Left and right ventricular performance after arterial switch operation

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Objective: Recent descriptions of decreased exercise capacity 10 to 15 years after arterial switch operation (ASO) suggest subclinical hemodynamic restrictions. Persistent impairment of ventricular performance following ASO may add to this. We aimed to characterize the time course of changes in biventricular performance within the first year following ASO.

Methods: We prospectively included 26 patients with transposition of the great arteries undergoing ASO and 20 age-matched controls. Left and right ventricular systolic and diastolic performance was assessed using tissue Doppler imaging-derived peak systolic velocity, peak diastolic velocity, and peak early wave Doppler flow velocity/early diastolic tissue Doppler imaging velocity as well as mitral and tricuspid annular plane systolic excursion. Furthermore, left ventricular longitudinal, radial, and circumferential strain were assessed using speckle tracking strain imaging. Studies were performed preoperatively, 1 day postoperatively, at discharge, and at medium-term follow-up (9 months [interquartile range, 6-23 months] postoperatively).

Results: After an initial decrease in biventricular systolic and diastolic performance 1 day postoperatively versus preoperatively, recovery was observed in all parameters during medium-term follow-up. At medium-term follow-up left ventricular systolic and diastolic performance parameters were comparable in patients and controls. In contrast, right ventricular systolic and diastolic performance were still impaired in patients versus controls roughly 1 year postoperatively (tricuspid annular plane systolic excursion, 11.6 $\pm$ 2.2 vs 18.6 $\pm$ 3.1 mm; right ventricular peak systolic velocity, 8.1 $\pm$ 2.3 vs 12.6 $\pm$ 1.8 cm/second; right ventricular peak diastolic velocity, 12.4 $\pm$ 3.0 vs 18.2 $\pm$ 4.2 cm/second; and right ventricular peak early wave Doppler flow velocity/early diastolic tissue Doppler imaging velocity, 6.7 $\pm$ 2.1 vs 4.3 $\pm$ 1.3; all *P*s $<$ .001).

Conclusions: If early ASO is performed, left ventricular performance recovers to control values within the first postoperative year. In contrast, right ventricular systolic and diastolic performance remained impaired during follow-up, which stresses the importance of postoperative follow-up of right ventricular performance. (J Thorac Cardiovasc Surg 2014;147:1561-7)

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Since the introduction of anatomical correction of transposition of the great arteries (TGA) with the arterial switch operation (ASO), patient survival has improved. In combination with ongoing refinements of the surgical technique, this has lead to low surgical mortality[1] and good long-term survival of patients undergoing ASO in the current era.[2] Nonetheless, recent descriptions of decreased exercise capacity 10 to 15 years after ASO suggest that subclinical hemodynamic restrictions remain.[3,4] Hemodynamic impairment could develop over time as a consequence of common residua and complications of ASO, including pulmonary artery obstruction and coronary artery problems.[4] However, persistent impairment of cardiac performance following surgical correction may also play a role.

Persistent impairment of cardiac performance has been previously described in pediatric patients after surgical correction of a congenital heart defect using cardiopulmonary bypass (CPB).[5] In patients born with TGA, decreased left ventricular (LV) performance has been described within the first 48 hours following ASO.[6,7] However, to our knowledge, continuing follow-up of the changes evoked by surgery and the time course and extent of recovery is limited. Furthermore, right ventricular (RV) performance is underexposed in most studies.

With the advent of echocardiographic techniques, including tissue Doppler imaging (TDI) and speckle tracking

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Abbreviations and Acronyms

- ASO = arterial switch operation
- CPB = cardiopulmonary bypass
- E′ = peak diastolic velocity
- E/E′ = peak early wave Doppler flow velocity/ early diastolic tissue Doppler imaging velocity
- FS = fractional shortening
- LV = left ventricular
- LVIDd = left ventricular internal diameter at end-diastole
- LVIDs = left ventricular internal diameter at end-systole
- MAPSE = mitral annular plane systolic excursion
- RV = right ventricular
- S′ = peak systolic velocity
- TAPSE = tricuspid annular plane systolic excursion
- TGA = transposition of the great arteries
- TDI = tissue Doppler imaging

strain imaging, the detection of subtle impairment of biventricular systolic and diastolic performance has been greatly enhanced.[8] Additionally, these techniques offer the advantage of regional assessment of myocardial performance. Accordingly, in our study we aimed to characterize the time course of changes in biventricular performance within the first year following ASO using TDI and speckle tracking strain imaging.

METHODS

We prospectively enrolled all consecutive patients with simple TGA, with or without a ventricular septal defect, who underwent ASO at our institution between 2009 and 2012. Patients with major additional defects, including Taussig-Bing anomaly and aortic arch pathology, were excluded. Additionally, 1 group of healthy children, who were referred to our institution with an asymptomatic, innocent heart murmur, were included as controls. This group was age-matched to patients at medium-term follow-up. The institutional review board at our institution approved this study and written informed consent was obtained from the parents.

Surgical correction was carried out via a median sternotomy using high-flow, moderate hypothermic CPB with bicaval cannulation. Before cross-clamping, the open ductus arteriosus was ligated. Subsequently the aorta was crossclamped and cold crystalloid cardioplegia was infused; this was repeated every 30 minutes. The operation included dissection of the aorta and pulmonary artery above the level of the commisures, transplantation of the coronary arteries from the aortic sinus into the corresponding pulmonary sinus using the coronary artery-button technique, switching of the aorta and pulmonary artery by the Lecompte manoeuvre whenever possible, and reconstruction of the neopulmonary trunk with an autologous pericardial patch.

Demographic parameters, including weight, body surface area, sex, and age were documented at study inclusion. Body surface area in square meters was calculated using Boyd's formula $(0.0004688 \times \text{weight}^{(0.8168-0.0154 \times \log[\text{weightweight}])})$ using weight in grams. Additionally, operative parameters were collected, including CPB time and aortic crossclamp time.

All patients and controls underwent transthoracic echocardiography, without sedation, to comprehensively assess biventricular systolic and diastolic performance. In patients examinations were performed preoperatively, 1 day postoperatively, at hospital discharge, and at a medium-term follow-up of roughly 1 year postoperatively. Subsequently changes in echocardiographic parameters in patients during follow-up were evaluated. Controls underwent only 1 examination, and were compared with patients at medium-term follow-up.

Echocardiography

Transthoracic echocardiography was performed to assess biventricular performance using a commercially available system (Vivid-7.0.0; General Electric Vingmed Ultrasound, Horten, Norway). Furthermore, the presence and severity of pulmonary artery obstruction at discharge was assessed using continuous Doppler flow velocity in the parasternal short-axis view. The maximal peak flow velocity in the main pulmonary artery or pulmonary artery branches was used as the maximal pulmonary artery velocity.[4] Images were stored in digital format to allow off-line analyses using EchoPac version 11.1.8 (General Electric Vingmed Ultrasound). Off-line analysis was performed by 1 observer (L.M.K.) to limit possible interobserver variability. Subsequently, results were reviewed and discussed with a second observer (A.D.J.H.). Patients without sinus rhythm at the time of echocardiographic investigation were excluded.

M-Mode

Fractional shortening (FS) was calculated from M-mode recordings of the LV long axis to assess LV systolic performance. To calculate FS, LV internal diameter at end-diastole (LVIDd) and LV internal diameter at end-systole (LVIDs) were assessed in millimeters and combined as follows $((\text{LVIDd}-\text{LVIDs})/\text{LVIDd})\times 100\%$.

In M-mode recordings of the apical 4-chamber view LV and RV systolic performance was assessed using measurements of respectively mitral annular plane systolic excursion (MAPSE) and tricuspid annular plane systolic excursion (TAPSE). The cursor was placed at the mitral or tricuspid annulus free wall, as previously described.[9] Subsequently the maximal excursion of the valve plane was assessed from end-diastole to end-systole.

TDI

Biventricular systolic and diastolic performance was characterized using pulsed-wave TDI. TDI images were obtained in 2-dimensional images of the 4-chamber view throughout 3 consecutive cardiac cycles. The angle of insonation was adjusted to align the ultrasound beam along the direction of myocardial motion. Subsequently, myocardial velocity curves were acquired by placing the cursor at the basal part of the LV lateral wall and RV free wall. In each curve, peak systolic velocities (S′) and peak early diastolic velocities (E′) were assessed. In addition, peak early wave Doppler flow velocity/early diastolic tissue Doppler imaging velocity (E/E′), a diastolic parameter strongly correlated with ventricular filling pressure,[10] was calculated to assess diastolic performance. LV and RV E were assessed by measurements of peak early wave velocity (centimeters per second) in spectral Doppler tracings recorded in the apical 4-chamber view at the tip of the mitral and tricuspid valve.

Speckle Tracking Strain Imaging

In addition to TDI, LV systolic performance was evaluated using speckle tracking strain analyses performed in grayscale images of the apical 4-chamber view (longitudinal analysis) and the LV parasternal short-axis view (radial and circumferential analysis). Images were obtained with optimized sector width and frame rate (preferably 60-90 frames/second). In these images, manual endocardial border tracing at end-systole was used to set the region of interest. The region of interest was automatically divided into 6 segments. In the 4-chamber view this included the

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