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Prevalence and imaging spectrum of coronary artery anomalies by coronary computed tomography angiography among patients with failed coronary artery catheterization; A single center cross-sectional study in Egyptian population

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ABSTRACT

Background: Anatomic variations and abnormalities of coronary arteries could affect the blood supply of the heart, hemodynamic characteristics and could be a risk of atherosclerosis. Knowledge about the variations of coronary artery origin and its course provides a valuable guide to Cardiothoracic Surgeons and Physicians and be useful for choosing the appropriate devices for such variant anatomical structures. The aim of the study was to estimate the prevalence of coronary artery anomalies among patients with fail ed coronary artery catheterization using CCTA to prevent misdiagnosis and reduce mismanagement of such anomalies.

Methods: One hundred MDCT coronary angiography examinations were done using a 128-detectors (Philips Healthcare Ingenuity) scanner for patients who had previously failed coronary artery catheterization. Dedicated software and post processing techniques were used for precise evaluation and description of the coronary artery tree to be a road map for future interventional procedures.

Results: Class A coronary artery anomalies were found in 53.2% of the detected anomalies (25 / 47 anomalies) in 20% of the included patients while class B coronary artery anomalies were recorded in 46.8% of the detected anomalies (22 / 47 anomalies) in 19% of the included patients. No cases showed class C anomalies in our cohort. Significant coronary artery disease (CAD) had no significant association with the presence of coronary artery anomalies.

Conclusions: Detection of different coronary artery anomalies among patients with previous failed coronary artery catheterization can help the cardiologists for better planning for the interventional procedures and better patient outcome.

Keywords: Coronary artery; Non-invasive; Origin; Coronary computed tomography angiography; Course.

INTRODUCTION

Coronary artery anomalies are seen in around 0.2% to 1.3% of the adult population and are generally asymptomatic and of little clinical importance. Certain forms of these anomalies, on the other hand, have been linked to unexpected mortality, particularly in young athletes. According to a study by the American Heart Association's Sudden Deaths Committee, these abnormalities may be responsible for about 19% of sudden death among athletics [1-3].

According to Angelini et al. [2] any variation from the normal anatomy that is found in more than 1% of the general population is considered a variant, while those occurring in less than 1% of population are considered anomalies.

About one-third of patients with anomalous aortic origin of a coronary artery (AAOCA) present with cardiovascular manifestations. The first presentation of these anomalies is variable, ranging from an incident finding to ischemic symptoms or sudden cardiac death (SCD) [4].

To detect coronary artery abnormalities, most prior investigations relied on traditional coronary angiography and autopsy where they classified various anomalies based on origin, course, branching pattern, and termination of coronary arteries, but these procedures have limitations being invasive, also two-dimensional (2D) imaging character of catheter angiography hinders the detection of ectopic coronary opening [3-5]. Coronary computed tomography angiography (CCTA) has become a

growing noninvasive technique with the potential to investigate coronary arteries and cardiovascular structures in a single short breath hold with high temporal and spatial resolution [6].

Multi detector computed tomography (MDCT) enables images to be processed in a variety of ways, including multiplanar reconstruction (MPR), maximum intensity projection (MIP), and volume rendering (VR). Moreover, it offers high-level vascular delineation of the coronary arterial tree that can decrease the incidence of technical difficulties during cardiac interventions or unpredictable complications during surgery [6,7].

The purpose of the study was to determine the prevalence of different coronary artery anomalies and cross-sectional appearances of the arteries among patients with failed coronary artery catheterization using CCTA in order to prevent misinterpretation of anomalies and failed catheterization leading to clinical mismanagement.

METHODS

We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement guidelines when reporting this manuscript [8].The study was approved by the local ethical committee at our institute (reference number: 9800) and written informed consents were taken from all patients. The study was conducted according to the ethical principles of Declaration of Helsinki's.

Study population

During the period from January 2022 to August 2022, in a single center prospective study a total number of 360 adult patients with normal heart rate were scheduled for elective MDCT coronary angiography. The patients were referred by a cardiologist to radiology department seeking CCTA for proper road mapping of the coronary arterial tree after failed coronary artery catheterization with a median time interval of 21 days between conventional coronary angiography (CCA) and CCTA. Of them, 259 patients underwent previous conventional coronary angiography and 117 were eligible for the current study. Inclusion criteria were i) Adult patients > 18 years, ii) patients complained of typical/atypical chest pain, ii) failed coronary catheterization procedures (such as failed coronary cannulation or failure to detect the ostium). Exclusion criteria included absolute contraindications such as i) Patients with elevated renal functions (creatinine ≥ 1.5 mg/dl), but not on dialysis (n=2), ii) Patients with contraindications to contrast media, iii) Pregnant females, iv) Morbid obesity (n=3), v) post-CABG surgeries (n=5) and vi) Poor image quality images (n=7). Relative contraindications i) Patients of renal diseases on dialysis, ii) hemodynamic instability, iii) Inability to hold breath for 12 sec, iv) tachycardia (> 70 b/m), v) arrhythmia and vi) thyrotoxic patients.

All patients were subjected to full history regarding risk factors for coronary artery disease, chest pain, cyanosis, revascularization procedures or conventional coronary angiography then revision of previous laboratory and other cardiac investigations. Basic and clinical characteristics of the included patients are summarized in (**Table S1)**. The flow of the study process is shown in (**Figure 1).**

Patient preparation

Prior to examination for HR control to be kept about 65 beats per minute for optimum image quality (Beta – blockers administration one day before examination or Ivabradine three days before examination), respiratory training as CCTA should be obtained during a single breath hold for 12 sec, I.V route in right antecubital vein, ECG gating for simultaneous acquisition of both the patients ECG tracing and the CT data.

CT coronary angiography examination

Patients were scanned using a 128-detectors scanner (Philips Healthcare Ingenuity, Philips Medical System, Best, Netherlands) We did scanogram, Calcium score (if > 500 abort the examination), C.M administration using bolus tracing technique, 80-100 ml of non-ionic CM injected with rate of 5-6 ml /sec injected via dual head Medrad stellant injector pump together with 50 ml saline chaser bolus was used to washout contrast medium from right side of heart. A retrospective ECG gated or semi-prospective (phases: 40-80%) CTA was done with single breath hold and image acquisition start from carina till 1cm below diaphragm for coronary CTA. The contrast threshold for starting image acquisition is 180 HU at descending aorta.

Image reconstruction & analysis

The obtained axial images were revised and reconstructed using post processing techniques as curved and oblique (MPR), (MIP) and volume rendering (VR) on an advanced Philips Brilliance workstation using small slice thickness of 0.6 mm of axial images for analysis of the small and tortuous coronary arteries.

First, choose the best phases based on best contrast filling of coronary arterial tree and least movement artifact, revision of axial images to

evaluate cardiac volume with attention to cardiac anatomy, degree of opacification of chamber and walls of the heart, and extra cardiac structures. Then, we analyze the coronary arterial tree in axial and reconstructed images for full identification of the coronary anatomy including the dominance, origin, course, caliber, termination and branches of each coronary artery to identify normal right and left coronary arterial systems as well as any coronary arteries congenital abnormalities and to localize associated CAD using 17- Segment model described by AHA. The final diagnoses were made by two radiologists with 7- and 10-years' experience in cardiac imaging.

Sample size and power calculation

The aim of the study to estimate the prevalence rate of coronary anomalies among patients with failed coronary catheterization for CAD. Assuming a prevalence rate of 18.9% as reported in a previous study by Abdel-rahman et al. [9], this study required at least 59 participants to detect a similar prevalence rate with 5% deviation and 95% confidence interval. Sample size was calculated using the Statistics and Sample Size app for Android (version 14). One snapshot from the sample size calculation software input and output are shown in **(Figure S2).**

Statistical analysis

Data were collected and submitted to statistical analysis using Microsoft Excel software. Data were then imported into Statistical Package for the Social Sciences (SPSS version 20.0) software for analysis. Qualitative data were represented as number (n) and percentage (%), quantitative data were represented by mean ± SD or median and interquartile range according to the results of the normality tests. Differences between quantitative paired groups were tested by paired t test for significance. The Chi square test was utilized to assess the association between coronary anomalies and significant coronary artery disease (CAD). P value was set at <0.05 for significant results.

RESULTS

The current study was conducted on eligible 100 patients with normal heart rate who were scheduled for elective CCTA in the period from January 2022 to August 2022. They were 71 male (71%) and 29 female (29%), their age ranged from 24 to 68 years (mean: 48.3 ± 13.9). The commonest age group of the selected patients was 50 - 60 years age (66%). There was no significant association between the gender and the coronary artery anomalies.

Dominance of the coronary system

Regarding dominance of coronary arteries, 83.3% of patients were right dominant, 6.7% were left dominant and 10% were co-dominant.

Prevalence of the coronary artery anomalies in the current study

The coronary arteries anomalies were classified according to 2007 classification described by **Angelini et al.** [2], 47 coronary artery anomalies were found in 39% of studied patients (n:39). They were classified into two groups: class A anomalies of the origin and course of coronary arteries were reported in (n: 25, 53.2%) and class B coronary artery anomalies of intrinsic anatomy were found in (n: 22, 46.8%). There were no cases of Class C coronary artery anomalies of termination e.g., Coronary artery Fistula.

Prevalence of Class A coronary artery anomalies

Class A coronary artery anomalies represented about 53.2% of detected anomalies (25/47 anomalies) in 20% of patients (**Table 2)**. These anomalies involved left coronary artery (n:5, 20%), right coronary artery (n:14, 56%) or both (n:6, 24%) where high take off RCA was the commonest detected anomaly (n:6, 12.8%) followed by malignant inter-arterial course of anomalous RCA (n: 4, 8.5%), absent LMA where LAD and LCX arising directly by a single common ostium from left coronary sinus (n:3, 6.4%) (**Figure 2),** coronary arteries arising from non- coronary sinus (n:3, 6.4%), RCA arising from left coronary sinus (n:2, 4.3%) with malignant inter-arterial course as RCA passes between RVOT and aorta (**Figure 3),** a single coronary artery accounts for 10.6% (n:5) of detected anomalies;(one case SCA arises from an interrupted aortic arch which had an abnormal course, two cases showed SCA arising from right coronary sinus (**Figure 4),** two cases showed SCA arising from left coronary sinus with malignant inter-arterial course. Moreover, the current study reported one pre-pulmonic course of LMA in the case of D-TGA.

Prevalence of Class B coronary artery anomalies

Class B of intrinsic coronary artery anomalies represented 46.8% of detected anomalies (22 /47 anomalies) in 19% of patients (**Table 3).** These anomalies involved left coronary artery (n:12, 54.5%), right coronary artery (n:9, 41%) or both (n:1, 4.5%). The most common coronary artery intrinsic anomaly was myocardial bridging of mid LAD and found in (n:9, 19.15%) (**Figure 2)** of all the detected anomalies followed by coronary artery ectasia (n:3, 6.4%) including ectasia of LMA in a Marfan patient

(Type 2) associated with aneurysmal dilatation of RCA, and ectasia of RCA in polycythemia rubra vera patient (Type 3) (**Figure S3).** However, the least intrinsic coronary anomaly reported in the current study was dual LAD type 2 (n:2, 4.3%) (**Figure 2).**

Prevalence of right and left coronary artery system anomalies

Regarding the prevalence of coronary artery anomalies between left and right arterial systems, the current study recorded a higher prevalence of right system anomalies than left system anomalies (48.9 % Vs 36.2%). Non specified cases reported 14.9% detected anomalies including single coronary artery arising from aortic sinus or interrupted aortic arch (**Figure S4)**.

Association between the coronary artery anomalies and coronary artery disease (CAD)

Among 100 cases investigated for coronary artery disease, 60 patients had significant coronary artery disease (CAD) from which only 13.3% were positive for coronary artery anomalies (n: 8). There was a non-significant association between significant CAD and positive coronary artery anomaly (*P*: 0.197) (**Table S5).**

Table 1. Prevalence of Class A anomalies of origin and course of coronary arteries among studied group

Anomalies of origin and course	N	Constituent ratio among anomalous cases %	Anomaly incidence among studied patients %
Single ostium of LAD & LCX (Absent LMA)	3	6.38	3
LMA origin from Non coronary sinus (NCS)	1	2.13	1
Pre-pulmonic course of LMA in D-TGA	1	2.13	1
High take-off RCA	6	12.77	6
RCA origin from Non coronary sinus (NCS)	2	4.25	2
RCA origin from left coronary sinus	2	4.25	2
Malignant inter-arterial course of anomalous RCA	4	8.5	4
Single coronary artery from RT coronary sinus (SCA)	2	4.25	2
Single coronary artery from interrupted aortic arch (SCA)	1	2.13	1
Single coronary artery from left coronary sinus (SCA)	2	4.25	2
Abnormal pre-pulmonic course of single coronary artery arising from an interrupted aortic arch.	1	2.13	1
Total	25	53.17	25

Table 2. Prevalence of Class B anomaly of intrinsic anatomy distribution among studied group.

Anomalies of Intrinsic anatomy	N	Constituent ratio among anomalous cases %	Anomaly incidence among studied patients %
Myocardial bridge of LAD	9	19.15	9
Ectasia of left main coronary artery in Marfan patient	2	4.2	2
Ectasia of Right coronary artery in polycythemia patient	1	2.13	1
Aneurysmal dilation of right coronary artery ostium in Marfan patient	1	2.13	1
Hypoplastic RCA	4	8.5	4
Dual LAD type 2	2	4.2	2
Slit ostium of RCA	3	6.38	3
Total	22	46.8	22

Table 3. Comparison between the prevalence of coronary artery anomalies in the current study and the previously published studies

Study ID	Year of publication	Country	Study design	Sample size	Device	Prevalence	Commonest anomaly	No. of readers	CAD
The current study		Egypt	Prospective	100	128-detectors scanner (Philips Healthcare Ingenuity, Philips Medical System, Best, Netherlands)	39%	High take-off RCA	2	13.3%
tenKate et al [15]	2008	Netherland	Case series	1000	64-slice dual source CT	0.01%	Anomalous origin of RCA	N/A	0.3%
Von Ziegler et al [16]	2009	USA	Prospective	748	64-slice scanner (Sensation 64 Cardiac, Siemens Healthcare, Malvern, PA)	2.3%	Anomalous origin of RCA (excluding myocardial bridge from study)	N/A	N/A
Kosar et al [11]	2009	Turkey	Retrospective	700	64-slice CT scanner (Aquillon 64, Toshiba Medical Systems, Tochigi, Japan)	41.3%	Myocardial bridge	2	N/A
Erol and Seker [7]	2011	Turkey	Retrospective	2096	64-detector CT (Lightspeed VCT; GE Healthcare, Milwaukee, Wis)	1.96%	Anomalous origin of RCA and absent LM	1	64.6%
Xu et al [17]	2012	China	Retrospective	12145	DSCT system (Somatom Definition; Siemens Medical Systems, Erlangen, Germany).	1.02%	Anomalous origin of RCA	2	23.3%
Turkvatan et al [18]	2013	Turkey	Retrospective	2375	16-slice (GE Lightspeed Ultra 16; General Electrical Medical Systems) or a 64-slice (Aquilion; Toshiba Medical Systems)	2.19%	Anomalous origin of LM	2	N/A
Namgung and Kim [19]	2014	Korea	Retrospective	8864	64-MDCT scanner (Aquilion 64, Toshiba Medical Systems, Otawara, Japan) or a 320-MDCT scanner (Aquilion ONE, Toshiba Medical Systems).	1.16%	Anomalous origin of RCA	2	N/A
Ghadri et al [20]	2014	Switzerland	Retrospective	1759	64-slice CT scanner (LightSpeed VCT, GE Healthcare	7.9%	Myocardial bridge	2	N/A
Abdel-rahman et al [9]	2015	Egypt	Prospective	1000	320-row CT scanners (Aquilion	18.9%	Myocardial bridge	2	N/A

Study ID	Year of publication	Country	Study design	Sample size	Device	Prevalence	Commonest anomaly	No. of readers	CAD
					ONE, Toshiba Medical Systems, Tochigi-ken,Japan)				
Graidis et al [21]	2015	Greece	Prospective	2572	64-slice scanner (LightSpeed VCT 64 GE Healthcare device)	2.33%	High-take off RCA	1	N/A
Tharwat e al [22]	2017	Egypt	Retrospective	4595	CCA	2.7%	Anomalous LCX	N/A	72.2%
Sirasapalli et al [23]	2018	India	Retrospective	8021	64-slice Dual Source CT scanner (SIEMENS SOMATOM DEFINITION)	10.09%	Myocardial bridge	N/A	61.5%
Kultida et al [6]	2018	Thailand	Retrospective	279	64-MDCT scanner (Brilliance TMCT, Philips, Netherlands)	61.6%	Myocardial bridge	3	N/A
G.Eldin et al [1]	2018	Egypt	Prospective	100	MDCT (Aquillon 64, V4.51 ER 010, Toshiba Medical Systems, Tochigi, Japan)	6%	Myocardial bridge	2	N/A
Chaosuwannokit [24]	2018	Thailand	Retrospective	924	dual-source CT scanner (Definition FLASH, Siemens Healthcare, Forchheim, Germany)	3.7%	Myocardial bridge	1	N/A
Gunduz [25]	2019	Turkey	Retrospective	700	128 slices CT [Siemens Definition AS +(Plus) device	15.3%	Myocardial bridge	N/A	28.1% of total patients
Umairi et al [26]	2019	Oman	Prospective	4445	dual source 256 slice (2 × 128) scanner (SOMATOM Definition Flash, Siemens AG)	1.3%	Anomalous origin of RCA	3	1.7%
Ganga et al [27]	2021	India	Retrospective	7694	dual-sources 128 or 384 slice (Siemens Somatom Definition, Erlangen, Germany)	9.6%	Myocardial bridge	N/A	N/A
Muhtaroglu et al [28]	2021	Cyprus	Retrospective	4099	Coronary angiography	1.85%	Absent LM	N/A	N/A

Anomalies of origin and course	N	Constituent ratio among anomalous cases %	Anomaly incidence among studied patients %
Single ostium of LAD & LCX (Absent LMA)	3	6.38	3
LMA origin from Non coronary sinus (NCS)	1	2.13	1
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Malignant inter-arterial course of anomalous RCA	4	8.5	4
Single coronary artery from RT coronary sinus (SCA)	2	4.25	2
Single coronary artery from interrupted aortic arch (SCA)	1	2.13	1
Single coronary artery from left coronary sinus (SCA)	2	4.25	2
Abnormal pre-pulmonic course of single coronary artery arising from an interrupted aortic arch.	1	2.13	1
Total	25	53.17	25

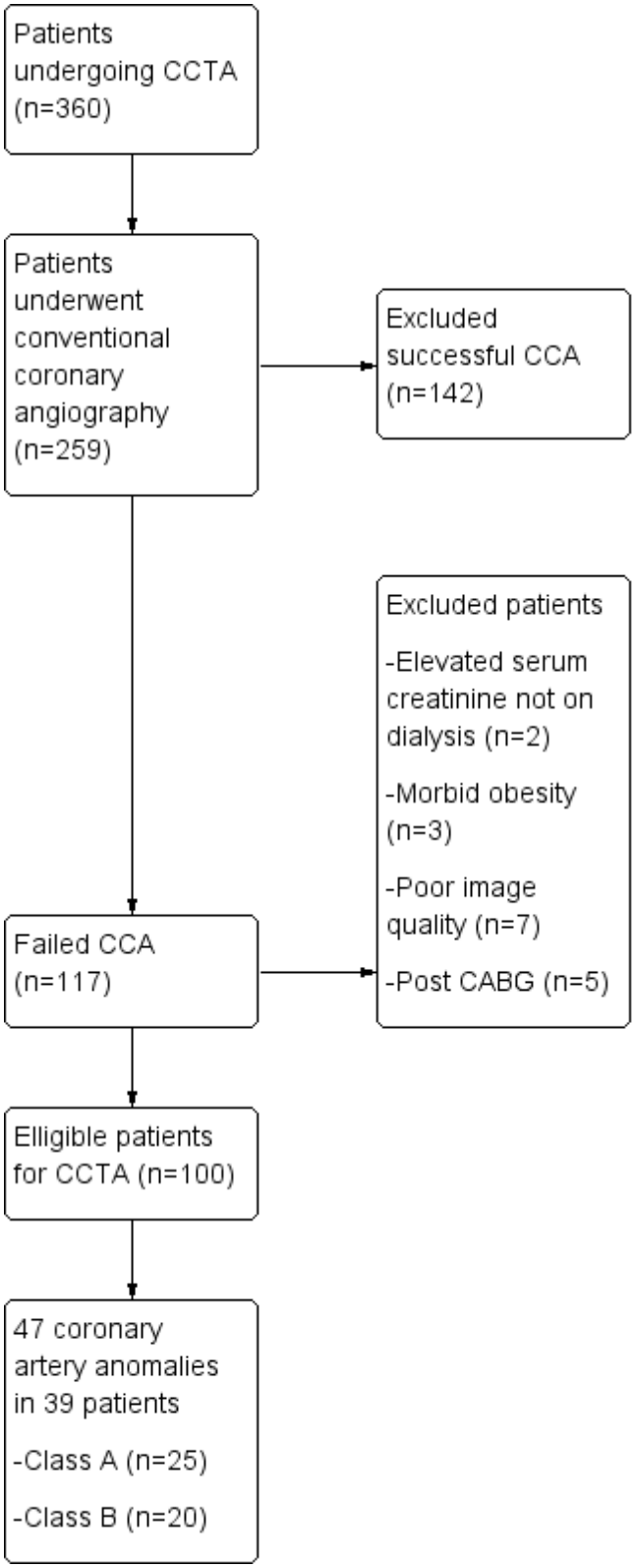


Figure 1. Flow chart of the study process.

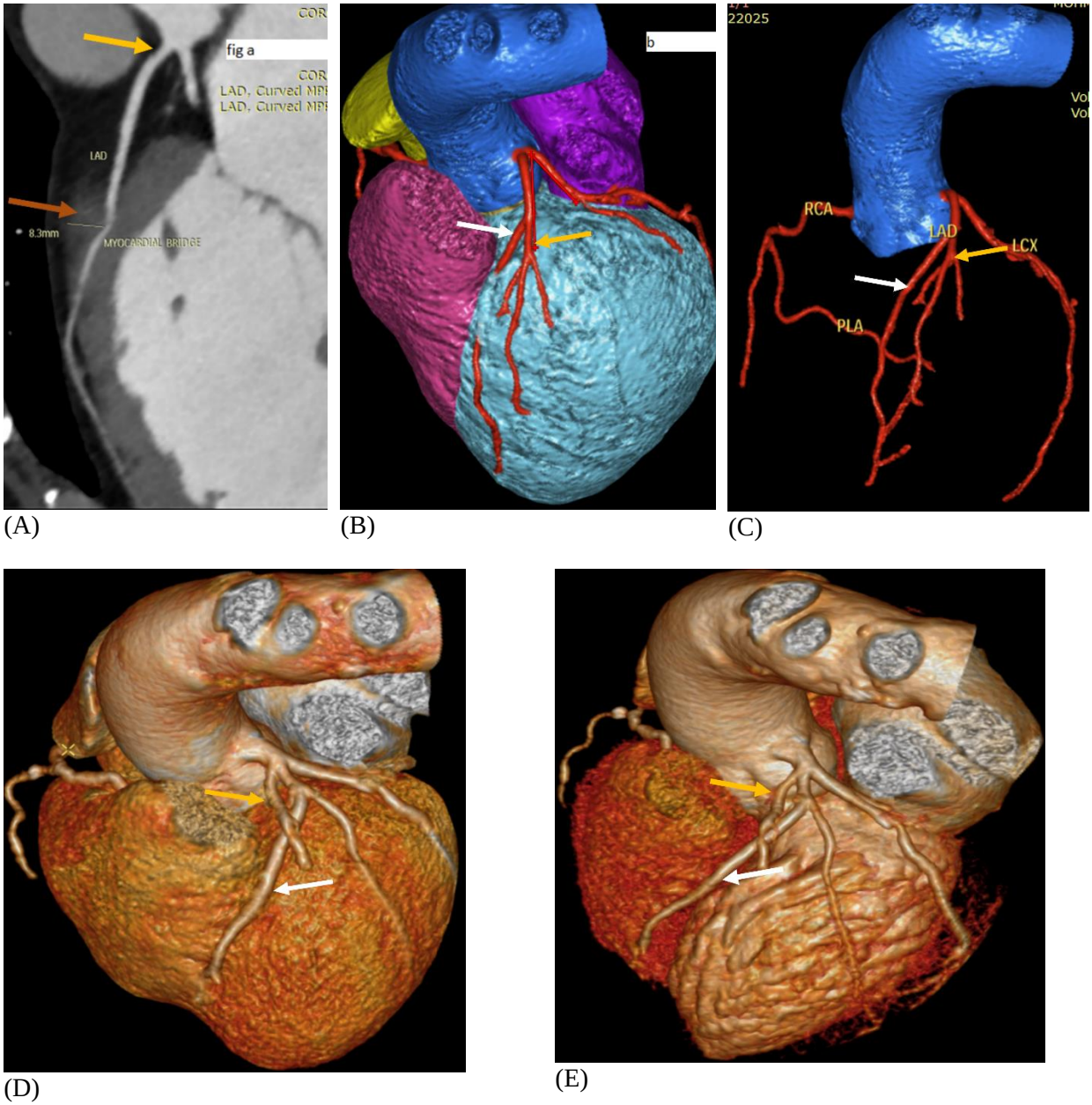
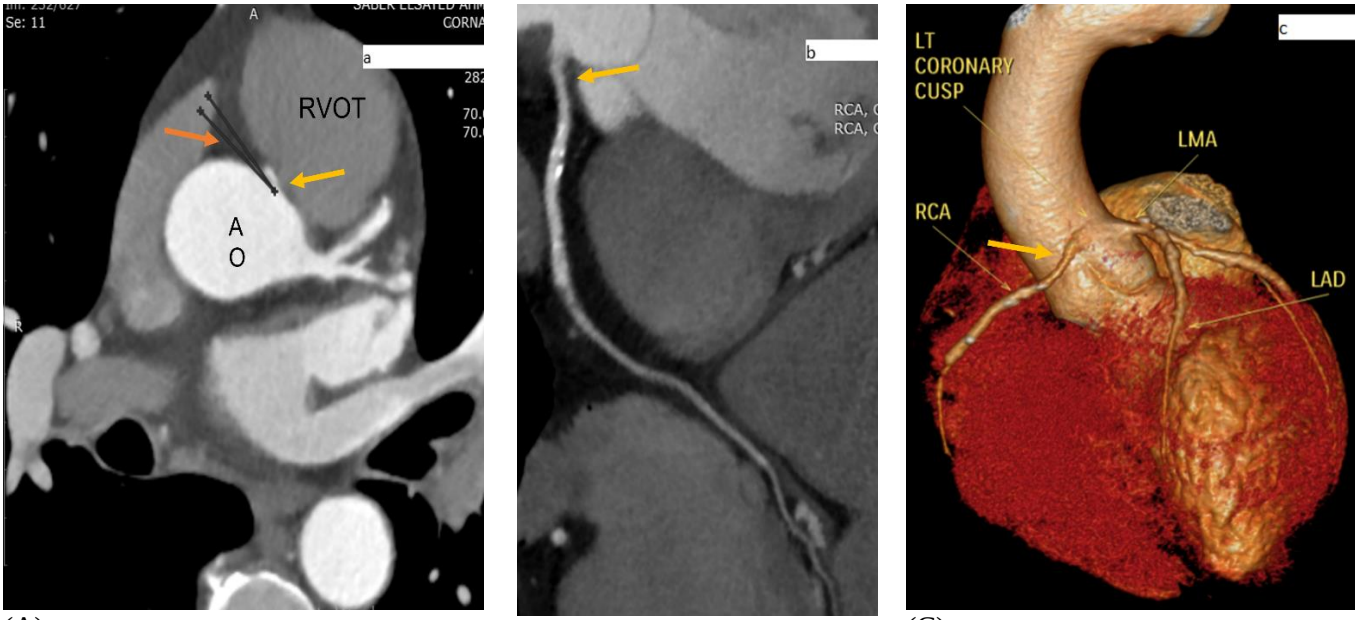
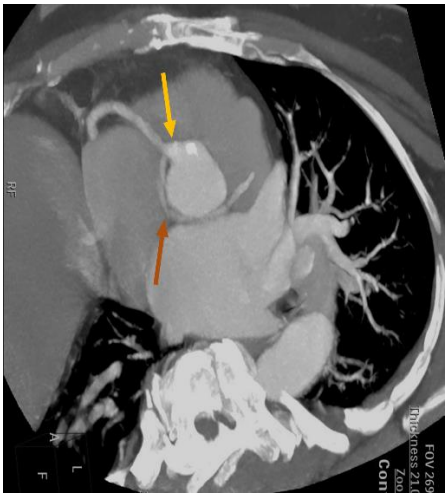


Figure 2. 35- year- old male patient, referred for acute onset chest pain and syncope. Curved MPR images **(a)** absent LMA, LAD and LCX arise by a single common ostium from LT coronary sinus (yellow arrow) with myocardial bridging of mid portion of long LAD for 8.5 mm depth and 32mm length exerting mild stenosis at systolic phases (orange arrow). 3D colour coded VR and 3D VR of coronary tree (anterior View) **(b) and (c)** images show dual LAD (type 2) with early splitting of LAD proper into a short LAD (yellow arrow) which terminates at mid inter-ventricular grove and a long LAD (white arrow) that runs parallel and to the right of the short LAD and continues its distal course at the interventricular groove. The short LAD supplies diagonal and septal branches thus ensures being LAD rather than diagonal branch. 3D colour coded VR **(d) and (e)** in another patient show splitting of LAD into dual LAD (type 2) where a short LAD (yellow arrow) arises from the right side of LAD proper then crossing anterior to it to end shortly at the left ventricular wall while long LAD (white arrow) continues its course along the anterior inter-ventricular groove and gives rise to one Diagonal branch (D1).

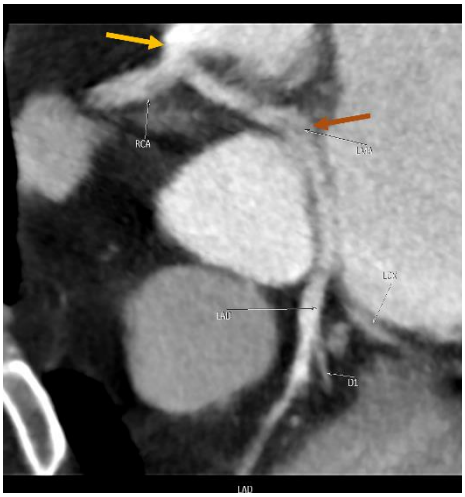


(A) (B) (C)

Figure 3. 53- year- old male patient, referred from a cardiologist for suspicion of having anomalous RCA due to failed RCA cannulation. Axial MIP, Curved MPR, 3D-VR (anterior view) **(a), (b) and (c)** images show anomalous origin of RCA from antro-superior aspect of Lt. Coronary sinus (yellow arrow) with acute take off (RCA- aorta angle measures 25.6) (orange arrow). Slit like ostium and proximal RCA stenosis is due to malignant inter-arterial course between aorta and RVOT.



(A)



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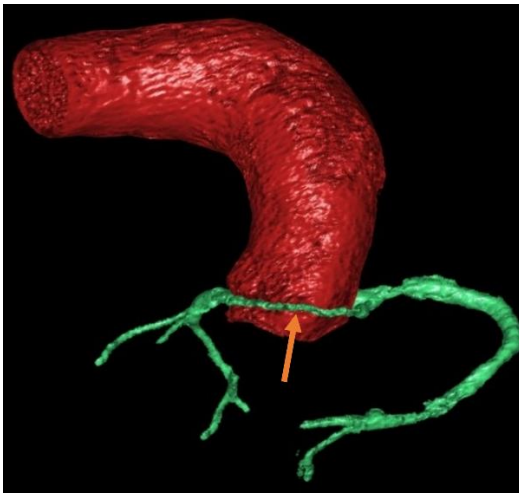

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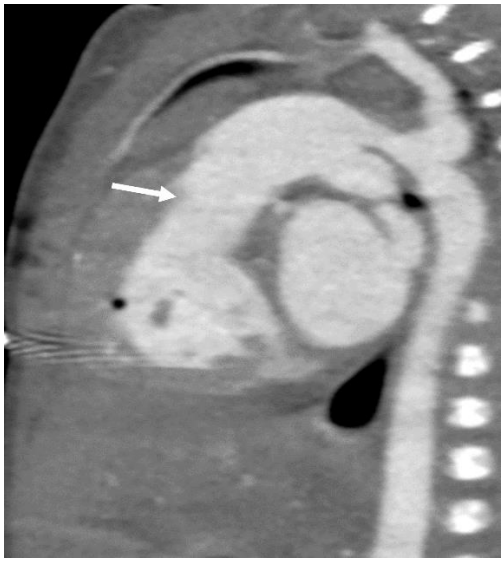
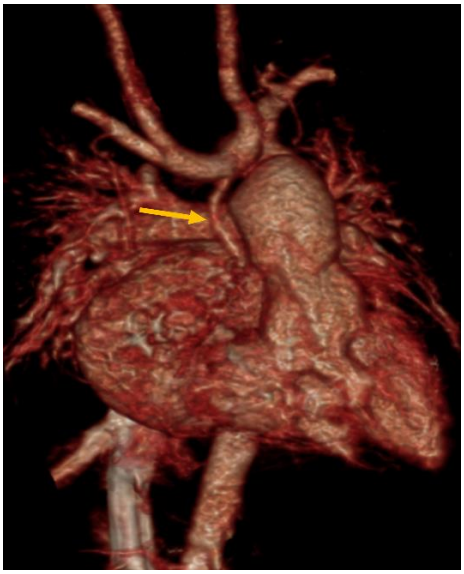


(D)



(E)

Figure 4. 40- year- old female patient presented with chest pain. Curved MPR and 3D VR of coronary tree (posterior view) **(a), (b) and (c)** show a single coronary artery (SCA) arises from anterior coronary sinus (yellow) giving rise to RCA and anomalous long LMA with circumaortic course then retroaortic course till it reaches anterior interventricular groove (orange arrow) where it bifurcates to LAD & LCX which continue at their normal course Curved planar reformatted image and 3D VR (lateral View) **(d) and (e)** in another patient show truncus arteriosus(white arrow) with interrupted aortic arch (type A4), it also shows a single coronary artery (SCA) (yellow arrow) arising from inferior surface of aortic arch, then runs inferiorly along the right side of the common trunk anterior to right pulmonary artery (pre-pulmonic course) .

DISCUSSION

Coronary artery anomalies are rare and usually are accidentally discovered. Given the increase of interventional procedures, the detection of coronary anomalies is becoming of major clinical significance [10].

For evaluating the coronary artery system, CCA has traditionally been the method of choice for many years. Even with its popular use, alternative

techniques of coronary artery system imaging are preferred. CCA has many drawbacks such as it is invasive and not very effective at identifying coronary artery abnormalities because of its limited 2D projections photos taken while having a catheter placed additionally and the lack of soft tissue data [11].

MDCT coronary angiography enables accurate noninvasive detection of normal anatomic variants and congenital anomalies of coronary arteries offering a road map before conventional coronary angiography and is also useful in diagnosis of significant coronary artery disease. The wrong evaluation of coronary anatomy may cause technical difficulties during revascularization procedures or lead to clinical misdiagnosis or catastrophic complications [12]. Recent improvement of spatial, temporal resolution, and recent post-processing techniques makes diagnosis of coronary anomalies more common with CTA than invasive angiography [13].

In the current study 47 coronary arterial anomalies were detected in 39% of the studied patients. Class A anomalies were more common than class B anomalies (53.2% Vs 46.8%) with (25% and 22% incidence among studied cases) and 0% incidence of class C anomalies of termination. Anomalies of the right system were higher than anomalies of the left system (48.9% Vs 36.2%) while non specified cases recorded 14.9% of the detected anomalies. The commonest type A anomaly detected was high take off RCA and anomalous origin of RCA while the commonest type B anomaly detected was LAD myocardial bridging.

In the current study upon 100 patients presented with chest pain and failed coronary artery catheterization, there was no statistically significant difference regarding the gender and the prevalence of coronary artery anomalies. This is in disagreement with **Kashyap et al.** [14] who reported male predominance for coronary anomalies (2.07:1 male to female ratio).

Multiple previous studies with variable sample sizes and different patient racial population reported different prevalence rates of coronary artery anomalies [1,6,7,9, 15-28] as shown in **(Table 5). Kashyap et al** [14] reported 2.06% prevalence of coronary anomalies, the anomalous origin and course of the coronaries were the most common anomaly seen in (1.29%) patients, followed by intrinsic anomalies of the coronary arterial system in (0.7%) patients and anomalies of coronary termination and anomalous anastomotic vessels in (0.03%). Most of the previously conducted studies either with CCTA or CCA reported higher prevalence than the current study owing to small sample size of the current study, and we conducted the study on a particular patient population with previous failed coronary artery catheterization.

While in a study conducted by **Namgung and Kim** [19] (over 8864 patients on 64- or 320-MDCT) class A anomalies were found in 87.4% Vs 12.6% compared to class C anomalies. Moreover, the origin anomalies were the most common reported abnormalities, and the anomalous origin of RCA was the most common detected anomaly (39.8%). These results are in line with the current study respecting that class A anomalies were the most commonly detected coronary anomalies.

Regarding absent LMA where the LAD and LCX originate separately or by single ostium from the left sinus of Valsalva, the incidence of this abnormality in the current study group was 3%. These results are in line with **G.Eldin** [1] and **Cademartiri et al**. [5] who reported absence of LMA in (2% and 4.1%) respectively, but higher than **Tharwat et al.** [22], **Sirasapalli et al** [23], **Chaosuwannakit** [24], **Kultida et al.** [6] and **Koşar et al.** [11] who observed this anomaly in (1.78%, 0.3%, 0.4% and 0.4%) respectively. The much lower incidences reported in those studies can be attributed to the larger sample size of their studies and some racial differences.

When the RCA or LMCA originates above the junctional zone between its sinus and the tubular portion of the ascending aorta, this is referred to as a "high take-off" [12]. However, there has been some debate concerning the origin position. Some reports [29] specified a high position of ostium as 5 mm above the sinotubular junction of the aorta. Others have specified that a high position of ostium is 10 mm above the sinotubular junction of the aorta [7,11,30]. In the current study, a cut-off of 10 mm above the sinotubular junction of the aorta was used. The current study reported that high take-off RCA was the most common detected class A anomaly accounting for 12.8% of the detected anomalies with 6% incidence among the studied cases. These results are higher than the results of **Graidis et al.** [21], **Erol and Seker** [7], **Chaosuwannakit** [24], and **Abdelrahman et al.** [9] who reported this anomaly in (0.78%, 0.43–0.8%, 0.4% and 0.2%), respectively. This might be attributed to the smaller sample size of the current study. However, the current study was in

line with **Graidis et al.** [21], who reported that high take-off RCA was the most common Class B anomaly detected.

In this study, the origin of RCA from left coronary sinus and non-coronary sinus was noted in 2% for each among the detected anomalies, these findings are higher than those reported by **Chaosuwannak**it [24] , **Kultida et al.** [6] , **G.Eldin et al.** [1] **Rao et al.** [3] , **Koşar et al.** [11], **Graidis et al.** [21] who observed abnormal origin incidence rate (0.3%-1.2%), and also **Bunce et al.** [32] who reported incidence rate of (0.03%- 0.17%), this difference might be attributed to relatively small sample size and the particular condition of the studied patient concerning failed coronary catheterization. In contrast, **Tharwat et al.** [22] reported a higher incidence of the anomalous RCA origin with a prevalence rate of 8.7% of the detected anomalies.

In terms of LMCA origin, the origin of LMCA was from the left coronary sinus of valsalva in 96%, from the non-coronary cusp in 1%, from the right coronary sinus of Valsalva as branch from single coronary artery in 2% and from the aortic arch in case of Truncus arteriosus type A4 in 1%, these findings are in agreement with **G.Eldin et al.** [1] who reported that the origin of LMCA was from the left coronary sinus of valsalva in 96% and from the right coronary sinus of valsalva in 2% among the detected coeonary anomalies, and in partial agreement with **Sirasapalli et al.** [23] who reported that LMCA originates from the right coronary sinus in 1.43%. Other studies conducted by **Bunce et al.** [32], **Chaosuwannakit** [24] and **Abdelrahman et al.** [9] recorded that the LMCA originates from the right coronary sinus in (0.09%, 0.2%, 0.4% respectively) of their study population.

Concerning single coronary artery (SCA), SCA was found in 10.6% of the detected anomalies with 5% incidence among studied patients while **Sirasapalli et al.** [23], **Chaosuwannakit** [24] and **Garidis et al.** [21] reported SCA with much lower incidence rate than the current study (1.43%, 0.4% and 0.12%) respectively.

Multiple previous studies reported a prevalence range (0.6-5.64) for coronary class B anomalies [2, 32, 33]. Myocardial bridging was the most commonly detected class B anomaly in our study (9% incidence). Moreover, MDCT enables assessment of the length, depth, diameter and degree of stenosis of the tunneled coronary segment whether superficial or deep bridging in both systolic and diastolic phases. **Alegria et al.** [34] and **Bourassa et al.** [35] reported an incidence rate from 15% - 85% in autopsy studies and from 0.5-2.5% in angiographic studies while **Hazirolan et al.** [36] found that the rate rises to 40% when provocation test was used during conventional angiography.

Coronary artery ectasia (CAE) commonly affects the proximal and mid right coronary artery with male predominance (75-88%) [37,38]. MDCT enables assessing the size and distribution of CAE. In the current study CAE was recorded in 6.38% of the detected anomalies with 3% incidence among the studied cases. It was encountered in 7.4% of patients in the study performed by **Farrag et al.** [39]. Another study conducted by **Lin et al.** [40] reported 0.3–12% prevalence.

There were no cases of class C recorded in the current study however, **Tharwat et al.** [22] recorded a high prevalence rate of such anomaly with a prevalence rate of 7.82%, this is owing to more complex patients' cardiac condition in their study compared to the enrolled patients of the current research. Moreover, the different technique of evaluation as **Tharwat et al.** [22] used CCA.

The current study showed some strength points, first; the images were analyzed by highly experienced radiologists in cardiac imaging, secondly; we used one of the recent MDCT devices with multiple processing capabilities and finally; the study was conducted on CAD patients with failed coronary artery catheterization which is more common with different cardiac conditions such as anomalous coronary artery origin and after TAVI procedures. The main limitations of this study were, first, it was a descriptive study with non-available gold standard comparative CCA study hinders calculating the diagnostic performance because it targeted specific patient population with no available CCA data, secondly; the relatively small number of study population, and finally; the selection bias might be introduced because many patients were referred to MDCT due to failed cannulation during CCA. Therefore, it does not represent the general population.

To the best of our knowledge, there were no similar studies conducted on patients after failed CCA and this study expands the literature with the prevalence of coronary artery anomalies among such patient population. Future research targeting this population are recommended to validate our detected coronary artery anomalies prevalence. CCTA is a non-invasive technique and can provide

clinicians with a dedicated road map of the coronary arterial tree helping in reducing CCA adverse events and improving the outcome.

CONCLUSIONS

CCTA is a valuable noninvasive modality for diagnosis and delineation of coronary artery anomalies. Early diagnosis of coronary artery anomalies using different post processing techniques of CCTA can help the physician in treatment planning, lead to reduction of failed coronary artery catheterization and cardiac surgery complications.

List of Abbreviations

SCD=sudden cardiac death, CABG=coronary artery bypass graft, CCTA=coronary computed tomography angiography, CAD= coronary artery disease, AHA= American heart association, SCA= single coronary artery, RVOT =right ventricular outflow tract, TGA =transposition of great vessels, CAE=coronary artery ectasia.

Disclosure of potential conflicts of interest

Declaration of interest: The authors report no conflict of interest.

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Supplementary Table & Figure

Table S1. Basic and clinical characteristics of the studied patients underwent MSCT coronary angiography.

Variable	The studied patients (N=100)	
Age (years)	**Mean ± SD**	**Median (range)**
	48.3 ± 13.3	
Sex	**No.**	**%**
Male	71	71%
Female	29	29%
Symptoms		
Typical chest pain	55	55%
Atypical chest pain	45	45%
Dyspnea	28	28%
Syncope	4	4%
Cyanosis	2	2%
Comorbidities		
Hypertension	56	56%
Diabetes mellitus	33	33%
Hyperlipidemia	47	47%
Smoking	29	29%
Family history of CAD	19	19%
Obesity	21	21%
Echocardiography		
EF (%)	58 (22)	

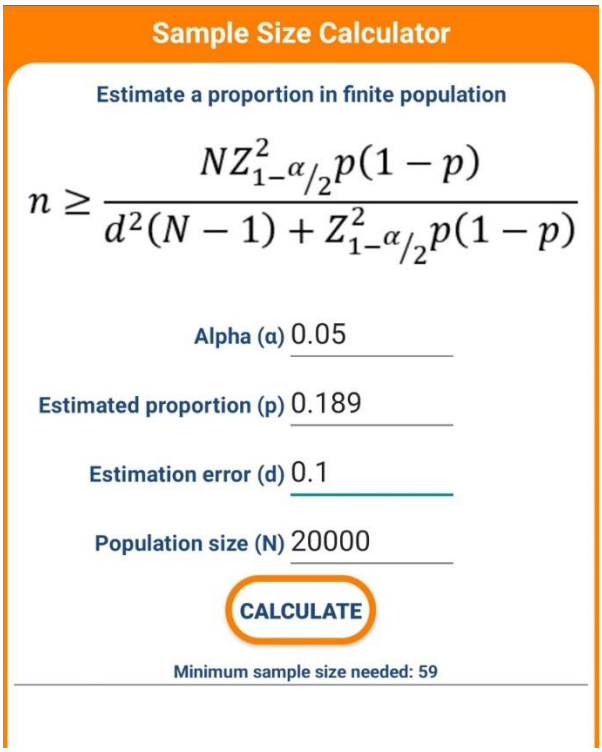
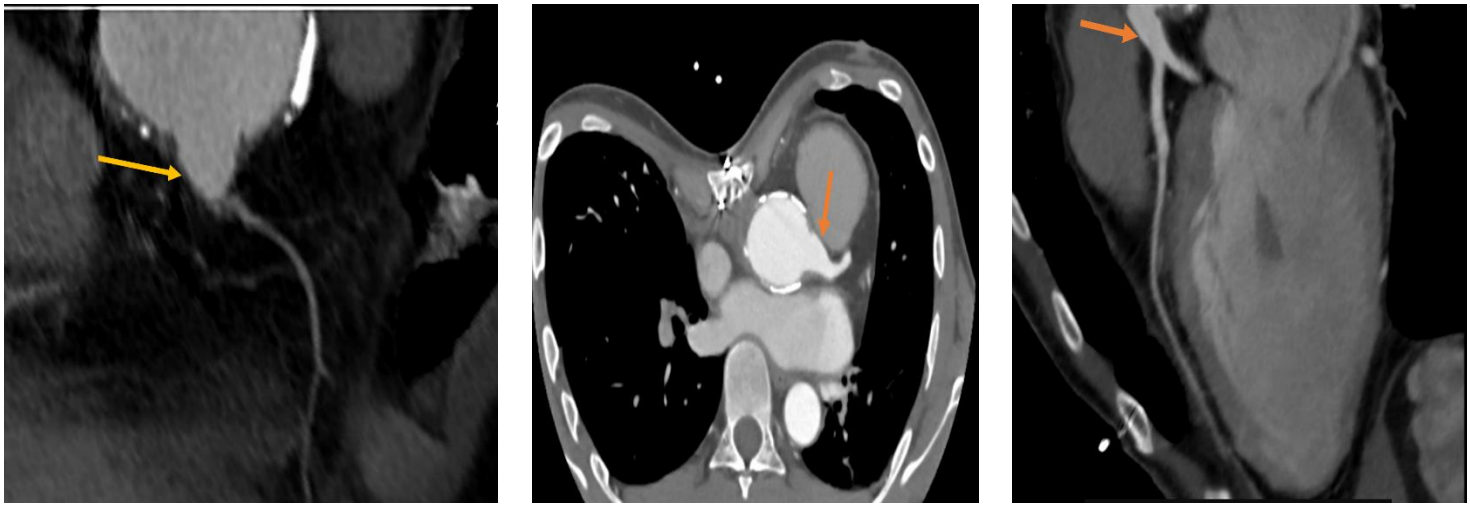


Figure S2. Snapshot of the inputs and outputs of the sample size calculator software.



(A) (B) (C)

Figure S3. 30 -year- old male patient with Marfan syndrome underwent TAVR. Curved MPR and Axial MIP images **(a), (b) and (c)** show osteal focal aneurysmal dilatation of RCA measuring 9 mm (yellow arrow) and abnormal diffuse ectasia of LMA measuring 11.1 mm in diameter (orange arrow) (type 2 coronary artery ectasia secondary to Marfan syndrome).

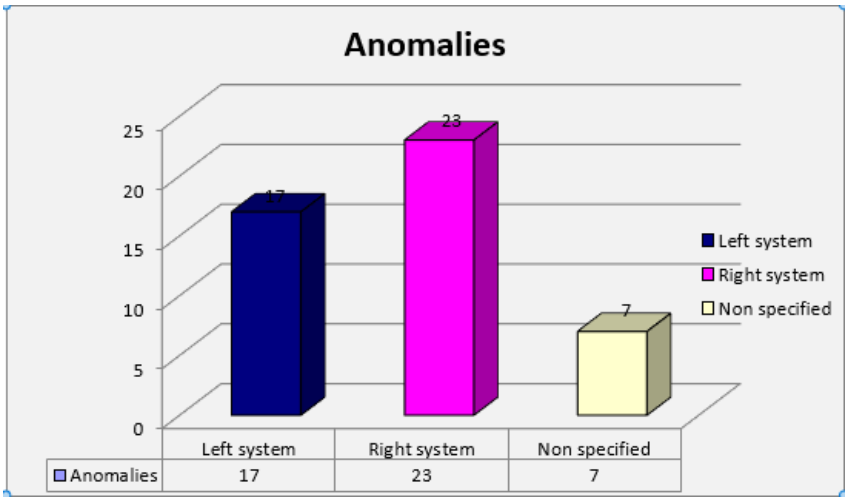


Figure S4. Bar chart displaying the prevalence of coronary artery anomalies concerning right and left coronary arterial systems.

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Table S5. Shows the association between coronary artery anomalies and significant CAD

Variables	Significant CAD (n=60)		χ^2	*P value*
	No	**%**		
Anomaly Positive	8	13.3	1.6	0.197 (NS)
Negative	52	86.7	67	

*** Chi-square test, P< 0.05 is significant.**

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	*N/A*
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*N/A*
Bias	9	Describe any efforts to address potential sources of bias	*N/A*
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	*N/A*
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	8
		(*c*) Explain how missing data were addressed	*N/A*
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	8
		(*e*) Describe any sensitivity analyses	*N/A*
Results			

	Item No	Recommendation	Page No
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5 and 8
		(b) Give reasons for non-participation at each stage	5
		(c) Consider use of a flow diagram	5
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8
		(b) Indicate number of participants with missing data for each variable of interest	8
Outcome data	15*	Report numbers of outcome events or summary measures	8,9,10
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	*N/A*
		(*b*) Report category boundaries when continuous variables were categorized	*N/A*
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	*N/A*
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	*N/A*
Discussion			
Key results	18	Summarise key results with reference to study objectives	11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12,13,14
Generalisability	21	Discuss the generalisability (external validity) of the study results	12
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	*N/A*

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.