3D Computer Modeling of Bicuspid Aortic Valve Repair

Robert Gorman, M.D.
Alison Pouch, Ph.D.

Gorman Cardiovascular Research Group, Department of Surgery

Perelman School of Medicine
University of Pennsylvania
Why 3DE?

- What have we learned from the mitral valve repair experience?
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- Things are not what they expected:
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• Things are not what they expected:
  • Results are not as good as we thought?
Why 3DE?

- What have we learned from the mitral valve repair experience?
- Things are not what they expected:
  - Results are not as good as we thought?
  - The anatomy is more complicated than we thought?
Recurrence of Mitral Valve Regurgitation After Mitral Valve Repair in Degenerative Valve Disease

Willem Flameng, MD, PhD; Paul Herijgers, MD, PhD; Kris Bogaerts, MSc

Background—Durability assessment of mitral valve repair for degenerative valve incompetence is actually limited to reoperation as the primary indicator, with valve-related risk factors for late death as a secondary indicator. We assessed serial echocardiographic follow-up of valve function as an indicator of the durability of mitral valve repair.

Methods and Results—In 242 patients who had undergone mitral valve repair for degenerative valve incompetence, echocardiographic follow-up of valve function, rate of reoperation, survival, and clinical outcome was studied. At 8 years after repair, clinical outcome was excellent, survival was 90.9±3.2%, freedom from reoperation was 94.2±2.3%, and freedom from anticoagulation bleeding and thromboembolic events was 90.4±2.7%. However, freedom from non-trivial mitral regurgitation (>1/4) was 94.3±1.6% at 1 month, 58.6±4.9% at 5 years, and 27.2±8.6% at 7 years. Freedom from severe mitral regurgitation (>2/4) was 98.3±0.9% at 1 month, 82.8±3.8% at 5 years and 71.1±7.4% at 7 years. The linearized recurrence rate of non-trivial mitral regurgitation (>1/4) was 8.3% per year and of severe mitral regurgitation (>2/4) was 3.7% per year. Inadequate surgical techniques (chordal shortening, no use of annuloplasty ring or sliding plasty) could only partially explain recurrence of regurgitation. In selected patients who did not have these risk factors, linearized recurrence rates were 6.9% per year and 2.5% per year, respectively.

Conclusion—The durability of a successful mitral reconstruction for degenerative mitral valve disease is not constant, and this should be taken into account when asymptomatic patients are offered early mitral valve repair. (Circulation. 2003; 107:1609-1613.)
Mitral-Valve Repair versus Replacement for Severe Ischemic Mitral Regurgitation

BACKGROUND

Ischemic mitral regurgitation is associated with a substantial risk of death. Practice guidelines recommend surgery for patients with a severe form of this condition but acknowledge that the supporting evidence for repair or replacement is limited.

METHODS

We randomly assigned 251 patients with severe ischemic mitral regurgitation to undergo either mitral-valve repair or chordal-sparing replacement in order to evaluate efficacy and safety. The primary end point was the left ventricular end-systolic volume index (LVESVI) at 12 months, as assessed with the use of a Wilcoxon rank-sum test in which deaths were categorized below the lowest LVESVI rank.

RESULTS

At 12 months, the mean LVESVI among surviving patients was 54.6±25.0 ml per square meter of body-surface area in the repair group and 60.7±31.5 ml per square meter in the replacement group (mean change from baseline, −6.6 and −6.8 ml per square meter, respectively). The rate of death was 14.3% in the repair group and 17.6% in the replacement group (hazard ratio with repair, 0.79; 95% confidence interval, 0.42 to 1.47; P=0.45 by the log-rank test). There was no significant between-group difference in LVESVI after adjustment for death (z score, 1.33; P=0.18). The rate of moderate or severe recurrence of mitral regurgitation at 12 months was higher in the repair group than in the replacement group (32.6% vs. 2.3%, P<0.001). There were no significant between-group differences in the rate of a composite of major adverse cardiac or cerebrovascular events, in functional status, or in quality of life at 12 months.

CONCLUSIONS
<table>
<thead>
<tr>
<th>Flat</th>
<th>Saddle</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Flat Design" /></td>
<td><img src="image2.png" alt="Saddle Design" /></td>
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<tr>
<td><img src="image3.png" alt="Flat Design" /></td>
<td><img src="image4.png" alt="Saddle Design" /></td>
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Flat Vs. Saddle Post repair
Aortic Valve Repair

- Results of this emerging therapeutic modality will likely be optimized if there is good communication between imagers and surgeons.

- Imaging need to know what the anatomic goals are.

- Surgeons need to know about emerging image analysis techniques.....
From 3D images of the BAV to interactive models for computational analysis

Visualization ✤ Quantification ✤ Simulation
Insights of 3D computational modeling into variable BAV clinical presentation

<table>
<thead>
<tr>
<th>CLINICAL HETEROGENEITY</th>
<th>MORPHOLOGICAL HETEROGENEITY</th>
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<tbody>
<tr>
<td>Isolated aortic stenosis</td>
<td>Left/Right cusp fusion</td>
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<tr>
<td>Isolated aortic insufficiency</td>
<td>Right/Non-coronary cusp fusion</td>
</tr>
<tr>
<td>Mixed aortic valve dysfunction</td>
<td>Left/Non-coronary cusp fusion</td>
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<tr>
<td>Root dilitation</td>
<td>True bicuspid</td>
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<td>Ascending aortic dilitation</td>
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Contributions of 3D computational modeling to mitral valve repair

- Annuloplasty ring design
- Leaflet curvature and stress estimation
- Pre-operative evaluation of leaflet prolapse

Can 3D image-based modeling of the BAV similarly advance aortic valve repair?
3D BAV modeling by manual tracing 3D echo image data

- **Hypothesis:** 3D image-based aortic valve modeling can resolve subtle geometric differences in patients with TAVs and BAVs.

- **Data:** Full-volume images from 5 patients with a normal TAV and 5 patients with a BAV (right-left cusp fusion, minimal calcification and insufficiency).

<table>
<thead>
<tr>
<th></th>
<th>TAV</th>
<th>BAV</th>
<th>P Value</th>
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<tbody>
<tr>
<td>Age (yrs)</td>
<td>64.8 ± 10.7</td>
<td>28.25 ± 20.6</td>
<td>0.01</td>
</tr>
<tr>
<td>Sex (% male)</td>
<td>40%</td>
<td>80%</td>
<td>0.52</td>
</tr>
<tr>
<td>Ejection Fraction (%)</td>
<td>61 ± 6.5</td>
<td>60 ± 3.5</td>
<td>0.77</td>
</tr>
<tr>
<td>Annular Diameter (cm)</td>
<td>2.54 ± 0.38</td>
<td>3.04 ± 0.61</td>
<td>0.61</td>
</tr>
<tr>
<td>Sinus Diameter (cm)</td>
<td>3.38 ± 0.4</td>
<td>3.5 ± 0.64</td>
<td>0.73</td>
</tr>
<tr>
<td>STJ Diameter (cm)</td>
<td>2.92 ± 0.22</td>
<td>2.9 ± 0.6</td>
<td>0.95</td>
</tr>
</tbody>
</table>
3D echo-based BAV modeling by manual tracing
Differences in TAV and BAV leaflet and coaptation areas

### TAV Leaflet Surface Area
- Noncoronary: $174 \pm 32 \text{ mm}^2$
- Right: $188 \pm 46 \text{ mm}^2$
- Left: $194 \pm 29 \text{ mm}^2$

### TAV Coaptation Area
- $298 \pm 118 \text{ mm}^2$

### BAV Leaflet Surface Area
- Noncoronary: $312 \pm 100 \text{ mm}^2$
- Fused right/left: $469 \pm 207 \text{ mm}^2$

### BAV Coaptation Area
- $177 \pm 43 \text{ mm}^2$
Differences in TAV and BAV aortic root morphology

- STJ-to-annulus ratio consistent in both cohorts
- Mid sinus-to-annulus ratio decreased in BAVs
- STJ-to-mid sinus ratio increased in BAVs

1) Loss of curvature in BAV sinus segment
2) Relative effacement of STJ in absence of remodeling

![Graph showing cross-sectional area comparison between BAV and TAV](image-url)
Automating the aortic valve segmentation process

- 3D target image
- Reference atlases
- Atlas registration and label fusion
- Multi-atlas segmentation
- Model deformation
- Deformable model
- Patient-specific model
Building a reference atlas set for bicuspid valves of varying morphologies

Right/Left cusp fusion

Right/Non-coronary cusp fusion

- fused R/L cusp
- non-coronary cusp
- left coronary cusp
- fused R/N cusp
Initial results of automated tricuspid aortic valve segmentation
Discussion

• End product: a system that generates and analyzes 4D image-derived patient-specific models of the BAV

• Image-derived measurements described herein may not be reproducibly derived from conventional 2D echocardiography

• Image-based computational modeling may help:
  • Better understand patterns in 3D leaflet and sinus asymmetry that would help optimize repair efficacy and durability
  • Identify high-risk geometric targets in patients that would benefit from early intervention
  • Determine which BAVs are amenable to repair rather than replacement
Acknowledgements

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