Augmented Reality Echocardiographic Navigation and Guidance for Beating Heart Transapical Mitral Valve Repair

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Disclosures

- Grant support
  - Canadian Institute of Health Research
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  - Ontario Research Fund
  - AMOSO
- Research lab support from Neochordae, Inc
- Speakers honorarium from Medtronic, Canada
• Emergence of Transcatheter MV Repair
  o Edge-to-edge repair
  o Coronary sinus cerclage
  o Annuloplasty
  o Chordal reconstruction

• Beating heart
• Without CPB
Current Imaging Modalities

- Fluoroscopy
  - Reasonable visualization of implantation device
  - Lacks 3D context
  - Only gross anatomic structures visible

Current imaging is limited and results in:

- Prolonged procedure times
- Larger IV contrast doses (nephrotoxicity)
- Inaccurate device deployment
- Complications
Transapical Beating Heart Neochordae Reconstruction

- Mini-thoracotomy
- Bi-plane echo navigation
- 3D echo positioning

- Postop validation
- Bi-plane echo leaflet capture
The guidance problem: safe and intuitive navigation

Limitations of 2D echo:
- Safety issue: is tool tip in-plane? Is target?

Problem:
- Difficult to maintain both tool tip AND target simultaneously in the image plane
Augmented TEE Imaging

Tracker integration:
- Tabletop magnetic field generator
- Sensors added to TEE and NeoChord DS1000 tool

Integration of real time echo:
- Virtual representation of transducer + tool, and anatomy of interest
OBJECTIVE

TEE alone vs Augmented Reality Image Guidance (+ TEE)

Evaluated 4 outcomes
1. Total length of the tool travelled
2. Distance error of tool from intended midline (from LV apex to MV leaflet)
3. Total navigation completion time
4. Assess for potential injury to neighbouring intracardiac structures
METHODS

- Porcine model
- 6 CV surgeons
- 12 attempts at navigating the Neochord tool from LV apex to intended MV leaflet
- Randomly assigned to TEE alone or AR image guidance (coin toss)
- Tracked tool paths recorded every $\frac{1}{2}$ sec
# RESULTS

<table>
<thead>
<tr>
<th>Navigation Data</th>
<th>TEE Alone</th>
<th>AR Guidance</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance Errors from Midline (mm)</td>
<td>16.8 ± 10.9</td>
<td>5.2 ± 2.4</td>
<td>0.003</td>
</tr>
<tr>
<td>Total Navigation Times from LV Apex to MV Leaflet (seconds)</td>
<td>92.0 ± 84.5</td>
<td>16.7 ± 8.0</td>
<td>0.004</td>
</tr>
<tr>
<td>Total Path Length (mm)</td>
<td>1128.9 ± 931.1</td>
<td>225.2 ± 120.3</td>
<td>0.003</td>
</tr>
</tbody>
</table>

- > 3x shorter distance errors
- > 4x shorter navigation times
- > 5x shorter tool path lengths
Tracked Tool Paths (n=6)
Tracked Tool Paths (n=6)

TEE alone

TEE + AR Image Guidance

FAILED
Expert vs Novice

- No significant difference in distance error, path length or navigation times (p=ns)
- However, AR has dramatically more narrow confidence intervals suggesting that AR imaging improves the reproducibility of the procedure and may help novice surgeons to overcome the steep learning curve
Our most experienced with many human implants

Under posterior leaflet

Entry into LVOT

TEE alone

TEE + AR Image Guidance
Does AR Imaging Improve Patient Safety?

Caught under anterior leaflet

Repeatedly caught under posterior leaflet (risk of perforation)

Passage into left ventricular outflow tract & aortic valve

\[ \sim 40 \times \text{improved patient safety with Augmented Reality image guidance} \]

Table 2) Potential Injury to other Intracardiac Structures

<table>
<thead>
<tr>
<th>Intracardiac Structures</th>
<th>TEE Alone</th>
<th>AR Guidance</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic Valve</td>
<td>34</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Anterior Leaflet Mitral Valve</td>
<td>20</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Posterior Leaflet/LV Free Wall</td>
<td>15</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>LA Roof</td>
<td>6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Failed Navigation</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>78</strong></td>
<td><strong>2</strong></td>
<td><strong>0.008</strong></td>
</tr>
</tbody>
</table>
Considerations

Limitations

• Porcine model
• Small sample sizes
• Rigid annuli

Strengths

• Cost effective
  o $18,000 magnetic tracking system
  o $250 per sensor

• Does not impede normal OR workflow
CONCLUSIONS

- Augmented Reality TEE image guidance:
  
  - demonstrated superior tool navigation accuracy (>3-4-fold) and significantly shorter navigation times (>5-fold) compared to TEE alone
  
  - may shorten the procedural learning curve of novices
  
  - Can improve navigation accuracy in experts
  
  - Significantly less tool mis-guidance into adjacent cardiac structures and improves the overall procedural safety.
Questions?

TEE alone

TEE + AR Image Guidance
Augmented Reality Image Guidance Improves Navigation for Beating Heart Mitral Valve Repair

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