SCIREA Journal of Clinical Medicine

http://www.scirea.org/journal/CM

May 27, 2019

Volume 4, Issue 4, August 2019

Two-dimensional (2D) speckle tracking deformation imaging for assessment of systemic right ventricular function in post Senning patients

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Abstract:

Background: Right ventricular (RV) dysfunction in atrial switch patients has an important prognostic significance. The quantitative echocardiographic modalities (strain & strain rate) enhanced RV function noninvasive assessment.

Methods: 28 patients with complete TGA who underwent Senning procedure were included and divided into 2 groups; group I: 20 patients beyond 5 years and group II: 8 patients less

than 5 years. All patients were subjected to echo assessment of RV function by traditional parameters and 2D global longitudinal strain (GLS) & global systolic strain rate (GSSR) before and after low dose dobutamine stress test (2.5 µg/kg/min, increased maximally to 10 µg/kg/min). Also all patients were subjected to 24 hours Holter monitoring.

Results: 2D GLS was worse in all patients than normal values (basally: -11.47±1.31% for group I and -17.78±0.96% for group II, P<0.001*) (post dobutamine: -12.30±2.93% for group I and -18.50±1.07% for group II, P<0.001*). Also, GSSR was worse (basally: -0.62±0.11/S for group I and -1.20±0.11/S for group II, P<0.001*) (post dobutamine: -0.66±0.13/S for group I and -1.44±0.11/S for group II, P<0.001*). Post dobutamine, however there was no significant improvement of GLS and GSSR in group I, there was statistically significant improvement of GLS and GSSR in group II (P<0.05*). Holter revealed 3 patients with infrequent atrial arrhythmias; all of them were >5 years.

Conclusions: 2D GLS and GSSR are useful indices for assessment of RV function in atrial switch patients. Age of the patients play an important role; younger patients showed significant improvement of strain indices post stress test.

Keywords: Senning patients; Strain indices; Right ventricular function; systemic right ventricle; Speckle tracking; global longitudinal strain.

Introduction:

Atrial switch operations (Mustard or Senning procedures) (1) in patients with complete transposition of the great arteries (TGA) are associated with increased delayed mortality, mainly because of heart failure (2) and ventricular tachycardia due to failure of the morphologic systemic subaortic right ventricle (RV) (3). Right ventricular (RV) function deterioration is a progressive accumulating condition. (4) And so, accurate assessment of RV function is mandatory to anticipate the need for heart failure treatment in these patients.

The systemic RV function can be assessed by various imaging modalities including angiography, radionuclide imaging and magnetic resonance imaging (MRI). (5) However, echocardiography is still used predominantly for the assessment of RV function, as it is non-invasive, easily applicable, widely available, inexpensive and has no adverse side effects. As

RV has complex geometry, so, the assessment of systemic RV function by echocardiography has remained mostly qualitative.

Advanced echocardiographic modalities allow for a more refined assessment of the RV function in various clinical conditions. These novel echocardiography variables may also be valuable in the functional assessment of the systemic RV. (6)

To redefine the role of echocardiography in the functional assessment of the systemic RV, we investigated the feasibility and variability of standard and novel echocardiographic variables in the assessment of the systolic function of the systemic RV during rest and also during dobutamine stress test in different age groups of patients underwent Senning procedure.

Patients and methods:

Patients

We enrolled twenty-eight clinically stable patients with complete TGA (D-TGA) who had undergone atrial redirection by the Senning procedure in childhood and who attended the Congenital Heart Disease Clinic at Tanta University Hospital, Egypt and were in sinus rhythm. Informed consent was obtained from each patient and the study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a priori approval by the institution's human research committee.

The patients were divided into 2 groups; group I: Twenty patients beyond five years age and group II: Eight patients less than five years of age.

Methods:

All patients were subjected to evaluation of saturation, blood pressure, electrocardiography and echo Doppler assessment of systemic RV systolic function using standard ultrasound parameters and 2D speckle tracking to measure global longitudinal strain (GLS), global systolic strain rate (GSSR) before and after low dose dobutamine stress test (Started at 2.5 µg/kg/min and increased gradually every 3 minutes and maximally to 10 µg /kg/min). Also all patients were subjected to 24 hours Holter monitoring which was recorded and analyzed.

Echocardiography

I. Standard echocardiography

Transthoracic echocardiography was performed using Vivid 9® (GE Vingmed Ultrasound A.S., Horten, Norway). All echocardiographic recordings were stored for offline analyses. Measurements were made in three cardiac cycles and average values were used for statistical analyses. Intra- and interobserver variability was analyzed on the basis of two consecutive results.

Common echocardiographic variables for RV function were estimated. In the apical four-chamber view, RV end-diastolic and end-systolic volumes were assessed. From these measurements, we calculated RV fractional shortening (RVFS) and RV ejection fraction (RVEF) by Simpson's one-plane method. (7) Tricuspid annular plane systolic excursion (TAPSE) was assessed in M-mode. Other parameters were assessed including tricuspid valve regurgitation, baffle obstruction or leak and also the outflow tracts were examined.

II. Two-dimensional (2D) longitudinal strain assessment of the RV

Myocardial deformation imaging by two-dimensional (2D) strain based on speckle tracking deformation imaging, as an index of contractile function, was assessed on greyscale echocardiographic images. (8) In the apical four-chamber view, the probe knob was rotated 180 degrees to alien the systemic RV longitudinally with the image. Then the myocardium was automatically tracked and divided into six segments (Basal-lateral, mid-lateral, apico-lateral, apico-septal, mid-sepatal and basal-septal). Global systolic strain (GLS) and Global systolic strain rate (GSSR) were assessed in the longitudinal direction.

III. Dobutamine stress test:

After six hours fasting, dobutamine stress test was used to assess traditional and novel parameters after low dose dobutamine (Started at 2.5 µg/kg/min and increased gradually every 3 min and maximally to 10 µg /kg/min). Heart rate and blood pressure were recorded at every stage. Dobutamine infusion was terminated with evident increase in heart rate (As the inotropic effect of dobutamine started before its chronotropic effect and as we need to examine the contractile reserve of the systemic RV; so we stopped dobutamine infusion with the increase of heart rate). Baseline and peak dose images were stored and compared offline. A normal response to dobutamine infusion was defined as a progressive increase in myocardial thickening and hyperdynamic wall motion as assessed by eye ball, regional longitudinal systolic strain and strain rate from rest to peak dose of dobutamine infusion (negative dobutamine stress Echo. (DSE)). An abnormal response to dobutamine infusion was defined as a reduction in myocardial thickening or wall motion at any stage of the

dobutamine infusion compared with the previous stage (positive DSE). The wall motion of the right ventricle was assessed with a 6 segment model.

Twenty four hours Holter assessment:

Also all patients were subjected to 24 hours Holter monitoring which was recorded and analyzed.

Statistical analysis

Data are presented as mean ± standard deviation. Relationships between traditional and new echocardiographic variables were evaluated by Pearson's correlation coefficient. P value < 0.05 was considered statistically significant. Statistical analyses were performed using SPSS version 25.

Results

Study population

Twenty-eight patients were included, all of whom had atrial redirection for TGA; all of these, had undergone the Senning procedure. Nine patients had associated ventricular septal defect and are therefore referred to as ‘complex TGA’; in these patients, the ventricular septal defect was closed at the time of the atrial redirection surgeries, without residual leaks. Mean age at Senning operation was 11.2 ± 1.30 months. Mean age at examination was 12.88 ± 3.12 years. Twenty patients (71.43%) were males and eight (28.57%) were females. Basal saturation was 97.75 ± 1.50 % and at peak dose dobutamine stress test was 96.25 ± 1.50 %. Basal heart rate was 89.75 ± 17.46 B/m and at peak dose stress test was 128.50 ± 24.20 B/m, only one case showed infrequent atrial ectopics during peak dose stress test, he was of group II (14 years of age). Most patients were in New York Heart Association (NYHA) function class I (88%). Table (1) showing the difference between the two groups in the baseline characteristics.

Echocardiographic results

Tricuspid systemic atrioventricular valve incompetence was evident in all cases, however it was mild in 18 patients (64.29%), moderate in 6 patients (21.43%) and severe in 4 patients (14.29%). Baffle leak was evident in two patients (7.14%) and no baffle stenosis was recorded in any of the patients. Overall RVEF assessed by echocardiography using Simpson's

method was 42.25 ± 9.94% for group I and 52.00 ± 2.62% for group II. 2D global longitudinal strain (GLS) was worsened significantly in all patients (-11.47 ± 1.31 % for group I and -17.78 ± 0.96 % for group II, P<0.001*) and with peak dobutamine (-12.30 ± 2.93 % for group I and -18.50 ± 1.07 % for group II, P<0.001*). There was no significant improvement of GLS in group I basally and with peak stress, however there was significant improvement of GLS in group II during dobutamine stress (P<0.008*). Also, basal 2D global systolic strain rate (GSSR) was worsened in all patients (-0.62 ± 0.11/S for group I and -1.17 ± 0.27/S for group II, P<0.001*) and with peak dobutamine were (-0.69 ± 0.17/S for group I and -1.20 ± 0.11S for group II, P<0.001*). There was no significant improvement of GSSR in group I basally and with peak stress, however there was significant improvement of GSSR in group II post stress (P<0.001*). Holter assessment revealed only three patients with infrequent atrial arrhythmias; all of them were beyond five years age.

Discussion

The aim of the study was to determine the role of echocardiography by evaluating the strength and weakness of echocardiographic variables including the usefulness of two dimensional (2D) strain indices of myocardial deformation based on speckle tracking for assessment of RV function after an atrial switch operation (Senning procedure). Also the study aimed to compare these new indices in assessment of RV function in such patients with different age groups basally and during peak dobutamine stress test.

Assessment of the RV using 2D echocardiography has been done for decades but remains challenging because of the complex anatomy of the RV.

For patients with a systemic RV, reference values are lacking. (7) Standard variables (TAPSE, tissue velocities) reflect mainly the long-axis function of the basal RV free wall, whereas RVEF using Simpson's method and RVFS reflect global systolic function. Overall RVEF assessed by echocardiography using Simpson's method was 42.25 ± 9.94% for group I and 52.00 ± 2.62% for group II. Kalogeropoulos et al. (8) reported a slightly lower RVEF of 37±11% using Simpson's method in 27 patients. However, it has to be mentioned that 11 of these patients were receiving pacing and the population was slightly older (mean age 30 ± 6 years).

Kalogeropoulos et al. reported good feasibility and reproducibility for the assessment of RV 2D longitudinal strain in patients with TGA and atrial redirection. (8) Moreover, it was

recently demonstrated that reduced GLS of the systemic RV is associated with an increased risk of clinical events among patients with TGA and atrial redirection by the Senning or Mustard procedures. (9) Global longitudinal peak systolic strain (GLS) greater than –10% optimally predicted future events (C = 0.83, 95% confidence interval 0.71–0.91, P < 0.001). (9) Our study results are consistent with the study by Kalogeropoulos (8, 9) and Becker (10), with longitudinal middle strain of –13.2 ± 3.8% (in a cohort of 27 patients). Despite the absence of correlation with MRI, this study results are consistent with clinical status regarding NYHA classification and might predict a good outcome regarding the cutoff established by Kalogeropoulos et al. (9)

Similar to Kalogeropoulos et al., we assessed RV deformation only in the longitudinal direction from a single apical view. This approach supports evaluation of only one aspect of myocardial deformation and leaves deformation in other dimensions undefined. Indeed, a recent study using TDI and cardiac MRI demonstrated that there is a shift in the contraction pattern of the systemic RV from longitudinal to circumferential shortening. (11) In addition to these important RV findings, Becker et al. (10) reported that in the systemic free RV wall, circumferential strain was greater than longitudinal strain.

In patients with D-TGA, the RV is enlarged and anteriorly placed, which makes it very difficult to asssess the ventricle in the short-axis view. Therefore, speckle-tracking echocardiographic imagings of the short-axis for circumferential and radial strain would not be applicable.

As echocardiographic imaging may be affected by the retrosternal position of the RV, strain measurements are more difficult to perform for the systemic RV than for the systemic left ventricle. In our experience, we overcome this problem by rotating the knob of the probe 180 degrees in apical four-chamber views which was accessible in all 28 patients.

As regard to RV Systolic Function with Exercise, evaluation of the systolic response to exercise by Dobutamine stress test demonstrated decrease of the RV systolic volumes (EDV, ESV) immediately after exercise compared with baseline measures, suggesting increased myocardial contractility with exercise. This response is similar to that reported using different exercise modalities. (12, 13, 14)

Myocardial strain has been used to estimate the systemic RV contraction pattern and myocardial function at rest (15) and during submaximal exercise in patients with d-TGA following atrial switch operations. (16) Until now, the response to maximal exercise has not

been investigated. The physiologic response of the systemic ventricle to exercise in a healthy population consists of an increase in systolic strain values in early exercise and maintenance of these values for the remainder of exercise. (16) In our patient population, evaluation of RV strain revealed no change in strain values after exercise in group I, and statistically significant improvement of RV function by all parameters in group II (Simpson EF, TAPSE, GLS and GSSR) in whom their age is still under 5 years and in whom the RV is still tolerating systemic circulation. This was in agreement with Merav Dvir-Organd et al (17), study in which the patients with D-TGA following an atrial redirection procedure, have lower exercise capacity and peak HRs than control subjects. This noninvasive method showed a qualitatively normal hemodynamic and RV systolic response to maximal exercise. Thus Dobutamine stress test can predict improvement or worsening of RV function early before changes take place in basal conditions.

Limitations of echocardiography

The RV function assessment remains difficult, partly due to its complex geometry. Measurements of RVEF, RV systolic function and TAPSE revealed great variability in normal and abnormal hearts. In Senning- or Mustard-operated patients, MRI is the only gold standard method for calculating RV volume and function. Technical difficulties in visualizing the RV, which is situated behind the sternum, should be taken into account. Furthermore, RV hypertrophy, mostly found in patients with a systemic RV, complicates contouring of the RV endocardium for volume assessment.

Clinical implications

Echocardiographic assessment of systolic function of the systemic RV in patients with TGA after atrial switch surgery is difficult. Nevertheless, echocardiography remains clinically important, due to its better accessibility and its lower cost compared with MRI. Besides, MRI is not available for patients with a pacemaker and up to 50% of patients who have undergone atrial switch surgery for TGA may have pacemakers. Furthermore, echocardiography is an irreplaceable investigation for evaluating the presence of tricuspid regurgitation, baffle leak or stenosis which are important features in the physiopathological process of systemic RV failure. This study suggests to assess a combination of multiple variables using

echocardiography to make a valuable estimation of RV systolic function; RVEF (Simpson's method), GLS at the junction of the RV free wall and the TAPSE.

Dobutamine stress test is very important in giving a hint on the patient condition during stress including HR, BP and arrhythmias and also can predict the subclinical impairment of RV function before appearance in basal conditions.

Conclusion

In this research, we describe the strengths and weaknesses of current non-invasive echocardiographic techniques in the assessment of the systemic RV after Senning redirection in TGA patients. Due to geometric changes, presumed contractility pattern shift and retrosternal position, conventional echocardiographic variables remain limited for RV function assessment compared with MRI. Nevertheless, echocardiography remains the technique of first choice for tricuspid regurgitation assessment, baffle leak and baffle stenosis. Although echocardiography does not permit complete assessment of the systemic RV after atrial redirection, it is fully complementary with MRI and should not be abandoned. Accessibility is wide and it is not cost limited compared with MRI. New echocardiographic techniques for assessment systemic RV function deserve broader investigation with Larger multicentre studies.

To make a valuable estimation of RV systolic function using echocardiography, a combination of multiple variables should be performed, as our study suggests that single variable are neither very reliable nor reproducible.

Figures and Tables

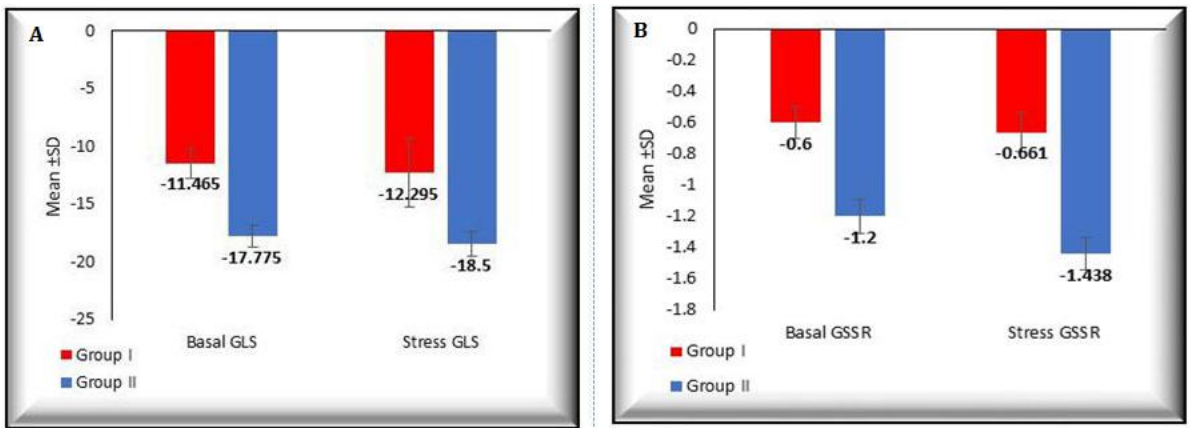

Figure (1): A, Comparison of global longitudinal strain (GLS) basally and at peak stress between both groups. B, Comparison of global systolic strain rate (GSSR) basally and at peak stress between both groups.

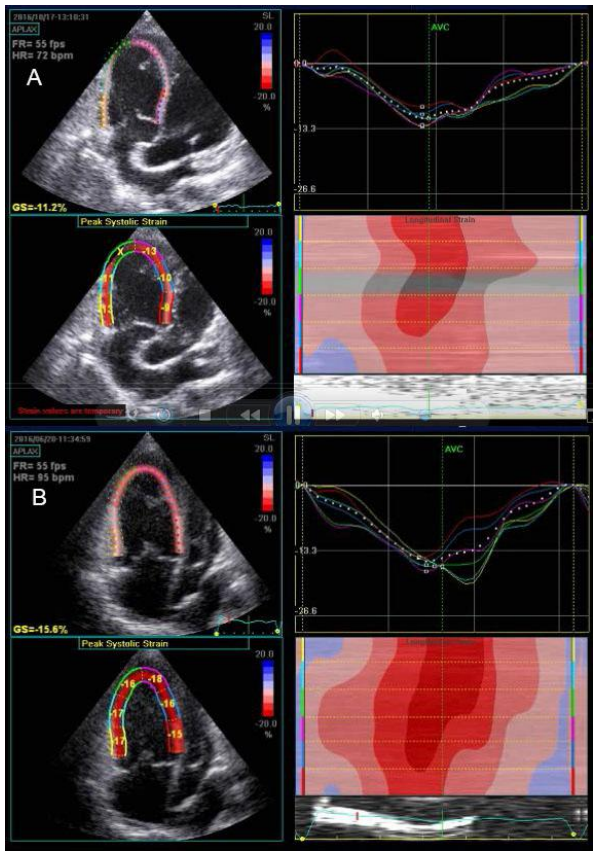

Figure (2): 2D speckle based global longitudinal strain echocardiography (GLS) measurements basally (A) and at peak stress (B) in a patient of group I; showing impaired GLS with no significant improvement at peak stress.

Table (1): Comparison of patient characteristics of the two groups.

	Group I	Group II	P value
Age at examination (years)	12.68 ± 2.6	2.50 ± 0.92	<0.001*
Age at Senning operation (months)	11.10 ± 1.55	9.62 ± 1.40	0.028*
Male/female	12/8	5/3	
Saturation (%) - Basal	97.75 ± 1.25	98.00 ± 0.93	0.615

- Peak Stress	96.60 ± 1.39	97.50 ± 0.76	0.098
Heart rate (B/m) - Basal - Peak Stress	 88.25 ± 14.80 122.15 ± 19.30	 101.38 ± 9.74 115.50 ±10.14	 0.030* 0.367
Blood pressure (mmHg) - Basal - Peak stress	 106.75±13.98/ 71.75±12.80 122.25±13.03/ 82.50±12.51	 94.50±6.09/ 62.50±4.24 107.50±6.55/ 70.00±4.63	 0.026* 0.005*

Table (2): Comparison of echocardiographic and Holter results between the two groups basally and with peak stress.

Echocardiography variable	Group I (20)	Group II (8)	P value between 2 groups
EDV (ml) - Basal - Peak stress - P value (Basal and stress)	 58.95 ± 10.31 55.25 ± 8.84 0.010*	 25.63 ± 1.85 22.13 ± 2.10 0.002*	 <0.001* <0.001*
ESV (ml) - Basal - Peak stress - P value (Basal and stress)	 33.15 ± 9.70 34.35 ± 9.50 0.391	 10.63 ± 2.13 8.250 ± 1.58 0.001*	 <0.001* <0.001*
RVEF (Simpson's method) (%) - Basal - Peak stress - P value (Basal and stress)	 42.25 ± 9.94 43.80 ± 8.68 0.073	 52.00 ± 2.62 55.13 ± 2.10 0.003*	 0.012* 0.001*
TAPSE (mm) - Basal - Peak stress - P value (Basal and stress)	 1.32 ± 0.12 1.24 ± 0.19 0.020*	 1.23 ± 0.10 1.413 ± 0.06 0.001*	 0.067 0.015*
2D global longitudinal strain (GLS) (%) - Basal - Peak stress - P value (Basal and stress)	 -11.47±1.31 -12.30±2.93 0.172	 -17.78±0.96 -18.50±1.07 0.008*	 <0.001* <0.001*
2D global systolic strain rate (GSSR) (/s) - Basal - Peak stress	 -0.62±0.11	 -1.20±0.11	 <0.001*

- P value (Basal and stress)	-0.66±0.13 0.048	-1.44±0.11 <0.001*	<0.001*
Tricuspid regurgitation Mild Moderate Severe	 11 5 4	 7 1 0	
Baffle leak	2	0	
Infrequent arrhythmias with Holter	3		

EDV: End-diastolic volume, ESD: End-systolic volume, RVEF: Right ventricular ejection fraction, TAPSE: Tricuspid annular plane systolic excursion, GLS: Global longitudinal strain, GSSR: Global systolic strain rate.

Acknowledgement of grant support:

We acknowledge Cardiology Department, Tanta University, Egypt for permitting working on its Echo machines and using its equipment.

Disclosure of interest:

The authors declare that they have no conflicts of interest concerning this article.

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