-LAD-group (Fig. 2A); 2) the middle group (Fig. 2B); 3) the beside-the-LCX--group (Fig. 2C).

### Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki (as was revised in 2013). The study was approved by Ethics Committee of the Cangzhou Central Hospital. Written informed consent was obtained from all participants.

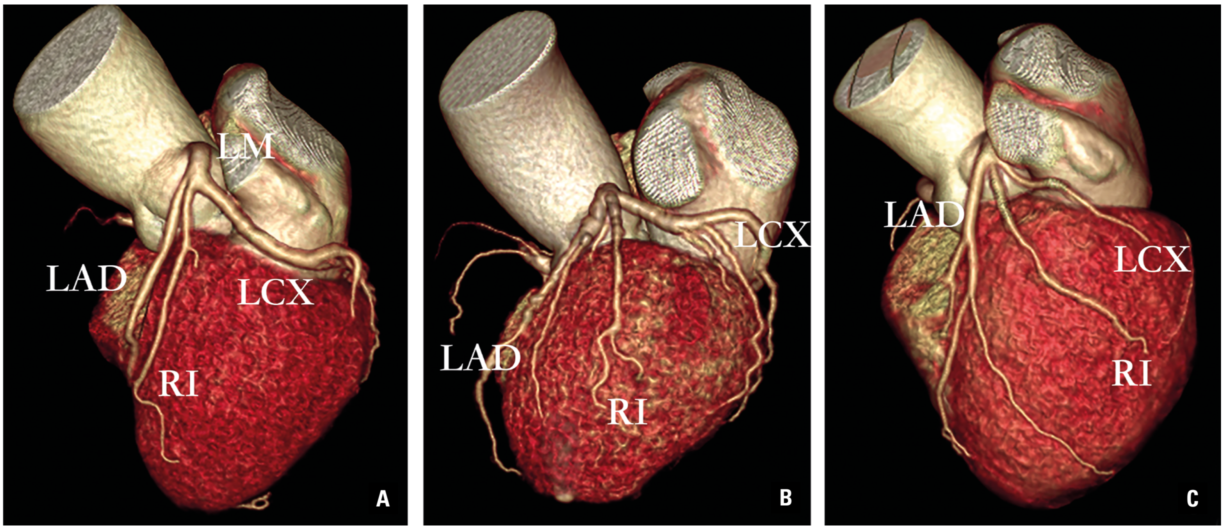


**Figure 2.** Distribution of ramus intermedius (RI); **A.** Ramus intermedius is close to the anterior interventricular branch of the left coronary artery (LAD); **B.** Ramus intermedius is located in the centre; **C.** Ramus intermedius is close to the circumflex branch of the left coronary artery (LCX); LM — left main coronary artery.

### Statistical analysis

All data were statistically analysed using the SPSS Statistics 26.0 software programme. The measurement data were expressed as mean ± standard deviation (x ± SD). A t-test and one-way analysis of variance was conducted for data with a normal distribution and a homogeneity of variance, and the least significant difference method was used for pairwise comparison. In contrast, a nonparametric test was used for the data that did not have either a normal distribution or homogeneity of variance. The enumeration data were expressed as n/% and compared using a chi-square test. A p-value below 0.05 indicated that the difference was statistically significant (test $\alpha$ level = 0.05 for both sides).

## RESULTS

### The RI detection rate

Among the 4,866 patients that underwent a CCTA examination in Cangzhou Central Hospital from January 1, 2021, to September 1, 2021, 1,202 were found with an RI (detection rate, 24.7%).

### Comparison of the left main coronary artery parameters in the RI group by gender

There were no statistically significant differences in the number of cases concerning the RI distribution by gender for any of the three types ($p > 0.05$, Table 1). There were no statistically significant differences in the RI diameter and length, RI distribution, or the LCX proximal diameter ($p > 0.05$, Table 1). The LAD proximal diameter in males was 4.09 ± 0.68 mm, while for females this was 3.86 ± 0.54 mm, indicating a significantly higher value in males than in females ($p < 0.05$, Table 1).

### Comparison of the proximal diameters of the LAD and LCX among the RI distribution groups

There were no statistically significant differences in the RI distribution between males and females ($p > 0.05$, Table 2). The LAD proximal diameter was 3.75 ± 0.55, 4.04 ± 0.63, and 4.00 ± 0.64 mm in the beside-the-LAD-group, the beside-the-LCX-group, and the middle group, respectively, and the differences were statistically significant ($p < 0.05$, Table 2). The pairwise comparison showed that, in terms of measurements, the beside-the-LAD-group was significantly lower than the beside-the-LCX-group ($p < 0.05$, Fig. 3A); the beside-the-LAD-group was significantly lower than the middle group ($p < 0.05$, Fig. 3A), and the middle group was significantly lower than the beside-the-LCX-group ($p > 0.05$, Fig. 3A). The LCX proximal diameters were 3.74 ± 0.66, 3.35 ± 0.66, and 3.64 ± 0.69 mm in the beside-the-LAD-group, the beside-the-LCX--group, and the middle group, respectively, and the differences were statistically significant ($p < 0.05$, Table 2). The pairwise comparison showed that measurement-wise, the beside-the-LCX-group was

**Table 1.** Correlation between gender and left coronary artery parameters in the ramus intermedius (RI) group

| | Male (n = 138) | Female (n = 129) | P |
|---|---|---|---|
| Age [years] | 54.05 ± 11.44 | 56.98 ± 9.84 | 0.026 |
| RI diameter [mm] | 2.74 ± 0.63 | 2.60 ± 0.65 | 0.081 |
| RI length [cm] | 6.61 ± 2.63 | 6.30 ± 3.01 | 0.260 |
| RI distribution (n/%): | | | |
| Beside LAD group | 21/15.2% | 22/17.1% | |
| Beside LCX group | 72/52.2% | 65/50.4% | 0.913 |
| Middle group | 45/32.6% | 42/32.6% | |
| LAD proximal diameter [mm] | 4.09 ± 0.68 | 3.86 ± 0.54 | 0.002 |
| LCX proximal diameter [mm] | 3.57 ± 0.74 | 3.44 ± 0.63 | 0.135 |

LAD — anterior interventricular branch of the left coronary artery; LCX — circumflex branch of the left coronary artery

**Table 2.** Comparison of the anterior interventricular branch of the left coronary artery (LAD) and the circumflex branch of the left coronary artery (LCX) proximal diameter in each the ramus intermedius (RI) distribution group

| | Beside LAD group (n = 43) | Beside LCX group (n = 137) | Middle group (n = 87) | $\chi^2$ or F | P |
|---|---|---|---|---|---|
| Gender (n/%): | | | | | |
| Male | 21/48.8% | 72/52.6% | 45/51.7% | 0.181 | 0.913 |
| Female | 22/51.2% | 65/47.4% | 42/48.3% | | |
| LAD proximal diameter [mm] | 3.75 ± 0.55 | 4.04 ± 0.63 | 4.00 ± 0.64 | 3.519 | 0.031 |
| LCX proximal diameter [mm] | 3.74 ± 0.66 | 3.35 ± 0.66 | 3.64 ± 0.69 | 7.955 | 0.000 |

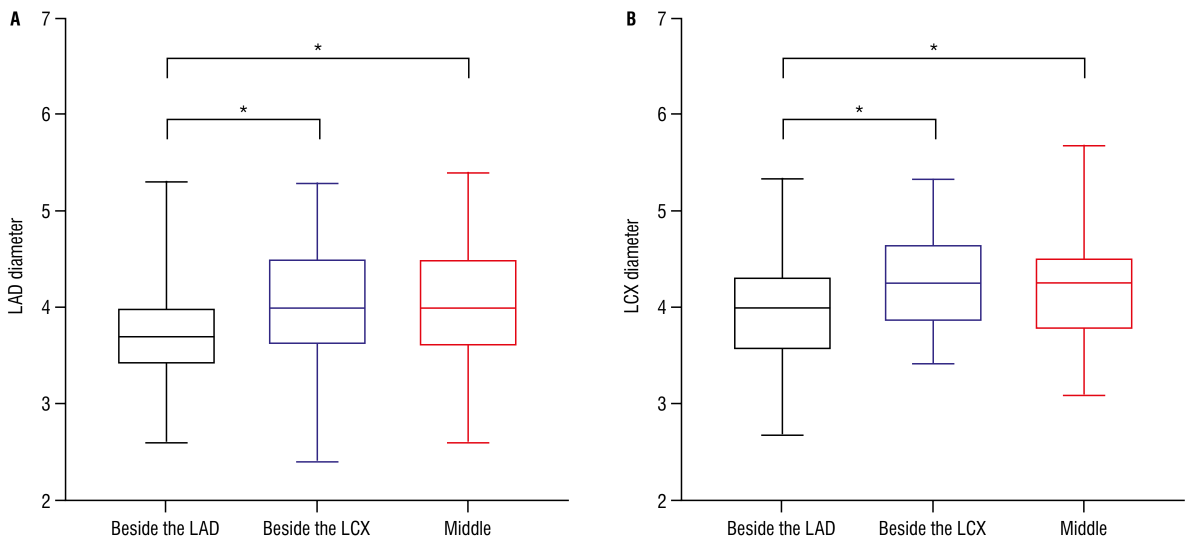


**Figure 3.** Pairwise comparison of anterior interventricular branch of the left coronary artery (LAD) (**A**) and the circumflex branch of the left coronary artery (LCX) (**B**) proximal diameter in each ramus intermedius distribution group; *The level of significance test for $\alpha$ is 0.05.

significantly lower than the beside-the-LAD-group ($p < 0.05$, Fig. 3B); the beside-the-LCX-group was significantly lower than the middle group ($p < 0.05$, Fig. 3B), and the middle group was significantly lower than the beside-the-LAD group ($p > 0.05$, Fig. 3B).

### Comparison of the proximal diameters of the LAD and LCX between the RI group and the control group

There were no statistically significant gender differences between the LAD and LCX groups ($p > 0.05$, Table 3). The LAD proximal diameter was 3.98 ± 0.63 mm

**Table 3.** Comparison of the anterior interventricular branch of the left coronary artery (LAD) and the circumflex branch of the left coronary artery (LCX) proximal diameter between the ramus intermedius (RI) group and the control group

| | With RI (n = 267) | Without RI (n = 134) | $\chi^2$ or Z | P |
|---|---|---|---|---|
| Gender (n/%): | | | | |
| Male | 138/51.7% | 69/51.5% | 0.001 | 0.971 |
| Female | 129/48.3% | 65/48.5% | | |
| LAD proximal diameter [mm] | 3.98 ± 0.63 | 4.57 ± 0.55 | –8.327 | 0.000** |
| LCX proximal diameter [mm] | 3.51 ± 0.69 | 4.08 ± 0.60 | –7.645 | 0.000** |

**The level of significance test for $\alpha$ is 0.001

in patients with an RI and 4.57 ± 0.55 mm in patients without an RI, indicating the diameter in patients with an RI was significantly smaller than in patients without an RI ($p < 0.05$, Table 3). The LCX proximal diameter was 3.51 ± 0.69 mm in patients with an RI and 4.08 ± 0.60 mm in patients without an RI, indicating that the diameter in patients with an RI was significantly smaller than in patients without an RI ($p < 0.05$, Table 3).

## DISCUSSION

Ajayi et al. [1] reported an RI incidence of 21.8%, while Liu et al. [11] reported a detection rate of 25.6% for RIs in Xinjiang. In the present study, the detection rate of RIs in the current authors' hospital was similar at 24.7%.

The present study compared the RI length and diameter, the RI distribution, and the LAD and LCX diameters between males and females for the first time and found no statistically significant differences concerning RI length, diameter, or distribution. The LAD diameter was significantly higher in males than in females (4.09 ± 0.68 vs. 3.86 ± 0.54 mm, $p < 0.05$), but there were no statistically significant differences in the LCX diameter ($p > 0.05$). The differences in the LAD and LCX diameters between males and females in the population without RIs have been compared in domestic and foreign studies. Verim et al. [15] measured the lumen area at the proximal segments of the branch vessels of the LCA in 108 patients and found that the LAD lumen area in males was significantly larger than in females; no gender difference was observed in the LCX lumen area. Liu et al. [11] compared the lumen intraluminal diameter of proximal vessels between males and females at the left main bifurcation area of patients with predominant right coronary arteries and without RIs and found significant differences in the LAD and LCX intraluminal diameters (larger in males than in females). The mean intraluminal diameter was smaller than the data in the present study because the tube wall was included in the measurement process in the current paper. Gong [5] found that the LAD diameter in males was significantly larger than in females in a school-age group (i.e. ≥ 6 and < 9 years old). The findings of the current study are consistent with the research results of domestic and foreign scholars on the non-RI population, suggesting that individuals with and without RIs follow the same gender rules. Ren [13] found that the LAD diameter in males was significantly larger than in females in a non-normalised condition. Still, no statistically significant differences were observed after normalising height, weight, and body surface area parameters, indicating that the differences above had been the result of body surface area. This study was not normalised due to data collection.

The current study found that the diameters of the LAD and LCX in patients with an RI were significantly smaller than those in patients without an RI ($p < 0.05$). The reason for this was because the RI, an additional branching vessel, undertakes delivering part of the blood supply to the myocardium. Compared to patients without RIs, the blood flow of the LCA experienced additional shunting, and the blood flow of each branch vessel was reduced. Furthermore, the diameter of blood vessels may become thinner in a compensatory manner during the development of the human body.

The RI distribution was also divided into the beside-the-LAD-group, the beside-the-LCX-group, and the middle group. There were statistically significant differences in the LAD and LCX proximal diameters between the three groups ($p < 0.05$), i.e. the closer the RI was to the coronary artery, the more significant the effect on the decrease of the LAD and LCX proximal diameters. When the RI was in the middle, it had little effect on the diameter of the LCA on either side. This indicated that the closer the RI was to the coronary artery, the higher the blood supply proportion of the original coronary artery was, with more obvious blood redistribution. Galbraith et al. [3] posited that the RI, a shunt vessel, would lead to a greater blood flow disturbance in the proximal segment of the LAD, and these blood flow disturbances may cause focal atherosclerosis. Meanwhile, studies [7, 9, 10] have indicated that 8.9%-19% of branch vessels were occluded following main branch stent implantation, with the severity associated with the diameters and lengths of the branch vessels. It is generally believed to be caused by the displacement of the bifurcation crest and plaque, as well as the suspension of the bifurcation opening stent. Compared to the population without an RI, those with an RI should be carefully monitored to observe whether the RI (a new branch of the LM) will be occluded after an LM and/or LAD proximal stent implantation, which will increase the incidence of myocardial infarction in the blood supply area. Further study of the anatomical structure and haemodynamics of the RI and the left main bifurcation area thus has great clinical significance.

## CONCLUSIONS

Coronary computed tomography angiography could accurately evaluate the anatomical characteristics of RI, which can influence the proximal diameter of the branch vessels of the LCA (i.e. LAD and LCX), with the degree of influence correlated with the RI distribution. The limitations of this study are as follows: 1) the present study was a single-centre retrospective observational study with a low level of evidence; 2) the included cases were patients who had been admitted to the hospital due to illness; accordingly, a degree of bias may have been included; 3) the distribution type of the coronary artery could affect its anatomical data. To ensure research objectivity, only the population with predominance in the right coronary area was included in this study. Other factors that could have affected the measurement data were excluded, which may also have caused a degree of bias to be included.

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**Conflict of interest:** None declared

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