Many patients born with complete transposition of the great arteries (TGA) had an atrial switch procedure (Mustard or Senning operation) leaving the morphological right ventricle (RV) to support the systemic circulation. Similarly, patients with congenitally corrected TGA (ccTGA) with atrioventricular and ventriculoarterial discordance have a morphological RV in systemic position. Over time, this leads to progressive right ventricular dysfunction, heart failure and increased mortality. As a consequence, early detection of myocardial dysfunction and objective assessment of RV function are paramount. Echocardiography remains the mainstay for serial assessment of ventricular function in patients with a systemic RV at most centers. Unfortunately, due to the complex anatomy of the multiple right ventricle assessing RV function on echocardiography using conventional parameters of ventricular function - such as ejection fraction - is not straightforward. Cardiac magnetic resonance imaging (CMR) offers the advantage of free choice of imaging plane and independence of acoustic windows and therefore allows for assessment of RV volumes throughout the cardiac cycle. However CMR requires expensive equipment, special expertise and is not universally available. Due to late loss of sinus node function a considerable proportion of TGA patients require pacemaker implantation and CMR is not feasible in this setting. In this study we aimed 1) to assess biventricular function in patients with a systemic RV using global systolic strain, 2) to investigate the relationship between systemic and subpulmonary ventricular function and 3) to evaluate the association to clinical outcome in the setting of a systemic RV.

Methods

This was a retrospective study. We studied 120 consecutive patients with a systemic RV (87 with TGA and atrial switch and 42 ccTGA). 71 male, age 35±12 years) attending the Adult Congenital Heart Disease Programme, Royal Brompton Hospital, London and the Adult Congenital and Valvular Heart Disease Center at the University of Muennster, Germany who had undergone a transthoracic echocardiogram between 05/2005 and 04/2010. Thirty-eight age- and sex-matched healthy volunteers (age 36±10 years) were studied in the same way with echocardiography, including speckle tracking analysis.

The cine loops for assessment of peak longitudinal 2D strain of the left and right ventricles were retrieved and offline analysis was performed with dedicated, commercial software (2D Cardic Performance Analysis SoftwareTM, TomTec, Unterschleissheim, Germany). In addition, patients were assessed for functional (NYHA) class, presence of signs of heart failure (peripheral edema or ascites) and history of documented clinical arrhythmias. Adverse clinical status was defined as NYHA class ≥ 3, history of clinically relevant arrhythmia, history of heart failure or death.

Global peak systolic longitudinal strain in the sub systemic (morphological right) ventricle was significantly reduced in patients compared to controls (-13±8%/s vs. -21±6%/s, P<0.001, Figure 1). When patients were stratified according to underlying diagnosis, reduced RV 2-D LS compared to controls was confirmed, both, in patients with cTGA (-11±8%/s vs. -20±5%/s, P<0.001) and with TGA after atrial switch operation (-12±9%/s vs. -21±6%/s, P<0.001). In addition, LV 2-D LS was significantly reduced in TGA patients compared to controls (-18±6%/s vs. 21±2%/s, P<0.007).

On univariate logistic regression analysis, both, RV 2-D LS (Odds ratio 1.13 [95% CI 1.04 – 1.24], P<0.01) and LV 2-D LS (Odds ratio 1.21 [95% CI 1.05 – 1.20], P<0.0006) were related to adverse clinical outcome. In addition, RV-LS and LV-LS were found to be related to clinical outcome independently of NYHA class (Odds ratio 1.32 [95% CI 1.02 – 1.61], P<0.02 and 1.30 [95% CI 1.04 – 1.23], P<0.005, for RV and LV strain, respectively) or underlying diagnosis (TGA vs. cTGA). On receiver operating characteristic (ROC) curve analysis cut-off values of 4.28 for RV-LS (sensitivity 75%), specificity 75% and 15.3 for LV-2D-LS (sensitivity 47%, specificity 82%) were calculated, providing the optimal combination of sensitivity and specificity for predicting adverse clinical events.

ROC analysis also confirmed the association between biventricular 2-D LS and clinical outcome found on logistic regression analysis (area under curve 0.67 [95% CI 0.59 to 0.75], P<0.004 and area under curve 0.67 [95% CI 0.54 to 0.71], P<0.0003, for RV and LV 2-D LS, respectively). In addition, RV-LS and LV-2D-LS were lower in patients who died (RV-2D-LS -11±7%/s vs. -15±5%/s, P<0.016 and LV-2D-LS -14±5%/s vs. -18±6%/s, P<12) although this did not reach statistical significance.

Overall, RV-LS and LV-2D-LS were found to correlate with each other (r=0.50, P<0.001) as illustrated in Figure 2. When patients were stratified into cTGA and TGA after atrial switch, it became apparent that this positive correlation was more prominent in patients with cTGA (r=0.64, P<0.001) compared to patients with TGA after atrial switch (r=0.46, P<0.001). To exclude the possibility that the association between biventricular 2-D LS is due to the correlation of the normal segments, left and right ventricular segments were compared. Peak global systolic strain of the lateral segments of the systemic and subpulmonary ventricles were also found to be significantly correlated (r=0.56, P<0.003) confirming the findings of global 2-D LS. In addition, the correlation between RV and LV strain was confirmed when ejection fraction on MRI was compared (r=0.59, P<0.001 and r=0.66, P<0.001, for TGA and cTGA patients, respectively). No significant direct correlation was found between ejection fraction on MRI and 2D strain on speckle tracking echocardiography (results not shown). To explore the reasons for the closer correlation of RV-LS and LV-2D-LS in cTGA patients, these patients were stratified into those with and without pulmonary stenosis with a Doppler gradient ≥ 50 mmHg. This revealed that cTGA patients without relevant pulmonary stenosis had a similar degree of correlation of RV-2D-LS and LV-2D-LS as TGA patients (r=0.53, P<0.005), while the correlation was much closer in ccTGA patients with pulmonary stenosis (r=0.87, P<0.0004, Figure 3).

Conclusions

Systemic 2-D LS is significantly reduced in patients with a systemic RV and relates to worse clinical outcome in this setting. Systemic and subpulmonary myocardial function are interrelated and this may be due to adverse ventricular-ventricular interaction. Right ventricular 2-D LS is readily available from routine echocardiography using modern commercial analysis software, represents an objective and reproducible measure of systemic function and should assist clinicians in objectively assessing RV function as part of regular follow-up for patients with a systemic RV.