The Egyptian Journal of Hospital Medicine (July 2018) Vol. 72 (4), Page 4270-4277

Role of MDCT Angiography in Diagnosis and Evaluation of Anatomical Variations and Anomalies of the Coronary Arteries

Mostafa M.G. Eldin, Wessam S Shokry, Aws R Al-Isawi
Department of Radiodiagnosis, Faculty of Medicine, Ain Shams University, Cairo, Egypt
Corresponding author: Aws R Al-Isawi; **Mobile:** 01009791336; **Email:** aws.alisawi@yahoo.com

ABSTRACT

Background: Coronary anomalies are often asymptomatic and may be accidentally discovered. With the increase of interventional coronary procedures, the detection of coronary anomalies is becoming of major clinical importance, the coronary anomalies cannot be considered just rare aspects because they may often lead to relevant clinical consequences. That is reason why the diagnosis of coronary anomalies should be a healthcare priority. **Aim of the Study:** This study was designed to identify the MDCTA appearance of the anatomic variations and anomalies of the coronary arteries and determine their prevalence. **Patients and Methods:** This study was conducted as a cross-sectional study in Radio-Diagnosis Department, Faculty of Medicine, Ain Shams University and other specialized private radiology centers, during the period between December 2017 and June 2018. All patients gave their written informed consent for taking part in this study. Patients inclusive of 70 males and 50 females with their ages ranged between 4-82 years. The study was approved by Ethical Committee of Faculty of medicine, Ain Shams University. It included 120 patients that were referred for MDCTA for coronary arteries study, Patients were referred for coronary CTA because of known or suspected coronary artery disease (CAD). **Results:** The total number of studies population were 100. 60 (60%) were males ages ranging 4-82 years and 49.5± 11.3 years mean age, and 40 (40%) were females with 25-77 age group and 52.75 years mean age. In 79 patient out of 100 (79%), the RCA was dominant giving off PDA and PLB, in 11 patient (11%) the left coronary artery were dominant and in the remaining patients 10 (10%) were Co-dominant. in 2% the LMCA originated from right sinus of valsalva with interarterial course. In 23.46 % the LMCA trifurcated to LAD, LCx and an intermediate ramus artery. The LAD showed myocardial bridging 16% more than other coronary arteries. One coronary aneurysm seen in the LAD. The LCx had abnormal origin from Rt. coronary sinus in two patients (2%) with retro aortic course. The myocardial bridging is very rare in LCX, present in 1% only. LCx fistula also rare detected in 1 patient (1%), no aneurysm was detected in the LCx. The origin of RCA was from right sinus of valsalva in 99 patients (99%) while one patient had abnormal origin from left coronary sinus (1%), in this case the RCA course was inter-arterial. In general, the normal variations and anomalies of coronary arteries were more common in LMCA 27%, in LAD 19%, LCx was 9 % and least 3% in RCA. **Conclusion:** Complex anatomy of the coronary artery system can accurately be depicted by MDCTA because of the improved isotropic spatial resolution and flexible post-processing tool. This noninvasive modality is useful in detecting coronary artery variants and anomalies and is a valid alternative to conventional coronary angiography in their diagnosis. Recommendations: Further studies are needed with large sample volume and correlate clinical presentation of patients with coronary anomalies & variant.

Keywords: Coronary artery, Anatomical variant, Multi detector cardiac Computed Tomography.

INTRODUCTION

In 1998, multi-detector computed tomography (MDCT) was introduced and since then, cardiac CT has played a major role in the evaluation of the coronary arteries [(1)].

In MDCT, the coronary anatomy is shown in axial slices, as in all other radiological studies. But besides these axial slices, coronary anatomy can also be evaluated using a three-dimensional visualization derived from these axial slices. With current software, oblique multiplanar reconstructions, curved multiplanar reconstructions, three- and four-dimensional volume rendering can be achieved without extensive manual manipulation necessary [(2)]. Excellent image acquisition required a normal resting sinus rhythm with a targeted rate of less than 65 beats per minute during the scan. Cardiac motion with higher diastolic interval was desirable for acquisition of nearly motion free images. This was achieved by administering beta blocker agent 2 hrs before the examination[(3)]. The occurrence of coronary artery abnormalities in the general population is reported to be approximately 0.2% to 1.3% based on the adult population[(4)]. These anomalies are usually not symptomatic and have no clinical significance. However, certain types of coronary artery abnormalities were related to sudden death, particularly in young athletes. According to the report of the Sudden Death Committee of the American Heart Association, approximately 19% of sudden death in athletes may be related to these anomalies[(5)].

Other studies also report that sudden cardiac death due to coronary anomalies, especially those which courses between the root of the aorta and the pulmonary artery (range from 19% to 33%

Received:26/4/2018
Accepted:5/5/2018

in healthy young individuals) [6]. Coronary angiography and autopsy were used to detect coronary artery anomalies, but these procedures have limitations because of their invasiveness. The new device, Multidetector Computed Tomography (MDCT), now replaces the catheter angiography for detecting coronary anomalies [7].

This study was aimed to identify the MDCTA appearance of the anatomic variations and anomalies of the coronary arteries and determine their prevalence.

PATIENTS AND METHODS

This cross-sectional study included a total of 120 patients that were referred for MDCTA for coronary arteries study. Patients were referred for coronary CTA because of known or suspected coronary artery disease (CAD). They were attending at Radio-Diagnosis Department, Faculty of Medicine, Ain Shams University, and some specialized private radiology centers. Approval of the ethical committee and a written informed consent from all the subjects were obtained. **This study was conducted between December 2017 and June 2018.**

Patients inclusive of 70 males and 50 females with their ages ranged between 4 - 82 years.

Inclusion Criteria: This study included any patient referred to MDCTA for coronary arteries with clear satisfied images.

Exclusion Criteria: Patients subjected to surgical procedures like Coronary Artery Bypass Grafting (CABG). Hypersensitivity to iodinated contrast media Poor renal function (Serum Creatinine > 2 mg/dl) Poor non satisfied image quality.

Technique of MDCT of the Heart and Great Vessels:- Technique of MDCT of the Heart and great vessels encompasses four consecutive steps that entail (1) Study planning. (2) Patient preparation (3) examination technique consisting of Data acquisition, image reconstruction and post processing. (4) finally, Image interpretation.

(1) Study planning:

Sequent to obtaining approval from institutional review board and medical ethics committee from Ain-shams University.

(2) Patient preparation.

All patients were subjected for: Proper full history taking from the patients, including last menstrual period for females. History of structural heart disease. History of allergy. History suggesting manifestations of low cardiac output, pulmonary congestion or systemic congestion. Family history of congenital heart disease or sudden death. Description of the Procedure to the patients with reassurance. Written informed consent for the procedure signed by the patients / legal guardians. General laboratory tests (blood urea and serum Creatinine) and imaging studies such as electrocardiography (ECG) and chest X-rays and echo cardiogram were performed. The patients were fasting for 4-6 hrs. Placement of Peripheral venous line (18-20 gauge canula) in the right antecubital fossa. Emergency drugs such as adrenaline and antihistamine were available in the CT department.

Scan Protocol and Image Reconstruction: The CT examination was performed in a calm and comfortable atmosphere (lights were dimmed, the staff speak quietly) avoiding anything that might affect patients heart rate, because a constant rate is crucial for image quality and diagnostic accuracy in coronary CT angiography, patient asked to avoid talking or moving too much during the scan. Patients were scanned with MDCT (Aquillon 64, V4.51 ER 010, Toshiba Medical Systems, Tochigi, Japan). The patient lies on the CT table in supine position. the patient learned how to stop breathing, and they told that they will feel mild heat in their arms during injection of contrast media, and they should be quiet, during examination to get a proper image free from motion artifact.

The scan field extended from the carina to the diaphragm. The imaging parameters were: Tube current 400 mAs, Tube voltage 120 KV, tube rotation time 400 ms, Section thickness 0.5 mm, increment 0.3 mm.

The detector collimation of 64×0.5 mm. A single breath-hold of approximately 8-10 seconds completed the examination.

Before undergoing MDCT, patient's heart rate was checked and when the pulse rate was more than 70 beats per minute, patients took 100 mg of an oral beta-blocker metoprolol tartrate. All patients took nitroglycerin sublingually just before examination.

Electrocardiography-gated CT examinations consisted of the following, injection of 80–85 mL of ominopaque 350 mg I/mL was injected with a flow rate of 5-6 mL/s, followed by a 60 mL saline chasing 3 mL/s. The scan timing was determinedwith automated bolus tracking technique by placing the region of interest over the proximal descending aorta and setting

the trigger threshold to 180 HU. Raw spiral CT data were reconstructed in various phases of the cardiac cycle to obtain images with the highest quality (without motion artifact). Reconstruction performed at four segments 40-75% of R-R interval ECG pulsing for radiation dose reduction was applied to all patients.

Image Reformation and Analysis: All reconstructed images were transferred to a dedicated workstation (Vitrea 2 workstation, Vital Images Inc., Plymouth, Minne-sota, USA). Image post-processing was performed using techniques of maximum intensity projection (MIP), multiplanar reformation (MPR), curved planar reformation (CPR) and volume rendering (VR) for the optimal phase data. Out of 120 patients, the limited evaluations were 20. Most of them were due to motion artifact. As a general rule; the optimum phase of the cardiac cycle, where all coronary arteries were best visualized, was the diastolic phase in which the R-R interval of the cardiac cycle ranging between 70-80% in a patient with heart rate less than 75 beat per minute.

Image Interpretation: All the MDCT examinations were reviewed by two experienced radiologist in cardio-vascular imaging.

After determining the dominance of the coronary artery system, the origin, termination, course, and caliber of the major coronary arteries and their branches were evaluated. Dominance of the coronary artery system was determined according to the origin of the PDA. Coronary artery systems with PDA originating from the right coronary artery were defined as right dominant, and those with PDA originating from the left coronary artery were defined as left dominant. Coronary artery systems where PDA was raised from RCA and the PLB from the circumflex artery (CX) were termed as Co-dominant [(8)].

Coronary artery anomalies were classified according to the classification system by Angelini [(9)] as anomalies of origination and course, anomalies of intrinsic coronary artery anatomy, and anomalies of termination.

Statistical analysis: Continuous variables are shown as mean±standard deviation, and compared by Student's t-test. Categorical variables are defined as number of patients and percentages and analyzed by a chi-square test. The Statistical Package for the Social Sciences (SPSS) statistical software (SPSS 15.0KO for Windows, Inc., Chicago, IL, USA) was used for all statistical calculations. $p \leq 0.05$ were considered statistically significant.

RESULTS

The total number of studies population were 100 after excluding 20 patients due to different causes, 13 of them due to unsatisfactory images with respiratory motion artifact, two with CABG surgery, five with heavy coronary calcification, the remaining 100 patients were enrolled in this study, 60 (60%) were males ages ranging 4-82 years and 49.5± 11.3 years mean age, and 40 (40%) were females with 25-77 age group and 52.75 years mean age (fig.1).

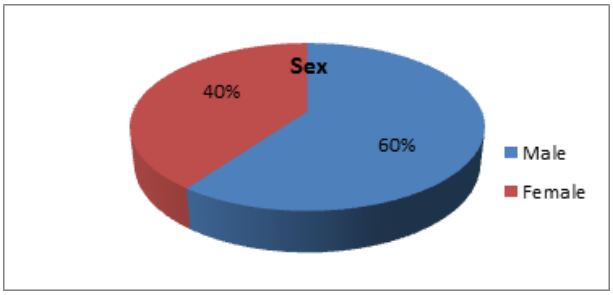

Fig. (1): Pie chart sex distribution of the study group.

The causes of patients' referral to MDCTA were chest pain with suspected coronary artery disease in 70 patients, re-evaluation of a kwon coronary artery disease in 20 patients, atypical chest pain with negative ECG in 10 patients (fig.2).

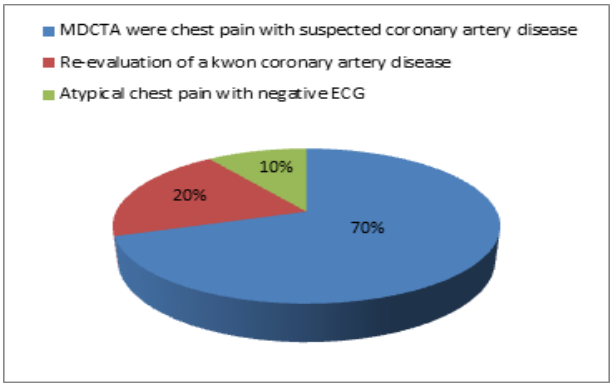

Fig. (2): Pie chart reasons for referral.

Dominancy

In 79 patient out of 100 (79%), the RCA was dominant giving off PDA and PLB, in 11 patient (11%) the left coronary artery were dominant and the remaining patients 10 (10%) were Co-dominant, the PDA raised from RCA while the PLB from LCx. (table 1).

Table (1): Coronary Artery Dominance.

Dominance	Number	Percent %
RCA	79	79
Left dominance	11	11
Co-dominance	10	10
Total	100	100%

Prevalence of LMCA normal variation and anomalies (table 2).

Table (2): Prevalence of Left Main Coronary Artery Variations.

Variant	Number	Percent
Origin From left sinus of valsalva From right sinus of valsalva	 96 2	 96% 2%
Absent	2	2%
Trifurcation (ramus intermedius)	23/98	23.46%
Length of LMCA (No. 98)		
Less than 1 cm	11	11.22%
1-2 cm	70	71.42%
More than 2 cm	17	17.34%

The origin of the LMCA is almost always from left sinus of valsalva 96% only two patients had LMCA origin from right sinus of valsalva with interarterial course (2%).And absent in 2 patients ((2%) due to split origin of the left coronary artery (LCA) to LAD and LCx.

The usual length of LMCA was between 1-2 cm seen in 71.42% of the patients (table 2).

Left Anterior Descending Artery.

The normal variation and anomalies detected in LAD seen in (tables 3 and 4).

Table (3): Normal Variation and Anomalies of the Left Anterior Descending Artery.

LAD	Number of patients	percent
Myocardial bridging	16	16%
No. of diagonal branches		
One	20	20%
Two	60	60%
More than two	17	17%
UD	3	3%
Fistula	0	0
Aneurysm	1	1%

Table (4): Number of diagonal branches in presence of intermediate ramus

Diagonal branches in 23 patients with intermediate ramus		
One	10	43.47%
Two	8	34.78%
More than two	3	13.04%
UD	2	8.69%

Left Circumflex Artery

The normal variant and anomalies detected in LCx seen in table (5).

Table (5): Left Circumflex Artery Normal Variants and Anomalies.

LCx variants		Number of patients	Percent
Hypoplasia		3	3%
Abnormal origin	From right coronary sinus	2	2%
	From left coronary sinus	2	2%
No. of OM			
UD		3	3%
One		80	80%
Two		17	17%
Myocardial bridging		1	1%
Fistula		1	1%
Aneurysm		0	0

Right Coronary Artery

The normal variant and anomalies detected in RCA seen in (table 6).

Table (6): Prevalence of Normal Variation and Anomalies of Right Coronary Artery.

Origin and course	From right coronary sinus		From left coronary sinus	Total
	99 (99%)		1 (1%)	100
Conus branch	From RCA		From Right coronary sinus	From aorta
	77 (77%)		8 (8%)	8 (8%)
UD		7 (7%)		
Sinus node artery	From RCA	From pulmonary artery	From LCx	From RCA and LCx
	65 (65%)	2 (2%)	22 (22%)	8 (8%)
UD	3 (3%)			
Myocardial bridging	2 (2%)			

In general, the normal variation and anomalies of coronary arteries were more common in LMCA 27%, in LAD 19%, LCx was 9 % and least 3% in RCA.

Case one: middle age male MDCTA MIP and ANGIO mode images demonstrate Long trunk LMT supplies the LAD.

LAD: long artery reach the apex, supplies three diagonal branches and many septal perforators.

LCX: Non dominant artery that arises from the proximal most segment of the RCA, its proximal segment runs a retro-aortic course. The LCX supplies two small OM branches

RCA: Dominant artery that supplies RV branches and ends by giving a long PDA (that approaches the apex) and long PL arteries.

OPINION: Anomalous origin of the non-dominant LCX from the proximal most segment of the RCA. Its proximal segment runs a retro-aortic course.

Case two: MDCTA, MIP and ANGIO mode images.

LAD: Long artery that arises from the left coronary sinus and reaches& wraps around the apex. The LAD supplies two long diagonal branches, the second diagonal is a large bifurcating artery, and many septal perforators.

LCX: Dominant artery that arises from the right coronary sinus by a common origin with the RCA, its proximal segment runs a retro-aortic course to reach the left AV groove. The LCX supplies two OM branches, small PL arteries and ends at the crus by giving a bifurcation PDA.

RCA: Non dominant artery that supplies RV branches.

OPINION: Congenital and atherosclerotic coronary artery disease;

Anomalous origin of the dominant LCx from the right coronary sinus by a common ostium with the RCA. Its proximal segment runs a retro-aortic course.

DISCUSSION

The wrong interpretation of a coronary variant or anomaly might cause technical difficulties during interventional procedures or lead to clinical misdiagnosis or major complications might occur during graft surgery. The need for an accurate anatomical evaluation of the coronary artery tree is relevant during angioplasty, due to revascularization purposes [(10)].

Coronary anomalies are often asymptomatic and may be accidentally discovered. With the increase of interventional coronary procedures, the detection of coronary anomalies is becoming of major clinical importance, the coronary anomalies cannot be considered just rare aspects because they may often lead to relevant clinical consequences [(11)]. That is reason the diagnosis of coronary anomalies should be a healthcare priority. Various imaging modalities are available for coronary artery assessment.

Traditional, catheter angiography has been used to evaluate the coronary arteries and their anomalies; however, it is an invasive technique, and the exact course of the coronaries can sometimes be difficult to determine precisely. This is because angiography provides a 2-dimensional depiction of coronary anatomy and relies on a limited number of imaging planes, in contrast to cardiac computed tomography, which is noninvasive and has multiplanar capability. In addition, the acquired imaging data can be post-processed and viewed in any desired plane. Magnetic resonance imaging (MRI) is another noninvasive technique that can depict the course of proximal coronary arteries, without ionizing radiation exposure or intravenous contrast. However, it is not as widely available as CT, and is limited in the evaluation of the distal coronary arteries and can be technically challenging to perform. For these reasons, introduction of MDCT provided significant improvement in spatial and temporal resolution. Its section thickness range (0.5-0.6)mm, data acquisition time (5s)&has various processing tools such as VR, MIP, CPR & MPR [(12)]. So, it is the imaging of choice for diagnosis coronary anomalies.

Dominance

In our study RCA was dominant in 79 %, the RCA was dominant giving off PDA and PLB, left coronary dominant in 11 % and in 10% patients were co-dominant. These results are close to the study done by ***Kini et al.*** [(13)], whom reported 80% -85% right dominant, 15%-20% left dominant and co-dominant in 5%, also close to the results of ***Cademartiri et al.***[(14)], who found that right coronary dominant in 86.6%; left dominant in 9.2%; and Co-dominance in 4.2%. In a different definition for the coronary dominance mentioned by ***Malouf et al.***[(15)], who considered the dominance depend on the origin of AV nodal branch, most of the time the right coronary artery gives off AV node artery, this seen in70% of the general population, 20% were co-dominant, and 10% were

left- dominant. In the other hand the currents results were slightly higher than results of ***Koşar et al.***[16], in their study RCA was dominant in (67%) while LCA was dominant in (9.1%). this mild difference in the results of dominance could be due to different sample volumes and different nations.

Right Coronary Artery

In present study the origin of RCA from right sinus of Valsalva was(99%), and 1% had abnormal origin from left coronary sinus, this finding was close to the results reported by ***Koşar et al.***[16] (0.5%) and ***Bunce et al.*** [17] (0.03%- 0.17%).

Anomalous coronary arteries which originate from the opposite coronary sinus may follow 4 main courses: an interarterial course, a retro aortic course, a prepulmonary course, or a transseptal course[18]. An interarterial course is clinically important and carries a high risk for sudden cardiac death in young adults[19]. The possible mechanism of myocardial ischemia remain unclear, but the acute take-off angle, the slit like ostium, compression of the RCA between the aorta and the pulmonary artery, and spasm of the anomalous RCA have been thought to be possible causes [20]. A recent study showed all types of interarterial courses are not considered clinically important, and classified anomalies into two subgroups according to the opening of the RCA ostium: the high and low interarterial course. Patients with a high interarterial course show more typical angina symptoms and major adverse cardiac events than a low interarterial course [21]. In our research, a high interarterial course was seen in one case. However, sudden cardiac death due to this anomaly is rare in asymptomatic patients.

The conus artery originated from proximal RCA seen in (77%), from right coronary sinus 8%, from aorta 8% and UD in 7%, these finding was similar to the results were reported by ***Koşar et al.*** [16], that the conus had separated ostium in (22%).The current study showed the conus was undetected in (7%) higher than results of ***Cademartiri et al.*** [22] which was (2%).

The sinus node artery was commonly originated from RCA (65%), from LCx in (22%), from RCA and LCx in (8%) and UD in (3%), this finding was consistent to results of Kosar et al. and ***Cademartiri et al.*** [16, 22]. Intramyocardial course of the RCA was rare seen in 2% only.

Left Main Coronary Artery

In the current study the common length of LMCA was 1-2 cm (71.42%), more than 2 cm seen in (17.34%) and less 1 cm seen in (11.22%), these results were incompatible with results reported by ***Cademartiri et al.*** [22], where the LMCA length between 1-2 cm seen in 47.3%, less than 1 cm in 41.6% and more than 2 cm seen in 7%.

This discrepancy possible related to different nation and different sample of populations. While the absence of LMCA in the current study was close to that seen by ***Duran et al***. [23].

The LMCA bifurcates to the LAD and CX. Occasionally the LMCA trifurcates giving third branch named ramus intermedius present between LAD and LCx. In our study the ramus intermedius present in (23.46%) which was lower than result of ***Koşar et al.*** [16] (31%), but compatible with ***Cademartir et al.*** [22] (21.9%).

The LMCA was absent in 2 cases (2%), there is some difference in the prevalance of LMCA absence in different studies, in the study of ***Cademartir et al.*** [22] it was (4.1%) while in ***Koşar et al.*** [16] study (0.4%) and in ***Duran et al.*** [23] was (0.4%-0.5%).

The origin of LMCA was from left coronary sinus of valsalva seen in 96% and from right coronary sinus of valsalva seen in 2%, in both cases it runs an inter-arterial course between the RVOT and the ascending aorta showing an average caliber, this was higher than result reported by ***Bunce et al.*** [17] (0.09% to 0.11%).

The LAD has two groups of branches, referred to as septal perforators and diagonals. In present study variable numbers of diagonal arteries were observed, commonly there was two diagonal branches seen in 60%, while more than two diagonal 17%, one diagonal was 20% and no diagonal branch observed in (3 %), number of diagonal branches were less in cases of presence intermedius artery which seen in 23 patients out of 100 patients, in these 23 patients one diagonal in 43.47%, two diagonal in 34.78%, more than two in 13.04% and no diagonal seen in 8.69%. this finding was incompatible with ***Cademartir et al.***[22], where the number of diagonal branches whether one, two or more of same percent around 25%.

In the current study, myocardial bridging was more evident in the LAD 16%, while in RCA 2% and in LCx was 1%, so total myocardial bridging was 19%, this finding was less than ***Koşar et al.*** [16] (37%) and more than ***Cademartiri et al.*** [14] (10.86%).

Coronary artery aneurysm seen in one patient affecting LAD (1%), which is compatible with ***Cademartiri et al.*** [14] (0.65%).

The current study showed the origin of LCx was generally from LMCA 96%.

In 2% the LCx originated directly from left coronary sinus of valsalva and in other 2% from right coronary sinus of valsalva with retro-aortic course, this anomaly was higher than what found in ***Koşar et al.*** [16] study (0.1%).

A coronary artery fistula is an abnormal termination of the coronary arteries which are characterized by a communication between the coronary arteries and either a cardiac chamber, systemic vein, or the pulmonary artery. In the majority of cases, the fistula has a single communication and is not clinically important. in the current study there was single fistula seen between LCx and right atrium, this finding much less than result reported by ***Angelini*** [9] (13%). LCx myocardial bridge also seen in one patient.

In general, the congenital anomalies detected in the current study was 6% including abnormal coronary arteries origin and course, fistula and aneurysm, this finding more common than congenital anomalies reported in different studies, it was 1.96% in Turkey by ***Erol and Seker*** [24], and 2.9% in Italy by ***Andreini et al.*** [25], this difference may be due to different samples volume and different nations.

CONCLUSION

Complex anatomy of the coronary artery system can accurately be depicted by MDCTA because of the improved isotropic spatial resolution and flexible post-processing tool. This noninvasive modality is useful in detecting coronary artery variants and anomalies and is a valid alternative to conventional coronary angiography in their diagnosis.

REFERENCES

1. **Ropers D, Moshage W, Danie L *et al.* (2001):** Visualization of coronary artery anomalies and their anatomic course by contrast-enhanced electron beam tomography and three-dimensional reconstruction., Am J Cardiol., 87:193–198.
2. **Schmid M, Achenbach S, Ludwig J *et al.* (2006):** Visualization of coronary artery anomalies by contrast-enhanced multi-detector row spiral computed tomography. Int J Cardiol., 111:430–435.
3. **Giesler T, Baum U, Ropers D *et al.* (2002):** Noninvasive visualization of coronary arteries using contrast enhanced multidetector CT: influence of heart rate on image quality and stenosis detection. AJR – Am J Roentgenol., 179:911–6.
4. **Ghersin E, Litmanovich D, Ofer A *et al.* (2004):** Anomalous Origin of Right Coronary Artery: Diagnosis and Dynamic Evaluation with Multidetector Computed Tomography. Journal of Computer Assisted Tomography, 28: (2), 293-294.
5. **Maron BJ, Shirani J, Poliac LC *et al.* (1996):** Sudden death in young competitive athletes. Clinical, demographic, and pathological profiles. JAMA.,276(3):199-204.
6. **Eckart RE, Scoville SL, Campbell CL *et al.* (2004):** Sudden death in young adults: a 25-year review of autopsies in military recruits. Ann Intern Med., 7:141(11):829-834.
7. **Budoff MJ, Achenbach S and Duerinckx A (2003):** Clinical utility of computed tomography and magnetic resonance techniques for noninvasive coronary angiography, Journal of the American College of Cardiology, 42 (11):1867-1878.
8. **Angelini P (1989):** Normal and anomalous coronary arteries: Definitions and classification. Am Heart J., 117:418-434.
9. **Angelini P (2002):** Coronary artery anomalies--current clinical issues: Definitions, classification, incidence, clinical relevance, and treatment guidelines. Tex Heart Inst J., 29:271-278.
10. **Cheng TO (1997):** Prevalence and relevance of coronary artery anomalies. Catheter Cardiovascular Diagnosis, 42:276–277.
11. **Becker AE (1995):** Congenital coronary arterial anomalies of clinical relevance. Coron Artery Dis., 6:187–193.
12. **Pannu HK, Jacobs JE, Lai S *et al.* (2006):** Coronary CT angiography with 64-MDCT: assessment of vessel visibility. AJR Am J Roentgenol., 187:119–126.
13. **Kini S, Bis KG and Weaver L (2007):** Normal and variant coronary arterial and venous anatomy on high-resolution CT angiography. AJR Am J Roentgenol., 188:1665-1674.

14. **Cademartiri F, La Grutta L, Malagò R *et al.* (2008):** Prevalence of anatomical variants and coronary anomalies in 543 consecutive patients studied with 64-slice CT coronary angiography. Eur Radiol., 18: 781–791.
15. **Malouf JF, Edwards WD, Tajik AJ *et al.* (2005):** Functional anatomy of the heart. In: Fuster V, Alexander RW, O'Rourke RA, Roberts R, King SB, Wellens HJJ, eds. Hurst's the heart. 11th ed. New York, NY: McGraw-Hill.
16. **Koşar P, Ergun E, Oztürk C *et al.* (2009):** Anatomic variations and anomalies of the coronary arteries: 64-slice CT angiographic appearance. Diagn IntervRadiol.,15:275–283.
17. **Bunce NH, Lorenz CH, Keegan J *et al.* (2003):** Coronary artery anomalies: assessment with free-breathing three-dimensional coronary MR angiography. Radiology, 227:201–208.
18. **Sundaram B, Kreml R and Patel S (2010):** Imaging of coronary artery anomalies. Radiol Clin North Am., 48(4): 711-27.
19. **Pelliccia A, Fagard R, Bjornstad HH *et al.* (2005):** Recommendations for competitive sports participation in athletes with cardiovascular disease: a consensus document from the Study Group of Sports Cardiology of the Working Group of Cardiac Rehabilitation and Exercise Physiology and the Working Group of Myocardial and Pericardial Diseases of the European Society of Cardiology. Eur Heart J., 26:1422–45.
20. **Singhi AK, Bari EA and Banerjee S (2017):** Anomalous origin of right coronary artery causing myocardial ischemia in a young patient, Ann Pediatr Cardio., 10(2): 212-214.
21. **Lee HJ, Hong YJ, Kim HY *et al.* (2012):** Anomalous origin of the right coronary artery from the left coronary sinus with an interarterial course: subtypes and clinical importance. Radiology, 262(1):101-108.
22. **Cademartiri F, Runza G, Luccichenti G *et al.* (2006):** Coronary artery anomalies: incidence, pathophysiology, clinical relevance and role of diagnostic imaging. Radiol Med., 111:376–391.
23. **Duran C, Kantarci M, SubasiDurur I *et al.* (2006):** Remarkable anatomic anomalies of coronary arteries and their clinical importance: a multidetector computed tomography angiographic study. J Comput Assist Tomogr., 30:939–948.
24. **Erol C and Seker M (2011):** Coronary artery anomalies: the prevalence of origination, course, and termination anomalies of coronary arteries detected by 64-detector computed tomography coronary angiography.J Comput Assist Tomogr., 35(5):618-24.
25. **Andreini D, Pontone G, Bartorelli A *et al.* (2010):** Comparison of the diagnostic performance of 64-slice computed tomography coronary angiography in diabetic and non-diabetic patients with suspected coronary artery disease, Cardiovasc Diabetol., 29: 9: 80.