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Coronary artery anomalies in tetralogy of Fallot patients evaluated by multi slice computed tomography; myocardial bridge is not a rare finding

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Abstract

Based on coronary angiography and interoperative inspection, anomalous origin of coronary artery crossing the right ventricular outflow tract (RVOT) is common in tetralogy of Fallot (TOF) patients. However, other coronary anomalies may be underestimated due to the overlying myocardium, epicardial fat, or adhesions due to previous palliative surgery. Currently, coronary artery visibility dramatically improved by multislice computed tomography (MSCT). We performed this study to assess the coronary arteries anatomy in TOF patients using MSCT.

All TOF patients underwent MSCT examination at our centre from 2013 till 2019 were included. Assessment of the coronary arteries' origin and course were performed. Presence of myocardial bridge were assessed, and indexed RV mass was calculated.

318 TOF patients were included, median age 2 years (range 1 month–46 years), 175 males (55%). The abnormal coronary artery origin and course were detected in 20 patients (6%); coronary artery crossed RVOT in 13 patients (65%), 5 patients (25%) had a retro-aortic course and 2 patient (10%) had inter-arterial course. Myocardial bridges of left anterior descending artery or/and right coronary artery were reported in 100 patients (36%), no myocardial bridge of left circumflex was reported. RV mass was 29.0 ± 21.1 g/m^2. There was no correlation between RV mass and presence of myocardial bridges.

MSCT is a useful imaging modality for detection of coronary arteries anomalies in TOF patients. Coronary artery crossing RVOT is not the only abnormal course and myocardial bridging is not a rare finding. Further studies are needed to demonstrate the clinical significance of these observations.

Abbreviations: LAD = left anterior descending, LCx = left circumflex, MSCT = multi slice computed tomography, PDA = posterior descending artery, PLB = posterolateral branch, RCA = right coronary artery, RV = right ventricle, RVOT = right ventricle outflow tract, TOF = tetralogy of Fallot.

Keywords: coronary anomalies, multi slice computed tomography, myocardial bridge, tetralogy of Fallot

1. Introduction

Anomalous coronary arteries as part of the spectrum of congenital heart diseases have been described since the 1960s.[1] Since then, many reports have described the prevalence of a particular coronary artery anomaly in specific congenital heart diseases. Based on coronary angiographic, surgical, and autopsy findings, an anomalous origin of a coronary artery crossing the right ventricular outflow tract (RVOT) is common in patients with Tetralogy of Fallot (TOF) with a prevalence between 2% and 23%.[2–6] This knowledge leads to change in the timing and type of surgical correction in TOF with this coronary anomalies.[7–9]

However, other coronary arteries anomalies in TOF patients may be underestimated because a clockwise rotation of the aortic root, this results in a more anterior position of the right coronary sinus, which add a potential complicating factor for the delineation of the coronary anomalies either coronary angiographically or intraoperatively in TOF patients. Moreover, the overlying myocardium, epicardial fat, or epicardial–pericardial adhesions due to previous palliative surgery make it difficult to visualize the coronary interoperative.[10–12]

Currently, coronary artery visibility significantly improved by modern-generation of multi-slice computed tomography (MSCT)

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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scanners which allows ECG-synchronized data acquisition and fast imaging with very short acquisition times that translates into high temporal and spatial resolutions.[13–18] However, the use of cardiac MSCT for assessment of coronary arteries anatomy in TOF patients was rarely reported. Therefore, we performed this study to comprehensively assess the detailed anatomy of coronary arteries, regarding the origin, course, and dominant artery, in TOF patients.

2. Patients and methods

Our study is retrospective, cross sectional, single center analysis of all TOF patients who underwent MSCT examination, at our centre from 2013 to 2019, for clinical purpose. The internal medical board has approved this study. There were 318 patients, all scanned at 128 dual source multi-slice SOMATOM scanner (Siemens, Erlangen, Germany). Examination was performed with retrospective ECG gating and tube current modulation to reduce the radiation dose.

2.1. CT imaging protocol: Scan protocol and image reconstruction

Data acquisition was performed in a craniocaudal direction from the level of the thoracic inlet down to the diaphragm. The scanning parameters include detector collimation of 128 to 0.6 mm, section collimation of 128–0.6 mm by means of a z-flying focal spot, gantry rotation time of 330 ms, pitch of (0.3–0.4) and adjusted according to heart rate and tube potential of 100 to 120 kVp. Rotation time is 0.28 second and its temporal resolution is good (75 milliseconds).

ECG-controlled tube current modulation (ECG pulsing on) was applied with a nominal tube current during diastole (70% to 80% of R-R interval) and a reduced tube current during systole (40% to 50% of R-R interval). The use of this technique leads to a considerable reduction in radiation dose (60% dose reduction).

2.2. Image analysis

Imaging post processing was performed on (Syngo.via. VA11B_HF06, Siemens, Erlangen, Germany) The axial curved multiplanar (MPR), maximum intensity projection (MIP) and 3D volume-rendered technique (VRT) reconstructions on diastolic (70% to 80% of the R-R) and systolic (40% to 50% of the R-R) phases of the cardiac cycle were used to assess the detailed coronary arteries anatomy.

1- **Assessment of the coronary artery origin:** Focused on the origin of the main coronary arteries: the right coronary artery (RCA) from the right coronary cusp and left main artery (LMA) which branches into the left anterior descending (LAD) artery and left circumflex artery (LCx) from the left coronary cusp. The anomalous coronary origin defined as coronary artery originating elsewhere, other than ipsilateral coronary sinus/main coronary artery; for example, high takeoff from above the sinotubular junction level, multiple ostia, single coronary artery, anomalous origin of coronary artery from pulmonary artery or origin of coronary artery or branch from opposite or noncoronary sinus and an anomalous (retroaortic, interarterial, prepulmonic, septal [subpulmonic]) course.[19]
2- **Assessment of coronary artery dominance:** The artery that supplies the posterior descending artery (PDA) and the posterolateral branch (PLB) determines the coronary dominance. If the PDA and PLB arise from the RCA, then the system is said to be right dominant (80% to 85% of cases). If the PDA and PLB arise from the LCx artery, then the system is said to be left dominant (15% to 20% of cases). If the PDA comes from the RCA and the PLB comes from the LCx artery, the system is codominant (about 5% of cases).[20]
3- **Assessment of the coronary artery course**: The epicardial course of the coronary arteries was traced from the base of the heart to the apex. Any course abnormalities such as inter-arterial course, retro-aortic course, crossing anterior to RVOT, or myocardial bridging were recorded.

   Myocardial bridge was classified into superficial or deep bridges. Superficial myocardial bridge was defined as the depth of tunneled coronary artery ≤ 2 mm.[21]
4- **RV mass** was measured by drawing RV epi- and enodocardial contours during diastole and indexed for BSA.

Measurement reproducibility determined by 2 independent readers in a random sample of 100 subjects were excellent for interobserver and intraobserver variability (interobserver intraclass correlation coefficient: myocardial bridge = 0.92, coronary system dominance = 0.98, and; intraobserver intraclass correlation coefficient: myocardial bridge = 0.97, coronary system dominance = 0.99, respectively).

3. Results

There were 318 TOF patients, median age 2 years (range 3 month– 46 years), 175 males (55%).

1- Assessment of coronary artery origin:

   Normal origin of LMA from left coronary cusp in 307 patients (96%), LMA gives origin to LAD artery and LCx artery. Normal origin of RCA from right coronary cusp in 312 patients (98%). Abnormal coronary artery origin was detected in 20 patients (6%); 10 patients (50%) had single coronary ostium and 10 patients (50%) had coronary artery originating from contralateral coronary artery or sinus of Valsalva. Table 1
2- Assessment of dominant system:

   Image quality was poor in 16 patients (5%) so they were excluded. The dominance was assessed in 302 patients. Right system was dominant in 247 cases (82%) and left system was dominant artery in 50 cases (16%), whereas it was co-dominant system in 5 cases (2%).
3- Assessment of coronary artery course:

   LAD artery had a normal course in 307 patients (96%), while in 11 patients (4%) LAD artery crossed anteriorly over the RVOT, Figure 1A. LCx had a normal course in 315 patients (99%) and it has a retro aortic course in 3 patients (1%). RCA has a normal course in 312 patients (98%), and an abnormal course in 6 patients (2%) (retroaortic course in 2 patients, pre-RVOT course in 2 patients, and inter-arterial course in 2 patients), Figure 1B, 2.

   3.1 Myocardial bridging

   The whole course of epicardial coronary arteries were traced in 279 patients (88%) as 39 patients (12%) were excluded due to inadequate image quality. Myocardial bridges were reported in 100 patients (36% of the cohort). Of which, 65 patients (65%) had myocardial bridge of LAD artery, 23 patients (23%) had myocardial bridge of RCA and 12 patients (12%) had myocardial bridge of

Table 1

Relation between abnormal coronary origin and anomalous course.

Abnormal coronary origin	e	Abnormal coronary course		
		Retro aortic	Inter-arterial	RVOT(+)
Single coronary ostium	10			
1-From left coronary sinus	6			
■ RCA from LAD	4		2	2
■ RCA from LMCA	2	2		
2- From right coronary sinus	4			4
Origin from contralateral coronary artery or sinus of V alsalva	10			
1-LAD from RCA	5			5
2-LAD from RCS	2			2
3-LCx from RCA	3	3		
Total	20 (100%)	5 (25%)	2 (10%)	13 (65%)

LAD = left anterior descending, LCx = left circumflex, RCA = right coronary artery, RVOT = right ventricle outflow tract.

both LAD artery and RCA, Figure 3. No myocardial bridge of LCx artery was reported.

Superficial myocardial bridge was detected in 106 coronary arteries (95%), while deep myocardial bridge was detected in 6 coronary arteries (5%).

All patients have hypertrophied RV, as RV mass was $29.0 \pm 21.1\,g/m^2$. There was no difference between the RV mass in patients with myocardial bridge compared to those with no myocardial bridge ($29.7 \pm 12.5\,g/m^2$ vs $28.6 \pm 11.9\,g/m^2$, $P = .48$ respectively).

4. Discussion

Our study demonstrated that MSCT, with its high temporal resolution and 3D reconstructions, is a useful imaging tool in systematic assessment of coronary artery anomalies in TOF patients. The abnormal origin of coronary artery associated with abnormal course were detected in 20 patients (6%); main coronary artery crossed the RVOT in 13 patients (65%), 5 patients (25%) had a retro aortic course and 2 patients (10%) had an inter-arterial course. Myocardial bridge of LAD artery or/and RCA was reported in 100 patients (36%), no cases reported to have myocardial bridge of LCx artery.

Evaluation of coronary arteries in TOF patients was traditionally performed either by coronary angiography or interoperative inspection.[2–6,8,9] The clockwise rotation of the aortic root, giving the right coronary cusp abnormal anterior position, makes the identification of the coronary arteries using the standard views of coronary angiography is a real challenge especially if there are anomalies in their origin and/or course. Delineation of the coronary artery anatomy at inspection of the

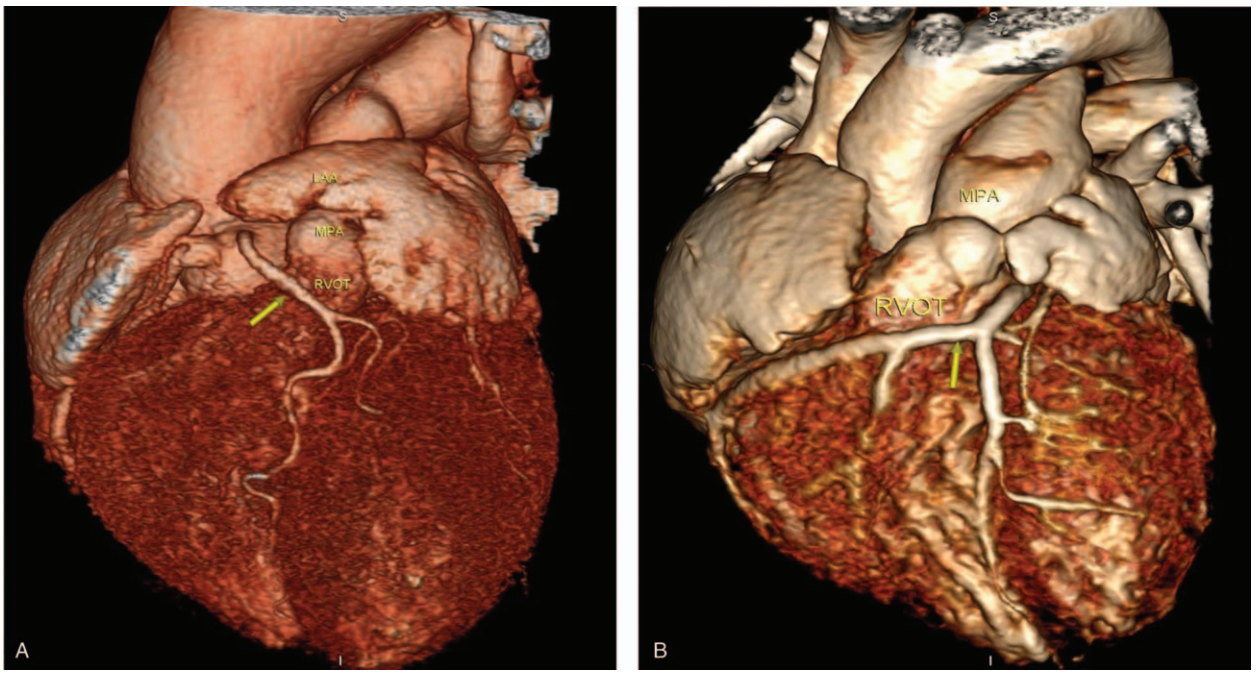

Figure 1. VRT 3D reconstruction images A: shows that LAD artery originating from right coronary cusp and crossing anteriorly the RVOT (the arrow). B: shows anomalous origin of the RCA from mid LAD artery with pre-pulmonic (Pre-RVOT) course, arrow points to proximal RCA.

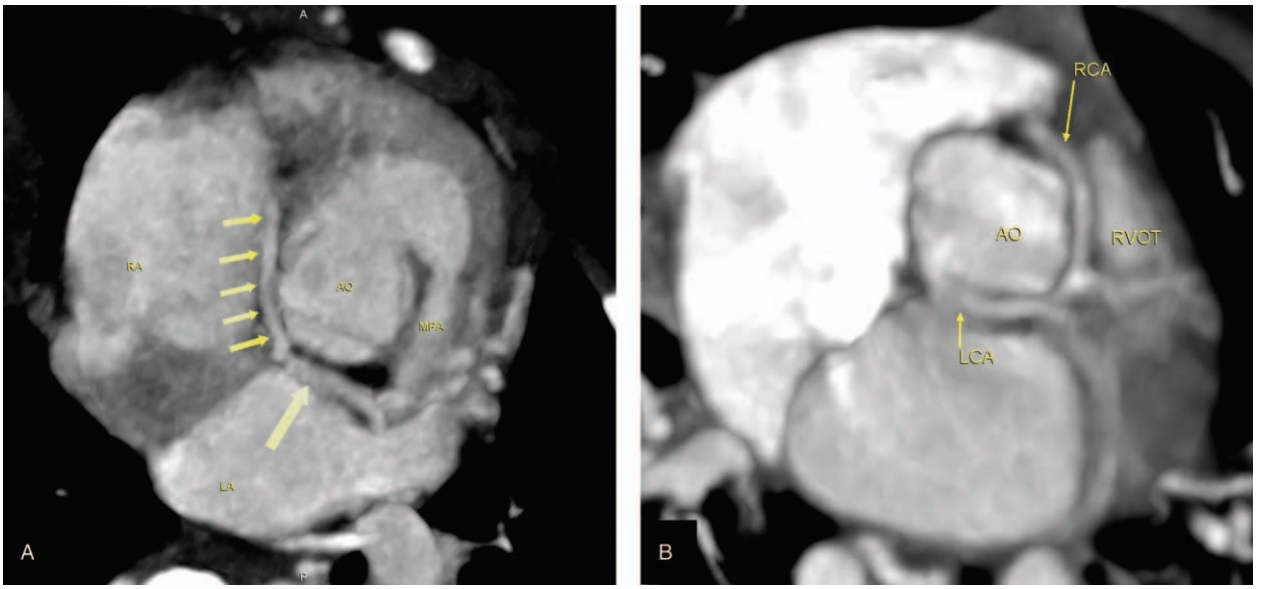

Figure 2. A: Axial oblique thick MIP image shows a retro-aortic course of RCA (small arrows) with its origin abnormally from the LCx artery (large arrow). B: Axial Oblique thin MIP image shows anomalous origin of the dominant RCA from proximal LAD artery with intra-arterial course between aorta and pulmonary.

cardiac surface during surgery could be complicated if the course of the vessels is intramyocardial, deeply embedded in epicardial fat or at reoperation due to scar tissue.[6–10]

With modern generation of MSCT, improvements in temporal resolution and the introduction of systolic reconstruction provided increasingly accurate images of the coronary arteries. Adequate opacification of the cardiovascular blood pool in our sample was achieved by injection of peripheral intravenous contrast medium, clearly revealing the course of the coronary arteries, with good diagnostic accuracy. Moreover, it provides 3D reconstructions that are extremely valuable to surgeons. The radiation dose is very low when a prospective, sequential, ECG triggered acquisition protocol is used.[13–17] A recent publication by Vastel -Amzallage et al, demonstrated the accuracy of preoperative MSCT analysis in detecting coronary artery abnormalities by using surgical findings as the reference standard. Compared with surgical findings, MSCT analysis had 100% sensitivity and 100% specificity for detecting coronary artery abnormalities.[22]

Generally, the use of MSCT in evaluating the coronary artery anomalies in patients with TOF still limited as compared to the use of coronary angiography in the clinical practice. Moreover, up to our knowledge, there are no available studies comparing the accuracy of both techniques in TOF cohorts. The published data showed a higher concordance rate between surgical findings and MSCT (92% to 100%) more than coronary angiography (50% to 100%).[23–26]

Our data was in agreement with other pervious publications, which used MSCT in TOF,[4,23–26] in demonstration of abnormal course as retro-aortic course, which is benign course, and an inter-arterial course, which is potentially malignant and pose a risk of sudden cardiac death during exercise and correction

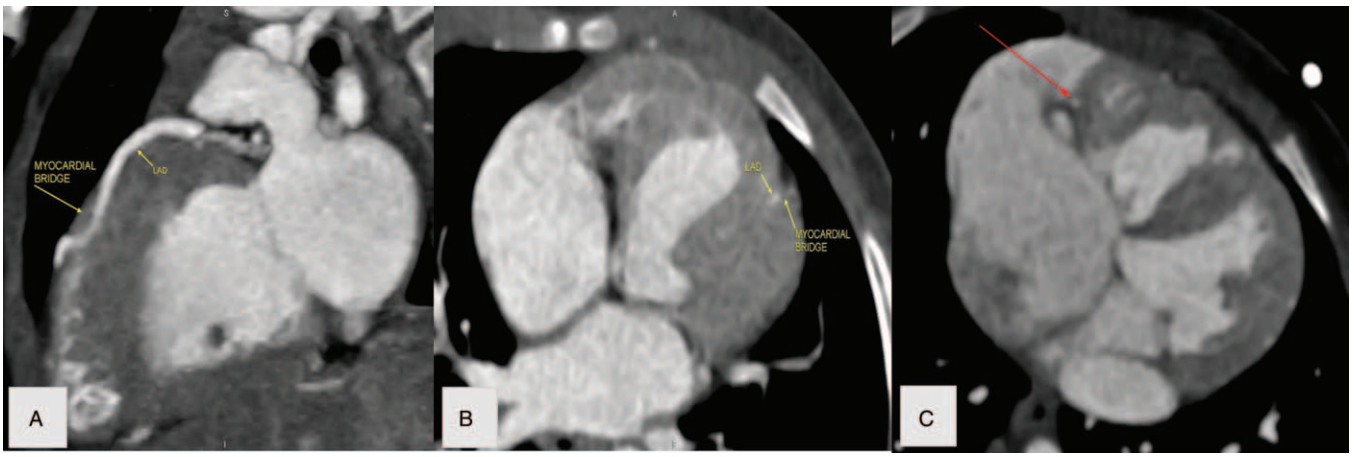

Figure 3. A: Sagittal view shows deep myocardial bridge of mid LAD artery (arrow). B: Axial view shows superficial myocardial bridge at of LAD artery at the apex (arrow). C: Axial view shows superficial bridge of proximal RCA at the right AV groove (arrow).

should take place. Both courses could not be detected by conventional coronary angiography but can accurately be detected by MSCT. This could add a potential important advantage for MSCT analysis of coronary arteries in TOF patients in detecting these abnormal courses.

To the best of our knowledge, our study is the first study to assess the myocardial bridge of main coronary arteries in TOF patients. Our data reported myocardial bridges in 36%. The majority (65%) had myocardial bridge of LAD artery, while 23% had myocardial bridge of RCA and 12% had myocardial bridge of both LAD artery and RCA. No myocardial bridge of LCx artery was reported.

The detection rate of myocardial bridge is greater with MSCT than with conventional coronary angiography due to the use of short-axis images obtained perpendicular to the long axis of coronary arteries for all analysis and measurement, and the consistently high image quality of MSCT. While the diagnosis of myocardial bridge with coronary angiography is not made by the direct visualization of the intramuscular course but the indirect finding of systolic compression of the coronary artery indicated by the milking effect.[27,28] Myocardial bridging is usually an incidental finding associated with an excellent survival rate of 97% at 5 years.[8] However, it is not entirely a benign entity. There have been reported associations with myocardial ischemia,[28] myocardial infarction,[5,29,30] arrhythmia,[23] and sudden death.[31]

It is worth to mention that patients with hypertrophic cardiomyopathy (HCM) have a high prevalence of myocardial bridging almost 30% and there is no correlation between LV mass and myocardial bridging.[32–34] In our study, all TOF patients had hypertrophied RV, RV mass was $29.0 \pm 21.1\ g/m^2$. There was no difference between the RV mass in patients with myocardial bridge compared to those with no myocardial bridge ($29.7 \pm 12.5\ g/m^2$ vs $28.6 \pm 11.9\ g/m^2$, $P = .48$ respectively). This similarity might shed some shadow that TOF behaves like HCM on the right side. However, further analysis of the clinical significance of this observation is still needed.

5. Study limitations

This is an observational study from a single center, clinical significance of the myocardial bridge needs future investigation.

6. Conclusion

MSCT, with its high temporal resolution and 3D reconstructions, is a useful noninvasive imaging modality for detection of coronary artery anomalies in patients with TOF. Anomalous coronary artery crossing the RVOT is not the only abnormal course in this cohort and myocardial bridging of coronary arteries is not a rare finding. However, further studies are needed to demonstrate the clinical significance of these observations.

Author contributions

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