Brief Report

Coronary computed tomography angiography assessment of relationship between right coronary artery-aorta angle and the development of coronary artery disease

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Abstract: Whilst a correlation has been established between wide left main coronary artery bifurcation [left anterior descending-left circumflex (LAD-LCx)] angle (>80°) and the development of coronary artery disease (CAD), this retrospective, causal-comparative pilot study aimed to explore whether a relationship exists between right coronary artery (RCA)-aorta angle and CAD. Thirty normal cases were identified via radiology reports and selected as the control group with coronary computed tomography angiography (CCTA) scans performed on a 320-slice computed tomography (CT) scanner. Thirty CAD cases were selected with invasive coronary angiography performed to confirm the degree of stenosis, and CCTA performed on dual source and 320-slice CT scanners. An independent sample *t*-test was used to compare the differences in coronary angles between the normal and CAD group, and analysis of variance (ANOVA) was used to assess for significant differences between coronary angles in normal and CAD subgroups. Coronary angle measurements were conducted by two independent assessors with high intraclass correlation (r=0.971–0.998, P<0.001). RCA-aorta angle measurements were significantly larger in the normal group [87.47°, 95% confidence interval (CI): 79.31° to 95.78°] compared to the CAD group (76.82°, 95% CI: 67.82° to 85.61°, P=0.05). No significant difference was found between RCA-aorta angle and degree of coronary stenosis (P=0.75). This study suggests a relationship between narrow RCA-aorta angle and CAD.

Keywords: Angle; measurement; coronary artery disease (CAD); coronary computed tomography angiography (CCTA); correlation; diagnosis

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Introduction

Between 2020 and 2021, an estimated 2.9% of the Australian population aged ≥18 years had coronary artery disease (CAD) (1). CAD is characterised by the formation of atherosclerotic plaques within the coronary arteries, and recent studies have determined that there is a relationship between left coronary artery (LCA) bifurcation angle and the development of CAD as assessed by coronary computed tomography angiography (CCTA) (2,3). Individuals with wide LCA bifurcation angles (>80°) are significantly more likely to develop CAD than those with narrow angles (2-4). To better understand the pathogenesis of CAD, Chaichana *et al.* used left coronary artery hemodynamics simulations to demonstrate that wide LCA bifurcation angles result in reduced wall shear stress, which is directly correlated with CAD development and atherosclerotic plaque formation (5).

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Table 1 Clinical characteristics of the study sample

Characteristics	Normal group (n=30)	CAD group (n=30)
Age (years), mean ± SD	61.7±9.1	67.5±10.3
M/F, n	19/11	24/6
Coronary artery involvement, n (%)		
1-vessel disease	N/A	5 (16.7)
2-vessel disease	N/A	18 (60.0)
3-vessel disease	N/A	7 (23.3)
Diabetes	42.9%	52%
Hypertension	56.1%	88%
Smoking history	50%	74%
Family history	58.5%	42%
Distribution of calcified plaques at coronary arteries		
LAD (n=30), n (%)		
1–3 plaques	N/A	26 (86.7)
4–5 plaques	N/A	4 (13.3)
LCx (n=15), n (%)		
1–3 plaques	N/A	15 (100.0)
4–5 plaques	N/A	0
RCA (n=11), n (%)		
1–3 plaques	N/A	11 (100.0)
4–5 plaques	N/A	0

CAD, coronary artery disease; SD, standard deviation; M, male; F, female; N/A, not applicable; LAD, left anterior descending artery; LCx, left circumflex artery; RCA, right coronary artery; CCTA, coronary computed tomography angiography.

Whilst invasive coronary angiography (ICA) has traditionally been used as the gold standard for coronary vessel assessment, CCTA has proven to be an accurate, less invasive tool for assessing LCA bifurcation angle [mainly left anterior descending (LAD)-left circumflex (LCx)] and diagnosing calcified plaques, demonstrating similar sensitivity, specificity and positive predictive values to those of ICA (6,7). Bifurcation angle assessment via CCTA also provides a reliable, accurate alternative to standard lumen assessment in patients with calcified plaques with improved specificity and positive predictive value (6). Although several studies have established and supported the relationship between LCA bifurcation angle and CAD (2-5), an association between right coronary artery-aorta (RCA-aorta) angle and the development of CAD is yet to be determined. This pilot study, to our knowledge, was the first to investigate such a relationship. Our primary aim was to measure and compare the RCA-aorta angles between normal and abnormal CCTA cases, hypothesising that a correlation exists between RCA-aorta angle and CAD development. We present the following article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-22-655/rc).

Methods

Participants

This study included the CCTA datasets of 30 normal and 30 CAD cases, and patient demographics are summarised in *Table 1*. The 30 normal cases were randomly selected from a previous study serving as the control group, with CCTA scans performed on a 320-slice CT (3), whilst the 30 CAD cases were also randomly obtained from another previous study serving as the study group with CCTA scans performed on a first and second-generation dual source CT and 320-slice scanner, respectively (6). Normal CCTA cases were identified using radiology reports and did not undergo ICA, due to the high negative predictive value of CCTA, whereas ICA was performed in all CAD cases to ascertain the degree of coronary stenosis (denoted as either <50% or ≥50% stenosis). This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Curtin University Human Research Ethics Committee. Individual consent for this retrospective analysis was waived.

Coronary angle measurements

RCA-aorta angle measurements were obtained via multiplanar reformation (MPR) images, using variable, obliqued planes to ascertain the best observable RCA-aorta angle for each case. Axial measurements were also acquired, to determine whether this is a valid method of analysing RCA-aorta angle, since current literature is yet to explore this technique due to lack of studies documenting this aspect. Additionally, the LAD-LCx angles were measured using both 2D axial images and MPR images, since the accuracy of LAD-LCx angles measured on 2D axial images is similar to those measured on 3D views (4). Measurements were conducted by two independent assessors to determine

Table 2 Prevalence of calcified plaques and degree of coronary stenosis determined on CCTA and ICA

Disease prevalence	Calcified plaques on CCTA			Degree of stenosis ≥50% on CCTA			Degree of stenosis ≥50% on ICA		
	RCA	LAD	LCx	RCA	LAD	LCx	RCA	LAD	LCx
No. of cases	27	30	21	18	29	15	5	15	4
Percentage	90%	100%	70%	60%	96.7%	50%	16.7%	50%	13.3%

CCTA, coronary computed tomography angiography; ICA, invasive coronary angiography; RCA, right coronary artery; LAD, left anterior descending; LCx, left circumflex.

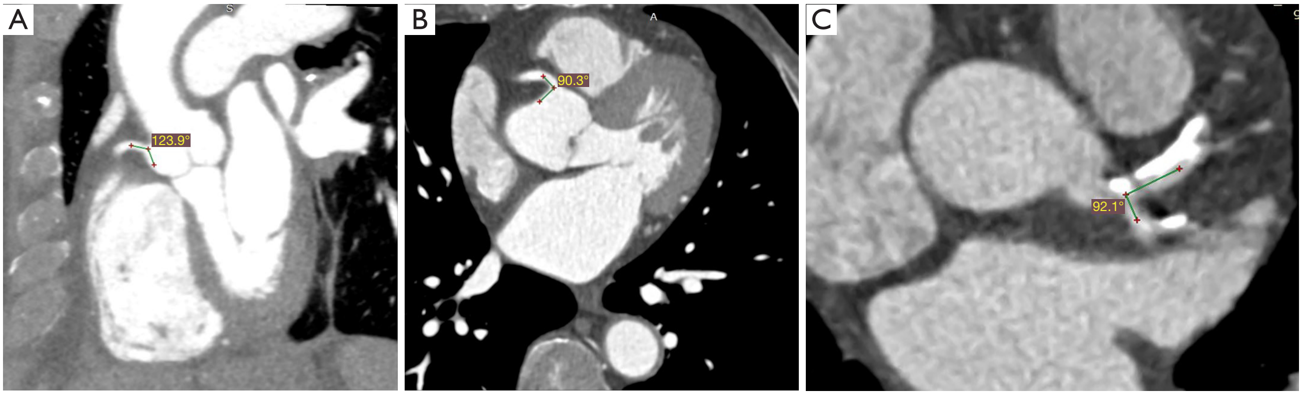

Figure 1 CCTA MPR demonstrating coronary angle measurements. (A) Image of a wide (123.9°) RCA-aorta angle in a 70-year-old female without CAD. (B) Image demonstrating a narrow (90.3°) RCA-aorta angle in a 72-year-old female with multiple calcified plaques in the RCA with more than 50% stenosis. (C) Image of a wide (92.1°) LAD-LCx angle obtained from a 72-year-old male, with several calcified plaques seen at the bifurcation site and proximal LAD and LCx arteries. CCTA, coronary computed tomography angiography; MPR, multiplanar reformation; RCA, right coronary artery; CAD, coronary artery disease; LAD, left anterior descending; LCx, left circumflex.

measurement reliability.

Statistical analysis

Data were entered into SPSS V 27.0 for statistical analysis, with continuous variables expressed as mean ± standard deviation (SD). A one sample *t*-test was used to assess for a significant mean difference between MPR and axially-acquired RCA-aorta measurements, and a Bland-Altman plot was produced to assess overall agreeance for the two measurement techniques. An independent sample *t*-test was used to compare the differences in coronary angles between the normal and CAD group, and analysis of variance (ANOVA) was used to assess for significant differences between coronary angles in normal and CAD subgroups (individuals with <50% and ≥50% coronary stenosis). P values ≤0.05 indicated statistical significance. Agreement between the measurements of the two independent assessors was determined using an intraclass correlation coefficient.

Results

Despite the high prevalence of calcified plaques seen in the RCA, and LAD and LCx arteries, less than half of CAD cases were confirmed to have ≥50% stenosis on ICA (*Table 2*). There were significant differences in both the right and left coronary angle measurements, with a significantly larger mean RCA-aorta angle observed in the normal case group compared to the diseased group (*Figure 1*) (P=0.05). *Figure 2* shows the distribution of RCA-aorta angle between normal and CAD groups. The mean RCA-aorta angle of the normal group was larger than that of the CAD group, with a greater number of cases exhibiting angles of 100° or higher in the normal group (11 cases in the normal group *vs.* 6 cases in the CAD group) as depicted by the histograms (*Figure 2*) and *Table 3*.

There was a significant mean difference between MPR and axially-acquired RCA-aorta measurements (27.64°±23.33°, P<0.001) (*Figure 3*), and the associated Bland-Altman plot suggests no agreement between the two

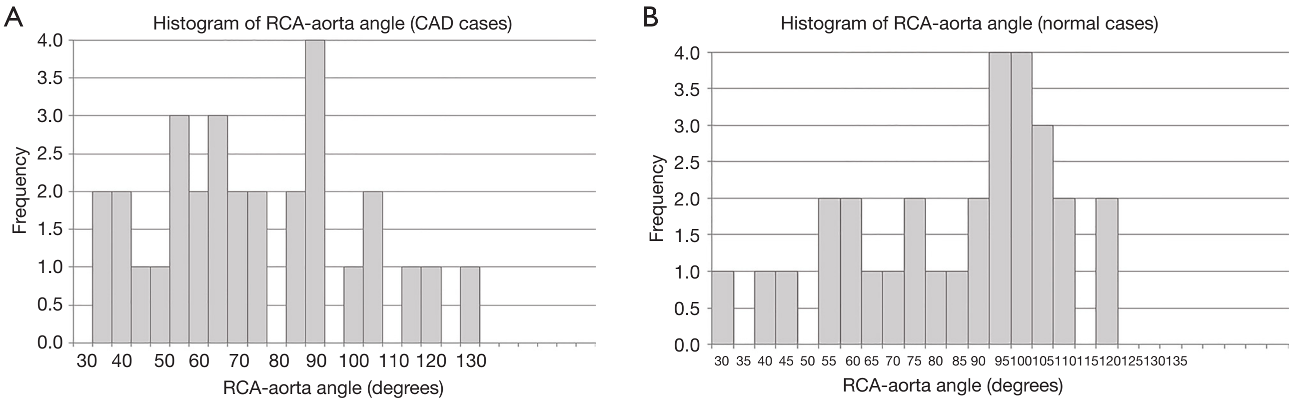

Figure 2 Histogram depicting RCA-aorta angle distribution amongst CAD and normal cases. The number of wide RCA-aorta angles is significantly less in the CAD group (A) compared to that of the normal group (B). RCA, right coronary artery; CAD, coronary artery disease.

Table 3 Summary of coronary angle measurements of the diseased and normal groups

Measurements	Normal group (n=30)		CAD group (n=30)		P value
	RCA-aorta angle	LAD-LCx angle	RCA-aorta angle	LAD-LCx angle	
Mean (95% CI)	87.47° (79.31° to 95.78°)	59.2° (50.39° to 68.75°)	76.82° (67.82° to 85.61°)	79.5° (69.72° to 89.09°)	0.05; 0.002*
Range	33.2° to 123.3°	26.1° to 130.0°	38.2° to 120.3°	37.9° to 136.6°	N/A
>100° for RCA angle, >80° for LCA angle, n (%)	11 (36.7)	5 (16.7)	6 (20.0)	16 (53.3)	N/A
≥50% *vs.* <50% stenosis, mean (95% CI)	N/A	N/A	80.18° (55.46° to 102.50°) *vs.* 76.14° (66.46° to 86.24°)	89.5° (72.83° to 103.42°) *vs.* 65.8° (54.99° to 75.38°)	0.75; 0.01#

*, indicates significant differences between normal and CAD groups for both angle measurements; #, indicates comparison for RCA-aorta and LAD-LCx angles between more than 50% and less than 50% stenosis, respectively. RCA, right coronary artery; LAD, left anterior descending; LCx, left circumflex; CAD, coronary artery disease; CI, confidence interval; N/A, not applicable; LCA, left coronary artery; SD, standard deviation.

measurement techniques (*Figure 4*). However, there was strong intraclass correlation between the two independent assessor measurements for both LAD-LCx (r=0.984–0.998, P<0.001) and MPR (r=0.971–0.993, P<0.001) and axially-acquired RCA-aorta angle measurements (r=0.994–0.998, P<0.001).

Conversely, a significantly smaller mean LAD-LCx angle was observed in the normal group compared to the CAD group (P=0.002), as presented in *Table 3*. Subgroup analysis between normal cases and CAD cases with <50% and ≥50% coronary stenosis yielded no significant difference regarding RCA-aorta angle (P=0.75). However, individuals with ≥50% stenosis had a significantly larger mean LAD-LCx angle (>80°) compared to those with <50% stenosis (P=0.01).

Discussion

This study provides further evidence supporting the relationship between wide LCA-LCx and CAD development, as suggested by several previous studies (2-6). Furthermore, our preliminary results show the correlation between RCA-aorta angle and CAD with a smaller angle observed in the CAD group compared to the normal group. Thus, measurement of RCA-aorta angle could be included in the diagnostic approach of CCTA in CAD to provide additional information such as prediction or risk stratification of CAD.

LAD-LCx angle measurement via axial and MPR images has been shown to be of similar accuracy to that measured on 3D views (4). However, there was a significant positive

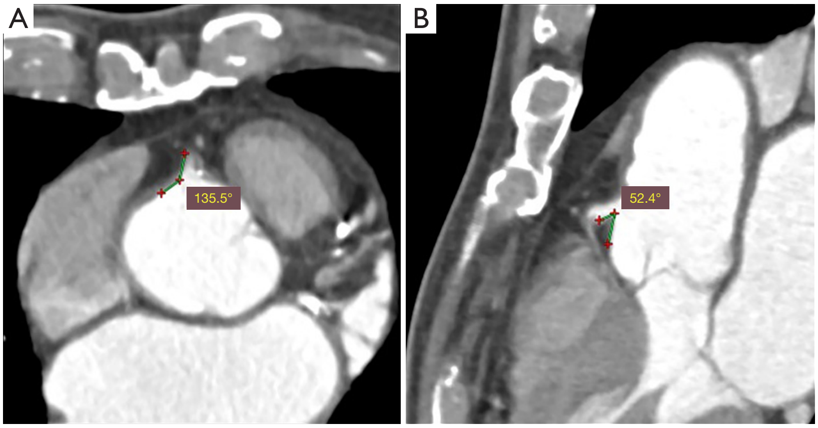

Figure 3 CCTA images demonstrating the significant discrepancy of using axial images for measuring RCA-aorta angle when compared to that measured on MPR views. (A) RCA-aorta angle of 135.5° measured on 2D axial view. (B) RCA-aorta angle from the same CCTA dataset measured at 52.4° on MPR. CCTA, coronary computed tomography angiography; RCA, right coronary artery; MPR, multiplanar reformation.

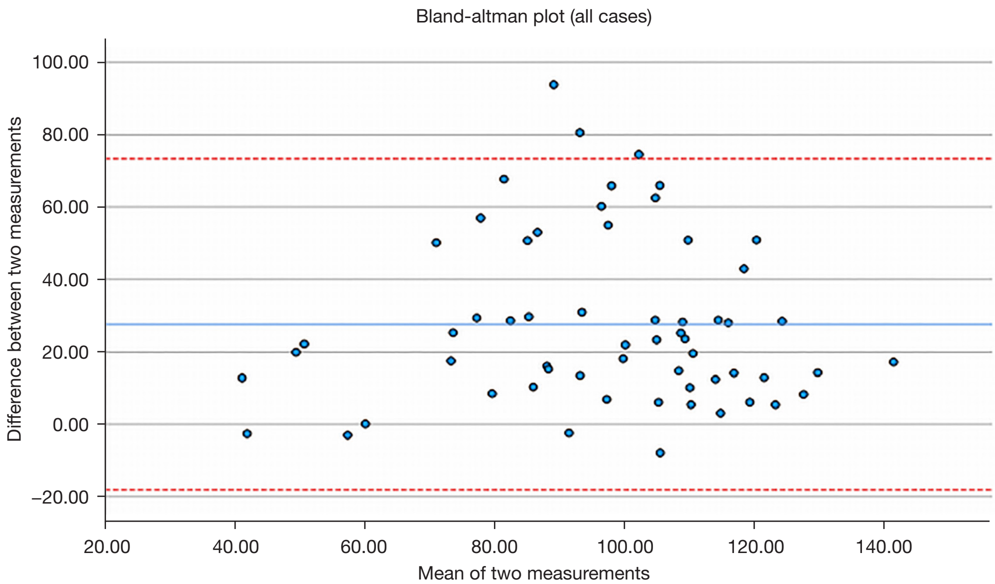

Figure 4 Bland-Altman plot for determining agreeance between MPR and axial measurements. There is very little to no agreement between the two sets of measurements, and axial measurements appear to be consistently overestimating RCA-aorta angle compared to those obtained from MPR. MPR, multiplanar reformation; RCA, right coronary artery.

mean difference between MPR and axially-acquired RCA-aorta measurements (27.64°±23.33°, P<0.001). This suggests a consistent overestimation of RCA-aorta angle when assessed on axial views alone (*Figure 3*), since the accuracy of this method is probably largely dependent on RCA trajectory, unlike the LAD-LCx angle which can be accurately measured using axial and MPR images (2-4). Additionally, the associated Bland-Altman plot suggests no agreement between MPR and axially-acquired measurements (*Figure 4*). Hence, valid analysis of this angle requires 3D assessment, which cannot be achieved using only one anatomical plane. Although MPR can facilitate a 3D evaluation of the RCA-aorta angle, due to limited number of cases analysed in this study, further research is required to determine whether the results of this method of assessment is comparable to that of 3D volume rendering, in order to ascertain the most accurate, reliable method of measuring this coronary angle.

There was a discrepancy between the apparent degree of coronary stenosis on CCTA *vs.* ICA, indicating that CCTA yields a high false positive rate due to blooming artifacts associated with extensive calcification, which is within expectation. This supports the findings of various existing studies exploring the characteristics of blooming artifacts associated with severe coronary calcification. The appearance of severe coronary stenosis is frequently exacerbated on CCTA due to partial volume averaging, impeding the accuracy of consequent lumen assessment (8-10). The limitations of CCTA in diagnosing calcified plaques have been addressed and overcome to some extent via several methods, such as dual-energy CT (11), image subtraction algorithms (12-14), iterative reconstruction (15,16), high-definition CT (17-19), and deep learning (DL) approaches (20-24). Of these methods, using DL seems to be a promising strategy to improve diagnostic value of CCTA in assessing calcified plaques, however, incorporation of coronary angle measurements into routine coronary lumen assessment could be a simple and convenient approach, according to this and other reports (2-7,25,26).

Most studies available in the existing literature focus on the correlation between LAD-LCx and CAD (2-7,25,26). There is no current research investigating possible relationships between RCA-aorta angle and CAD. This could be due to the fact that the RCA path is relatively straight, unlike the left coronary artery and its bifurcation angle, which results in hemodynamic changes such as low wall shear stress and flow turbulence due to wide angulation. By contrast, smaller RCA-aorta angles may result in unstable hemodynamics in the proximal RCA, reducing wall shear stress, which could damage the intimal coronary wall and lead to atherosclerosis (27). This pilot study has supported our hypothesis, and its results lay foundation for further research in this direction. Specifically, research investigating hemodynamic changes using computational fluid dynamics between RCA-aorta angle and CAD development is necessary to elaborate on this relationship.

Additionally, our findings indicate that there is likely a correlation between narrow RCA-aorta angle and the development of CAD, suggesting that RCA-aorta angle assessment may be incorporated into diagnostic evaluation for patients with calcified plaques to enhance the diagnostic accuracy of CCTA. However, subgroup analysis did not yield any significant differences between the RCA-aorta angles of normal cases, or those with <50% and ≥50% coronary stenosis. Degree of coronary stenosis is commonly used in the current literature to characterise CAD severity (25,26,28-30). However, this alone is not necessarily indicative of ischemic severity, which is an inherent limitation for CCTA, as the degree of coronary stenosis does not always translate to the hemodynamic significance of coronary lesions. Recent studies suggest the diagnostic accuracy of CT-derived fractional flow reserve (FFRCT) may more accurately correspond to ischemic severity, and hence guide patient treatments more effectively (31,32). Consequently, future studies should aim to correlate coronary angles with changes in physiology, characterising CAD severity with tools such as FFR, in order to better understand these relationships.

This study has several limitations. This was a pilot study involving a small sample size and further studies with larger sample sizes are necessary to validate our results. Secondly, although our findings suggest a relationship between narrow RCA-aorta angle and CAD, this study's CAD group consisted only of patients with calcified plaques. Further, only a very small number of cases had significant RCA stenosis indicating another limitation of the diseased group. Subsequent studies should include patients with different plaque types, and of different risk groups (low, intermediate and high risk) in order for more robust, comprehensive conclusions to be formed. Cardiac CT radiomics is an emerging area enabling quantitative analysis of plaque features for cardiac risk prediction and prevention (33,34), thus this could be a future research direction with inclusion of RCA-aorta angle as another variable in the CT radiomics analysis.

In conclusion, this preliminary study suggests there may be a correlation between RCA-aorta angle and the development of CAD. Measurements of coronary angles, including both RCA-aorta and LAD-LCx could be incorporated into routine diagnostic CCTA to improve its diagnostic value. Further studies involving large sample sizes, in particular, testing different approaches of measuring RCA-aorta angles are warranted to validate our findings.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-22-655/rc

Conflicts of Interest: Both authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-22-655/coif). ZS serves as an unpaid associate editor of *Quantitative Imaging in Medicine and Surgery*. The other author has no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Curtin University Human Research Ethics Committee. Individual consent for this retrospective analysis was waived.

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