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Is there any role for computed tomography imaging in anticipating the functional status in adults late after total cavopulmonary connection? A retrospective evaluation

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KEY WORDS
cardiopulmonary exercise test, computed tomography, total cavopulmonary connection

ABSTRACT

BACKGROUND The Fontan procedure is performed in patients with congenital heart diseases and abnormal anatomy of the heart, which precludes intracardiac repair involving a separation of the systemic and pulmonary circulations. The role of computed tomography (CT) in assessing patients' clinical status after the total cavopulmonary connection (TCPC) procedure is not well defined.

AIMS To determine a potential role and diagnostic capability of CT in the functional assessment of adults with the TCPC.

METHODS Data obtained from 18 patients (10 women; mean [SD] age, 27.9 [6.3] years) with the TCPC were analyzed retrospectively. All patients underwent laboratory work-up, cardiopulmonary exercise test, transthoracic echocardiography, and CT. Upon CT examination, the dimensions of the left and right pulmonary arteries, superior and inferior venae cavae, all pulmonary veins, and extracardiac conduits were measured. The measurements acquired by CT were correlated with the results of transthoracic echocardiography, cardiopulmonary exercise test, and biochemical analysis.

RESULTS The mean (SD) time after the TCPC was 18.5 (6.5) years. The area and circumference of the inferior vena cava significantly correlated with age ($r = 0.503$, $P < 0.05$). A significant positive correlation was found between the area and circumference of a conduit and the predicted maximal oxygen uptake ($r = 0.664$, $P < 0.01$). The area ($\beta = 0.746$, $R^2 = 0.556$, $P < 0.01$) and the circumference ($\beta = 0.757$, $R^2 = 0.572$, $P < 0.01$) of a conduit were considered significant predictors in estimating the value of maximal oxygen uptake.

CONCLUSIONS Our study showed an association between the dimensions of an extracardiac conduit and patient functional status, time elapsed since the procedure, and age of adults who underwent the TCPC in childhood. These findings support a more extensive use of CT in patients with TCPC, complemented by the measurements of the superior and inferior venae cavae and the conduit.

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INTRODUCTION The Fontan procedure is performed in patients with congenital heart diseases and abnormal intracardiac anatomy, which precluded any repair that would involve separating the systemic and pulmonary circulations. This procedure is reserved for patients who cannot undergo biventricular repair for anatomical reasons. The first procedure was performed by Francis Fontan in 1968.[1,2] Since then, many technical modifications have been

WHAT'S NEW?

Patients who underwent the total cavopulmonary connection procedure are a very special group of patients. In order to assess their clinical status, it is necessary to perform comprehensive diagnostic examinations including laboratory tests, functional tests (cardiopulmonary exercise test), and imaging (transthoracic echocardiography, magnetic resonance imaging, computed tomography [CT]). CT, especially CT angiography, is an imaging method that allows for the anatomical assessment of the large thoracic vessels and connections—both surgically formed and abnormal (collaterals). The aim of our study was to evaluate the importance of CT in the functional evaluation of patients in whom the total cavopulmonary connection was established. The data obtained from CT correlated with the maximal oxygen uptake assessed by cardiopulmonary exercise testing, age, and time since the procedure. Moreover, they help predict the value of the maximal oxygen uptake.

implemented; however, the concept of treatment remains the same. Nowadays, the superior vena cava (SVC) is connected directly to the right pulmonary artery, whereas the inferior vena cava (IVC) to the pulmonary artery using an intracardiac lateral tunnel or extracardiac conduit, which results in establishing a total cavopulmonary connection (TCPC). In these settings, pulmonary blood flow is passive and driven mostly by the pressure gradient between the systemic veins and the left atrium.[3] A successful procedure reduces chronic volume overload in the ventricle, normalizes arterial saturation, and improves the survival rate.[4-7] Despite these obvious advantages, the Fontan circulation is associated with unfavorable late sequelae such as progressive heart failure, thromboembolism, protein-losing enteropathy, plastic bronchitis, and Fontan-associated liver disease resulting from chronically increased pressure in the systemic veins, disorders of lymphatic flow, and increased pulmonary vascular resistance.[8-11] Therefore, the clinical evaluation of this patient cohort is very complex and requires performing blood tests, noninvasive imaging, cardiopulmonary exercise test (CPET), and cardiac catheterization.[12] Transthoracic echocardiography (TTE) is the most widely available imaging method but its effectiveness in the evaluation of conduits is substantially limited. Cardiac magnetic resonance imaging is the noninvasive method of choice for the postoperative evaluation of the cardiac anatomy and function in patients with TCPC. It provides a comprehensive insight into the cardiovascular anatomy, both regional and global ventricular function, as well as blood flow velocity and volume.[13,14] In the case of contraindications to cardiac magnetic resonance imaging or ambiguous morphological data, computed tomography (CT) may be a valuable alternative method of examination, which allows for the assessment of morphological abnormalities and complications such as thrombi, or stenosis of a conduit, pulmonary embolism, pulmonary arteriovenous malformations, arterial and venous collaterals.[15,16] Cardiac CT is a method used for morphological evaluation. Its role in an overall assessment of patients with the Fontan circulation is not well defined.

Therefore, the aim of this retrospective analysis is to answer the question whether there is any role for CT imaging in predicting the functional status of adults late after the TCPC procedure.

METHODS Our retrospective study involved patients with TCPC who underwent routine follow-up examinations including biochemical evaluation, TTE, and CPET, and in whom CT imaging was additionally performed between 2012 and 2018 in the Department of Congenital Heart Diseases (Institute of Cardiology, Warsaw).

The protocol was approved by the ethics committee of the Institute of Cardiology in Warsaw. All patients provided written informed consent to undergo CT.

Contraindications to CT included renal insufficiency, hypersensitivity to iodine-containing contrast medium, and uncontrolled hyperthyroidism.

Dual-source CT (DSCT) was used. In 7 patients, the examination was carried out with a second-generation DSCT scanner (Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany) and in 11, with a third-generation DSCT scanner (Siemens Healthcare).

The CT acquisition parameters of the second-generation DSCT scanner were: gantry rotation time, 280 ms; tube voltage, 100 to 120 kV; and collimation, 128 × 0.6 mm. The parameters of the third-generation DSCT scanner were: gantry rotation time, 250 ms; collimation, 192 × 0.6 mm; tube voltage, 70 to 100 kV; tube current, 320 to 500 mAs, depending on patient body mass. A retrospective or prospective electrocardiographically gated acquisition protocol was used at the operator's discretion.

The CT protocol included arterial and delayed phase images (the scan time was calculated after a 10–20-ml bolus of a contrast agent). The contrast medium (Ultravist 370, Bayer Pharma AG, Berlin, Germany) was introduced through the antecubital vein at a rate of 45 ml/s.

We evaluated possible conduit-related complications. Subsequently, the dimensions of the left and right pulmonary arteries, both venae cavae, pulmonary veins, and a conduit were measured.

The SVC was measured 1 cm above the anastomosis with the right pulmonary artery (RPA); the IVC, 1 cm below the anastomosis with an extracardiac conduit or intracardiac tunnel;

the RPA, 1 cm distal to the anastomosis; and the left pulmonary artery (LPA), 1 cm distal to the pulmonary trunk. A conduit was measured 2 cm above the anastomosis with the IVC. All measurements (long- and short-axis diameter, area, and circumference) were performed orthogonally to the centerline of the vessel. Area and circumference were indexed to body surface area (BSA). All analyses were performed by the same person experienced in cardiac CT and trained in interpreting scans of adults with congenital heart diseases.

All patients underwent complete TTE with the Vivid E95 system (GE Healthcare, Chicago, Illinois, United States) with a 2.5-MHz transducer. The TTE protocol included a complete 2-dimensional and Doppler echocardiographic evaluation of cardiac chambers, atrioventricular and semilunar valves, pulmonary and systemic veins, and great arteries in multiple imaging planes. The univentricular end-diastolic diameter (UVEDD) and volume (UVEDV), as well as ventricular wall thickness were measured in the long-axis view at the level of base segments. The wall thickness was calculated as the arithmetic mean of the posterior wall and intraventricular septum thickness. The systolic function of a single (systemic) ventricle was evaluated by ejection fraction (EF) and global longitudinal strain (GLS). EF was calculated using the single-plane Simpson rule. For the evaluation of the GLS, the analysis of the 2-dimensional strain was performed offline by tracking a single (systemic) ventricle manually. The GLS was defined as the arithmetic mean of the negative systolic strains of 6 segments in the apical 4-chamber view. TTE was performed by a cardiologist highly experienced in the evaluation of congenital heart defects.

Each patient underwent CPET with the modified Bruce protocol (Sheffield protocol) to evaluate their exercise tolerance. The following parameters were recorded: exercise time, heart rate, blood pressure, maximal oxygen uptake (VO_2max), percentage of VO_2max (normalized to age, sex, and weight-based normative values predicted VO_2max).

Blood samples were taken after overnight fasting. The parameters of laboratory tests (total protein, albumin, N-terminal pro-brain natriuretic peptide [NT-proBNP], C-reactive protein [CRP], bilirubin, creatinine, and hemoglobin) were measured by standard assays.

Statistical analysis The descriptive statistics for nominal variables were presented as absolute number and percentage given in relation to the entire study group, and continuous variables as mean (SD). Nonparametric tests (the Spearman correlation test) were performed for variables with a non-normal distribution and the linear regression analysis for variables with a normal distribution. The tested regression models were assessed for one predictor. P <0.05 was considered statistically significant. The results of the statistical analysis were obtained using the SPSS Statistics software, version 20.0 (IBM Corp., Armonk, New York, United States).

RESULTS The analysis involved 18 patients who underwent the TCPC procedure (10 women; mean [SD] age, 27.9 [6.5] years). Nine patients had a lateral tunnel (FIGURE 1) and other 9—an extracardiac conduit (FIGURE 2).

The mean (SD) time since the TCPC procedure was 18.5 (6.5) years. The anatomical characteristics of the patients are shown in TABLE 1.

The most common indication for CT was the assessment of the TCPC anatomy prior to cardiac catheterization (10 patients), suspicion of pulmonary arteriovenous malformations (5 patients), and suspicion of thrombosis in the Fontan circulation (3 patients).

The results of laboratory investigations, CPET, TTE, and CT are shown in TABLE 2.

TABLE 3 shows the correlations between the measurements performed upon CT examination and TTE, CPET, and biochemical parameters. The area and circumference of the IVC correlated significantly both with age (r = 0.503, P <0.05, and r = 0.587, P <0.01, respectively) and the time since the TCPC procedure (r = 0.673, P <0.01, and r = 0.701, P <0.01, respectively). A significant predictor of the IVC circumference was age (β = 0.665, R^2 = 0.429, P <0.01).

A significant positive correlation was found between the area and circumference of the conduit and both the VO_2max (r = 0.757, P <0.01, and r = 0.710, P <0.01, respectively) and predicted VO_2max (r = 0.735, P <0.01, and r = 0.664, P <0.01, respectively). A significant predictor of the anticipated VO_2max was the area (β = 0.746, R^2 = 0.556, P <0.01) (FIGURE 3) and circumference (β = 0.757, R^2 = 0.572, P <0.01) of the conduit (FIGURE 4).

Considerable correlations between parameters of the conduit indexed to BSA and the results of CPET were also observed (TABLE 3).

Except for a moderate correlation between the RPA diameter and the GLS and a weak correlation between the SVC area and the GLS, no other correlations were found between the CT and TTE parameters. Also, no correlation was found between the CT parameters and NT-proBNP concentration.

DISCUSSION Cardiac CT gained a wide acceptance in the clinical evaluation of patients with congenital heart diseases, although the method is intended for morphological evaluation. Our retrospective study aimed to establish a possible relation

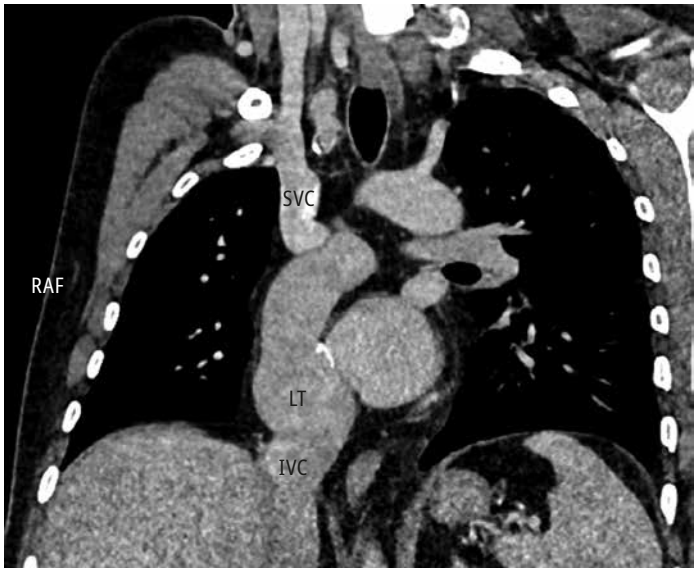

FIGURE 1 Computed tomography: a coronal reformatted image showing the lateral tunnel of the total cavopulmonary connection

Abbreviations: IVC, inferior vena cava; LT, lateral tunnel; RAF, right anterior foot; SVC, superior vena cava

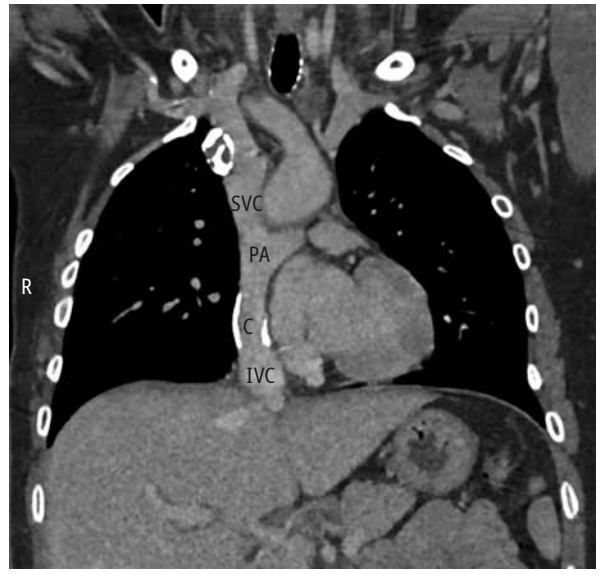

FIGURE 2 Computed tomography: a coronal reformatted image showing the extracardiac conduit of the total cavopulmonary connection

Abbreviations: C, conduit, PA, pulmonary artery; others, see FIGURE 1

TABLE 1 Anatomical characteristics of patients

1. TA, VSD, TGA, PDA, PS, LV morphology, extracardiac conduit; trace of AVVI
2. TA, LV morphology, extracardiac conduit; trace of AVVI
3. TA, PS, LPAHy, LV morphology, intracardiac lateral tunnel; mild AVVI
4. DORV, MS, PS, RV morphology, intracardiac lateral tunnel; mild AVVI
5. PS, TGA, LSVC, LV morphology, extracardiac conduit; mild AVVI
6. PS, TGA, LSVC, LV morphology, extracardiac conduit; trace of AVVI
7. DILV, TGA, LV morphology, intracardiac lateral tunnel; trace of AVVI
8. DILV, TGA, LV morphology, extracardiac conduit; mild AVVI
9. TA, PS, LV morphology, intracardiac lateral tunnel; moderate AVVI
10. TA, ccTGA, VSD, LV morphology, extracardiac conduit; mild AVVI, a low number of systemic and pulmonary collateral vessels
11. DORV, TGA, VSD, ASD, CoA, RV morphology, intracardiac lateral tunnel, fenestration; mild AVVI
12. DORV, PS, RV morphology, intracardiac lateral tunnel; moderate AVVI
13. DILV, PS, LV morphology, extracardiac conduit; mild AVVI
14. DORV, PS, AVSD, RV morphology, extracardiac conduit; trace of AVVI
15. PS, TGA, LV morphology, extracardiac conduit; trace of AVVI
16. HRHS, TD, LV morphology, intracardiac lateral tunnel, fenestration; mild AVVI
17. TA, PS, PAHy, LV morphology, intracardiac lateral tunnel; mild AVVI
18. TA, PS, LV morphology, intracardiac lateral tunnel; trace of AVVI, a low number of systemic and pulmonary collateral vessels

Abbreviations: ASD, atrial septal defect; AVSD, atrioventricular septal defect; AVVI, atrioventricular valve insufficiency; ccTGA, congenitally corrected transposition of the great arteries; CoA, coarctation of the aorta; DILV, double inlet left ventricle; DORV, double outlet right ventricle; HRHS, hypoplastic right heart syndrome; LPAHy, left pulmonary artery hypoplasia; LSVC, persistent left superior vena cava; LV, left ventricular; MS, mitral stenosis; PAHy, pulmonary artery hypoplasia; PDA, patent ductus arteriosus; PS, pulmonary stenosis; RV, right ventricular; TA, tricuspid atresia; TD, tricuspid dysplasia; TGA, transposition of the great arteries; VSD, ventricular septal defect

TABLE 2 Results of biochemical evaluation, cardiopulmonary exercise test, transthoracic echocardiography, and computed tomography

Parameter	Mean (SD)	Min	Max
Laboratory evaluation			
Total protein, g/dl	7.5 (0.9)	3.9	8.5
Albumin, g/dl	4.6 (0.8)	2.0	5.7
NT-proBNP, pg/ml	271.0[a]	52.9	2603.0
CRP, mg/dl	0.6 (0.7)	0.1	2.2
Total bilirubin, mg/dl	1.5 (1.2)	0.5	4.5
Creatinine, mg/dl	0.9 (0.2)	0.5	4.5
Hemoglobin, mg/dl	14.7 (2.3)	8.7	18.0
CPET			
VO_2max, ml/kg/min	20.1 (7.7)	9.4	38.1
Predicted VO_2max[b], %	48.4 (16.2)	21.0	76.0
RER	1.0 (0.1)	0.8	1.1
HR_{max}, bpm	133 (35.7)	85.0	195.0
Predicted HR_{max}, %	67.2 (17.5)	43.0	96.0
TTE			
UVEDD, mm	55.0 (10.0)	42.0	75.0
UVEDV, ml	100.7 (52.9)	52.9	220.0
Wall thickness, mm	10.1 (1.7)	7.8	13.0
UVEF, %	50.3 (10.5)	25.0	70.0
GLS	–17.2 (5.1)	–3.5	–23.8
SVC V_{max}, m/s	0.5 (0.2)	0.3	1.0
IVC V_{max}, m/s	0.5 (0.2)	0.3	1.1
CT			
SVC area, cm^2	2.2 (1.2)	1.0	5.6
SVC circumference, cm	5.3 (1.2)	3.8	8.6
IVC area, cm^2	7.7 (3.5)	2.8	15.2
IVC circumference, cm	9.9 (2.1)	6.4	14.2
Conduit area, cm^2	3.5 (2.2)	1.0	8.2
Conduit circumference, cm	6.6 (1.9)	3.9	10.3
RPA area, cm^2	2.4 (1.0)	1.0	5.0
RPA circumference, cm	5.7 (1.0)	4.0	8.4
LPA area, cm^2	2.2 (0.9)	0.9	4.0
LPA circumference, cm	5.5 (1.1)	3.7	7.4

SI conversion factors: to convert total protein, albumin to g/l, multiply by 10; CRP to nmol/l, by 9.524; total bilirubin to μmol/l, by 17.104; creatinine to μmol/l, by 88.4; hemoglobin to g/l, by 0.1.

a The value of NT-proBNP was presented as median.

b Predicted VO_2max percentage, normalized to age, sex, and weight-based normative values

Abbreviations: CPET, cardiopulmonary exercise test; CRP, C-reactive protein; CT, computed tomography; GLS, global longitudinal strain; HR, heart rate; LPA, left pulmonary artery; max, maximal value; min, minimal value; NT-proBNP, N-terminal fragment of the prohormone brain natriuretic peptide; RER, respiratory exchange ratio; RPA, right pulmonary artery; TTE, transthoracic echocardiography; UVEDD, univentricular end-diastolic diameter; UVEDV, univentricular end-diastolic volume; UVEF, univentricular ejection fraction; V, velocity; VO_2max, maximal oxygen uptake; others, see TABLE 1

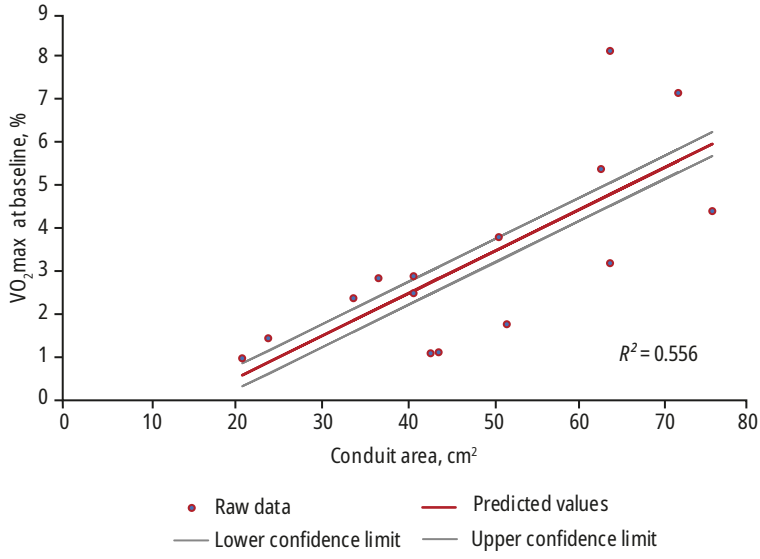

FIGURE 3 A predictive linear regression model of the conduit area and maximal oxygen uptake (VO_2max) at baseline

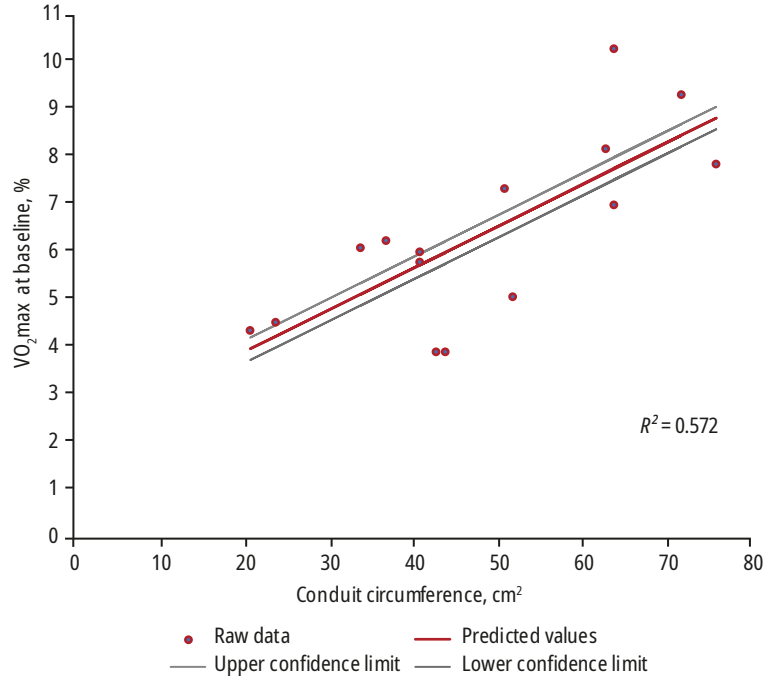

FIGURE 4 A predictive linear regression model of the conduit circumference and maximal oxygen uptake (VO_2max) at baseline

between the selected CT parameters and functional status of adults late after the TCPC procedure.

The morphology and performance of cavopulmonary connections and pulmonary circulation are major determinants of circulatory efficiency late after the surgery.[10] As a result, a failure of a single segment influences the function of the rest. In this study, we found correlations between the dimensions of the IVC and both age and time elapsed since the TCPC procedure. It may be speculated that the dilatation of the IVC results from increased systemic venous pressure secondary to elevated pulmonary vascular resistance, which is a part of the unfavorable natural history of the TCPC circulation.

In patients with TCPC, CPET is a widely acknowledged tool that provides information about the prognosis, including the need for heart transplantation.[17-19] Our study revealed a strong positive correlation between the dimensions of the conduit and the results of CPET: the area and circumference of the conduit helped anticipate the predicted VO_2max. This finding emphasizes the role of selecting the proper initial size of the conduit before the operation, bearing in mind a patient's natural growth process.[20]

Previous studies have shown that both the TCPC geometry and the size of the pulmonary arteries play an important role in determining short- and long-term patient outcomes.[21-25] We found a significant correlation between the diameter of the right pulmonary artery and the GLS of a single (systemic) ventricle. This correlation probably results from the influence of the pulmonary vascular system on the function of a single ventricle. However, no correlation was found between the CT parameters and EF of a single ventricle, which confirms a limited value of the single-plane Simpson rule applied in this group of patients.[26] The Simpson rule for calculating the left ventricular EF is not applicable for the evaluation of systolic function of a single ventricle due to its complex geometry. In this population, such a method may be useful for long-term follow-up of an individual patient.

Eindhoven at al[27] reported a significantly higher concentration of NT-proBNP in patients with the Fontan circulation who had a moderate to severe impairment of ventricular function. However, data on the clinical use of brain natriuretic peptides in the Fontan circulation should be interpreted with caution, as their levels depend on the type of the Fontan procedure and the involvement of the right atrial tissue in the Fontan circulation.[28] Trojnarska et al[29] reported higher serum concentrations of NT-proBNT in patients who underwent the Fontan procedure, which did not correlate with the results of CPET. An increased level of NT-proBNP was also confirmed in the patients included in our study. However, we did not find any significant correlation between the NT-proBNP level and CT and TTE parameters.

Limitations This study has several limitations due to its retrospective nature and a small number of patients examined in a single center. CT is the second-choice imaging method and was used only because of particular clinical indications. Therefore, we included 2 types of TCPC (intra- and extracardiac) and 2 types of univentricular morphology (right- and left-ventricle) in one group (eg, in the evaluation of the GLS).

TABLE 3 Correlations between computed tomography parameters and transthoracic echocardiography, cardiopulmonary exercise test, and biochemical parameters

Parameter	SVC area	SVC circ.	IVC area	IVC circ.	Conduit area	Conduit circ.	Conduit area BSA indexed	Conduit circ. BSA indexed	RPA area	RPA circ.	LPA area
UVEF	$r = -0.09$ $P = 0.70$	$r = -0.17$ $P = 0.49$	$r = -0.20$ $P = 0.41$	$r = -0.09$ $P = 0.71$	$r = 0.38$ $P = 0.12$	$r = 0.34$ $P = 0.16$	$r = 0.38$ $P = 0.12$	$r = 0.46$ $P = 0.06$	$r = -0.42$ $P = 0.09$	$r = -0.42$ $P = 0.08$	$r = -0.16$ $P = 0.52$
GLS	$r = 0.48$ $P < 0.05$	$r = 0.34$ $P = 0.15$	$r = -0.19$ $P = 0.44$	$r = -0.13$ $P = 0.61$	$r = -0.25$ $P = 0.32$	$r = -0.26$ $P = 0.31$	$r = -0.11$ $P = 0.65$	$r = -0.01$ $P = 0.97$	$r = -0.66$ $P < 0.01$	$r = -0.59$ $P < 0.01$	$r = -0.06$ $P = 0.82$
VO_2max	$r = 0.1$ $P = 0.77$	$r = -0.06$ $P = 0.82$	$r = 0.2$ $P = 0.46$	$r = 0.23$ $P = 0.39$	$r = 0.76$ $P < 0.01$	$r = 0.71$ $P < 0.01$	$r = 0.64$ $P = 0.01$	$r = 0.55$ $P < 0.05$	$r = 0.17$ $P = 0.54$	$r = 0.21$ $P = 0.44$	$r = -0.05$ $P = 0.86$
Predicted VO_2max	$r = 0.22$ $P = 0.49$	$r = 0.15$ $P = 0.58$	$r = 0.31$ $P = 0.25$	$r = 0.37$ $P = 0.16$	$r = 0.74$ $P < 0.01$	$r = 0.66$ $P < 0.01$	$r = 0.73$ $P < 0.01$	$r = 0.65$ $P < 0.01$	$r = 0.16$ $P = 0.55$	$r = 0.2$ $P = 0.46$	$r = -0.22$ $P = 0.41$
Albumin	$r = -0.12$ $P = 0.64$	$r = -0.2$ $P = 0.42$	$r = -0.22$ $P = 0.38$	$r = -0.24$ $P = 0.33$	$r = 0.06$ $P = 0.9$	$r = 0.14$ $P = 0.58$	$r = 0.36$ $P = 0.16$	$r = 0.53$ $P < 0.05$	$r = 0.19$ $P = 0.44$	$r = 0.17$ $P = 0.47$	$r = 0.36$ $P = 0.13$
NT-proBNP	$r = -0.2$ $P = 0.42$	$r = -0.06$ $P = 0.8$	$r = 0.07$ $P = 0.79$	$r = 0.004$ $P = 0.99$	$r = -0.196$ $P = 0.44$	$r = -0.18$ $P = 0.48$	$r = -0.39$ $P = 0.11$	$r = -0.35$ $P = 0.15$	$r = -0.12$ $P = 0.63$	$r = -0.06$ $P = 0.82$	$r = -0.14$ $P = 0.56$
CRP	$r = -0.16$ $P = 0.51$	$r = -0.003$ $P = 0.99$	$r = 0.07$ $P = 0.77$	$r = 0.17$ $P = 0.49$	$r = 0.15$ $P = 0.54$	$r = 0.08$ $P = 0.77$	$r = 0.30$ $P = 0.23$	$r = 0.24$ $P = 0.33$	$r = 0.1$ $P = 0.67$	$r = 0.18$ $P = 0.45$	$r = -0.39$ $P = 0.1$
Total bilirubin	$r = -0.29$ $P = 0.23$	$r = -0.37$ $P = 0.14$	$r = 0.32$ $P = 0.19$	$r = 0.19$ $P = 0.45$	$r = 0.14$ $P = 0.61$	$r = 0.22$ $P = 0.4$	$r = -0.15$ $P = 0.57$	$r = -0.16$ $P = 0.54$	$r = 0.29$ $P = 0.24$	$r = 0.3$ $P = 0.23$	$r = 0.25$ $P = 0.31$
Age	$r = 0.17$ $P = 0.5$	$r = 0.38$ $P = 0.11$	$r = 0.5$ $P < 0.05$	$r = 0.59$ $P < 0.01$	$r = 0.44$ $P = 0.07$	$r = 0.35$ $P = 0.16$	$r = 0.35$ $P = 0.16$	$r = 0.160$ $P = 0.52$	$r = 0.25$ $P = 0.31$	$r = 0.25$ $P = 0.31$	$r = -0.31$ $P = 0.2$
Time after TCPC	$r = 0.06$ $P = 0.81$	$r = 0.11$ $P = 0.65$	$r = 0.67$ $P < 0.01$	$r = 0.7$ $P < 0.01$	$r = 0.31$ $P = 0.21$	$r = 0.22$ $P = 0.39$	$r = 0.01$ $P = 0.95$	$r = 0.02$ $P = 0.95$	$r = 0.3$ $P = 0.21$	$r = 0.2$ $P = 0.42$	$r = 0.09$ $P = 0.71$

A *P* value of less than 0.05 was considered significant.

Abbreviations: BSA, body surface area; circ., circumference; TCPC, total cavopulmonary connection; others, see TABLES 1 and 2

The study population was heterogeneous with regard to the time since the surgery and the initial diagnosis.

Conclusion Our study proved an association between the dimensions of the tunnel and time since the TCPC procedure, and a patient's age. It also revealed a relationship between the functional status of patients and time since the TCPC late after the surgery. These findings advocate for measuring the SVC, IVC, and tunnel routinely in patients with TCPC upon CT examination.

ARTICLE INFORMATION

CONFLICT OF INTEREST None declared.

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