Reference Values for Ventricular Volumes and Pulmonary Artery Dimensions in Pediatric Patients with Transposition of the Great Arteries After Arterial Switch Operation

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Background: Pulmonary artery (PA) anatomy in patients with transposition of the great arteries (TGA) after arterial switch operation (ASO) with Lecompte manoeuvre is different compared to healthy subjects, and stenoses of the PA are common. Magnetic resonance imaging (MRI) is an excellent imaging modality to assess PA anatomy in TGA patients. However, disease-specific reference values for PA size are scarce.

Purpose: To establish disease-specific reference ranges for PA dimensions and for biventricular volumes and mass.

Study Type: Retrospective.

Subjects: A total of 69 pediatric patients with TGA after ASO (median age 12.6 years; range 5–17.8 years; 13 females and 56 males).

Field Strength/Sequence: 3.0 T, steady-state free precession (SSFP) and gradient echo cine sequences and four-dimensional time-resolved magnetic resonance angiography with keyhole.

Assessment: Right and left PA (RPA, LPA) were each measured at three locations during its course around the aorta. Ventricular volumes, mass, and ejection fraction were measured from a stack of short axis cine images.

Statistical Tests: The lambda-mu-sigma (LMS) method of Cole and Green, univariate and multivariate linear models, and t-test.

Results: Centile graphs and tables for PA dimensions, biventricular volumes, mass, and ejection fraction were created. Univariate linear analysis showed significant associations (P < 0.05) between body surface area (BSA), height, and weight with systolic MPA and RPA diameter. In multivariate linear analysis, only BSA remained a strong predictor for main PA and RPA diameters. For biventricular volumes, the univariate linear model revealed a strong influence of BSA, height, weight, and age (all P < 0.05). On multivariate linear analysis, only body height remained associated.

Data Conclusion: Uni- and multivariate linear analyses showed a strong association between BSA and PA diameters, as well as between height and biventricular volumes, and therefore, centile tables and graphs are presented accordingly. Our data may improve MR image interpretation and may serve as a reference in future studies.

Level of Evidence: 4
Technical Efficacy Stage: 2
complication.\textsuperscript{1, 2} PA stenosis might impact right ventricular (RV) hemodynamics, as well as RV geometry and function.\textsuperscript{3, 4} However, even in the absence of a significant PA stenosis, RV hypertrophy and RV relaxation abnormalities have been observed and were related to increased peak flow in the pulmonary trunk after the Lecompte maneuver.\textsuperscript{5} Other studies have shown that left ventricular (LV) functional changes are also present in TGA patients after ASO.\textsuperscript{6-8}

Magnetic resonance imaging (MRI) is an excellent imaging modality to study the anatomy of the PAs, as well as ventricular size and function.\textsuperscript{9} Current guidelines recommend that MRI be integrated into the routine evaluation of all post-operative patients with TGA.\textsuperscript{10} However, MRI reference values for PA dimensions after the Lecompte maneuver, as well as for parameters of ventricular size and function for TGA patients after ASO, are desirable.

The primary goal of this study was therefore to establish disease-specific normative ranges for PA dimensions and for biventricular volumes and mass in patients with TGA after ASO. We also sought to investigate the relationship between PA dimensions and measures of ventricular size, function, and mass.

| TABLE 1. Characteristics and Ventricular Measurements of the Study Population |
|---------------------------------|-----------------|-----------------|-----------------|
| Parameter                      | Study Subjects (N = 69) | Female (N = 13) | Male (N = 56)   |
| Age, y                         | 12.3 ± 3.6 (range 5–17.8) | 12.7 ± 3.3 | 12.1 ± 3.7    |
| Female/male, N (%)             | 13 (19)/56 (81)         | –              | –              |
| Body weight, kg                | 46.4 ± 18.1            | 44.1 ± 14.5 | 46.6 ± 17.8   |
| Body height, cm                | 154.9 ± 21.4           | 152.4 ± 17.3 | 155.5 ± 22.0 |
| BSA, m\(^2\)                  | 1.4 ± 0.4              | 1.4 ± 0.3    | 1.4 ± 0.4     |
| LVEDV, mL                      | 126.1 ± 45.7           | 110.4 ± 38.7 | 129.4 ± 44.7 |
| LVEDVi, mL/cm                  | 0.8 ± 0.2              | 0.7 ± 0.2    | 0.8 ± 0.2     |
| LVESV, mL                      | 49.8 ± 23.2            | 42.5 ± 17.1  | 51.6 ± 23.9   |
| LVESVi, mL/cm                  | 0.3 ± 0.1              | 0.3 ± 0.1    | 0.3 ± 0.1     |
| LVSV, mL                       | 76.3 ± 26.5            | 67.9 ± 22.6  | 77.7 ± 25.5   |
| LVSVi, mL/cm                   | 0.5 ± 0.1              | 0.4 ± 0.1    | 0.5 ± 0.1     |
| LVEF, %                        | 61.2 ± 6.6             | 62.2 ± 5.2   | 60.8 ± 6.8    |
| LV mass, g                     | 84.3 ± 30.8            | 74.0 ± 27.2  | 86.2 ± 29.9   |
| Cardiac index, liter/min/m\(^2\) | 4.5 ± 1.5              | 3.8 ± 0.7    | 4.6 ± 1.6     |
| RVESV, mL                      | 45.5 ± 20.9            | 42.8 ± 18.9  | 45.0 ± 19.1   |
| RVESVi, mL/cm                  | 0.3 ± 0.1              | 0.3 ± 0.1    | 0.3 ± 0.1     |
| RVSV, mL                       | 64.3 ± 25.1            | 57.1 ± 19.2  | 64.6 ± 23.3   |
| RVSVi, mL/cm                   | 0.4 ± 0.1              | 0.4 ± 0.1    | 0.4 ± 0.1     |
| RVEF, %                        | 58.9 ± 6.2             | 58.1 ± 5.3   | 59.1 ± 6.4    |
| RV mass, g                     | 33.8 ± 14.4            | 30.3 ± 12.5  | 33.9 ± 14.0   |

Continuous variables are shown as mean and SD, categorical variables as absolute numbers (percentages). BSA = body surface area; LVEDV = left ventricular end-diastolic volume; LVEDVi = ventricular end-diastolic volume indexed to height; LVEF = left ventricular ejection fraction; LVESV = left ventricular end-systolic volume; LVESVi = left ventricular end-systolic volume indexed to height; LV mass = left ventricular muscle mass; LVSV = left ventricular stroke volume; LVSVi = left ventricular stroke volume indexed to height; RVEDV = right ventricular end-diastolic volume; RVEDVi = right ventricular end-diastolic volume indexed to height; RVEF = right ventricular ejection fraction; RVESV = right ventricular end-systolic volume; RVESVi = right ventricular end-systolic volume indexed to height; RV mass = right ventricular muscle mass; RVSV = right ventricular stroke volume; RVSVi = right ventricular stroke volume indexed to height.
Materials and Methods

The study was performed in accordance with the Declaration of Helsinki and was approved by the local ethics committee (reference number: D 533/19). General research consent was obtained from all participants, parents, or legal guardians, as appropriate.

MRI scans from 69 patients with TGA after ASO from a single center (median age 12.7 years, range 5–17.8 years, 56 males) were retrospectively analyzed. All scans were performed during routine follow-up after ASO. Included were all pediatric patients with dextro-TGA after ASO (age < 18 years) who underwent a routine MRI scan in our department. Scans from patients ≥ 18 years and those with insufficient imaging data for the measurement of PA size and ventricular volumes were excluded.

Body surface area (BSA) was calculated using the Mosteller formula. Characteristics of the study population are given in Table 1.

MRI Acquisition

MR scans were performed with a 3.0 Tesla MRI scanner (Philips Achieva Philips Medical Systems, Netherlands) using a dedicated 32-channel coil for cardiac imaging.

Steady-state free precession (SSFP) or gradient echo sequences were used to obtain cine images of the main PA (MPA) and the branch PAs. The sequence parameters were as follows: 1) gradient echo sequence: voxel size 0.91 × 0.91 × 7 mm, repetition time (TR)/time to echo (TE) = 4.5/2.6 ms, flip angle 15°, temporal resolution 34 ms; 2) SSFP sequence: voxel size 1.25 × 1.25 × 6–8 mm, TR/TE = 2.9/1.4 ms, flip angle 45°, temporal resolution 27.1 ms.

Four-dimensional time-resolved MR angiography (MRA) with keyhole was performed in all patients to measure cross-sectional areas of the MPA and the PA branches with 70–85 slices; keyhole percentage, 20%; 20 dynamics; keyhole scan time, 1.7 s; TR/TE, 2.0/0.8 ms; spatial resolution, 1.2 × 1.2 × 1.4 mm; scan duration, 0:40 minutes. Gadolinium (Magnevist or Gadovist, Bayer Schering Pharma AG, Germany) was injected intravenously (dose of 0.1 mmol/kg, injection rate 2 mL/s) and flushed with a volume of saline solution (20 mL, injection rate 2 mL/s).

SSFP and gradient echo cine imaging with retrospective electrocardiography gating were performed for the acquisition of a stack of short axis cine images covering both ventricles from the base to the apex. The imaging parameters were: 1) gradient echo sequence: voxel size 0.98 × 0.98 × 6 mm, TR/TE = 3.69/1.78 ms, 25 cardiac phases, flip angle 15°, temporal resolution 24 ms; 2) SSFP sequence: voxel size 1.2 × 1.2 × 6–8 mm, TR/TE = 2.8/1.4 ms, flip angle 40°, temporal resolution 31 ms.

MRI Analyses

All measurements were performed by CB (1 year of experience) with dedicated software (Extended MR WorkSpace, version 2.6.3.2 HF3 2010; Philips Medical Systems). All ventricular contours and measurement lines were carefully reviewed by the second observer (IV) with more than 14 years of experience.

MPA systolic and diastolic diameters were obtained from a sagittal oblique SSFP or gradient echo cine image (Fig. 1) and were measured at the middle between the pulmonary valve and the pulmonary artery bifurcation. The right and left PA (RPA and LPA, respectively) systolic (phase of maximal systolic expansion) and diastolic (phase of minimal dimension) diameters were each measured at three locations during its course around the aorta from the acquired cine images as demonstrated in Fig. 2. Sites of measurements for both branch PAs were as follows: 1) largest diameter of the proximal RPA and LPA, 2) smallest diameter of RPA and LPA.
To assess interobserver variability, PA diameters were measured twice by two observers in 20 patients (CB, IV). CE-MRA datasets were used to measure cross-sectional areas of the MPA, RPA, and LPA at the same locations as described above. The LV and RV endocardial and epicardial contours were manually traced at end-diastole and end-systole by one observer (CB) and checked by a second observer (IV). LV and RV end-systolic and end-diastolic volumes (LVEDV, RVESV, LVESV, RVEDV), stroke volume, mass, and ejection fraction were automatically calculated by the software.

Statistics

The software R, version 3.6.2 and MedCalc®, version 19.4.0 were used for the statistical analysis. All tests were two-sided, and a significance level of 0.05 was chosen. Measurement outliers were double-checked for measurement errors and corrected or excluded where appropriate. Visual inspection of histograms and boxplots was used to determine normality. Linear regression analyses were performed using univariate and multivariate models. Influence variables that remained significant in the multivariate linear model are shown in bold.

Beta = coefficient of the linear model; BSA = body surface area; LVEDV = left ventricular end-diastolic volume; LVESV = left ventricular end-systolic volume; RVEDV = right ventricular end-diastolic volume; RVESV = right ventricular end-systolic volume.

at the level of the aorta, and 3) largest diameter of the distal RPA and LPA. To assess interobserver variability, PA diameters were measured twice by two observers in 20 patients (CB, IV).

CE-MRA datasets were used to measure cross-sectional areas of the MPA, RPA, and LPA at the same locations as described above.

The LV and RV endocardial and epicardial contours were manually traced at end-diastole and end-systole by one observer (CB) and checked by a second observer (IV). LV and RV end-systolic and end-diastolic volumes (LVEDV, RVESV, LVESV, RVEDV), stroke volume, mass, and ejection fraction were automatically calculated by the software.

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### TABLE 2. Continued

| Influence Variable | Beta | Standard Error | P value |
|--------------------|------|----------------|---------|
| **RVEDV (mL)**     |      |                |         |
| Gender, reference male | −9.90 | 12.22 | 0.42 |
| BSA (m²) | 93.01 | 7.54 | <0.0001 |
| Body height (cm) | 1.60 | 0.12 | <0.0001 |
| Body weight (kg) | 1.87 | 0.16 | <0.0001 |
| Age (years) | 8.35 | 0.87 | 6.4 x 10⁻¹⁴ |
| **RVESV (mL)**     |      |                |         |
| Gender, reference male | −2.10 | 6.01 | 0.73 |
| BSA (m²) | 40.19 | 4.58 | <0.0001 |
| Body height (cm) | 0.69 | 0.077 | <0.0001 |
| Body weight (kg) | 0.81 | 0.097 | <0.0001 |
| Age (years) | 3.76 | 0.47 | <0.0001 |

Influence variables that remained significant in the multivariate linear model are shown in bold.
used to ensure that no relevant deviations from the normal distribution existed.

Comparisons between RPA and LPA measurements were performed using the paired \( t \)-test.

Centile graphs and tables were generated according to the lambda-mu-sigma (LMS) method of Cole and Green.\(^1\) An extended version of this method is implemented in the R package gamlss, which was used for the analysis.\(^2\)

The impact of demographic parameters (gender, BSA, age, height, weight) on PA and ventricular measurements was analyzed using univariate and multivariate linear models, with and without interactions, and Pearson’s correlation coefficient (\( r \)). Dependent variables were MPA, LPA, and RPA diameters, as well as LVESV, RVESV, LVEDV, and RVEDV. Model selection was performed by backward selection and a \( P \) value threshold of 0.05. Intraclass correlation (ICC) analysis was used to assess interobserver variability.

### TABLE 3. Comparison Between RPA and LPA Diameters and Cross-Sectional Areas

|        | RPA     | LPA     | \( P \) value |
|--------|---------|---------|--------------|
| **Proximal** |         |         |              |
| Systolic diameter (mm) | 12.0 ± 3.0 | 9.7 ± 2.6 | <0.0001     |
| Diastolic diameter (mm) | 9.8 ± 2.4 | 8.6 ± 2.3 | 0.0051      |
| Cross-sectional area (mm\(^2\)) | 168.8 ± 72.9 | 119.9 ± 67.6 | 0.0002      |
| **Aortic level** |         |         |              |
| Systolic diameter (mm) | 10.5 ± 2.8 | 8.4 ± 2.8 | <0.0001     |
| Diastolic diameter (mm) | 8.3 ± 2.2 | 7.4 ± 2.3 | 0.056      |
| Cross-sectional area (mm\(^2\)) | 143.7 ± 55.2 | 99.0 ± 65.6 | 0.0001      |
| **Distal** |         |         |              |
| Systolic diameter (mm) | 12.3 ± 2.7 | 10.8 ± 3.0 | 0.0027      |
| Diastolic diameter (mm) | 10.0 ± 2.9 | 9.6 ± 2.3 | 0.31       |
| Cross-sectional area (mm\(^2\)) | 168.7 ± 64.9 | 129.1 ± 65.3 | 0.0012      |

LPA = left pulmonary artery; RPA = right pulmonary artery.

![FIGURE 3: Centile charts of systolic and diastolic main pulmonary artery diameters with regard to body surface area. The different colors correspond to the given centiles.](image)
FIGURE 4: Centile charts of systolic and diastolic left pulmonary artery diameters with regard to body surface area measured at all three levels. The different colors correspond to the given centiles.
FIGURE 5: Centile charts of systolic and diastolic right pulmonary artery diameters with regard to body surface area measured at all three levels. The different colors correspond to the given centiles.
Results

None of the patients had a significant PA stenosis (defined as \( >50\% \) local reduction of PA diameter on cine images). Strong correlations were observed between influence variables such as age, BSA, weight, and height \((r = 0.86-0.99)\). Univariate linear analyses (Table 2) showed a significant influence \((P < 0.05)\) of BSA, height, and weight on systolic MPA and RPA diameter (BSA: beta = 3.16 and 2.57, height: beta = 0.056 and 0.041, weight: beta = 0.060 and 0.052, respectively). Age was only significant \((P < 0.05)\) for systolic MPA diameter, and gender had no significant effect on both variables \((P = 0.38 \text{ and } P = 0.59)\). In the multivariate linear model, only BSA remained a strong predictor for systolic MPA and RPA diameters.

For LVEDV, RVEDV, LVESV, and RVESV a strong influence of BSA, height, weight, and age was detected (all \( P < 0.05)\), whereas gender again was not associated with any of these variables \((P = 0.18, \ P = 0.42, \ P = 0.21, \text{ and } P = 0.73\), respectively; Table 2). In the multivariate linear model, only body height remained associated.

PA Normative Ranges

Systolic and diastolic diameters, as well as cross-sectional areas of the LPA, were significantly lower compared to those of the RPA (proximal: systolic diameter 9.7 ± 2.6 vs. 12.0 ± 2.0, diastolic diameter 8.6 ± 2.3 vs. 9.8 ± 2.4, cross-sectional area 119.9 ± 67.6 vs. 168.8 ± 72.9; aortic level: systolic diameter 8.4 ± 2.8 vs. 10.5 ± 2.8, cross-sectional area...
99.0 ± 65.6 vs. 143.7 ± 55.2; distal: systolic diameter 10.8 ± 3.0 vs. 12.3 ± 2.7, cross-sectional area 129.1 ± 65.3 vs. 168.7 ± 64.9; all P < 0.05; Table 3) apart from the diastolic branch PA diameter at the aortic and distal levels (aortic level: diastolic diameter 7.4 ± 2.3 vs. 8.3 ± 2.2; distal: diastolic diameter 9.6 ± 2.3 vs. 10.0 ± 2.9; P > 0.05, Table 3).

The narrowest diameter of both branch PAs was at the aortic level (Table 3). Mean systolic/diastolic diameters of the MPA were 15.1 ± 3.0/13.2 ± 2.9 mm, respectively, and mean cross-sectional MPA area was 267.5 ± 82.6 mm².

Using the LMS method of Cole and Green,¹³ centile curves and tables with regard to BSA were created for systolic and diastolic MPA diameters (Fig. 3, Appendix S1), as well as for systolic and diastolic LPA and RPA diameters at all three levels (Figs. 4, and 5; Appendix S1) with regard to BSA.

**Ventricular Normative Ranges**

Centile curves and tables for RV and LV volumes and mass were created with respect to body height (Figs. 6 and 7, Appendix S1).

Mean indexed RV and LV volumes, as well as ventricular functional markers, are shown in Table 1.

**Relation Between PA and Ventricular Measures**

LPA and RPA systolic and diastolic diameters at all three levels; MPA systolic diameter; and MPA, LPA, and RPA
## TABLE 4. Relationship Between Ventricular Volumes and Mass and Pulmonary Artery Diameters

| Parameters | RV end-Diastolic Volume (Correlation Coefficient) Mean | RV end-Systolic Volume (Correlation Coefficient) SD | RV Stroke Volume (Correlation Coefficient) | RV Mass (Correlation Coefficient) |
|------------|------------------------------------------------------|---------------------------------------------------|------------------------------------------|----------------------------------|
| MPA        |                                                     |                                                   |                                          |                                  |
| Systolic diameter (mm) | 0.40** | 0.29 | 0.44** | 0.29 |
| Diastolic diameter (mm) | 0.25 | 0.25 | 0.22 | 0.15 |
| Cross-sectional area (mm$^2$) | 0.57** | 0.53** | 0.55** | 0.35** |
| RPA (proximal) | | | | |
| Systolic diameter (mm) | 0.45** | 0.38** | 0.46** | 0.33** |
| Diastolic diameter (mm) | 0.38** | 0.34** | 0.37** | 0.33** |
| Cross-sectional area (mm$^2$) | 0.37** | 0.31* | 0.38** | 0.22 |
| RPA (aortic level) | | | | |
| Systolic diameter (mm) | 0.41** | 0.32* | 0.36** | 0.28* |
| Diastolic diameter (mm) | 0.35** | 0.28* | 0.44** | 0.27* |
| Cross-sectional area (mm$^2$) | 0.32* | 0.23 | 0.36** | 0.25 |
| RPA (distal) | | | | |
| Systolic diameter (mm) | 0.53** | 0.42** | 0.57** | 0.36** |
| Diastolic diameter (mm) | 0.54** | 0.44** | 0.56** | 0.44** |
| Cross-sectional area (mm$^2$) | 0.45** | 0.39** | 0.44** | 0.34** |
| LPA (proximal) | | | | |
| Systolic diameter (mm) | 0.49** | 0.47** | 0.44** | 0.33** |
| Diastolic diameter (mm) | 0.49** | 0.49** | 0.44** | 0.37** |
| Cross-sectional area (mm$^2$) | 0.30* | 0.30* | 0.26 | 0.15 |
| LPA (aortic level) | | | | |
| Systolic diameter (mm) | 0.36** | 0.37** | 0.32* | 0.23 |
Reproducibility of PA Diameters
Excellent interobserver agreement was shown for the measurements of MPA, RPA, and LPA diameters. The ICC coefficient ranged from 0.93 to 0.99.

Discussion
TGA is the second most common cyanotic congenital heart disease and is normally treated by ASO in the first days of life. During long-term follow-up, MRI plays a major role in TGA after ASO, and specific reference values are therefore of importance. In this study, we therefore established disease-specific MRI reference values for pediatric TGA patients after the ASO. In the multivariate linear model, BSA proved to be the strongest determinant for PA diameters, and height was the strongest predictor for biventricular volumes. Thus, reference curves and tables are either presented with regard to BSA or body height. These data may help clinicians working in the field of congenital MRI and could be a useful reference for future research studies on TGA patients.

PA Size in TGA
In this study, we have provided centile graphs and tables for the MPA and the RPA and LPA at three levels. Both graphs and tables were created with respect to BSA because stepwise backward multivariate linear analysis identified BSA as the strongest determinant for PA diameters. We did not create gender-specific reference values because the number of female patients included in this study was low, which is due to the known male predominance in TGA. BSA was calculated with the Mosteller formula, and we do not know if the results from the regression analysis would have been similar if we had used a different BSA formula. However, it has recently been shown that the Mosteller formula provides the most accurate estimate of BSA in young children with congenital heart disease. The fact that BSA is a function of height and weight implies that there is some redundancy in the investigated influence variables, which is expressed in the high correlations between these three variables. This is why only one of these variables remain in the final models after backward selection (BSA for PA diameters and height for biventricular volumes). Previous MRI studies have reported normal PA values in healthy volunteers and tetralogy of Fallot patients and have documented that the PA changes with age and/or BSA. Similar to our study, Kutty et al demonstrated the superiority of BSA as an influence variable compared to age in a multivariate linear model, and therefore, normal values for the MPA areas were established using BSA.

### TABLE 4. Continued

| Parameters                  | RV end-Diastolic Volume (Correlation Coefficient) | RV end-Systolic Volume (Correlation Coefficient) | RV Stroke Volume (Correlation Coefficient) | RV Mass (Correlation Coefficient) |
|-----------------------------|--------------------------------------------------|--------------------------------------------------|------------------------------------------|----------------------------------|
| Diastolic diameter (mm)     | 0.46**                                           | 0.48**                                           | 0.40**                                   | 0.35**                           |
| Cross-sectional area (mm²)  | 0.23                                             | 0.24                                             | 0.20                                     | 0.13                             |
| LPA (distal)                |                                                  |                                                  |                                          |                                  |
| Systolic diameter (mm)      | 0.49**                                           | 0.50**                                           | 0.43**                                   | 0.35**                           |
| Diastolic diameter (mm)     | 0.50**                                           | 0.49**                                           | 0.46**                                   | 0.38**                           |
| Cross-sectional area (mm²)  | 0.31*                                            | 0.32*                                            | 0.28*                                    | 0.20                             |

*P < 0.05.
**P < 0.01.
Several other studies reporting normal PA values used computed tomography or echocardiography and are not directly comparable to our work.\textsuperscript{21-24}

RV outflow tract and PA stenosis is a common complication in patients with TGA after ASO and often affects the supravalvar PA and the PA branches.\textsuperscript{25, 26} In our cohort, we found that the LPA was significantly smaller than the RPA at most measurement levels, but none of our patients had a significant stenosis. This size discrepancy has been described by Morgan et al\textsuperscript{27} and is thought to result from the rightward position of the neopulmonary root.\textsuperscript{27} Other authors have found preferential blood flow to the RPA and a significantly reduced cross-sectional vessel area of the LPA during systole\textsuperscript{28} using four-dimensional flow MRI and have suggested that an anterior pulmonary trunk position may trigger pulmonary blood flow alterations.\textsuperscript{28} Another factor might be a dilated aortic root compressing the LPA and facilitating blood flow to the right lung.\textsuperscript{27, 28}

**Ventricular Size, Function, and Mass in TGA**

MRI is an alternative and complementary imaging modality to echocardiography after ASO\textsuperscript{10} and allows for the accurate quantification of ventricular size, ejection fraction, and myocardial mass.\textsuperscript{29} In the current study, we presented reference graphs and tables for ventricular volumes, ejection fraction, and myocardial mass in pediatric TGA patients, which may improve MRI reporting in this group of congenital heart disease patients. A previous study has reported gender-specific percentiles in a large cohort of Fallot patients.\textsuperscript{30}

Compared to previous studies in healthy children,\textsuperscript{31} biventricular mass and LVEDV and LVESV were higher in the group of TGA patients reported here. This difference might be explained by methodological differences in ventricular contouring and also by the fact that some degree of aortic regurgitation is not rare in TGA after ASO.\textsuperscript{32}

Our reference curves are presented with respect to height because the multivariate linear model with backward selection revealed that height was the strongest predictor. Other groups have found that height-based methods of indexing ventricular mass have a high allometric power\textsuperscript{33} and that the predictive value of hypertrophy is better with an index that accounts for both weight and height.\textsuperscript{34} In addition, the method of indexing ventricular volumes using actual BSA may underestimate ventricular volumes in obese patients.\textsuperscript{35}

**Limitations**

This is a retrospective study, but consecutive nonselected patients were included. The number of boys was higher than the number of girls, which is related to the known male predominance of TGA.\textsuperscript{17}

Our reference curves and tables represent postoperative values, and it is therefore not possible to label them as normal values. In addition, the overall number of included pediatric TGA patients is too small for true normative values, which would have required a significantly larger number of children, as well as sedation or general anesthesia in small children. In addition, we did not compare MRI results from TGA patients with MRI findings in healthy controls.

Assessment of biventricular volumes and function was performed in a well-known and standardized manner. We therefore did not include interobserver variability data for volumetric results, but ICC coefficients for PA diameters are presented. No interobserver data for the measurements of cross-sectional PA diameters are given.

Finally, we did not analyze the relationship between time since surgery and biventricular volumetric data, as well as PA diameters.

**Conclusions**

We provide percentile curves and tables for PA diameters, ventricular volumes, RV and LV ejection fraction, and RV and LV mass in pediatric patients with TGA. Our data may be of use for routine image analysis in TGA patients and for future congenital heart disease research.

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