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Coronary artery fistulas morphology in coronary CTA

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Abstract

Background: The aim of the study was to evaluate coronary artery fistulas (CAF) in coronary tomography angiography (coronary CTA) and verify whether there is correlation between the fistula's morphology and other cardiac functional findings and clinical data.

Materials and methods: A group of 14308 patients who were diagnosed in coronary CTA was retrospectively analysed. Achieved data were related to referrals.

Results: Coronary artery fistula frequency was 0.43% in the examined population. The assessment of coronary artery disease was the most frequent indication for the examination. In two out of three cases the diagnosis of CAF was incidental. Fistulas to cardiac chambers were significantly shorter than those to other vascular structures (19.9 vs 61.8 mm respectively, p=0.001). Pulmonary trunk was most often the drainage site. Fistulas with singular supply and drainage constituted the majority. The new morphologic classification of coronary artery fistulas was introduced with linear, spiral, aneurysmal, grid-like and mixed types. Most numerous was the spiral type group. Patients with aneurysmal fistulas had a tendency for wider diameter of aorta and pulmonary trunk. Smallest left ventricle fraction was observed in grid-like fistulas (48.0%, comparing to 59.2% for all patient with fistulas, p=0.001). Concomitant abnormalities were found in 13.1% of CAF patients.

Conclusions: Computed tomography angiography has proven to be a useful tool in coronary artery fistulas detection and morphological assessment. Proposed classification may simplify the predictions whether fistula has a significant influence on cardiac function, however further studies are needed.

Key words: coronary, fistula, coronary CTA, angiography, classification

Introduction

Coronary artery fistulas (CAFs) are additional, abnormal pathways of communication between a coronary artery and other vascular structures (coronary arteriovenous fistulas - CAVFs) or cardiac chambers (coronary cameral fistulas – CCFs) [1,2]. First described by Krause in 1865 [3] CAFs were found throughout the years by means of coronary angiography, recently in coronary computed tomography angiographies (Coronary CTAs), magnetic resonance angiographies (MRAs) and exceptionally cardiac echocardiography.

The frequency of CAFs varies excessively. Lowest frequency, reaching 0.002% was reported in the general population [4], whereas in patients undergoing invasive coronarography varies within the range 0.05%-0.9% [4-9]. General occurrence is only insignificantly altered by sporadic acquired CAFs as a result of cardiac surgery or trauma [10,11].

Symptomatic CAFs in adults constituted about 40% of all [12]. Detection of this abnormality may be crucial in symptomatic patients to provide successful treatment [13]. Symptoms were reported to occur especially in large left to right shunting fistulas[12]. The vessels leading the blood flow to right ventricle and right atrium can possibly be the reason of local micro ischaemia. Individuals presenting these symptoms may experience continuous heart murmur, dyspnoea, chest pain, right-ventricular dysfunction - related conditions in cases of large fistulas. Haemoptysis may appear in coronary to bronchial artery fistulas [14]. Sudden cardiac death being one of the manifestations, highlights the importance of diagnosis [15]. Complications such as endocarditis, arrhythmia, myocardial ischaemia, pulmonary hypertension, congestive heart failure and local fistula conditions such as rupture or thrombosis may occur.

High percentage of CAF detection, the possibility of complex evaluation of the vessels together with the concomitant heart abnormalities and lower radiation doses in modern CT scanners provides the CT with the chance to displace coronary angiography as the gold standard for CAFs diagnosis. The aim of the study is to give detailed features of CAFs in coronary CTA and relate those findings to cardiac function, clinical and previously acquired data by means of angiography and former CT-based studies.

Materials and methods

A total group of consecutive 14308 patients (males -6821, females- 7487, mean age 58.2± 14.8 years; age range 1-93) who underwent ECG-gated multidetector CT examination in First Department of Radiology, Medical University of Lublin between January 2006 and January 2018, was retrospectively reviewed for CAF. In over 70.0% of cases coronary artery disease (CAD) or control after invasive treatment were the main indications for coronary CTA.

CT protocol: CT data were acquired with retrospective ECG-gated cardiac CT scans by MDCT in 9727 cases by 64-row scanner (LightSpeed VCT, General Electric Healthcare, Milwaukee Wisconsin USA) and both retrospectively or prospectively in 4581 cases by 256-row scanner (Revolution, General Electric Healthcare, Milwaukee Wisconsin USA). The scan parameters were set as following: for 64 row scanner – collimation 64x0.6mm with a z-flying focal spot, pitch 0.16:1-0.25:1; gantry rotation time 0.35s; for 256 row scanner – tube voltage of 120 kV; collimation 256x0.625mm with a cardiac axial spot, gantry rotation time 0.28s. In all examinations ECG-dependent tube current modulation was used. If a patient's heart rate exceeded 65 beats/min, the heart rate was controlled with the oral β1- receptor blocker metoprolol.

For coronary CTA, each patient was given an injection of 70-140 ml of iodine contrast agent (Ultravist 370, 370 mg I/mL, Bayer Schering Pharma; or Iomeron 400, 400 mg I/mL, Bracco) depending on weight, at a flow rate of 4-5.5 mL/s followed by a 50-mL injection of saline solution. Injection was performed through an antecubital vein. Administration of the contrast material was controlled by bolus tracking in the ascending aorta. The scan delay was chosen manually in SmartPrep technique or test bolus technique. The scan direction was craniocaudal and the range from the level of the tracheal bifurcation to the level of the inferior margin of the heart for routine coronary CTA and from the level of the clavicle to the level of inferior margin of the heart for patients who had undergone coronary artery bypass grafts. The images were reconstructed in 10 series with 10% R-R interval (5-95%).

Image reconstruction: All the imaging data were transferred to dedicated workstation (Advantage Workstation version 4.3, 4.6 or 4.7, General Electric Healthcare, Milwaukee Wisconsin USA), post-processed and carefully reviewed. The data from 14308 consecutive patients were assessed by two cardiac radiologists. Apart from that further analysis of 61 patients with fistulas was performed, by three experienced radiologist (with 16, 10 and 2 years of experience in CT cardiac imaging).

The CAFs were evaluated with the original transverse images (Figure 1a, 1b), multiplanar reconstructions (MPR), maximum intensity projections (MIP, Figure 1c), volume-rendered images, as well as curve reconstructions (cMPR, Figure 1d).

The CAFs characteristics included the vessels of origin, the drainage vessels, the presence of aneurysms (defined as dilatation 1.5 times the diameter of vessels), combined congenital or acquired anomalies, and the relations with the adjacent structures.

Following morphological parameters of CAF were measured: shortest distance of connection (SDC) along the vessel in longitudinal reconstructions between the origin of the fistula and the drain location (Figure 1e), fistula range (FR) basing on oblique and curved reconstructions, with supplementary use of 3D reconstructions to give the largest extent of a fistula in one dimension, for fistulas consisting of one main vessel additionally diameter and area of beginning, diameter and area of the end, diameter and area in the narrowest point of CAF (Figure 1f). Diameters of ascending aorta and pulmonary trunk, ejection fraction of right and left ventricles were also calculated. Furthermore, coronary arteries were evaluated for coronary artery disease (CAD).

Single supply single drain fistulas were classified as simple fistulas, in contrast to multiple fistulas with more than one supplying vessel or more than one drainage site.

For the aim of classifying fistulas to large and small ones a border of 1.5mm of minimal diameter in simple fistulas and 1.5mm of minimal diameter of the broadest collateral in multiple fistulas was set to distinguish large from small fistulas. The diameter was chosen basing on former studies, which predicted haemodynamically significant flow and negligible CT artefacts role during the assessment. [16].

Based on CAF images in coronary CTA an attempt of classifying fistulas was made. Fistulas leading directly to cardiac chamber or vessel were assigned to linear type (Figure 2a). Those having at least one 180 degree turn throughout their run were the spiral type (Figure 2b). When at least one local dilatation larger than 150% of the regular fistula diameter was observed fistula was classified as aneurysmal type (Figure 2c). Grid-like type fistulas were characterized by multiple supplying vessels and/or multiple drainage sites (Figure 2d). When a fistula was combining at least 2 features of spiral, aneurysmal and grid-like types was assigned to mixed type (Figure 2e).

Statistical analysis was performed with SPSS 16.0, SPSS Inc, Chicago, IL. χ^2 test was used to compare qualitative data, and the Mann-Whitney test for quantitative data. Correlation of linear measurements has been assessed with Pearson coefficient. Values of $p \leq 0.05$ were considered to be significant.

This study have been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments and was approved by the local ethical committee of Medical University of Lublin (reference number KE-0254/186/2015).

Informed consent was obtained from all individual participants included in the study.

Results

Coronary artery fistulas were found in 61 (0.43%) of all 14308 coronary CTAs performed in our department throughout the period 01.01.2006-31.01.2018. All of them were classified as congenital. Mean age in the group of patients with CAF was 58.2± 16.5, age range 18-81 (33F; 54.1%). CAD suspicion was the most frequent clinical indication to coronary CTA (n=24; 39.3%), followed by previous CAF diagnosis or suspicion (n=21; 34.4%) and other vascular pathologies other than fistulas (n=10; 16.4%). Least numerous groups referred to CCTA consisted of patients before pulmonary veins ablation and arrhythmia of unknown origin (both 3; 4.9%).

There were 44 simple fistulas and 17 multiple ones. There were 10 fistulas classified as large.

In the examined group there were 68 drainage sites. Not only coronary cameral fistulas were less numerous than coronary arteriovenous fistulas (21; 30.9% vs 47; 69.1%), but also were statistically significantly shorter (average SDC 19.9mm; range 1-62.0mm, SD 16.7mm vs 61.8mm; range 7.0-256.8mm, SD 52.5mm; p=0.001) (Table 1). Fistula to pulmonary trunk (n=34) represented 55.7% of all, and was most often found CAF. Most often found coronary cameral fistula was leading to right ventricle (n=8, 13.1% of all fistulas).

In the group there were 78 supplying vessels. RCA was the supply for fistulas leading to left atrium (n=7), pulmonary trunk (n=4), right atrium (n=3), right ventricle (n=2), and singular fistula to heart vein. Left coronary artery, regarding all branches, supplied fistulas to pulmonary trunk (n=24), bronchial arteries (n=7), right ventricle (n=6), heart veins (n=2) and singular aortic and left ventricle fistulas. In one case left coronary artery had direct connection to RCA.

Both RCA and LCA supplied 6 fistulas to pulmonary trunk and singular fistulas to right atrium, left ventricle and bronchial arteries (Table 2).

Fistulas originating from the RCA had the average SDC of 46.2mm (range 0.9-257.0mm; SD 60.8mm), whereas from the LCA of 49.5mm (range 1.0-220.0mm; SD 44.0). Left circumflex artery gave most of the longest fistulas (n=10) with the mean length of 103.4mm (range 27.0-220.0mm; SD 68.6mm), on the contrary it was the left anterior descending branch (LAD) to have the shortest mean distance of connection - 38.4mm (range 1.0-119.0mm; SD 23.8mm).

The majority of fistulas (71.1%) resulted to be single supply single drain type (Table 3). For this type the mean diameter at origin was 2.2mm with the range 0.6-17mm, SD 3.0mm, at ending the mean diameter was 2.1 with the range 0.7-5.0mm, SD 1.8mm. Mean narrowest point was 1.2mm, range 0.6-5.5mm, SD 1.2mm, mean narrowest area was 2.2 mm^2, SD 6,5mm. A strong positive correlation between the diameter at origin and shortest distance of connection was found in the single supply single drain type (correlation coefficient 0.6, p=0.001). Detailed analysis for multiple fistulas was abandoned due to limited number of examples and negligible hemodynamic role.

Spiral type of fistula occurred most often (n=18; 29.5%), followed by linear type (n=15; 24.6%). The former type had both mean SDC and FR greater than the latter. Largest mean SDC was observed in the aneurysmal group (81.2mm, SD 48.5mm), whereas it was the mixed type to have the largest mean FR (50.0mm, SD 19.6mm) due to containing most complicated structure. Detailed data are given in Figure 3.

On average aneurysmal and mixed fistulas combining spiral features with aneurysmal dilatation were wider than linear and spiral, regardless of the location of measurement (Table 4). Significant coronary artery stenosis was found in 13 individuals out of 61 with CAF (6F, 7M). Patients with aneurysmal fistulas were less likely to have significant changes in coronary arteries comparing to the whole investigated group (11.1% vs 21.3%), although this correlation was not statistically significant. Furthermore, aneurysmal group fistulas' mean diameters of ascending aorta and pulmonary trunk slightly exceeded the normal limits (35.2mm; SD 5.7mm, and 29.2mm; SD 5.9mm respectively), whereas in other fistula types mean diameters were within the normal values (33.3mm; SD 5.3mm and 28.1mm; SD 4.9mm respectively for the whole group).

In the examined group mean ejection fraction for the left ventricle was 59.2% (range 30.7-82.1%, SD 9.8%), for the right ventricle 45.8% (range 11.1-66.2%, SD 10.8%). Ejection fractions for both ventricles were the smallest in grid-like type fistulas, with mean value of 48.0%, SD 11.9% for the left ventricle, whereas in other types than grid-like type types amounted to 60.4%, SD 9.8%.

The correlation for differences in ejection fraction in grid-like type fistulas comparing to the entire population with fistulas has proven to be statistically significant (p=0.001). Individuals with grid-like fistulas were referred for the coronary CTA with CAF suspicion or other vascular pathologies, none of them was referred for isolated further diagnosis of CAD. Patients with grid-like fistulas were the youngest with mean age 51.2. 5 in 6 patients with the grid-like type had a large fistula. All of the patients in grid-like type fistula were having left-to right shunting, whereas in the whole group it was 80.3% (49 of 61 patients).

Concomitant abnormalities were: VSD (n=3), other coronary anomalies (n=3), bicuspid aortic valve (n=3), ASD (n=2), partial absence of pericardium (n=1). Those 12 abnormalities were observed in 8 patients. In 53 patients (87%) RCA was the dominant artery.

Discussion

In the examined population the prevalence of CAF was 0.43%, whereas in previous coronary CTA researches it amounted to 0.2-0.9% [6-8], similarly to angiography reports – 0.3-0.9% [9]. The majority of detected fistulas reported in previous reports were described as congenital [10,17], our study proved this findings, no fistula in our group was classified as acquired. Out of the

61 patients CAF was previously diagnosed or suspected in 21 cases (34%). The accessible literature lacks comparable data.

Pulmonary trunk was most often the drainage site (55.7%), similarly to previous reports [7,18], so was the LAD the supplying vessel (54.1%). A large, recent, coronarography study, which included 298558 patients with 261 noted fistulas in Polish population gives alike most often found drainage site and supplying vessel [19].

Including multiple fistulas, CCFs accounted for 69.1% of all CAF cases. Even though fistulas originating from the LAD branch were the shortest (38.4mm), this fact does not determine they also provided the highest blood flow, as shortest fistulas had also the smallest diameter.

Since most CAFs are reported to be congenital they were included in the Ogden classification of congenital variations of the coronary artery and assigned to the group of major coronary anomalies [20]. Angelini and Dodge-Khatami's classification, and Angelini and Dodge-Khatami's modified classifications are currently used for coronary anatomy anomalies, both extracting coronary artery fistulas [21, 22]. The Sakakibara et al. classification, basing on angiography, divides fistulas basing on dilatation of supplying vessel [23]. The mentioned and accessible classifications do not divide the fistulas basing on their clinical or functional relevance. Taking the advantage of CT, which enables the morphological assessment of a fistula and potential additional findings, a novel system of classifying the fistulas was proposed by the authors, with 5 types: linear, spiral, aneurysmal, grid-like and mixed. The presented morphological classification may be used by radiologists to assess all coronary artery fistulas, regardless of the supplying vessel, fistula diameters and the drainage site, being a useful tool for qualification to intravascular or surgical corrections.

Linear type fistulas were the shortest with the shortest fistula range. Spiral type fistulas, found most often (29.5%), were longer than linear due to their course. Possibly relevant findings were observed in the aneurysmal type fistulas. Firstly, patients with aneurysmal fistulas had wider ascending aorta and pulmonary trunk in comparison to other fistula types. This may correspond to congenital tendency in cases of multiple aneurysms in other locations. Secondly, less cases with relevant CAD were found in the aneurysmal group.

Individuals with grid-like type were among the youngest and with the lowest left ventricle fraction. In the grid -like type fistulas there were 5 patients with large fistula (83%), comparing to the general occurrence of 8%. This difference has proven to be statistically significant. All of the grid-like fistulas were left-to right shunting. Mentioned features, combined with the fact that neither of them was referred for the coronary CTA due to CAD, suggests these patients had haemodynamically significant fistulas. Potentially clinically relevant findings in aneurysmal and grid-like fistula types need further researches due to limited number of patients in mentioned groups.

Fistulas attached to aneurysmal and mixed types were connected with aneurysms, in 18 out of 61 individuals (29.5%), which confirms the previously reported tendency of aneurysmal occurrence in fistulas [23]. No typical concomitant anomalies were bound with the new fistula types. No statistically significant relationship was observed between coronary artery domination and type of the fistula.

The proposed classification due to correlation with clinical findings can possibly be helpful in improving the communication between radiologists and clinicians. Blood flow through the CAF may be of a significant importance especially in patients with severe CAD in which distal to the stenosis perfusion may be furtherly reduced due to the leakage through the fistula.

Eight patients (13%) had concomitant heart abnormalities. VSD were most often observed, as well as other coronary anomalies and bicuspid aortic valve. According to the previous reports CAFs occur with concomitant congenital pathologies in 20 - 45%. [24]. Tetralogy of Fallot, ventricular septal defect, aneurysm of the sinuses of Valsalvae, anomalous origin of the LAD, atrial septal defect, patent ductus arteriosus, tricuspid and pulmonary valve disorders were observed in previous studies [25, 26]. The difference of concomitant abnormalities occurrence may be due to the fact that all of examined patients were adults.

Pre-operative planning based on CT multiplanar and 3D reconstructions gives surgeons the chance to localize all sections of complex configurations, being probably more clinically relevant than short and mostly narrow linear fistulas. Adequate clinical indications need to be fulfilled for the examination as it uses ionizing radiation and possible iodinated contrast side effects. In previous studies CCTA has proven to be a compelling diagnostic tool before surgery [27, 28] and probably it may reduce the chance of misdiagnosis, which was reported in the case of echocardiography imaging. [29].

The limitations of the research arise mostly from the methodology and the pursuit of least invasive diagnostic attitude. In terms of asymptomatic fistulas, which were observed most often, further coronarography or surgery would not be justified only to verify the CTA findings. What is more, small number of cases in the aneurysmal type and grid-like type fistulas may demand further analysis in a larger group to verify potentially important findings, such as lowered left ventricle ejection fraction in the grid-like type fistulas.

Conclusions

Coronary CTA gave a detailed spatial image of coronary fistulas and enabled the evaluation of coronary artery disease and cardiac function being a reliable non-invasive diagnostic tool. Coronary artery fistulas are rare, often asymptomatic findings. Coronary CTA is a useful tool for

CAF detection and morphological characterisation. New morphological classification may be a helpful tool in anticipating CAF influence on the cardiac function.

Disclosures

This study have been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments and was approved by the local ethical committee of Medical University of Lublin (reference number KE-0254/186/2015).

Informed consent was obtained from all individual participants included in the study.

Conflict of interest: The authors declare that they have no conflict of interest.

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Abbreviations:

CAD - coronary artery disease

CAF- coronary artery fistula

Coronary CTA - coronary computed tomography angiography angiography

FR -fistula range

LAD - left anterior descending coronary artery

LCX - left circumflex coronary artery

LMCA - left main coronary artery

RCA - right coronary artery

SDC - shortest distance of connection

Table 1. Average shortest distances of CAF connection depending on drainage site. (CAVF – coronary arteriovenous fistula, CCF – coronary cameral fistula, SDC – shortest distance of connection).

CAF type	**CCF**				**CAVF**				
Drainage site	Right atrium (n=4)	Right ventricle (n=8)	Left atrium (n=7)	Left ventricle (n=2)	Pulmonary trunk (n=34)	Bronchial artery (n=8)	Other coronary artery (n=1)	Heart vein (n=3)	Aorta (n=1)
SDC (mm)	24.0	19.3	17.1	22.5	49.3	75.6	119.0	163.7	14.0
Range (mm)	14.0-42.0	1.0-57.0	0.9-62.0	22.0-23.0	7.0-120.0	27.0-170.0	-	14.0-257.0	-

Table 2. Number of fistulas originating from the right coronary artery (RCA) and left coronary artery (LCA) leading to various locations; PT – pulmonary trunk.

	RCA (n)	LCA (n)
PT	4	24
Left atrium	7	0
Right ventricle	2	6
Bronchial arteries	0	7
Right atrium	3	0
Heart vein	1	2
Aorta	0	1
Left ventricle	0	1
LAD-RCA (combined)	1 (2)	
PT (combined)	6 (12)	
Right atrium (combined)	1 (2)	
Left ventricle (combined	1 (2)	
Bronchial arteries (combined)	1 (2)	
Total	78	

Table 3. Fistulas supply and drainage types

Type of CAF	1 supply 1 drain	2 supplies 1 drain	1 drain 2 supplies	2 or more supplies/drains
No (%)	44 (71.1)	4 (6.6)	6 (9.8)	7 (11.5)

Morphological type of CAF/ measurement	Diameter of beginning (mm)	Diameter of ending (mm)	Diameter of narrowest point (mm)	Area at the beginning (mm^2)	Area at the ending (mm^2)	Area of narrowest point (mm^2)
Linear n=15 (Range)	1.3 (0.8-2.3)	1.4 (0.8-2.4)	1 (0.6-2.1)	1.4 (0.5-4.2)	1.8 (0.5-4.5)	0.9 (0.3-3.5)
Spiral n=18 (Range)	1.7 (1.1-2.3)	1.9 (0.7-4.5)	1 (0.4-1.6)	2.3 (0.9-4.2)	3.6 (0.4-15.9)	0.8 (0.1-2.0)
Aneurysmal n=9 (Range)	3.5 (0.4-17.0)	2.4 (0.8-5.5)	1.4 (0.4-5.0)	27.9 (0.1-226.9)	6.8 (0.5-23.7)	2.9 (0.1-19.6)
Mixed n=2 (Range)	7.8 (2.3-13.3)	6.7 (2.5-11.0)	4.1 (1.1-7.0)	71.6 (4.2-138.9)	50.0 (4.9-95.0)	19.7 (0.9-38.5)

Table 4. Diameter and area of single supply single drain fistulas (n= 44)

Figure 1. Methods of fistulas evaluation

a) A Mixed Type Fistula with aneurysmal widening and visible contrast jet to the pulmonary trunk („*” - pulmonary trunk, „⇦” – a Mixed Type Fistula).

b) A visible contrast intensity in the right ventricle tip, consistent with left coronary artery (LCA) fistula to right ventricle („*” – right ventricle, „⇩” – contrast extravasation from the LCA fistula)

c) A Linear Type Fistula originating from the right coronary artery (RCA) in maximum intensity projection („*” - left atrium, „⇩” – RCA, „⇨” – RCA fistula).

d) Example of left coronary artery fistula (LCA) to right ventricle in curve reconstruction („ *” – right ventricle, „⇩” – LCA fistula).

e) Example of fistula’s shortest distance of connection measurement in longitudinal reconstruction („*” – right ventricle, „⇩”- LCA fistula).

f) Example of diameter measurement in a left coronary artery fistula („*” – pulmonary trunk, „⇩” – fistula vessel).

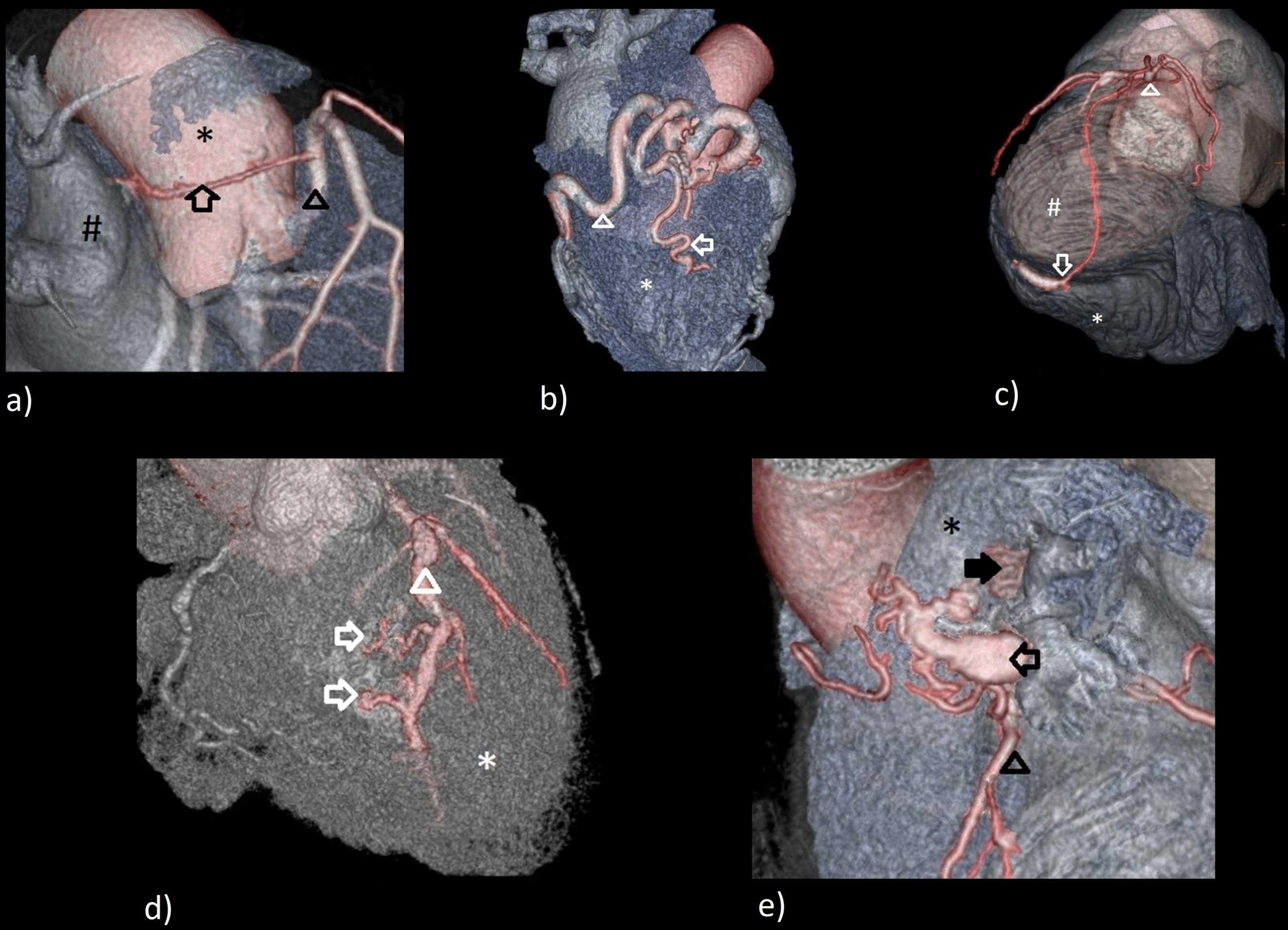

Figure 2. CAF types

a) Linear Type Fistula - ,,⇧”; right coronary artery (RCA) - ,,△” supply; left atrium - ,,#” drainage; ascending aorta - ,,*”.

b) Spiral Type Fistula - ,,⇦”; RCA supply - ,,△”; right ventricle - ,,*” drainage.

c) Aneurysmal Type Fistula - ,,⇩”; left coronary artery (LCA) - ,, △” supply; right ventricle - ,,*” drainage; left ventricle - ,,#”

d) Grid-like Type Fistula - ,,⇨”; LCA - ,, △” supply; left ventricle - ,,*” drainage.

e) Mixed Type Fistula. Aneurysmal part of the fistula - ,,⇦”, spiral part of the fistula - ,,⇨”; LCA - ,, △” supply; pulmonary trunk - ,,*” drainage.

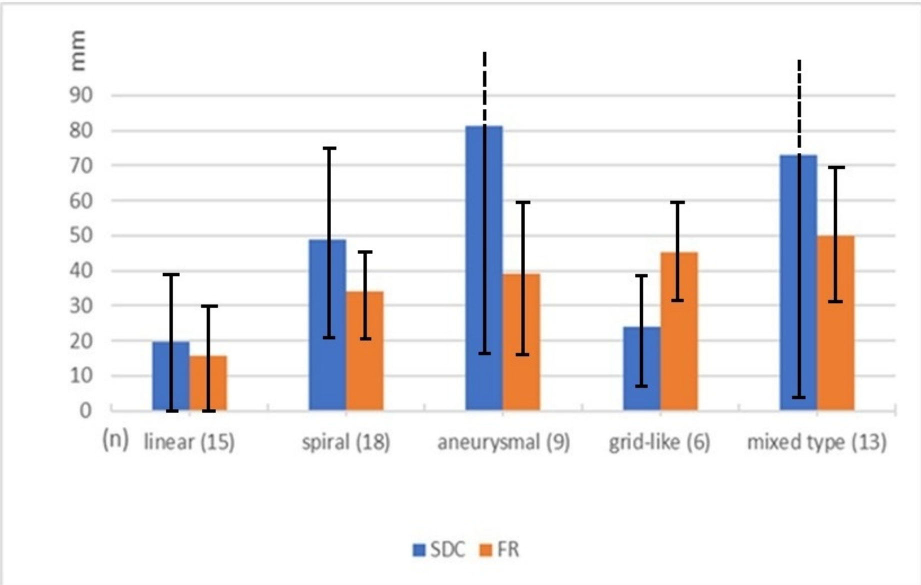

Figure 3. Characteristics of the fistula types;

SDC – shortest distance of connection,

FR – fistula range