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Prevalence of congenital coronary artery anomalies as shown by multi-slice computed tomography coronary angiography: a single-centre study from Turkey

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Abstract

Objective: Coronary artery anomaly (CAA) is a remarkable etiological factor for sudden cardiac death in young adults. The incidence of CAA is unknown, with most reliable data available based on postmortem/angiography investigations. This study aimed to assess the prevalence of different forms of coronary anomalies, and to investigate the relationships between demographic data and occurrence of CAA.

Methods: A total of 2401 consecutive patients (1805 men; mean age, 56 ± 11.7 years), who were referred between January 2005 and December 2008 for noninvasive multi-slice computed tomography (MSCT) imaging, were retrospectively analysed.

Results: A total of 225 cases (191 men; mean age, 55.9 ± 12) of CAAs were identified (9.37%). Because 11 patients had multiple muscular bridges of the coronary arteries, 236 coronary artery anomalies were found in these 225 patients. Cases were classified into three groups: group 1, coronary anomalies of origin and distribution (n = 36, 1.5%); group 2, anomalies of intrinsic coronary arterial anatomy (n = 180, 7.49%); and group 3, anomalies of coronary termination (n = 9, 0.4%).

Conclusion: The prevalence of CAA was 9.37% in our single-centre study, which is consistent with previous research. A minimally invasive tool, such as MSCT angiography, should be used to identify CAA.

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Introduction

Coronary artery anomalies (CAAs) presenting in adulthood are rare and associated with adverse cardiac events, including sudden cardiac death.[1] These anomalies are generally diagnosed incidentally during conventional coronary angiography (CAG). However, CAG is not the ideal modality to define the course of these vessels. Since the early 1990s, a variety of non-invasive techniques have been introduced in coronary artery imaging with an attempt to replace invasive conventional CAG.[2] Multi-slice computed tomography CAG (MSCT-CA) is currently considered the ideal tool to visualize the complex anatomy of coronary arteries three dimensionally.[3]

This study aimed to assess the prevalence of CAAs in patients who underwent 64-slice MSCT-CA to determine their precise localization. This study also aimed to classify CAAs and to investigate the associations between CAAs and parameters, such as age, sex, and other risk factors.

Patients and methods

Population

A total of 2401 consecutive patients (1805 men, 596 women; mean age, 56 ± 11.7 years; range, 15–88 years) who underwent electrocardiographically-gated 64-slice MSCT-CA from January 2005 to December 2008 were retrospectively reviewed for CAAs. Demographical data and the patients' history were recorded. The presence of atherosclerotic coronary artery lesions was analysed using a dedicated workstation in a single institution (Maçka Emar, Istanbul, Turkey). The indications for MSCT-CA were atypical angina, typical angina with an inconclusive stress test, the presence of risk factors and high-risk patients for major coronary events, proximal stent patency at follow-up and bypass graft patency at follow-up.

Patients with unstable angina or acute coronary syndrome, atrial fibrillation, renal insufficiency (without the need for dialysis and a serum creatine level higher than 2.0 mg/dl), a history of contrast allergy and pregnant women were excluded. Verbal and written informed consent was obtained from all of the patients during their cardiovascular evaluation before MSCT-CA.

Imaging

Upon presentation to the CT scanner, patients with a heart rate > 70/beats/min received 50 mg atenolol per os (po) 40 min before the study, unless they had known overt heart failure, significant atrioventricular conduction abnormalities (second-degree atrioventricular block) or bronchospastic lung disease. Additional doses (up to a total of 15 mg metoprolol at 5 mg/min, 5 min apart) were administered if the target heart rate (< 65 beats/min) was not achieved and if systolic blood pressure was > 100 mmHg). In patients with major bronchospastic disease or with other contraindications to beta-blocker use, calcium channel blockers were used to control heart rate (intravenous diltiazem at a dose of 5 mg over 1 min repeated up to four times: total dose of 20 mg) every 5 min until the target heart rate was achieved and as long as systolic blood pressure was > 100 mmHg. All of the patients were scanned with a 64-slice CT

scanner (GE LightSpeed VCT; GE® Healthcare). Angiographic scan parameters were as follows: number of slices per rotation was 64; individual detector slice width of 0.625 mm; and 12.5-cm spatial coverage in 5 s at a gantry rotation speed of 330 ms. After the patient was advanced into the scanner bore, the first acquisition consisted of a localizer image of the chest. The second acquisition was a non-contrast scan for calcium scoring. This second acquisition was performed with the following scanning parameters: gantry rotation time of 330 ms, tube voltage of 120 kVp, tube current of 225 mA, prospective gating at 70% of the R–R interval, and collimation of 64 × 0.625 mm. The third acquisition consisted of a test bolus scan, which was performed using a bolus of 20 cc of non-ionic iodinated contrast material (Optiray 350 [ioversol]; Mallinckrodt-Tyco Healthcare, USA). Segmental images were then obtained at 1 image/s over the aortic root. The scan was continued until a threshold of 100 Hounsfield units was reached in a region of interest positioned in the ascending aorta. This allowed graphical estimation of the timing needed for acquisition of the coronary angiogram. The final acquisition was a contrast-enhanced angiogram. Patients were asked to breathe deeply and then hold their breath at end-inspiration. Ioversol was administered according to the following protocol: 5 cc/s, according to the estimated prescan time (prescan time: timing bolus + 9 s [5 s breath hold time + 4 s for filling the distal coronary artery]), followed by a chaser bolus of normal saline (70 cc at a rate of 4 cc/s). The imaging parameters for this scan were as follows: rotation time of 330 ms, tube voltage of 12 0 kVp, and collimation of 64 × 0.625 mm. Image reconstruction was performed at 10% increments through the R–R cardiac cycle. After acquisition of images, images were transferred to a dedicated GE® AW Workstation for analysis.

CT image analysis

The CT data set was analysed by two independent experienced readers who were blinded to the patients' clinical data. For analysis of the coronary arteries, the original axial dataset pre- (for calcium scoring) and post-contrast was examined. Volume rendering images and curved multi-planar reconstructions were also used for analysis. Types of abnormal coronary arteries were classified using the patients' demographic data according to the American Heart Association scheme.[4] This scheme clearly describes the coronary artery map used by the Bypass Angioplasty Revascularization Investigation study for segmentation of coronary arteries, and was used to define and classify individual CAAs.[5,6] The types of abnormal coronary artery, including its origin, proximal course, intrinsic coronary anomalies and termination anomalies as seen by MSCT-CA, were collected.

Statistical analysis

Statistical analysis was performed using SPSS, version 15.0 (SPSS Inc., Chicago, IL, USA). Normality of distribution was evaluated with the Kolmogorov–Smirnov test. Normally distributed data are expressed as mean ± standard deviation and Q1–Q3 if data were not normally distributed. Results were analysed with the Student's t test for quantitative data that were normally distributed and with the Mann–Whitney U-test for quantitative data that were not normally distributed. Categorical data were analysed with the chi-square or Fisher's exact test (when Levene's test was significant). P-values < 0.05 were considered statistically significant.

This study was approved by the No. 1 Clinical Research Ethics Committee of Istanbul at Istanbul University with no D-012 on November 10, 2009. The study conformed to the guiding principles of the Declaration of Helsinki.

Results

MSCT-CA was performed without any complications in all of the patients. Table 1 shows demographic data for all patients who underwent MSCT-CA. A total of 225 (9.37%) patients were identified as having CAAs and a total of 236 CAAs were found because 11 patients had more than one type of anomalies of coronary arteries. In one patient, the left circumflex artery (CX) arose from the right anterior sinus of Valsalva with a muscular bridge. The CX arose from the right anterior sinus with coronary ectasia in one patient. One patient had coronary ectasia with a coronary aneurysm. Two patients had coronary aneurysms with a muscular bridge and six patients had coronary ectasia with muscular bridges at the same time. The details of coronary anomalies are shown in Table 2 and demographic data of the patients with coronary anomalies are shown in Table 3. The frequency of male sex was significantly higher than that of female sex ($P < 0.001$). Patients with CAAs had a significantly greater degree of atherosclerotic changes and stenosis than did control patients with normal coronaries ($P = 0.001$, $P = 0.007$).

Table 1. Demographic data of the patient population.

Variables	n = 2401	%
Age, years	56 ± 11.7 (15–88)	
Sex (M/F)	1805/596	75.2/24.8
Categorized BMI[a]		
Normal (BMI < 25)	575	23.9
Overweight (BMI 25–30)	1196	49.8
Obese (BMI > 30)	630	26.2
Hypertension	1170	48.7
Diabetes mellitus	522	21.7
Smoker	874	36.4
Hyperlipidaemia	1349	56.2
Family history	1357	56.5
Patients with known CAD	394	16.4
Patient who underwent CABG	186	7.7
Patients who underwent stent implantation	209	8.7
Symptomatic[b]	823	34.3

Abbreviations: M, male; F, female; BMI, body mass index; CAD, coronary artery disease; CABG, coronary artery bypass grafting.

[a]Calculated as weight in kilograms divided by the square of height in meters (kg/m^2).

[b]Assessed considering symptoms in accordance with American College of Cardiology/American Heart Association guidelines.

Patients with CAAs were divided into the following subgroups: group 1, coronary anomaly of origin and distribution (AOC) (n = 36, 1.5%); group 2, anomaly of intrinsic coronary arterial anatomy (AICA) (n = 191, 7.9 %); and group 3, anomalies of coronary termination (n = 9, 0.4%). AOCs were identified in 36 cases (1.5 %). Table 4 shows the demographic characteristics of these patients. AICAs were the most common abnormality (n = 180, 7.49%) including the three main problems of muscular bridges, coronary ectasias, and coronary aneurysms (Table 5). There were significant differences in atherosclerotic and sclerotic changes in coronary arteries in the AOC ($P = 0.015$, $P = 0.04$) and AICA subgroups ($P = 0.007$ for a muscular bridge, $P = 0.001$ for coronary ectasia, $P = 0.046$ for coronary aneurysm). When patients with CAAs were compared with patients with normal coronary arteries, the AOC and the AICA subgroups were less symptomatic ($P < 0.001$). Muscular bridges and coronary aneurysms were most commonly localized in the proximal and middle segments of the left coronary artery, but coronary ectasia was more frequently situated in the right coronary artery (RCA).

Anomalies of coronary termination (coronary artery fistulas) were detected in only nine (0.4%) patients. Among these patients, fistulas from coronary arteries to the right heart chambers were the most common.

Table 2. Prevalence of coronary artery anomalies.

Type of coronary anomaly	n	%
1. Anomalies of origination and course	36	1.5
Absent left main trunk (split origination of the LMCA)	4	0.17
Anomalous location of the coronary ostium within the aortic root or near the actualaortic sinus of Valsalva (for each artery): high, low, commissural	1	0.04
Anomalous location of the coronary ostium outside normal "coronary" aortic sinuses	3	0.12
Anomalous origination of the coronary ostium from opposite, facing the "coronary" sinus	25	1.05
a. RCA arising from the left anterior sinus	12	
b. LAD arising from the right anterior sinus	0	
c. CX arising from the right anterior sinus	11	
d. LMCA arising from the right anterior sinus	2	
Single coronary artery	2	0.08
1. Conal artery arising from the LMCA	1	0.04
2. Anomalies of intrinsic coronary arterial anatomy	191	7.9[b]
Congenital ostial stenosis or atresia (LMCA)	1	
Coronary ectasia	53	
Coronary aneurysm	32	
Coronary hypoplasia	1	
Intramural coronary artery (muscular bridge)	100	
Double LAD	4	
3. Anomalies of coronary termination (fistulas)	9	0.4
4. Anomalous collateral vessels	0	0
Total	236	9.37[a]

[a]CAAs are listed by classification among a total of 225 patients with 236 coronary artery anomalies. The total prevalence was 9.37% (225/2401).

[b]One patient had a CX arising from the right anterior sinus of Valsalva together with a muscular bridge, one patient had a CX arising from the right anterior sinus together with a coronary ectasia, one patient had coronary ectasia together with a coronary aneurysm, two patients had coronary aneurysms together with a muscular bridge and six patients had coronary ectasia together with muscular bridges. Because of this overlapping in 11 patients, the total rate of anomaly of intrinsic coronary arterial anatomy was high (191/2401).

Abbreviations: LMCA, left main coronary artery; RCA, right coronary artery; CX, left circumflex artery; LAD, left anterior descending coronary artery.

Figure 1 shows different demonstrative anomalies found in our patient population.

Discussion

Prevalence

The prevalence of CAA reported by MSCT-CA and by conventional CAG studies varies from 2.04% to 18.4% depending on the definition used and on the focus of the study.[7,8] Different results of the incidence of CAA from the literature are shown in Table 6. Unfortunately, most of the previous studies focussed on AOCs.[9–16] These studies did not use the same classification system to define CAA. Some groups included solely AOCs in their study population, while others included AOCs together with coronary

Table 3. Demographic data of patients with or without CAAs.

		Coronary anomaly				
		+		−		
		n	%	n	%	
Sex	Female	34	15.1	562	25.8	$\boldsymbol{P < 0.000}$
	Male	191	84.9	1614	74.2	$\chi^2 = 12.54$
Diabetes	+	45	20.0	477	21.9	$P = 0.506$
	−	180	80.0	1699	78.1	$\chi^2 = 0.44$
Hypertension	+	97	43.1	1073	493	$P = 0.077$
	−	128	56.9	1103	50.7	$\chi^2 = 3.13$
Hyperlipidaemia	+	111	49.3	1238	56.9	$\boldsymbol{P = 0.030}$[a]
	−	114	50.7	938	43.1	$\chi^2 = 4.73$
Smoker	+	74	32.9	800	36.8	$P = 0.250$
	−	151	67.1	1376	63.2	$\chi^2 = 1.32$
Family history	+	113	50.2	1244	57.2	$\boldsymbol{P = 0.045}$[a]
	−	112	49.8	932	42.8	$\chi^2 = 4.00$
Categorized BMI, normal (BMI < 25)[b]	+	52	23.1	523	24.0	$P = 0.915$ $\chi^2 = 0.177$
Categorized BMI, overweight (BMI 25–30)[b]	+	115	51.1	1081	49.7	
Categorized BMI, obese (BMI > 30)[b]	+	58	25.8	572	26.3	
Atherosclerotic changes in the coronary arteries	+	190	84.4	1624	76.6	$\boldsymbol{P = 0.001}$[a]
	−	35	15.6	552	25.4	$\chi^2 = 10.6$
Stenotic changes in the coronary arteries[c]	+	153	68.0	1246	58.8	$\boldsymbol{P = 0.007}$[a]
	−	72	32.0	873	41.2	$\chi^2 = 7.15$
Symptomatic[d]	+	40	17.8	783	36.0	$\boldsymbol{P < 0.000}$[a]
	−	185	82.2	1393	64.0	$\chi^2 = 30.0$

[a] $P < 0.05$; correlations between patients with or without coronary anomalies by the chi square test.
[b] Calculated as weight (kg) divided by the square of height (m).
[c] Based on luminal stenosis > 50%.
[d] Assessed considering symptoms in accordance with American College of Cardiology/American Heart Association guidelines.
Abbreviations: M, male; F, female; BMI, body mass index.

termination anomalies (i.e., using a modified classification).[17] This difference in classification systems is the major cause of dissimilar incidences reported in these studies. The classification criteria for CAA have been widely discussed. Angelini *et al.* reported a classification that covers all possible coronary anatomical variations independently from their clinical and haemodynamic importance.[5,6] Altin *et al.*'s study compared the incidence of CAA in the same patient population. This incidence was calculated according to Angelini *et al.*'s classification and a modified classification, with two different frequencies of 1.4% and 2.7%, respectively. This finding indicates the importance of the classification system that is used for calculating the incidence of CAA.

In the current study, the prevalence of coronary anomalies was 9.37% (225/2401), including all types of coronary anomalies with specified classification (as described by Angelini *et al.*). The current study showed that the incidence of AOCs was

Table 4. Demographic data of patients with or without coronary anomaly of origin and distribution.

		Coronary anomaly				
		+		−		
		n	%	n	%	
Sex	F	6	16.7	590	24.9	0.254
	M	30	83.3	1775	75.1	$\chi^2 = 1.30$
Diabetes	+	1	2.8	521	22	$\boldsymbol{P = 0.005}$[a]
	−	35	97.2	1844	78	$\chi^2 = 7.72$
Hypertension	+	11	30.6	1159	49	$\boldsymbol{P = 0.028}$[a]
	−	25	69.4	1206	51	$\chi^2 = 4.83$
Hyperlipidaemia	+	17	47.2	1332	56.3	$P = 0.275$
	−	19	52.8	1033	43.7	$\chi^2 = 1.19$
Smoker	+	15	41.7	859	36.3	$P = 0.508$
	−	21	58.3	1506	63.7	$\chi^2 = 0.438$
Family history	+	13	36.1	1344	56.8	$P = 0.013$[a]
	−	23	63.9	1021	43.2	$\chi^2 = 6.193$
Categorized BMI, normal (BMI < 25)[b]	+	12	33.3	563	23.8	$P = 0.171$ $\chi^2 = 3.53$
Categorized BMI, overweight (BMI 25–30)[b]	+	19	52.8	1177	49.8	
Categorized BMI, obese (BMI > 30)[b]	+	5	13.9	625	26.4	
Atherosclerotic changes in the coronary arteries	+	21	58.3	1793	75.8	$P = 0.015$[a]
	−	15	41.7	572	24.2	$\chi^2 = 5.86$
Stenotic changes in the coronary arteries[c]	+	13	36.1	1386	60.1	$P = 0.004$[a]
	−	23	63.9	922	39.9	$\chi^2 = 8.44$
Symptomatic[d]	+	8	22.2	815	34,5	$P = 0.125$
	−	28	77.8	1550	65.5	$\chi^2 = 2.358$

[a]$P < 0.05$; correlations between patients with or without anomalies of origination and course by the chi square test.
[b]Calculated as weight in kilograms divided by the square of height in meters.
[c]Based on luminal stenosis > 50%.
[d]Assessed considering symptoms in accordance with American College of Cardiology/American Heart Association guidelines.
Abbreviations: M, male; F, female; BMI, body mass index.

1.5% (36/2401), which is in line with previous studies.[7,9,18] Reports from Turkey generally identify the incidence of AOCs by conventional CAG.[10,11,17,19,20] Because conventional CAG is not the gold standard for the diagnosis of CAA, interpretation of these results is not accurate. To render different results comparable, investigators should use a strict classification system for coronary anomalies and include dedicated staff for analysis. The real prevalence of coronary anomalies is difficult to determine intrinsically because the techniques used for diagnosis are costly and time-consuming.

Among our population, 12 patients with AOCs had the RCA arising from the left anterior sinus of Valsalva. Eleven of the remaining 24 patients had the CX arising from the right anterior sinus of Valsalva (Table 2). Chaitman *et al.*[13] reported that

Table 5. Demographic data of patients with or without anomalies of intrinsic coronary arterial anatomy (by subgroup classification, such as muscular bridge, coronary ectasia and coronary aneurysm).

		+		−		
		n	%	n	%	Statistic
Muscular bridge						
Sex	F	17	17	579	25.2	$P = 0.064$
	M	83	83	1722	74.8	$\chi^2 = 3.422$
Diabetes	+	27	27	495	21.5	$P = 0.193$
	−	73	73	1806	78.5	$\chi^2 = 1.69$
Hypertension	+	51	51	1119	48.6	$P = 0.643$
	−	49	49	1182	51.4	$\chi^2 = 0.21$
Hyperlipidaemia	+	50	50	1299	56.5	$P = 0.203$
	−	50	50	1002	43.5	$\chi^2 = 1.62$
Smoker	+	29	29	845	36.7	$P = 0.116$
	−	71	71	1456	63.3	$\chi^2 = 2.46$
Family history	+	56	56	1301	56.5	$P = 0.915$
	−	44	44	1000	43.5	$\chi^2 = 0.011$
Categorized BMI, normal (BMI < 25)[b]	+	15	15	560	24.3	$P = 0.096$
Categorized BMI, overweight (BMI 25–30)[b]	+	57	57	1139	49.5	$\chi^2 = 4.69$
Categorized BMI, obese (BMI > 30)[b]	+	28	28	602	26.2	
Atherosclerotic changes in the coronary arteries	+	87	87	1727	75.1	$\mathbf{P = 0.007}$[a]
	−	13	13	574	24.9	$\chi^2 = 7.40$
Stenotic changes in the coronary arteries[c]	+	71	71	1328	59.2	$\mathbf{P = 0.018}$[a]
	−	29	29	916	40.8	$\chi^2 = 5.55$
Symptomatic[d]	+	17	17	806	35	$\mathbf{P < 0.000}$[a]
	−	83	83	1495	65	$\chi^2 = 13.82$
Coronary ectasia						
Sex	F	10	18.9	586	25	$P = 0.310$
	M	43	81.1	1762	75	$\chi^2 = 1.03$
Diabetes	+	9	17	513	21.8	$P = 0.396$
	−	44	83	1835	78.2	$\chi^2 = 0.722$
Hypertension	+	23	43.4	1147	48.9	$P = 0.432$
	−	30	56.6	1201	51.1	$\chi^2 = 0.617$
Hyperlipidaemia	+	31	58.5	1318	56.1	$P = 0.732$
	−	22	41.5	1030	43.9	$\chi^2 = 0.117$
Smoker	+	17	32.1	857	36.5	$P = 0.508$
	−	36	67.9	1491	63.5	$\chi^2 = 0.438$
Family history	+	27	50.9	1330	56.6	$P = 0.408$
	−	26	49.1	1018	43.4	$\chi^2 = 0.685$
Categorized BMI, normal (BMI < 25)[b]	+	15	28.3	560	23.9	$P = 0.722$
Categorized BMI, overweight (BMI 25–30)[b]	+	24	45.3	1172	49.9	$\chi^2 = 0.653$
Categorized BMI, obese (BMI > 30)[b]	+	14	26.4	616	26.2	
Atherosclerotic changes in the coronary arteries	+	50	94.3	1764	75.1	$\mathbf{P = 0.001}$[a]
	−	3	5.7	584	24.9	$\chi^2 = 10.35$
Stenotic changes in the coronary arteries[c]	+	43	81.1	1356	59.2	$\mathbf{P = 0.001}$[a]
	−	10	18.9	935	40.8	$\chi^2 = 10.36$
Symptomatic[d]	+	4	7.5	819	34.9	$\mathbf{P < 0.001}$[a]
	−	49	92.5	1529	65.1	$\chi^2 = 17.18$

(continued)

Table 5. Continued.

		+		−		
		n	%	n	%	Statistic
Coronary aneurysm						
Sex	F	1	3.1	595	25.1	$P = 0.004$[a]
	M	31	96.9	1774	74.9	$\chi^2 = 8.18$
Diabetes	+	7	21.9	515	21.7	$P = 0.985$
	−	25	78.1	1854	78.3	$\chi^2 = 0.00$
Hypertension	+	12	37.5	1158	48.9	$P = 0.201$
	−	20	62.5	1211	51.1	$\chi^2 = 1.63$
Hyperlipidaemia	+	14	43.8	1335	56.4	$P = 0.153$
	−	18	56.3	1034	43.6	$\chi^2 = 2.03$
Smoker	+	13	40.6	861	36.3	$P = 0.617$
	−	19	59.4	1508	63.7	$\chi^2 = 0.250$
Family history	+	15	46.9	1342	56.6	$P = 0.268$
	−	17	53.1	1027	43.4	$\chi^2 = 1.22$
Categorized BMI, normal (BMI < 25)[b]	+	7	21.9	568	24	$P = 0.809$
Categorized BMI, overweight (BMI 25–30)[b]	+	15	46.9	1181	49.9	$\chi^2 = 0.425$
Categorized BMI, obese (BMI > 30)[b]	+	10	31.2	620	26.1	
Atherosclerotic changes in the coronary arteries	+	29	90.6	1785	75.3	$P = 0.046$[a]
	−	3	9.4	584	24.7	$\chi^2 = 3.98$
Stenotic changes in the coronary arteries[c]	+	22	68.8	1377	59.6	$P = 0.292$
	−	10	31.3	935	40.4	$\chi^2 = 1.10$
Symptomatic[d]	+	7	21.9	816	34.4	$P = 0.137$
	−	25	78.1	1553	65.6	$\chi^2 = 2.21$

[a]$P < 0.050$.
[b]Calculated as weight in kilograms divided by the square of height in meters.
[c]Based on luminal stenosis > 50%.
[d]Assessed considering symptoms in accordance with American College of Cardiology/American Heart Association guidelines.
Abbreviations: M, male; F, female; BMI, body mass index.

the prevalence of AOCs was 0.83%. They also found that the RCA arising from the left anterior sinus of Valsalva was the most common type of anomaly with a prevalence of 70%.[13] Other studies have also postulated that the CX arising from the right anterior sinus of Valsalva or split origination of the left main coronary artery is the most common type of AOC.[8,9] Additionally, the RCA arising from the left anterior sinus of Valsalva has been reported as the most common type of AOC.[19] These studies included important data. However, because of the differences in the study populations, the techniques used, and their limitations, they are not eligible for comparison with the current study.

Clinical relevance

Although CAA is the second most common cause of exercise-related sudden death in athletes younger than 35 years, many patients with coronary anomalies are asymptomatic and are diagnosed at post-mortem.[1] Similarly, in the present study, patients with CAA and the subgroup including patients with coronary ectasia and a muscular bridge were less symptomatic compared with patients without coronary

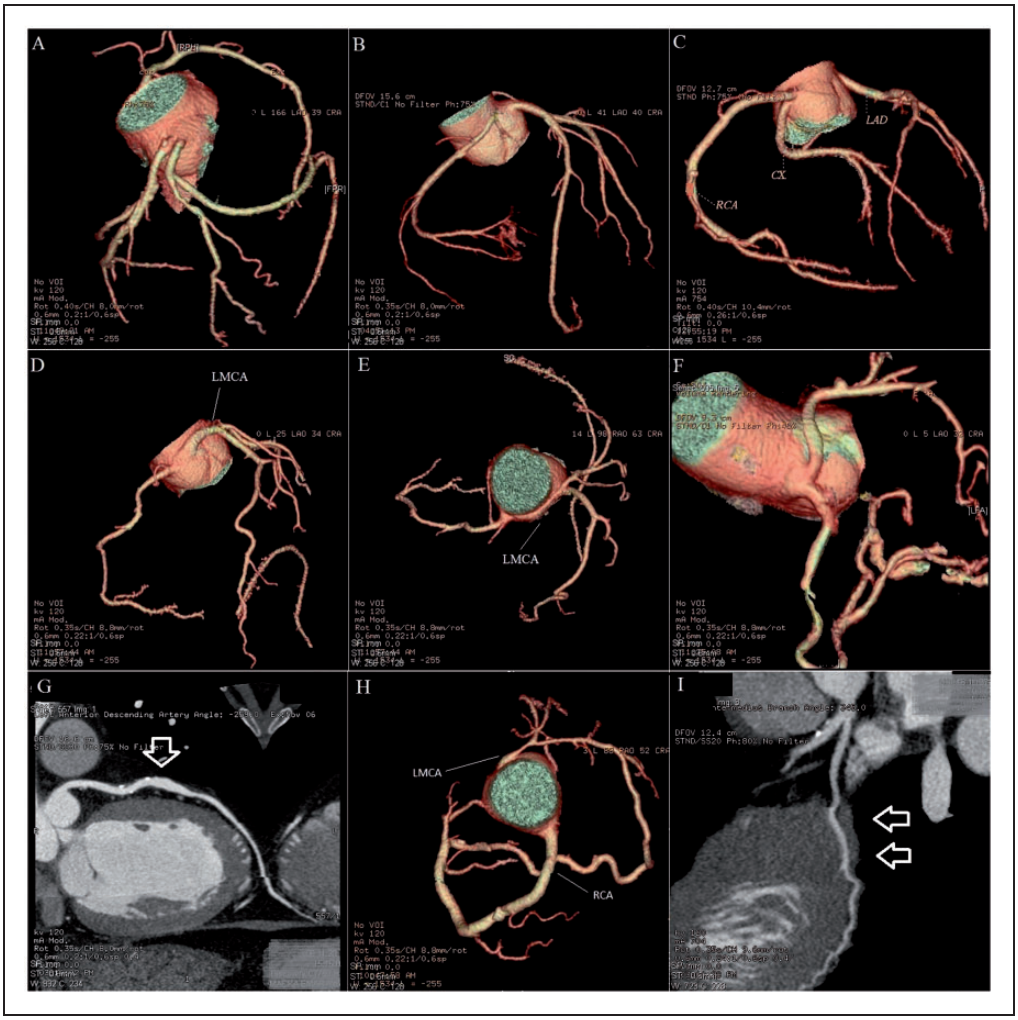

Figure 1. (A) Split origination of the LMCA. Multi-slice computed tomography coronary angiography (MSCT-CA) image shows the absence of the LMCA and the separate origins of the LAD and CX. (B) RCA arising from the left anterior sinus of Valsalva. (C) Anomalous origin of the CX from the right anterior sinus of Valsalva. (D,E) LMCA arising from the right anterior sinus of Valsalva. Image shows the opening of the LMCA and its interarterial course between the ascending aorta and the pulmonary artery. (F) A volume rendering image of MSCT-CA shows a single coronary artery originating from the right sinus of Valsalva. This was classified as the type RI pattern, with passage of the LMCA between the pulmonary artery and aorta. (G) Image shows coronary ectasia of the proximal segment of the LAD, which is indicated with a white arrow. (H) Volume rendering image of the coronary arteries shows no atherosclerotic lesion, but hypoplasia of the LMCA with compensatory enlargement of the RCA. (I) Intramural coronary artery (muscular bridge). MSCT-CA image shows an example of proximal and mid segments of the LAD with myocardial bridging, which is indicated with white arrows.

Abbreviations: RCA, right coronary artery; CX, left circumflex artery; LAD, left anterior descending coronary artery; LMCA, left main coronary artery.

Table 6. Incidence of CAA as shown by CAG and MSCT studies in various populations.

Authors	n	Coronary anomaly (n)	(%)
Incidence of coronary artery anomalies according to CAG studies			
Eid *et al.*[8]	4650	95	2.04[a]
Yamanaka *et al.*[9]	126595	1686	1.3[a]
Tuncer *et al.*[10]	70850	73	0.3[a]
Aydınlar *et al.*[11]	12059	100	0.8[a]
Chaitman *et al.*[13]	3750	31	0.8[a]
Angelini *et al.*[31]	1950	110	5.6
Topaz *et al.*[19]	13010	80	0.6
Güntekin *et al.*[20]	2398	55	2,3[b]
Incidence of coronary artery anomalies according to MSCT studies			
Cademartiri *et al.*[7]	543	100	18.4
Srinavastan *et al.*[16]	1495	11	0.8[a]
Shi *et al.*[22]	242	16	6.6[a]
Ten Kate *et al.*[18]	1000	10	1[a]
Knickelbine *et al.*[37]	4543	201	4.4[b]
Zeina *et al.*[26]	300	78	26[c]

[a]Studies including coronary anomalies of origin and distribution only.
[b]Studies including coronary anomaly of origin and distribution and anomalies of coronary termination.
[c]Studies including muscular bridges only.

anomalies. Most patients with an anomalous origin of a coronary artery from the aorta are symptom-free.[14,21] A proposed mechanism of sudden death is believed to be episodic myocardial ischaemia. However, this mechanism cannot explain the clinical course because this hypothesis mainly proposes recurrent and rapid deterioration during exercise, but not the infarct size, as the responsible factor.

Shirani *et al.*[15] reported that sudden cardiac death cases with a single coronary artery were all free of signs of myocardial ischaemia or asymptomatic. Similarly, Datta and colleagues[14] reported that no patients with an anomalous coronary artery diagnosed by MSCT were symptomatic. These results could explain why coronary anomalies are generally diagnosed incidentally.

Demographic data

The aetiology of coronary anomalies is unknown and whether a hereditary background is involved has yet to be determined. In the current study, male sex was associated with CAA, which is in accordance with other studies that reported a male predominance (58%–80%).[8,10,14,16,18,22,23,24] Similarly, Basso *et al.* reported that 80% of deaths caused by CAA in young athletes occur in male patients.[1] The current study showed a frequency of 96.9% of male patients with aneurysmal coronary artery dilatation, similar to that reported by Swaye *et al.* (88.2%).[25]

Eid *et al.*[8] reported no association between atherosclerotic comorbidities, lipid profiles, and significant atherosclerotic lesions in patients with normal or anomalous coronary

arteries. Other studies have also shown no association between anomalous coronary arteries, such as myocardial bridging,[26,27] coronary ectasia,[28] and aneurysmal dilatation of the coronary arteries,[29,30] with coronary artery disease risk factors, such as diabetes, hypertension, hyperlipidaemia and smoking.

Increased risk of coronary atherosclerotic disease

Whether coronary anomalies predispose to early atherosclerosis or precede lethal influences is unknown. The current study showed a significantly higher incidence of coronary atherosclerotic changes and stenotic changes in anomalous versus normal coronary arteries. This finding has not been demonstrated by previous studies.[7,19] However, these results should be interpreted with caution because of their different haemodynamic and pathophysiological properties. Angelini *et al.* showed no association between the location of atherosclerotic coronary disease and anomalies of coronary anatomy/course. Many other studies have also reported similar results showing no association between AOC, such as single coronary artery and, an increased incidence of atherosclerosis.[5,8,13,19,31] In patients with a single coronary, if atherosclerosis occurs in the common trunk, the clinical consequences would be unusually severe because of the lack of collateral circulation.[31]

However, the discussion is quite different for intrinsic coronary arterial anatomy abnormalities. Recent studies have focussed on the occurrence of atherosclerotic plaques in myocardial bridge localization.[32] They reported that the tunnelled segment was unusually affected by atherosclerosis, unlike the proximal epicardial segment, where atherosclerotic plaques were commonly found. There have been some reports on haemodynamic hypotheses on the association between a tunnelled coronary segment (intramyocardial segment) and ischaemia.[33] However, the contribution of haemodynamic factors caused by a tunnelled segment on atheromatous plaque formation is still controversial. The current finding of a higher incidence of atherosclerotic changes and stenotic coronary lesions in this subgroup of patients with muscular bridges supports the hypothesis stating that the intramyocardial segment is an anatomical risk factor for coronary artery disease.[26,32]

Coronary artery dilatations are usually associated with an underlying factor, which is atherosclerosis in Western countries and Kawasaki disease in Japan.[34] The most common cause of coronary dilatation is thought to be atherosclerosis.[25,30,35] The current study supports the idea that coronary artery dilatation is an anomaly that develops based on atherosclerotic disease. Coronary artery ectasia is also associated with hyperlipidaemia, systemic hypertension, and male sex.[28,36]

The current study has some limitations. Although the sample size in the current study is not small, this study was not able to determine the actual prevalence of CAA because the study group consisted of a relatively select group of patients (asymptomatic high-risk patients, asymptomatic patients with risk factors, high-risk patients for atherosclerotic lesions and symptomatic cardiac patients). Comparisons with other modalities, such as conventional CAG, or collecting long-term follow-up data are outside of the scope of this study.

Conclusion

Based on recent advances in imaging technology, especially those that can provide high-quality measurements for the diagnosis of CAA, MSCT-CA is currently the main method of identifying CAA. The reason why MSCT-CA is the main method of identifying CAA is because of its capacity to gather a large amount of information on the complex

three-dimensional anatomy of vessels. In conclusion, the prevalence of CAAs was 9.37% in our select group of patients and the most common coronary artery anomalies were AICAs. Male sex showed a high tendency for occurrence of CAA and AICA, and thus it may be considered as a predisposition to atherosclerosis of the coronary arteries.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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