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Research article

Cardiac CT to assess the risk of coronary compression in patients evaluated for percutaneous pulmonary valve implantation

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ABSTRACT

Background: Coronary compression (CC) is a life threatening complication that can occur during percutaneous pulmonary valve implantation (PPVI). We describe our experience using cardiac CT prior to PPVI to identify patients at high CC-risk due to a close relationship between the coronary arteries and pulmonary trunk (PT).
Methods: A retrospective evaluation of candidates for PPVI who underwent CT prior to the procedure was done. Measurements of PT were performed using double oblique reconstructed images, with special attention to the stenotic tract of the PT. The analysis of coronary arteries included detection of anomalies of origin and course and assessment of their relationship with the PT, measuring the minimum distance between the coronary artery and the intended site of the future percutaneous valve implantation.
Results: CT analysis was performed for 52 patients. Thirty patients underwent PPVI after CT and 22 didn't. In 6/22 cases the reason not to receive a PPVI was high CC-risk detected at CT. In 6 other patients CT detected an intermediate CC-risk but the test balloon performed during angiography prior to valve placement was safe and the patients successfully underwent the procedure. None of the patients deemed as no CC-risk at CT had CC during PPVI.
Conclusion: CT can detect patients with high and intermediate CC-risk and therefore may identify which patients are unlikely to undergo successful PPVI and those who need a careful analysis with balloon testing. CT can also rule out CC-risk identifying those patients in which balloon inflation testing could be omitted.

1. Introduction

Percutaneous pulmonary valve implantation (PPVI) is an effective procedure in patients with congenital heart diseases involving the right ventricular outflow tract (RVOT) [1,2]. These patients undergo multiple surgical interventions early in life to correct the anomaly, but are often faced with RVOT dysfunction due to pulmonary regurgitation and/or stenosis later in life.

Coronary artery compression (CC) is a life-threatening complication that can occur during RVOT pre-stenting and subsequent deployment of the valve. To avoid this severe complication, aortic root or selective coronary angiography is routinely performed with simultaneous balloon inflation in the pulmonary valve landing zone prior to pre-stenting and PPVI, with a balloon size that mimics the valve size that will be deployed [3–5]. About 5% of patients demonstrate CC during test balloon inflation before PPVI [3]. Non-invasive cardiac CT may be a valuable technique in the pre-procedural work-up to identify patients at high CC-risk by demonstrating a close relationship of the RVOT with the potential to omit invasive angiography in some patients since they are unlikely to undergo successful PPVI. It may also aid the operator during the procedure by indicating which coronaries need a careful analysis during balloon inflation testing. At present, even though many studies exist about the PPVI procedure, outcomes, and risk such as CC, little is known about the usefulness of CT as a pre-interventional examination and clear guidelines are lacking.

The aim of our single centre study was to describe and retrospectively evaluate our experience with pre-procedural cardiac CT in the work-up for PPVI with regard to the relationship between the coronary arteries and pulmonary trunk (PT) in order to predict the risk of coronary compression.

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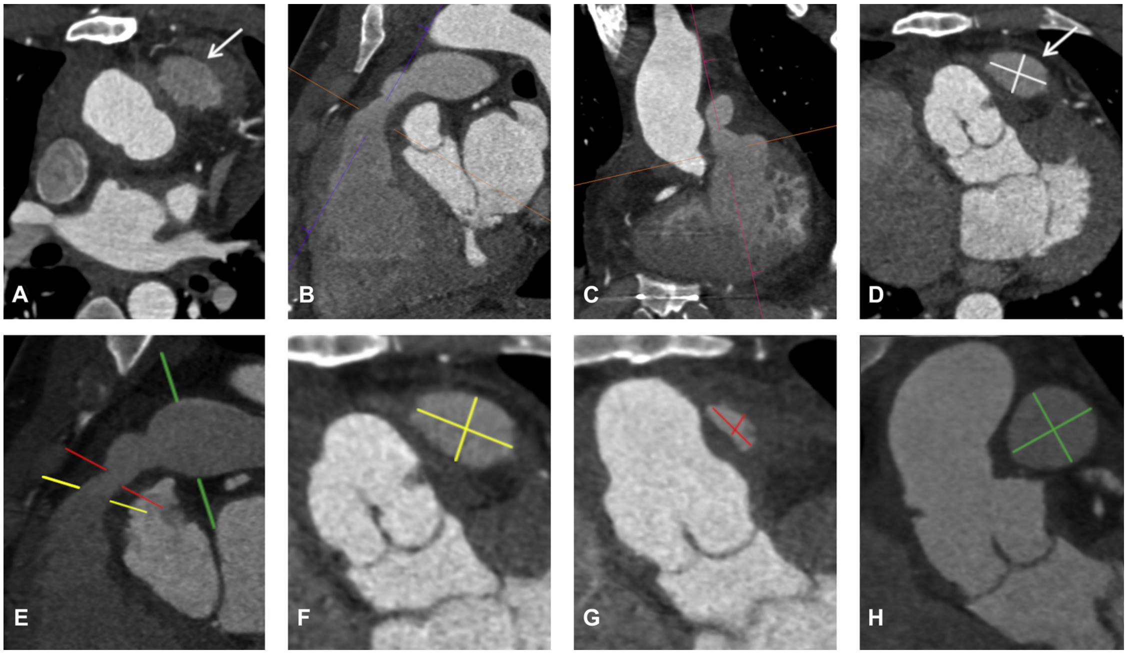

Fig. 1. CT Analysis: Assessment of the pulmonary trunk size.
Reconstruction planes in a patient with homograft stenosis. A multiplanar viewer is used where the three imaging planes are locked at 90 °s angles. Initial axial image (A). The axial plane is tilted by rotating the sagittal (B) and coronal (C) planes to be in line with the axis of pulmonary artery. The initial axial imaging plane now provides a plane perpendicular to the right ventricular outflow tract (RVOT) and allows an accurate measurement of the true long and short axes (D).
Different levels for measurements of the pulmonary trunk (PT): long and short-axis diameters for RVOT (yellow, F), narrow tract (red, G) and pulmonary artery bifurcation (green, H) with imaging planes reconstructed using the same method. Colors correspond to the levels indicated in E.

2. Methods

2.1. Patient selection, characteristics and exclusion criteria

Patients who underwent the work-up for PPVI, aged ≥5 years and weighing ≥30 kg, were selected by reviewing the lists of the weekly congenital heart disease meeting held in our hospital. All patients in whom a cardiac or thoracic CT with intravenous contrast was performed during the work-up for PPVI or prior to it between April 2007 and January 2016 were retrospectively included, irrespective of the primary indication for the CT (not only coronary compression risk assessment, pulmonary trunk or homograft evaluation, but also other non PT-related reasons (e.g. aortic valve evaluation). Patient data were obtained from the electronic patient files and included age at CT and PPVI, primary diagnosis and RVOT substrate.

If patients were deemed unsuitable for PPVI for a reason different from CC-risk, the specific reason (inadequate size or shape of RVOT) or the motivations to postpone the percutaneous implantation (like active endocarditis or psychological issues) were recorded and re-assessed with an experienced congenital cardiologist.

2.2. CT and analysis

CT scans of all patients were retrieved from the PACS system. Acquisition data for each scan were recorded such as scan date, thinnest slice thickness available (mm), non-gated or ECG-gated acquisition and the cardiac phases available for the analysis (diastolic and/or systolic). Radiation dose was calculated using the Dose Length Product (mGycm) with a conversion factor of 0.0145 [6].

Analysis was performed by one experienced CT-observer using two commercially available software packages (Syngovia, version VB10 A, Siemens and IntelliSpace Portal, version 6, Philips). For patients who had both diastolic and systolic phases available, measurements were performed in both phases.

The analysis of RVOT and PT included size of the RVOT and of the pulmonary artery bifurcation, pulmonary artery narrowing (in cases with stenosis) and the location of narrowing. All measurements were performed using double oblique reconstructed images, using software that allows free manipulation of planes, with references lines that are fixed at 90-degree angles (Fig. 1A-H).

Analysis of the coronary arteries included anatomic features like origin (normal, right coronary artery (RCA) from the left coronary sinus, left main (LM) or left anterior descending artery (LAD) from the right coronary sinus, re-implantation of coronaries in a non-native position) and normal or anomalous course.

The relationship between coronary arteries and PT was assessed separately for each coronary artery (RCA, LM, LAD and left circumflex artery (LCx)) by measuring the minimum distance to the part of PT intended to be the site of the future valve implantation, with special attention to the stenotic part, if present (Fig. 2, 3). In patients excluded from PPVI because of a high CC-risk, or who underwent a careful balloon test because of estimated intermediate CC-risk (see paragraph 3.3 below) the length of the coronary at risk was measured (Fig. 4J). When scar tissue or extensive calcification were present eccentrically in the PT wall the minimum distance to the coronary artery was measured considering that they could also be responsible for compression of the coronary artery after conduit expansion.

Based on the measurements and clinical features each patient was retrospectively classified to be at high, intermediate or low risk for CC using the following criteria: patients excluded from PPVI and with less than 2 mm distance were considered at high CC-risk; patients who had been suggested to undergo a careful balloon testing analysis of the coronary artery at risk prior to the PPVI and with a distance from PT > 2 mm but ≤5 mm were considered at intermediate CC-risk; a distance of > 5 mm was considered to be low risk for CC.

2.3. PPVI procedure

Data about the angiographic procedures performed for intended PPVI were retrieved from the stored angiogram images and reviewed

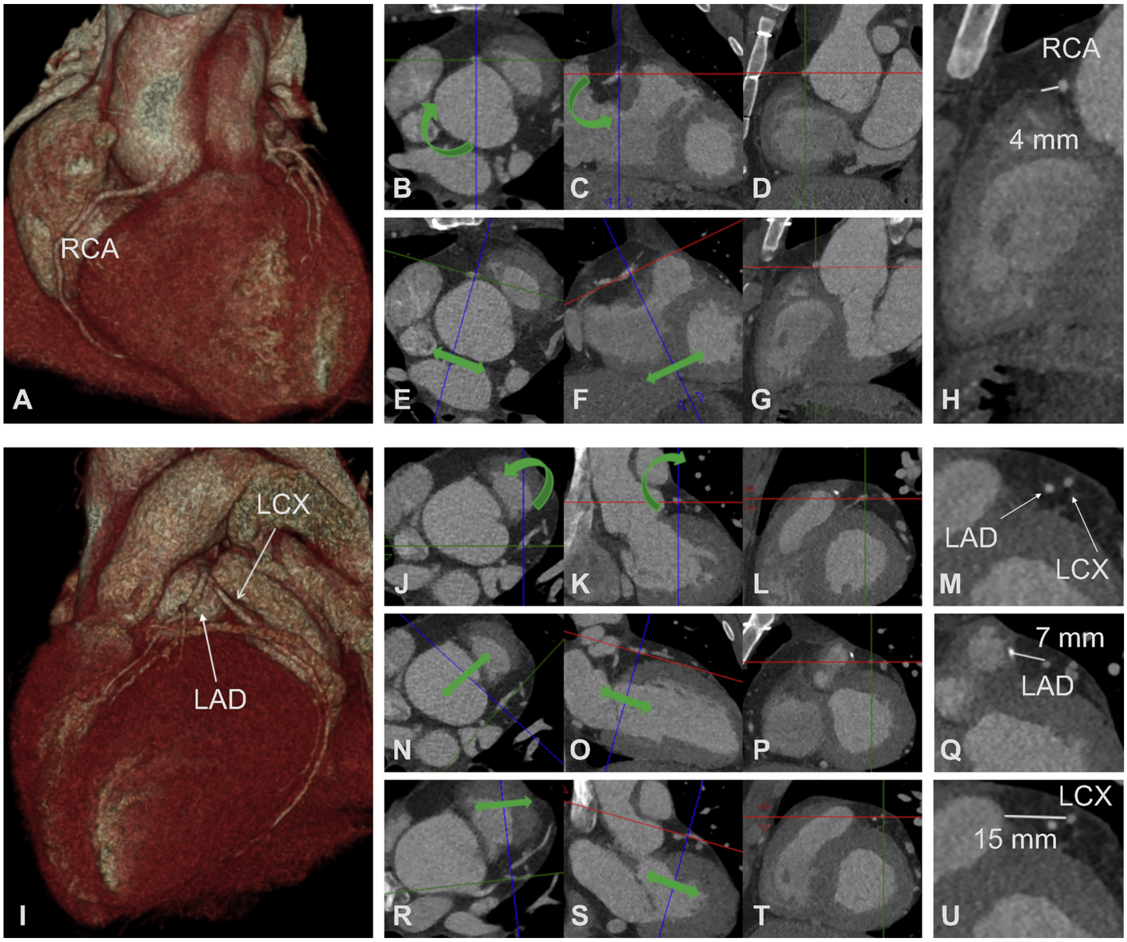

Fig. 2. CT Analysis: Relationship between RCA, LAD, LCX and pulmonary trunk (PT).
Volume rendering showing a patient who underwent Ross procedure (A, I). Relationship between RCA and PT: initial standard axial (B), coronal (C) and sagittal (D) planes; the center of the imaging crosshairs (that are locked at 90 ° angles) is placed on the RCA and are rotated (see arrows) to be in-line with the RCA (E, F). The final image is perpendicular to the long axis of the coronary artery (G) and by scrolling through this imaging planes (as indicated by the arrows in E and F) the site with the shortest distance to the stenotic part of the PT (sub-valvular tract of PT) is determined and measured, which in this case was 4 mm (H). Relationship between LAD and PT: initial standard axial (*J*), coronal (K) and sagittal (L) planes; the planes are rotated to be in-line with the LAD and again in the resulting image plane perpendicular to the long axis of the coronary artery (P) the shortest distance to the PT is then determined by scrolling through these images as indicated by the arrows in N and O and measured (7 mm) (Q). Relationship between LCX and PT: planes already rotated to be in line with the LCX (R, S) with final image (T) perpendicular to the LCX and distance to PT of 15 mm (U). RCA, right coronary artery; LAD, left descending artery; LCX, left circumflex artery.

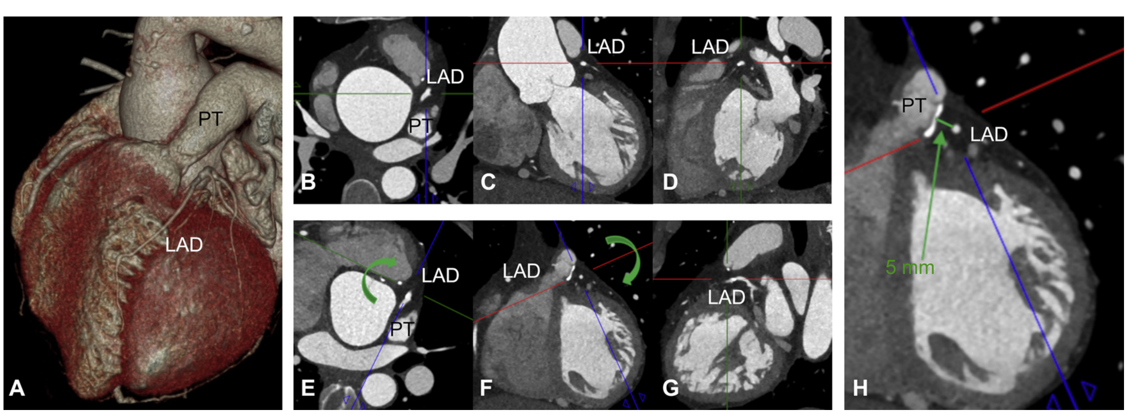

Fig. 3. CT Analysis: Relationship between LAD and pulmonary trunk (PT).
Volume rendering showing a patient who underwent Ross procedure (A). Initial standard axial (B), sagittal (C) and coronal (D) planes; the imaging crosshairs that are locked at 90 ° angles are rotated clockwise (see arrow) so the blue line is in-line with the LAD (E, F). By scrolling through these images as well as the third imaging which is perpendicular to the long axis of the coronary artery (G) the site with the shortest distance to the stenotic part of the PT is determined and measured, which in this case was 5 mm (F).PT, pulmonary trunk; LAD, left descending artery.

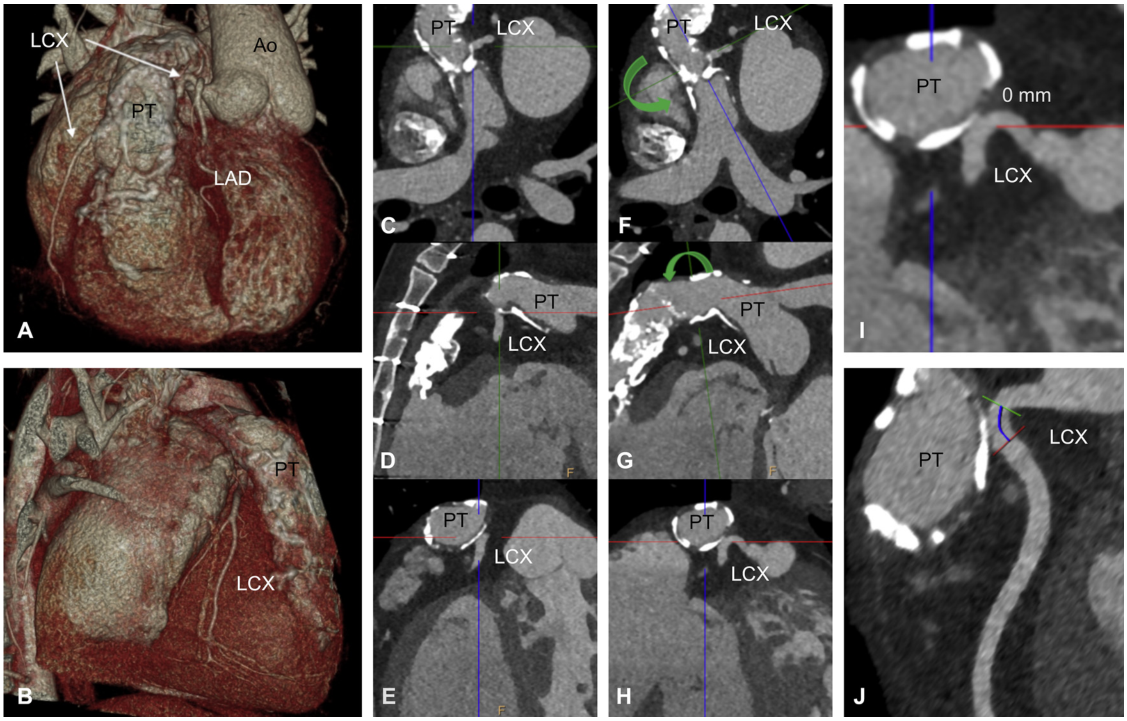

Fig. 4. CT Analysis: Relationship between LCX and pulmonary trunk (PT) in a patient with double discordant heart.
Three dimensional volume rendering shows the complex anatomy because of double discordant heart in frontal (A) and right lateral views (B): there is both atrioventricular and ventriculoarterial discordance with consequent anomalous course of the coronary arteries. Initial standard axial (C), sagittal (D) and coronal (E) planes; the planes are rotated to be in-line with the PT (see arrows) at level of LCX (F, G, H). By scrolling through these images the minimal distance of the coronary artery to the PT is determined. The final image that was used for measuring shows the LCX is at 0 mm from the PT (I). Using a curved-multiplanar reformatted image (MPR) image (that can be obtained by routine coronary segmentation) shows the length of the coronary artery at high risk to be 5 mm long (*J*). PT, pulmonary trunk; Ao, aorta; LCX, left circumflex artery.

together with an experienced cardiologist, who performed most of the procedures. Collected data included the size of the balloon used for the inflation testing compared to the pulmonary valve size of the subsequent valve implantation; the use of pre-stenting as well as type and size of the implanted valve (Melody valve (Medtronic, Minneapolis, Minnesota, USA), 18, 20 or 22 mm [7,8], and the SAPIEN transcatheter heart valve (Edwards Lifesciences, Irvine, California), 23, 26 or 29 mm [9,10].

2.4. Statistical analysis

We used descriptive statistical analyses. Categorical data for patient characteristics are summarized as frequencies and percentages; continuous values are presented as mean ± standard deviation. The paired sample-T test for data with normal distribution and the Wilcoxon signed-rank test for data with non normal distribution were used to compare the differences between systolic and diastolic cardiac phases. All analyses were performed using SPSS software (version 12.0, SPSS Inc., Chicago, Illinois). All statistical tests were 2-tailed and a p-value < 0.05 was considered statistically significant.

3. Results

3.1. Patient characteristics

A total of 52 patients (33 males) was considered for PPVI and underwent pre-interventional CT. Mean age at evaluation was 30.4 ± 13.4 years. In the majority of cases the primary diagnosis was tetralogy of Fallot, the PT was surgically corrected with a homograft and the initial indication for PPVI a stenosis which was located at the valvular level (Table 1).

Eventually 30/52 patients (58%) underwent PPVI and 22/52 did not (42%). In 6 patients (11%) the main reason not to perform PPVI was the risk for CC. Sixteen patients (31%) were not eligible for PPVI for reasons different from CC-risk being a large RVOT size (not suitable for a percutaneous valve) in 10 cases, difficult venous access in 1 case and another intervention (coronary revascularization) in 1 case; PPVI was planned but not performed in 4 cases (it was postponed in 2 cases because of psychological issues and endocarditis).

3.2. CT characteristics

The mean interval between CT and PPVI was 5.8 ± 12.1 months (range 0–70 months). In one case the interval between CT and the procedure was 70 months: the patient underwent a work-up for PPVI 5 years after a gated-CT scan performed to assess coronary artery disease. All CT scans were assessed except one, in which the image quality was acceptable but during retrospective analysis it was not possible to reperform double oblique reconstructed images because of a technical error in the PACS system. Based on the previously reconstructed images and report the patient was considered not to be at high risk for coronary compression; however, no measurement of the distances could be performed.

CTs were performed both non-gated (n = 6) and ECG-gated/triggered (n = 46). For 20 CT scans both diastolic and systolic phases were available. Slice thickness was 1 mm or thinner for all scans. Effective dose was 4.6 ± 5.3 mSv with a wide range (0.4–26.9 mSv), due to the use of different CT protocols and scanners over an almost ten-year period.

3.3. CT analysis of CC risk

The sixteen patients that didn't undergo PPVI because of other than CC-risk reasons were not classified as high, intermediate or low risk for

Table 1
Primary diagnosis, PT characteristics and coronary anomalies of origin and course.

Primary diagnosis		
Tetralogy of Fallot		24/52(46%)
Pulmonary atresia		11/52(21%)
Transposition of Great Arteries		7/52(14%)
Ross procedure		4/52(8%)
Rastelli procedure		4/52(8%)
Truncus arteriosus		2/52(4%)
PT characteristics or type of correction		
Homograft		37/52(71%)
Transannular patch (TAP)		7/52(14%)
Native pulmonary valve		6/52(12%)
Bio-prosthetic valve		2/52(4%)
Initial indication for PPVI		**Stenosis verified at CT**
Stenosis	22/52(42%)	All
Regurgitation	16/52(31%)	3 more cases with PT stenosis
Stenosis and regurgitation	14/5 (27%)	3 cases with no PT stenosis
Total PT stenosis	36/52(69.2%)	
Stenosis site		
Valvular or at homograft level		26/36
Supra-valvular or mid-distal PT		9/36
Sub-valvular		1/36
Coronary anomalies of origin and course		
RCA from LAD + ventral course to Ao (ToF)		No CC-risk
LM originating from right cs (Rastelli)		High CC-risk (LAD)
LAD originating from right cs + no LM (pulmonary atresia/ VSD)		High CC-risk (LAD)
Double discordance (TGA)		No CC-risk
Double discordance (pulmonary atresia/VSD)		High CC-risk (Lcx)
Le Compte manoeuvre (2 pts, TGA)		No CC-risk

CC. The remaining 36 patients were retrospectively stratified based on the CC-risk as determined by CT (Fig. 5).

Twenty-four patients were considered to be at low risk for CC based on CT findings and successfully underwent the procedure (19 with balloon test showing no CC and 5 without balloon testing). Six patients were considered as intermediate CC-risk at CT with a distance between coronary arteries and PT of more than 2 mm but less than 5 mm. All underwent balloon testing which showed no CC and all six patients successfully underwent PPVI. Overall, 30 patients underwent PPVI without complications.

CT detected six patients at high CC-risk, because of a distance less than 2 mm. In one patient, who had a close relationship between coronary artery and PT at CT, balloon testing showed CC and the procedure was aborted; in the other five patients, it was decided not to perform PPVI because of the close relationship, and a surgical option was considered. Eventually, two out of six had already received homograft replacement, one out of six is waiting to receive homograft replacement and three out of six have been are in a watchful waiting program.

3.4. CT pulmonary conduit findings

Pulmonary conduit dimensions are listed in Table 2. Evaluation of differences during the cardiac cycle was performed in 20 patients in whom diastolic and systolic phases were available and showed a statistically significant difference (Table 2), with diameters in systole being larger than in diastole.

3.5. CT coronary anatomy

Seven patients had an anomalous origin or course of the coronary arteries (Table 1). In three out of these seven patients the coronary artery was at high CC-risk (Fig. 6A-B).

The distance between coronary arteries and PT differed significantly between systolic and diastolic phases for the RCA and LAD (Table 2). Since the PT expands in systole, the distance to the target point tends to decrease in this phase (Fig. 7A-F). Comparison between diastolic and systolic phases could not be performed in intermediate and high CC-risk

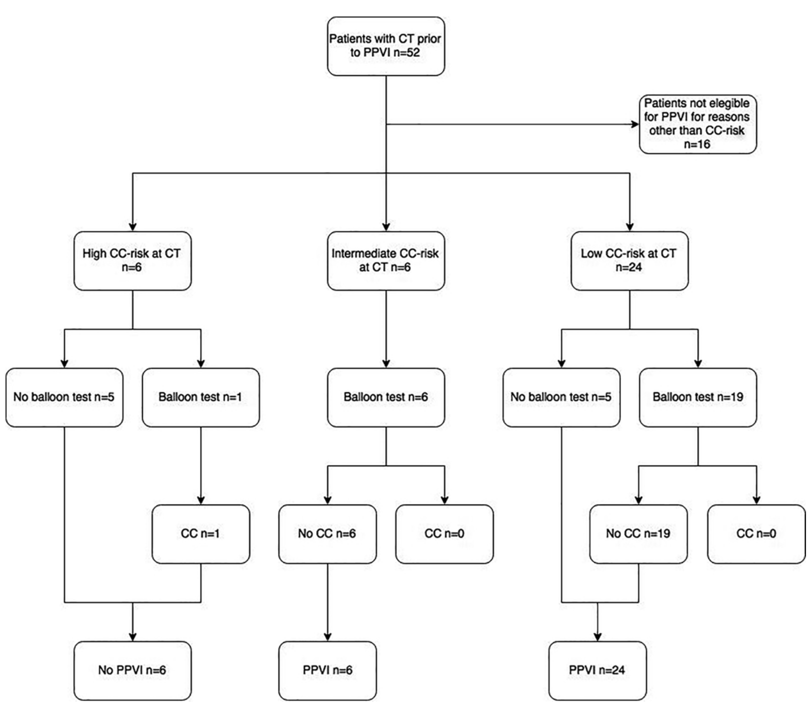

Fig. 5. Flowchart.

Table 2
Measurements of RVOT / PT with absolute difference between diastole and systole and overall dimensions for both non-gated and gated CT scan.

		Gated CT – ED and ES phases (n = 20)				All CT scans (n = 51) (mm)
		ED (mm)	ES (mm)	*p* value	Absolute difference ED-ES(mm)	
RVOT	La	22.2 ± 6.7	23.7 ± 7.1	0.001	1.5 ± 1.7 (from 0 to 7)	24.8 ± 8.3
	Sa	16.5 ± 6.8	17.6 ± 7.8	0.029	1.3 ± 1.8 (from -2 to 5)	18.8 ± 7.2
PA narrow tract	La	16.4 ± 8.6	17.7 ± 8.3	0.002	1.4 ± 1.3 (from 0 to 5)	16.7 ± 5.1
	Sa	10.8 ± 3.7	11.7 ± 4.1	0.031	1.4 ± 1.9 (from -2 to 5)	12.3 ± 5.0
PA bifurcation	La	30.7 ± 37.5	32.3 ± 17.2	0.001	1.8 ± 1.4 (from -1 to 4)	31.2 ± 12.5
	Sa	28.7 ± 17.2	29.6 ± 17.1	0.046	1.1 ± 1.4 (from -1 to 5)	26.8 ± 11.9
RCA to PT		11.4 ± 5.7	10.8 ± 5.7	0.030	0.9 ± 0.8 (from -2 to 2)	12.1 ± 0.9
LM to PT		15 ± 12.2	14.5 ± 12.1	0.136	1.4 ± 1 (from -3 to 3)	14.4 ± 9.6
LAD to PT		12.9 ± 11.8	12.2 ± 11.7	0.005	0.8 ± 0.8 (from -1 to 3)	11.3 ± 10.9
LCx to PT		22.2 ± 12.2	21.1 ± 12.3	0.084	1.9 ± 1.7 (from -4 to 7)	20.1 ± 11.9

Data are presented as mean ± standard deviation. RVOT, right ventricular outflow tract; PT, pulmonary trunk; ED, end-systolic; ES, end-diastolic; LA, long axis; Sa, short axis; PA, pulmonary artery.

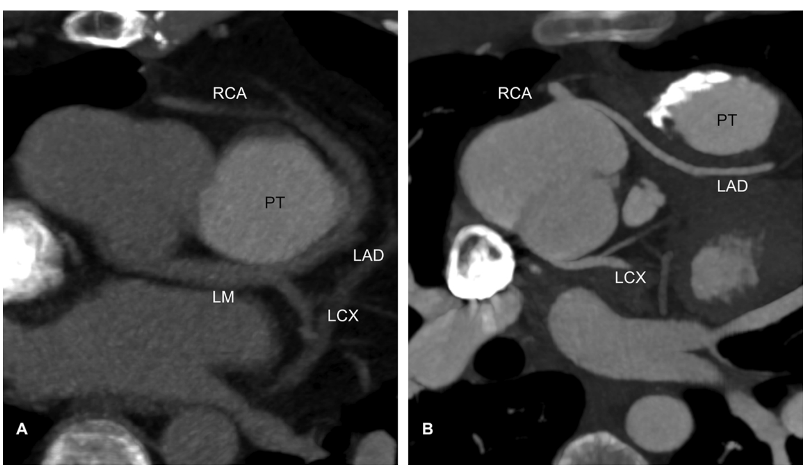

Fig. 6. Anomalies of origin and course.
Non-gated CT scan with right coronary artery (RCA) originating from left main (LM) with anomalous course ventral to the right ventricular outflow tract (RVOT), and PPVI without complications (A). Left anterior descending artery (LAD) originating from the right coronary sinus in a patient who didn't undergo balloon test and PPVI because of high CC-risk and who underwent a homograft replacement (B).

groups because of the small numbers of patients with both phases available.

The length of the coronary artery at risk for CC was measured both for patients with high CC-risk who didn't receive PPVI (9.2 ± 3.9 mm) and for patients at intermediate CC-risk who eventually underwent PPVI after a safe balloon test was performed (11.4 ± 12.9 mm).

3.6. PPVI procedure

An angiographic procedure with the intent to perform PPVI was done in 31/52 patients: all except one successfully underwent PPVI; one patient was previously referred for PPVI due to severe homograft stenosis, but CT detected a high CC-risk because of a close relationship (1 mm) of the RCA to the PT, just above the stenosis. The case was discussed at the congenital meeting and the decision was made to perform balloon testing to assess the RCA and abort the procedure if CC was confirmed (Fig. 8).

Balloon inflation testing was performed in 26/31 patients. Excluding the patient that showed CC, the size of the balloon was compared to that of the finally deployed valve in 25 cases. It was the same in 14/25, smaller in 9/25 and bigger in 2/25. All 30 patients except two had pre-stenting. The implanted valve was a Melody in 25/30 patients (22 mm size in 19, 20 mm in 4 and 18 mm in 2) and Edwards in 5/30 cases (all 26 mm).

3.7. Comparison between high, intermediate and low-cc risk

If the group with high CC-risk, who did not receive PPVI, is compared with the group that underwent balloon inflation testing, a wide range of distances is evident (Fig. 9).

Patients were retrospectively divided in 3 groups based on the minimum distance between coronary arteries and PT evaluated at CT (Table 3). Six cases were evaluated as intermediate CC-risk at CT because of a distance to the pulmonary conduit smaller than 5 mm, but the balloon inflation testing showed no compression. Eventually also these patients successfully underwent the procedure.

3.7.1. Descriptive comparison between high and intermediate CC-risk at CT

The minimum distance between coronary arteries and PT for the six patients in whom it was decided not to perform PPVI was 1 mm for the RCA, 1 or 2 mm for the LAD (four cases) and 0 mm for the LCX.

The patient who had high RCA CC-risk had a close relationship to the PT just above the site of stenosis. A balloon test confirmed compression of the RCA. In patients with high LAD CC-risk the distance was

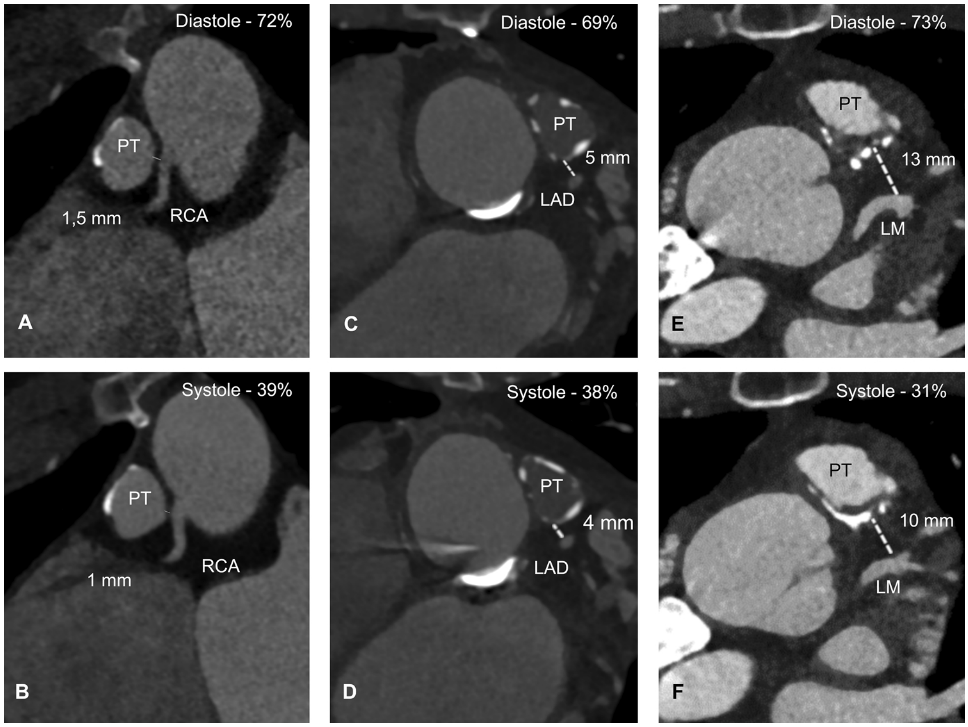

Fig. 7. Difference of distance of coronary arteries from PT in diastole and systole.
The minimum distance has been evaluated in both phases for high (A, B), intermediate (C, D) and low (E, F) CC-risk. Pulmonary trunk (PT), right coronary artery (RCA), left descending artery (LAD), left main (LM).

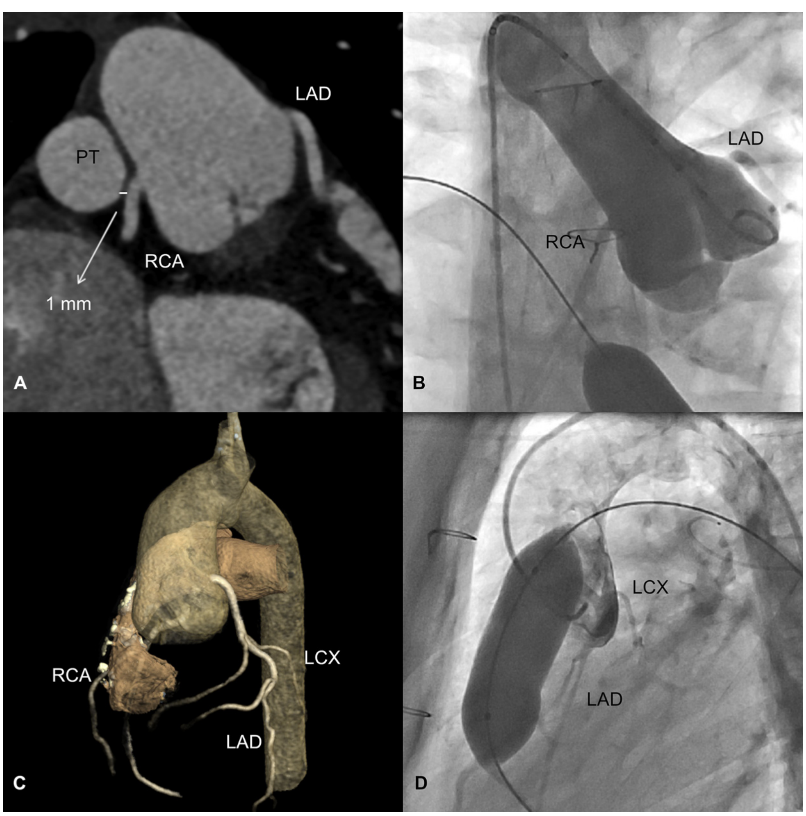

Fig. 8. Patient with CC confirmed at balloon testing. Multiplanar reconstructed image (A) showing close relationship (1 mm) between right coronary artery (RCA) and pulmonary trunk (PT); RCA correctly fills with contrast before the balloon is inflated in pulmonary position (B). Volume Rendering showing calcified homograft (C). Selective coronary angiogram performed during balloon inflation (D): RCA is not visible because it doesn't fill with contrast, confirming compression. CT images are presented in the same projection of angiograms. LAD, left descending artery; LCX, left circumflex artery.

assessed in three out of four cases to a stenotic-PT; in one case out of four the PT was non-stenotic (the indication to PPVI was only regurgitation) but distance to the site of future valve deployment was only 1 mm. The patient with high LCX CC-risk had a double discordant heart and CT detected a close relationship to the stenotic PT (0 mm).

In six patients considered at intermediate CC-risk the decision was to carefully perform a balloon testing prior to PPVI. Three patients had homograft stenosis and the distance to PT was assessed below or above the narrowest tract (measured in two patients for RCA and in one patient for LAD as 4 and 4,5 mm, respectively). In three cases without PT

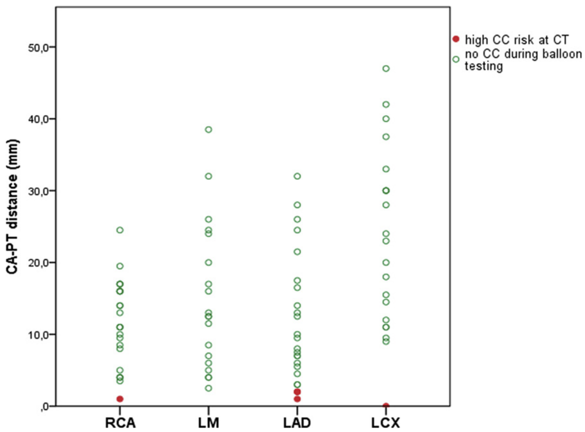

Fig. 9. Comparison between high CC-risk at CT and no-CC risk at test balloon. Scatter plot showing the distances between coronary arteries (CA) and pulmonary trunk (PT) in patients with high coronary compression (CC)-risk at CT and patients with no CC during balloon testing and their distribution for every coronary. RCA, right coronary artery; LM, left main; LAD, left descending artery; LCX, left circumflex artery.

stenosis the distance was detected to the future site of valve deployment (measured in two patients for LAD and in one patient for RCA and LM as 3 and 4 mm, respectively).

4. Discussion

In the present study, CC-risk in PPVI candidates was retrospectively systematically evaluated using CT, measuring the minimum distance between each coronary artery and the part of the PT intended to be the site of future valve implantation, with particular attention to the stenotic point, if present. This reflects our clinical work-up of patients referred for PPVI. Based on our retrospective evaluation, we determined distance thresholds of less than 2 mm (considered high risk); > 2 but < 5 mm (intermediate risk) and > 5 mm (low-risk, for those patients in which the procedure confirmed the absence of coronary compression).

The anatomy of the pulmonary trunk and coronary arteries in patients considered for PPVI is often complex. Therefore, we propose the following criteria in order to achieve reliable results when measuring the coronary to PT distance. First of all, every measurement needs to be accurately performed using double oblique reconstructions. Since CT assessment both in diastole and systole showed a significant size change for the PT, which also affects the relationship between coronary arteries and PT, it is important to perform and evaluate ECG-gated CT acquisitions in both systolic and diastolic phases. In single-phase studies, the systolic phase should be preferred. Even though in our experience no patient had high CC-risk only in one phase and no risk in the other, the distance between the PT and RCA and LAD undergoes significant changes during the cardiac cycle.

Furthermore, it is fundamental to evaluate the minimum distance between each coronary artery at the site intended to be the place of future valve implantation. In cases of PT stenosis, it is compulsory to consider not only the expansion of the narrowest PT point but also the possible expansion of all of the contiguous tract, that would become the site of future valve implantation. Obviously, the stenotic point is the most affected by PPVI, but also the tract that is contiguous to the narrowest point can undergo a certain degree of expansion.

PPVI can lead to a decrease of the distance between PT and coronary arteries but unfortunately it is not possible to predict the exact amount of conduit excursion or possible asymmetric expansion (potentially due to the presence of rigid scar tissue) when the valve is deployed.

In our experience, patients considered at intermediate CC-risk both with and without PT stenosis underwent a careful balloon inflation testing prior to PPVI but this demonstrated no compression of the coronary arteries, but a greater number of patients would be needed to prove the distance threshold that we suggest and to identify more risk factors involved in CC-risk. In all patients with low CC-risk at CT, the procedure confirmed the absence of coronary compression. In these cases the operator may consider the possibility of omitting the balloon test.

To our knowledge there are no solid studies that systematically evaluate the minimum distance that should be considered as safe to avoid CC-risk. Non-invasive pre-procedural imaging in PPVI is often recommended in patient selection in order to enhance anatomic definition [11–13], but CC evaluation is still a challenge and in some cases diagnostic imaging failed to predict it. Only a few cases were reported of patients who had CC and previously underwent an MRI, but we don't know if evaluation of relationship between coronary arteries and PT was performed or not [11,14,15]. Fraisse et al. [4] reported that the sensitivity of MR and CT for evaluation of CC-risk is poor, because CC was suspected in their study in only three out of the six patients who experienced CC, but we don't know whether the exam that failed to predict CC during pre-interventional imaging was MR or CT.

MR is useful for cardiac function and valves evaluation, but thanks to its high resolution and anatomic definition CT is more reliable for the assessment of distance between coronary arteries and PT. Currently, we use a prospectively ECG-triggered acquisition protocol similar to that used for coronary artery assessment in ischemic heart disease. Radiation dose for such an acquisition is typically less than 5 mSv. The contrast injection protocol is adapted to have opacification of both the pulmonary arteries and the aorta as well as coronary arteries. This is achieved by a longer injection duration.

Several limitations of this study need to be addressed. Due to the small number of patients statistical analysis is limited to descriptive statistics.

This is a retrospective study with its inherent limitations. Five out of 12 patients were considered at high CC-risk from CT, but since they were unlikely to undergo successful PPVI no balloon inflation testing was performed to confirm compression so it is not possible to determine that they would have shown compression. Moreover, the PT can sometimes undergo asymmetric expansion after valve implantation, but cardiac CT was not routinely performed after PPVI so it was not possible to compare how exactly the conduit would expand and deviate after

Table 3
Minimum distances between the PT and the Coronary arteries in patients with high CC-risk who didn't receive PPVI, intermediate CC-risk who successfully underwent balloon inflation testing and low-CC risk.

Relationship between PT and Coronary arteries	Minimum distance in high CC-risk patients (6/52)	Minimum distance in intermediate CC-risk patients (6/52)	Minimum distance in low CC-risk patients (24/52)
RCA	1 mm	4 ± 0 mm	14.5 ± 7.6 mm
LM	/	4mm	18.7 ± 8.7 mm
LAD	1.8 ± 0.4 mm	3.5 ± 0.8 mm	16 ± 8.3 mm
LCX	0mm	/	22.8 ± 11.5 mm

Data are presented as mean ± standard deviation. PT, pulmonary trunk; PPVI, percutaneous pulmonary valve implantation; CC, coronary compression; RCA, right coronary artery; LM, left main; LAD, left descending artery; LCX, left circumflex artery.

PPVI.

Since balloon inflation testing was not performed in all patients and no references for a minimum safe distance between coronary arteries and the PT are available, the distance threshold was retrospectively arbitrarily chosen based on our clinical experience. The chosen cut-off values of 2 and 5 mm did seem to perform well but other factors may also influence the risk of CC (e.g. asymmetric expansion, heavily calcified conduits and scar tissue).

Follow-up and prospective studies in which balloon testing is performed in all patients irrespective of CT findings are therefore required to validate these thresholds and to identify more factors that predict the risk of CC during PPVI.

5. Conclusions

CT seems to able to detect patients at high and intermediate risk of coronary compression and therefore may identify which patients are unlikely to undergo successful PPVI and those who need a careful analysis with balloon testing. Alternatively, CT may also identify patients that are not at risk for coronary compression in which balloon inflation testing could be omitted.

Conflict of interest

All authors have no conflict of interest to declare.

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