Decremental Left Ventricular Deformation after Pulmonary Artery Band Training and Subsequent Repair in Ventriculoarterial Discordance

Heather Y. Sun, MD, Fariborz Behzadian, MD, Rajesh Punn, MD, and Theresa A. Tacy, MD, *Palo Alto, California*

Background: Patients with ventriculoarterial discordance, such as congenitally corrected and d-transposition of the great arteries, may undergo a morphologic left ventricular (LV) training strategy consisting of surgical pulmonary artery band (PAB) placement and subsequent anatomic repair to establish ventriculoarterial concordance. The purpose of this study was to characterize morphologic LV function and deformation longitudinally using speckle-tracking strain analysis in patients with ventriculoarterial discordance who underwent LV training.

Methods: Twenty-nine patients (12 with d-transposition of the great arteries and 17 with congenitally corrected transposition of the great arteries) who underwent LV training with PAB placement were evaluated retrospectively. LV ejection fraction and global and regional longitudinal strain and strain rate were measured before and 7 ± 5 days after PAB placement and subsequent anatomic repair.

Results: PAB placement caused reductions in the mean LV ejection fraction from 76.1 ± 10.2% to 66.7 ± 7.8% (P < .001), in mean global strain from −17.7 ± 9% to −13.3 ± 7.5% (P = .01), and in mean lateral wall strain from −23.3 ± 12.8% to −17.5 ± 10.3% (P = .01). After anatomic repair (a median of 21 months after PAB placement; range, 0.5–104 months), mean LV ejection fraction decreased further from 63.3 ± 8.6% to 52.4 ± 14.9% (P < .05). Mean global strain declined from −17.6% ± 4.4 to −12.6 ± 4% (P = .01), and mean lateral wall strain decreased from −18.2 ± 11.4% to −12.6 ± 5.3% (P = .04).

Conclusions: In patients with ventriculoarterial discordance undergoing PAB placement for LV training and anatomic repair, the morphologic left ventricle demonstrated decremental systolic function and global longitudinal deformation acutely. Frequent functional assessment is warranted to understand long-term myocardial mechanics in these patients. (J Am Soc Echocardiogr 2013;26:765-74.)

Keywords: Pediatric cardiology, Myocardial strain, Transposition, Ventriculoarterial discordance, Pulmonary artery banding

In patients with ventriculoarterial discordance, the morphologic right ventricle supports the systemic circulation, while the morphologic left ventricle supports the pulmonary circulation. Before the development of the arterial switch operation, many patients with d-transposition of the great arteries (d-TGA) underwent atrial switch procedures (such as the Senning or Mustard procedure), which surgically baffled the systemic venous return to the subpulmonary left ventricle and pulmonary venous return to the subsystemic right ventricle. A similar physiologic state exists in congenitally corrected transposition of the great arteries (cc-TGA), in which systemic venous return enters the subpulmonary left ventricle, and pulmonary venous return enters the systemic right ventricle. A subset of these patients develop morphologic right ventricular (RV) dysfunction and failure because the right ventricle may be intrinsically incapable of supporting the systemic circulation over the long term.[1]

Patients with ventriculoarterial discordance, such as d-TGA palliated with atrial switch, unrepaired d-TGA, or cc-TGA,[2] may undergo anatomic repair to restore the morphologic left ventricle to the systemic circulation and decrease the risk for morphologic RV dysfunction and failure.[1] First, morphologic left ventricular (LV) training entails pulmonary artery band (PAB) placement, which mimics a systemic afterload and attempts to condition the left ventricle by stimulating myocardial hypertrophy.[3,4] Anatomic repair in patients with d-TGA with prior atrial switch involves takedown of the initial atrial switch with an arterial switch operation,[5,6] while patients with cc-TGA undergo the double-switch procedure, which combines the atrial and arterial switch operations (Figure 1).[7,8] Despite LV training and anatomic repair, these patients continue to be at risk for morphologic LV dysfunction postoperatively.[9]

Strain evaluation provides an angle-independent measure of global and regional myocardial deformation,[10] which has been shown to correlate with normal and abnormal ventricular function in healthy subjects[11,12] and in patients with a congenital heart

From Lucile Packard Children's Hospital, Stanford University, Palo Alto, California.

Reprint requests: Heather Y. Sun, MD, Lucile Packard Children's Hospital, Stanford University, Division of Pediatric Cardiology, 750 Welch Road, Suite 325, Palo Alto, CA 94304 (E-mail: *heather.sun@stanford.edu*).

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Abbreviations
cc-TGA = Congenitally corrected transposition of the great arteries
d-TGA = D-transposition of the great arteries
LV = Left ventricular
LVEF = Left ventricular ejection fraction
PAB = Pulmonary artery band
RV = Right ventricular
VVI = Velocity Vector Imaging

defect.[13-17] We hypothesize that insufficient myocardial response during the LV training period, indicated by abnormal decreased global longitudinal strain before anatomic repair, predicts patients at risk for unsuccessful anatomic repair and development of ventricular dysfunction. We anticipated acutely decreased global strain after PAB placement; however, strain that fails to recover before anatomic repair may indicate patients at risk for ventricular failure. In this study, we measured morphologic LV deformation at each stage of LV training using strain analysis in patients with d-TGA and cc-TGA who had undergone PAB placement. Global and regional longitudinal strain and strain rate were analyzed along with LV ejection fraction (LVEF). Follow-up clinical outcomes were also evaluated to discern whether specific echocardiographic measurements could predict adequate LV training with eventual anatomic repair and subsequent successful clinical outcomes. This investigation is, to our knowledge, the first to evaluate the effect of PAB placement and LV training on LV myocardial deformation in patients with ventriculoarterial discordance.

METHODS

The study protocol was approved by the Stanford University Institutional Review Board.

Patient Population

The Lucile Packard Children's Hospital Heart Center database was retrospectively searched to identify all eligible patients with d-TGA or cc-TGA who underwent PAB placement at the institution between July 2002 and December 2010.

The morphologic LV training group consisted of patients with diagnoses of either d-TGA or cc-TGA who underwent PAB placement in preparation for anatomic repair. Patients with single-ventricle palliation were excluded. Patients who had inlet ventricular septal defects were also excluded because of the inability to measure strain in the missing segment from the apical four-chamber view.

Each patient's diagnosis, gender, date of birth, dates of surgical procedures, height, weight, and body surface area (calculated using the DuBois formula) were obtained from the electronic medical record. Follow-up information on each patient's clinical status was obtained from the most recent clinic visit to his or her primary cardiologist.

Echocardiographic Data

Echocardiographic studies were routinely performed in all patients as part of their preoperative and postoperative evaluations. Images were acquired according to American Society of Echocardiography guidelines[18] and stored on our institution's secure server. The ultrasound equipment used for the echocardiographic studies was either the Siemens Sequoia C512 (Siemens Medical Solutions USA, Inc., Mountain View, CA) or the Philips iE33 (Philips Medical Systems, Bothell, WA). For each patient, preoperative and postoperative echocardiograms were selected before and after the initial PAB placement and subsequent anatomic repair at our institution. Offline measurements were made using syngo Dynamics workstation (Siemens Medical Solutions USA, Inc.; syngo Dynamics Solutions, Ann Arbor, MI).

The highest quality apical four-chamber view image was identified to perform systolic strain measurements using syngo Velocity Vector Imaging (VVI) software (Siemens Medical Solutions USA, Inc.), which provides analysis independent of ultrasound machine vendor.[19,20] The image frame rate was 30 frames/sec, the standard compression performed upon storage of Digital Imaging and Communications in Medicine images by the syngo Dynamics workstation. A single investigator (F.B.), blinded to clinical outcome data, performed all strain measurements. The endocardial border was manually traced and automatically tracked by the VVI software, producing graphs of strain and strain rate (Figure 2). The apical segments were excluded because of the poor tracking capability of these segments. Global and regional longitudinal strain and strain rate were defined as the peak of the average of instantaneous systolic strain values for each, excluding apical segments. Therefore, global longitudinal strain and strain rate measurements were the average of basal and mid segment values, while regional measurements were the average of basal and mid segment values of the lateral or septal wall.

A second reader (H.Y.S.) performed measurements of global longitudinal strain and strain rate on a randomly selected subset of 10 patients to determine interobserver and intraobserver variability. The reader was blinded to initial analysis, and the two measurements were separated by $\geq$14 days. Variability is expressed as the mean percentage error, calculated as the absolute difference of the two observers' measurements divided by the mean of the measurements, multiplied by 100%.

LVEF was measured in the single-plane apical four-chamber view and calculated as the difference in end-diastole and end-systole LV volumes divided by the end-diastole LV volume, multiplied by 100%. In addition, noninvasive systolic blood pressure, PAB gradient, and morphologic LV free wall thickness in diastole and systole were obtained. Noninvasive systolic blood pressure was documented at the time of each echocardiographic study. The PAB gradient was the peak pressure gradient quantified by continuous-wave Doppler in the view most parallel to flow (the parasternal, five-chamber apical, or subcostal view). LV free wall thickness was measured offline either from M-mode imaging in the parasternal short-axis view in patients with d-TGA or from two-dimensional images in the subcostal coronal view in patients with cc-TGA (Figure 3). A *Z* score was then calculated according to the patient's body surface area.[21]

Magnetic Resonance Imaging Data

The adequacy of LV myocardial mass before anatomic repair was assessed using cardiac magnetic resonance imaging.

Statistical Analysis

Values are expressed as mean $\pm$ SD, unless otherwise specified. All statistical calculations were performed using SAS Enterprise Guide version 4.2 (SAS Institute Inc., Cary, NC) and Microsoft Excel (Microsoft Corporation, Redmond, WA). Two-tailed *t* tests were used to compare echocardiographic data; paired two-tailed *t* tests were used to compare measurements before and after procedural