The Utility of Stress Echocardiography in Pediatric Populations

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Outline

• Background
• Our Clinical Questions
• Our Method
• Our Experience
• Advantages and Disadvantages
• Concluding Thoughts
Background

• Stress echocardiography allows for imaging of the heart under stress. In children, stress echocardiography can be performed using exercise or pharmacological agents.

• While pharmacologic agents, like dobutamine, mimic exercise, they are not physiologic and are not well tolerated in children.

• Semi-supine cycle ergometry (SSCE) stress echocardiography allows for images to be taken during exercise and eliminates the time delay that occurs between cessation of exercise and image acquisition.
Background

• With advances in technology, the application of stress echo in pediatric heart disease is also evolving, with changing indications and a change in the practice of techniques used over time (Cifra et al, 2015 Eur Heart J-Cardiovasc Imaging)

• Over the years, we have used SSCE stress echo in our institution to answer a variety of clinical questions in our pediatric congenital heart disease population
OVERVIEW OF CLINICAL QUESTIONS

Eligible Patients
- >8 years old
- able to complete semi-recumbent exercise
- stable condition

Exercise Capacity and Function
LV and RV Systemic Function
Myocardial Reserve
Segmental Wall Motion and LV Contractility to test for ischemia
Valvar and Venous Obstruction
Our Method

• Height
• Weight
• SBP & DBP
• Heart Rate
• Echo LV Dimensions & Function
• Doppler cardiac output
• Tissue Doppler
• Metabolic Assessments

Stress Echocardiography
<table>
<thead>
<tr>
<th>PATIENT GROUPS</th>
<th>Total Tests=818</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Congenital Heart Disease</strong></td>
<td>361</td>
</tr>
<tr>
<td>- Transposition of Great Arteries (Atrial and Arterial switch)</td>
<td></td>
</tr>
<tr>
<td>- Tetralogy of Fallot</td>
<td></td>
</tr>
<tr>
<td>- Left sided heart disease (aortic stenois, insufficiency etc.)</td>
<td></td>
</tr>
<tr>
<td>- Fontan</td>
<td></td>
</tr>
<tr>
<td>- Atrial and ventricular septal defects</td>
<td></td>
</tr>
<tr>
<td>- Miscellaneous</td>
<td></td>
</tr>
<tr>
<td>- 50 (atrial)/26 (arterial)</td>
<td></td>
</tr>
<tr>
<td>- 31</td>
<td></td>
</tr>
<tr>
<td>- 48</td>
<td></td>
</tr>
<tr>
<td>- 9</td>
<td></td>
</tr>
<tr>
<td>- 9 (VSD); 8 (ASD)</td>
<td></td>
</tr>
<tr>
<td>- 45</td>
<td></td>
</tr>
<tr>
<td><strong>Heart Transplants</strong></td>
<td>134</td>
</tr>
<tr>
<td><strong>Cardiomyopathy</strong></td>
<td>76</td>
</tr>
<tr>
<td><strong>Acquired Heart Disease</strong></td>
<td>16</td>
</tr>
<tr>
<td>- Kawasaki disease</td>
<td></td>
</tr>
<tr>
<td>- Marfan syndrome</td>
<td></td>
</tr>
<tr>
<td>- Vasculopathy</td>
<td></td>
</tr>
<tr>
<td><strong>Arrhythmia</strong></td>
<td>11</td>
</tr>
<tr>
<td><strong>Oncology</strong></td>
<td>106</td>
</tr>
<tr>
<td><strong>Eating Disorders</strong></td>
<td>114</td>
</tr>
</tbody>
</table>
Clinical Question #1
-Evaluation of Exercise Capacity-

- Used in patients with acquired heart disease, those exposed to cardiotoxins (anthracyclines), post myocarditis, eating disorders, non-specific symptoms of chest pain or fatigue.

- A normal result may serve to reassure the family. While, for certain diagnoses, an abnormal result may help make the decision for intervention.
### Responses of Healthy Children

<table>
<thead>
<tr>
<th>N=54</th>
<th><strong>REST</strong></th>
<th><strong>PEAK EXERCISE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>IQR</td>
</tr>
<tr>
<td><strong>Systolic BP (mmHg)</strong></td>
<td>118</td>
<td>110-124</td>
</tr>
<tr>
<td><strong>Diastolic BP (mmHg)</strong></td>
<td>73</td>
<td>68-78</td>
</tr>
<tr>
<td><strong>HR (bpm)</strong></td>
<td>78</td>
<td>69-85</td>
</tr>
<tr>
<td><strong>Stroke Volume Index (mL/m²)</strong></td>
<td>37</td>
<td>31-43</td>
</tr>
<tr>
<td><strong>Cardiac Index (L/min/m²)</strong></td>
<td>2.8</td>
<td>2.1-3.5</td>
</tr>
</tbody>
</table>
## Responses of Healthy Children

<table>
<thead>
<tr>
<th>N=54</th>
<th>REST</th>
<th>PEAK EXERCISE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>IQR</td>
</tr>
<tr>
<td>LVEDi (cm/m²)</td>
<td>4.0</td>
<td>3.1-4.6</td>
</tr>
<tr>
<td>LVESi (cm/m²)</td>
<td>2.5</td>
<td>1.9-2.9</td>
</tr>
<tr>
<td>FS (%)</td>
<td>37</td>
<td>33-39</td>
</tr>
<tr>
<td>MVCFc (circ/s)</td>
<td>1.17</td>
<td>1.06-1.29</td>
</tr>
<tr>
<td>σPS (gm/c³)</td>
<td>77</td>
<td>64-85</td>
</tr>
</tbody>
</table>
Rowland et al. Am Ht J 1999
Fig. 2. Mean MVCFc versus σPS relationship at rest and peak exercise for AP and CON. Mean values ± SEM are shown.

De Souza et al. 2007 Pediatr Blood Cancer 49: 56-64
Anorexia Patients

- We evaluated the exercise capacity and cardiac responses in a subgroup of 66 patients with Anorexia (Escudero 2016-submitted).

- The total workload achieved and peak HR, CI, SVI, FS and MVCFc were less in the anorexia patients; however, the pattern of change of these parameters was similar to controls.

- Of importance, there were no patients whose exercise tests were accompanied by any adverse reactions confirming that it was safe to exercise at these levels.
Anorexia Patients

• Measured changes in the QT interval during exercise and determined QT/RR-interval slopes

• At rest, HR and QT/QTc intervals were similar

• Mean QTc intervals were longer at peak exercise in patients and at comparable sub-maximal heart rates

• Despite the absence of QT prolongation at rest, these anorexic females were shown to have impaired repolarization with exercise

Take Home Message #1
Stress echo allows for the evaluation of exercise capacity and provides information on the cardiovascular responses to exercise.
Clinical Question #2
-Left and Right Ventricular Function-

Why do we test LV/RV function?

• Decision making for intervention for individual patients
• Compare groups of patients
• Follow patients over time
• Detect or monitor for known or unforeseen sequelae.
Mustard or Senning Operation for Transposition of the Great Arteries
Transposition of Great Arteries
-Mustard or Senning Operation-

• Lower exercise capacity, further affected by SVC stenosis and pacemakers

• HR increased with exercise but was lower at peak exercise. Resting stroke index was higher and did not change with exercise

• RV systolic dimensions immediately post-exercise decreased compared to pre-exercise, suggesting increased myocardial contractility with exercise

• Abnormal myocardial mechanics and strain patterns

Dvir Orgad M 2016-submitted
At rest, arterial switch patients had significantly larger aortic cross sectional areas and LV dimensions. Stroke volume was higher and heart rate was lower.

Arterial switch patients were able to do more work than atrial switches, but less work than controls.

Interestingly, one-third of arterial switch patients had a normal exercise capacity.
Transposition of Great Arteries
-Arterial Switch-

- At peak exercise, LV dimensions remained larger in the patients but FS was lower. Peak exercise heart rates were lower and wall stress was higher. The cardiac output response was identical between groups.

- The long term-follow up for the re-implanted coronary arteries is not known. SSCE may be an excellent non-invasive method of screening for myocardial ischemia in this group of patients.

Presented at the European Pediatric Congress 2012
Take Home Message #2
Stress echo allows for the evaluation of both the right and left ventricle during exercise. It can help us better understand the mechanisms of the heart during exercise.
Clinical Question # 3
-Evaluation of Myocardial Reserve-

• The decision on when to operate on patients with either aortic or mitral valve regurgitation is not well established in pediatrics.

• The underlying principle is that surgery should be performed while the patient can still recruit adequate myocardial reserve.
Aortic Stenosis and Insufficiency

• Exercise capacity (total work) was similar to controls.

• Patients achieved an adequate increase in FS and MVCFc indicating good contractility and myocardial reserve. Wall stress did not stress decrease appropriately.

• Our criteria for a normal test were a 12% increase in FS, a 0.30 circ/s increase in MVCFc, and a decrease in wall stress of 11 g/cm$^3$
Take Home Message #3
Stress echo may provide additional objective information that could be included in the decision making for timing of surgery
Clinical Question #4-Segmental Wall Motion and LV Contractility for Ischemia-

- Patients who have had Kawasaki disease with coronary aneurysms, an arterial switch operation, surgery for anomalous left coronary artery arising from the pulmonary artery or a Ross or Bentall procedure all have the potential for myocardial ischemia from coronary insufficiency.

- This may be helpful in determining clinical status without necessarily resorting to invasive procedures.
Clinical Question #4-Segmental Wall Motion and LV Contractility for Ischemia-

- Diffuse coronary artery disease is a complication of chronic rejection in cardiac transplantation patients resulting in generalized ischemia. The optimal method for detection is not known.

- We have reported serial data in a group of heart transplants. Contractility is diminished in these patients.

- Over time, hemodynamics and LV function remained constant

Using New Modalities

• We have recently introduced assessment of the coronary flow reserve in heart transplants patients. We have been able to look at coronary flow in some patients undergoing SSCE and in most patients undergoing dobutamine stress (Toma et al. Exp Clin Cardiol 2013, p 1-5)

• Further work is needed to ascertain the predictive accuracy of this test in this patient population

• We have also been acquiring tissue Doppler, strain, and twist images during exercise. The clinical significance of our findings are not yet known

Take Home Message #4
Stress echo can be used for routine follow-up in heart transplant patients. New modalities can be added to stress echo and may help to detect coronary artery vasculopathy.
Clinical Question #5
-Valvar and Venous Obstruction-

• Stenosis of the superior vena cava (SVC) post atrial repair of TGA or surgery for sinus venosus ASD with partial anomalous venous return may not be accompanied by classic symptoms of facial flushing or headaches.

• We adapted the SSCE stress echo-Doppler technique to look for SVC stenosis and were able to unmask obstruction by the development of an exercise induced significant increase in the pulse Doppler velocity distal to the site of stenosis.
## Unmasking of SVC stenosis in post operative atrial repair of TGA

<table>
<thead>
<tr>
<th>Group</th>
<th>Tests #</th>
<th>Upper SVC Velocity (m/s)</th>
<th>Lower SVC Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre-Ex</td>
<td>Post-Ex</td>
</tr>
<tr>
<td>No Int</td>
<td>25</td>
<td>0.60</td>
<td>0.99</td>
</tr>
<tr>
<td>Pre-Int</td>
<td>9</td>
<td>0.56</td>
<td>0.74</td>
</tr>
<tr>
<td>Post-Int</td>
<td>10</td>
<td>0.63</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Presented at 18\textsuperscript{th} Int. Symposium on ACHD Toronto 2008
Take Home Message #5
Stress echo can be used to unmask SVC obstruction in patients with the Mustard operation
Cardiopulmonary Testing

• The measurement of VO\textsubscript{2} peak during the stress echo provides an objective measurement of exercise capacity and allows for other parameters such as systemic vascular resistance and arterio-venous O\textsubscript{2} difference to be calculated

• Given the positional differences, peak HR is lower and VO\textsubscript{2}peak is lower on the semi-recumbent ergometer compared to treadmill values

• We have also used this method to guide workloads for a pediatric cardiac rehabilitation program
Comparison of VO$_2^{\text{peak}}$ in Pediatric Heart Transplants
Pediatric Considerations - Challenges and Disadvantages -

1. Need an excellent sonographer
2. Age of patient > 8 years
3. Technically difficult windows in post operative patients
4. Unusual cycling position for many children, but good compromise
5. Time factor for obtaining information
Advantages of SSCE Stress Echo in Pediatrics

- Stress echo allows us to better understand the mechanisms affecting exercise capacity and cardiovascular function in a variety of pediatric populations.

- Despite clinically normal function at rest, exercise unmasks cardiac dysfunction in certain groups that is not otherwise seen.

- Routine follow-up stress echoes may be a way to monitor for changes over time.
Concluding Thoughts

• SSCE stress echocardiography can be safely used in many forms of congenital and acquired heart disease and offers additional information that cannot be obtained from other forms of exercise testing.

• Its expanded utility may answer different clinical questions than are normally asked, give new insights into the cardiovascular adaptive mechanisms utilized in exercise, or aid in decision making for medical or surgical intervention.
Acknowledgements

• Dr. George Sandor
• Dr. Jim Potts
• Dr. Thomas Rowland
• Dr. Derek Human
• Dr. Paul Brooks
• Dr. Martin Hosking
• Dr. Anita Cote
• Our team of physicians

• Our Cardiac Fellows

• Our amazing Echocardiography Laboratory
  – Jessica Cochrane
  – Lindsey Williams
  – Raman Gill
  – Eustace De Souza
  – AJ Hollinger
  – Shona Hennessy
  – Josh Coulson
  – Jessica Vander Zaag
  – Terri Zadorsky
  – Holly Zhang
THANK YOU!