Impact of Aortic Annular Geometry on Aortic Valve Insufficiency: Insights from a Pre-Clinical, Ex-vivo, Porcine Model

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Disclosures

- None
Normal Functioning Aortic Valve

Valve Cusps

Functional Aortic Annulus
Repair-Oriented Classification of Aortic Insufficiency

<table>
<thead>
<tr>
<th>AI Class</th>
<th>Mechanism</th>
<th>Repair Techniques (Primary)</th>
<th>Repair Techniques (Secondary)</th>
</tr>
</thead>
<tbody>
<tr>
<td>la</td>
<td>STJ remodeling</td>
<td>Ascending aortic graft</td>
<td>SCA</td>
</tr>
</tbody>
</table>

*Boodhwani et al. JTCVS 2009 Feb; 137(2):286-294*
Challenge:
- Restore normal geometry
- Restore normal function

Novel surgical techniques:
- Surgical Intuition
- Expertise
- No prior validation
• Knowledge of AI patho-anatomy is limited by the lack of a pre-clinical model of AI.

• Developing a pre-clinical model of AI
  – Understand mechanisms of AI
  – Facilitate innovation in aortic valve repair
OBJECTIVES

• Create a model of AI in a left heart simulator (LHS)
  + 3D Echocardiography
  + Finite element modeling (FEM)

• Effect of aortic root geometry alteration on AI
METHODS
Control (N=8)

Pig weights: 90-105 kg

Coronaries Tied

Subvalvular tissue preserved
Intervention (N=8)

Patches: - Fashioned from pulmonary artery
- 10-18 mm → create graded ↑STJ
ViVitro Left Heart Simulator*

* ViVitro Systems Inc., Victoria, BC, Canada
Finite Element Modeling

Quantify Valve Stresses

Analyze valve and annular motion
RESULTS
## Baseline Measurements

<table>
<thead>
<tr>
<th></th>
<th>Control (N=8)</th>
<th>Intervention (N=8)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Root Measurements</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Root weight (g)</td>
<td>70 ± 2.7</td>
<td>61 ± 4.1</td>
<td>0.084</td>
</tr>
<tr>
<td>Ascending aorta diameter (mm)</td>
<td>23 ± 1.0</td>
<td>23 ± 1.0</td>
<td>0.715</td>
</tr>
<tr>
<td>STJ diameter (mm)</td>
<td>26 ± 0.7</td>
<td>26 ± 0.4</td>
<td>1.000</td>
</tr>
<tr>
<td>Sinuses of Valsalva diameter (mm)</td>
<td>30 ± 1.0</td>
<td>29 ± 0.6</td>
<td>0.639</td>
</tr>
<tr>
<td>VAJ diameter (mm)</td>
<td>21 ± 0.4</td>
<td>18 ± 1.4</td>
<td>0.123</td>
</tr>
<tr>
<td>Cusp height (mm)</td>
<td>21 ± 0.9</td>
<td>20 ± 1.2</td>
<td>0.414</td>
</tr>
<tr>
<td>Patch width (mm)</td>
<td>15 ± 2.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Intervention Leading to AI

\[
p < 0.001
\]
Intervention Leading to AI

\[ p < 0.001 \]

\[ p = 0.004 \]

- **Regurgitant Fraction (%)**
- **Regurgitant Volume (mL)**
Intervention Leading to AI

- Regurgitant Fraction (%)
- Regurgitant Volume (mL)
- Effective Regurgitant Area (mm²)

Statistical significance:
- p<0.001
- p=0.004
- p=0.016

Control vs. Intervention comparison:
Measuring aortic valve coaptation surface area using three-dimensional transesophageal echocardiography

Sohmer et al. Can J Anesth 2013. 60:24-31
Coaptation Surface Area

![Bar graph showing comparison between Control and Intervention groups with a p-value of <0.001.](image-url)
The graph shows the relationship between the STJ/VAJ Ratio and the Regurgitant Fraction (%). The red line represents the regression line with $R^2 = 0.65$ and $p = 0.003$. The control group is represented by circles, and the intervention group is represented by crosses.
Finite Element Modeling

\[ R^2 = 0.82 \]
\[ p = 0.013 \]

- Severe Al
- Moderate Al
- Mild Al
Finite Element Modeling

20-45% Increase in STJ

79-255% Increase in diastolic cusp stresses (p<0.001)
Implications for Aortic Valve Repair

• Require at least 35-40% STJ increase to observe AI

• STJ/VAJ > 1.5 → AI

Optimal repair:
1) Eliminate AI → STJ/VAJ ratio < 1.5
Implications for Aortic Valve Repair

• Although 20% increase in STJ may not lead to AI
  • Increases end-diastolic cusp stresses
    • Lead to long-term failure of repair?

Optimal repair:
1) Eliminate AI $\rightarrow$ STJ/VAJ ratio $< 1.5$
2) Minimize cusp stresses $\rightarrow$ STJ/VAJ ratio $\approx 1.2$
Limitations

- Animal model
- Acute AI
Conclusions

• First clinically relevant, ex-vivo model of AI

• \( \uparrow \text{STJ and specifically } \uparrow \text{STJ/VAJ ratio} \)
  – Linearly related to AI severity
  – \( \downarrow \) Cusp coaptation surface area

• Keep STJ/VAJ ratio \( \approx 1.2 \) to ensure adequate coaptation and minimize cusp stresses

• Reproduce different AI mechanisms and evaluate novel interventions for AV repair in a safe and simulated environment
Acknowledgements

• Surgery:
  • Dr. Munir Boodhwani
  • Dr. Hadi Toeg

• Imaging:
  • Dr. Benjamin Sohmer

• Mechanical Engineering
  • Michel Labrosse
  • Reza Jafar
Future Directions

• Create models of AI that reflect the various types of AI

• Use these models to evaluate repair techniques (undergoing)

• Use FEM to
  – Correlate porcine and human data (undergoing)
  – Model individual patient AVs preoperatively to predict optimal repair techniques (undergoing)
## Measurements Post-Intervention

<table>
<thead>
<tr>
<th>Hemodynamic and Echo Measurements (mean ± SEM)</th>
<th>Control (N=8)</th>
<th>Intervention (N=8)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regurgitant volume (mL)</td>
<td>5 ± 2</td>
<td>28 ± 7</td>
<td>0.004</td>
</tr>
<tr>
<td>Regurgitant fraction (%)</td>
<td>7 ± 1</td>
<td>36 ± 5</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Effective regurgitant orifice area (mm²)</td>
<td>0</td>
<td>15 ± 5</td>
<td>0.016</td>
</tr>
<tr>
<td>Coaptation surface area (cm²)</td>
<td>1.80 ± 0.08</td>
<td>1.03 ± 0.11</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
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