Functional anatomy of aortic regurgiation

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What are the prerequisites to successful aortic valve repair?
1- To have a clear understanding of the mechanisms of aortic valve dysfunction
« Surgeons are not basically concerned with lesions. We care more about function. Therefore one may define the aim of a valve reconstruction as restoring normal valve function rather than normal valve anatomy »

A. Carpentier. The « French Correction » 1983
• Identification of the mechanism / dysfunction causing mitral valve dysfunction is key to a successful repair.

• This requires a systematic and thorough valve analysis, which will help in choosing the appropriate repair techniques.
Functional Anatomy of Aortic Regurgitation
Lesson n°2 : Look for multiple dysfunctions

• Mitral regurgitation can have several concomitant causes / dysfunctions.

• Failure to identify each and every dysfunction will lead to incomplete surgical correction and is a frequent cause of immediate and late repair failure.
### Functional Anatomy of Aortic Regurgitation

Carpentier's classification of mitral valve dysfunction

<table>
<thead>
<tr>
<th>Dysfunction</th>
<th>Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I: normal motion</td>
<td>• Annular dilatation</td>
</tr>
<tr>
<td></td>
<td>• Leaflet perforation</td>
</tr>
<tr>
<td>Type II: excess leaflet motion</td>
<td>• Chordal rupture or elongation</td>
</tr>
<tr>
<td></td>
<td>• Papillary muscle rupture or elongation</td>
</tr>
<tr>
<td>Type III: restricted leaflet motion</td>
<td>• Commisural ± chordal fusion</td>
</tr>
<tr>
<td></td>
<td>• Valve thickening and/or calcification</td>
</tr>
</tbody>
</table>

**Type I:**
- Normal motion
- Annular dilatation
- Leaflet perforation

**Type II:**
- Excess leaflet motion
- Chordal rupture or elongation
- Papillary muscle rupture or elongation

**Type III:**
- Restricted leaflet motion
- Commisural ± chordal fusion
- Valve thickening and/or calcification
El Khoury's classification of aortic valve dysfunction

<table>
<thead>
<tr>
<th>Dysfunction</th>
<th>Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I:</td>
<td>• Annular (FAA) dilatation</td>
</tr>
<tr>
<td>normal motion</td>
<td>• Cusp perforation</td>
</tr>
<tr>
<td>Type II:</td>
<td>• Cuspal prolapse (spontaneous or surgical)</td>
</tr>
<tr>
<td>excess leaflet motion</td>
<td>• Commisural disruption</td>
</tr>
<tr>
<td>Type III:</td>
<td>• Commisural</td>
</tr>
<tr>
<td>restricted leaflet motion</td>
<td>• Valve thickening and/or calcification</td>
</tr>
</tbody>
</table>
Mitral regurgitation leads to mitral annulus dilatation which in turn aggravates the severity of regurgitation.

Leaflet repair should always be accompanied by a ring annuloplasty, to restore the matching between leaflet and annulus area.
Functional Anatomy of Aortic Regurgitation

- Sinotubular junction
- Commissures
- Aortic cusps
- Valsalva sinuses
- Aorto-ventricular junction
- Aortic annulus
Functional Anatomy of Aortic Regurgitation

The normal aortic root and valve

- right coronary ostium
- left coronary ostium
- sinus of Valsalva
- Arantius node
- Coaptation surface
Functional Anatomy of Aortic Regurgitation
Functional Anatomy of Aortic Regurgitation
The functional aortic annulus
Functional Anatomy of Aortic Regurgitation

The functional aortic annulus
2- To understand the anatomical features associated with post-operative results
Functional Anatomy of Aortic Regurgitation
Outcome after aortic valve repair: long-term survival

Boodhwani et al., J Thorac Cardiovase Surg 2009;137:286-294
Functional Anatomy of Aortic Regurgitation
Outcome after aortic valve repair: freedom from recurrent regurgitation

Boodhwani et al., *J Thorac Cardiovasc Surg* 2009;137:286-294
### Functional Anatomy of Aortic Regurgitation

Pre-operative characteristics of patients with recurrent regurgitation

<table>
<thead>
<tr>
<th></th>
<th>No AR (n=112)</th>
<th>1+ - 2+ AR (n=23)</th>
<th>3+ AR (n=41)</th>
<th>P value or $\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marfan (%)</td>
<td>2 (2%)</td>
<td>2 (9%)</td>
<td>6 (15%)</td>
<td>0.005</td>
</tr>
<tr>
<td>Type 3 AR (%)</td>
<td>15 (14%)</td>
<td>10 (43%)</td>
<td>19 (46%)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Annulus (mm)</td>
<td>25 ± 4</td>
<td>24 ± 4</td>
<td>26 ± 6</td>
<td>0.27</td>
</tr>
<tr>
<td>Sinus (mm)</td>
<td>39 ± 8</td>
<td>35 ± 9</td>
<td>41 ± 13</td>
<td>0.61</td>
</tr>
<tr>
<td>ST junction (mm)</td>
<td>35 ± 9</td>
<td>35 ± 9</td>
<td>34 ± 9</td>
<td>0.93</td>
</tr>
<tr>
<td>Tubular Aorta (mm)</td>
<td>42 ± 11</td>
<td>40 ± 8</td>
<td>37 ± 13</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Le Polain de Waroux et al., *J Am Coll Cardiol Imag* 2009;2:931-939
Functional Anatomy of Aortic Regurgitation
Outcome after aortic valve repair: freedom from recurrent regurgitation

Boodhwani et al., J Thorac Cardiovasc Surg 2009;137:286-294

Time from surgery (years)

Freedom from AI > 2 (%)

Type I / II
Type III

log rank  p = 0.03
Functional Anatomy of Aortic Regurgitation
Outcome after aortic valve repair: impact of cuspal configuration

Time (years)

Freedom from reoperation (%)

log rank  p < 0.001

Functional Anatomy of Aortic Regurgitation
Outcome after bicuspid valve repair: impact of pericardial patching

Functional Anatomy of Aortic Regurgitation
Outcome after bicuspid valve repair: impact of commissural orientation


Time (years)

Freedom from reoperation (%)

log rank  p < 0.001

< 160°

> 160°
Functional Anatomy of Aortic Regurgitation
Outcome after bicuspid valve repair: impact of annular size

Functional Anatomy of Aortic Regurgitation
Outcome after aortic valve repair: impact of annular stabilization

Time from surgery (years)

Freedom from recurrent AI (%)

log rank  p = 0.002

Reimplantation

No annular stabilization

de Kerkhove et al., J Thorac Cardiovasc Surg 2011;142:1430-1438
Repairability was determined based on tissue quality and leaflet calcifications.

- Smooth, thin and large leaflets with redundant tissue were considered as repairable.
- Small, restrictive, fibrous or thickened leaflets were thought to preclude surgical repair.
- Heavily calcified valves (≥ grade 3) were usually considered as non repairable (except if localized at the level of the free margins)

Le Polain de Waroux et al., *Circulation* 2007;116:I-264
Functional Anatomy of Aortic Regurgitation

Pre-operative echocardiographic evaluation
Identification of AR dysfunction
Functional Anatomy of Aortic Regurgitation
Feasibility of aortic repair: a team approach

SURGEON
Direct vision
Valve Analysis

CARDIOLOGIST
Echo vision
Functional Anatomy of Aortic Regurgitation
Surgical classification of aortic dysfunction

I  Normal cusp motion
II Increased cusp motion
III Poor cusp quality or quantity
Functional Anatomy of Aortic Regurgitation

Type Ib: Aortic root and Valsalva sinus aneurysm

Aortic root aneurysm
Functional Anatomy of Aortic Regurgitation
Type Ib: Aortic root and Valsalva sinus aneurysm
Functional Anatomy of Aortic Regurgitation
Type Ib: Aortic root and Valsalva sinus aneurysm

Sinus of Valsalva aneurysm
Functional Anatomy of Aortic Regurgitation
Type Ib: Aortic root and Valsalva sinus aneurysm

Sinus of Valsalva aneurysm
Functional Anatomy of Aortic Regurgitation
Type Ic: "Annular dilatation"

Annular dilation
Functional Anatomy of Aortic Regurgitation

Type Ic: Annular dilatation

Annular dilation
Functional Anatomy of Aortic Regurgitation
Type II: flail aortic cusp

Cusp prolapse
Functional Anatomy of Aortic Regurgitation
Type II: flail aortic cusp

Cusp prolapse
Functional Anatomy of Aortic Regurgitation
Type II: partial cusp prolapse
Functional Anatomy of Aortic Regurgitation
Type II: partial cusp prolapse

Cusp prolapse
Functional Anatomy of Aortic Regurgitation
Type II: partial cusp prolapse

Cusp prolapse
Functional Anatomy of Aortic Regurgitation
Type II: whole cusp prolapse

Cusp prolapse
Functional Anatomy of Aortic Regurgitation
Type II: whole cusp prolapse

Cusp prolapse
Functional Anatomy of Aortic Regurgitation
Type III: Heavily calcified valve

Cusp restriction
Functional Anatomy of Aortic Regurgitation
Type III: Heavily calcified valve

Cusp restriction
Functional Anatomy of Aortic Regurgitation
Type III: Heavily calcified valve

Cusp restriction
Functional Anatomy of Aortic Regurgitation
Type Id: Endocarditis and cusp perforation

Cusp perforation
Functional Anatomy of Aortic Regurgitation
Type Id: Endocarditis and cusp perforation

Leaflet perforation
Functional Anatomy of Aortic Regurgitation

Echocardiographic prediction of aortic valve repairability
Functional Anatomy of Aortic Regurgitation
Echo prediction of valve pathology and repairability

<table>
<thead>
<tr>
<th>TEE</th>
<th>Surgery</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 1</td>
<td>Type 2</td>
</tr>
<tr>
<td>TEE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td>36</td>
<td>3</td>
</tr>
<tr>
<td>Type 2</td>
<td>3</td>
<td>58</td>
</tr>
<tr>
<td>Type 3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>41</td>
<td>62</td>
</tr>
</tbody>
</table>

Le Polain de Waroux et al., *Circulation* 2007;116:I-264
Functional Anatomy of Aortic Regurgitation
Echo prediction of valve pathology and repairability

Le Polain de Waroux et al., Circulation 2007;116:I-264
## Functional Anatomy of Aortic Regurgitation

Echo prediction of valve pathology and repairability

<table>
<thead>
<tr>
<th></th>
<th>Surgery</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cusp flail</td>
<td></td>
</tr>
<tr>
<td>Cusp flail</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Whole cusp prolapse</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Distal cusp prolapse</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Free edge fenestrations</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Type 3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>62</td>
</tr>
</tbody>
</table>

|                  | Whole cusp prolapse       |       |
| Whole cusp prolapse | 25                      | 26    |
| Distal cusp prolapse | 0                      |       |
| Free edge fenestrations | 1                      |       |
| Type 1           | 0                        | 3     |
| Type 3           | 0                        | 1     |
| Total            | 30                       | 62    |

|                  | Partial cusp prolapse     |       |
| Partial cusp prolapse | 2                       | 14    |
| Distal cusp prolapse | 11                      |       |
| Free edge fenestrations | 1                      |       |
| Type 1           | 0                        | 3     |
| Type 3           | 0                        | 1     |
| Total            | 12                       | 62    |

|                  | Fenestrations             |       |
| Fenestrations    | 2                        | 14    |
| Distal cusp prolapse | 1                       |       |
| Free edge fenestrations | 11                     |       |
| Type 1           | 0                        | 3     |
| Type 3           | 0                        | 1     |
| Total            | 17                       | 62    |

Le Polain de Waroux et al., *Circulation* 2007;116:I-264
Functional Anatomy of Aortic Regurgitation

Echo prediction of valve pathology and repairability

Repairability was determined based on tissue quality and leaflet calcifications.

- Smooth, thin and large leaflets with redundant tissue were considered as repairable.
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- Heavily calcified valves ($\geq$ grade 3) were usually considered as non repairable (except if localized at the level of the free margins)

Le Polain de Waroux et al., Circulation 2007;116:I-264
Functional Anatomy of Aortic Regurgitation
Echo prediction of valve pathology and repairability

<table>
<thead>
<tr>
<th>TEE-predicted procedure</th>
<th>Final surgical procedure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>replacement</td>
<td>repair</td>
</tr>
<tr>
<td>replacement</td>
<td>35</td>
<td>17</td>
</tr>
<tr>
<td>repair</td>
<td>3</td>
<td>108</td>
</tr>
<tr>
<td>Total</td>
<td>38</td>
<td>125</td>
</tr>
</tbody>
</table>

Le Polain de Waroux et al., *Circulation* 2007;116:I-264
Functional Anatomy of Aortic Regurgitation
AR repair: prediction of valve repairability

Le Polain de Waroux et al., Circulation 2007;116:I-264
Functional Anatomy of Aortic Regurgitation
Echo prediction of valve pathology and repairability

Years after surgery
Event free survival (%)

Type 1
Type 2
Type 3

log rank   p = 0.04

Le Polain de Waroux et al., *Circulation* 2007;116:I-264
Intra-operative echocardiographic evaluation:
Risk of recurrent AR
• 186 consecutive AR repair patients with available pre-operative, intraoperative and follow-up echo data.

- 122 pts (group A, 53 ± 13 yrs) with no AR recurrence
- 23 pts (group B, 50 ± 16 yrs) with 1+ to 2+ recurrent AR
- 41 pts (group B, 63 ± 12 yrs) with 3+ recurrent AR
Over a mean follow-up of 24 months, 41 pts had recurrent 3+ AR, 23 of whom needed a redo operation.

F-up Echocardiography identified the cause of repair failure as
- Presence cusp prolapse (type 2 AR) : 26 pts
- Restrictive cusp motion (type 3 AR) : 9 pts
- Dehiscence of valvar sutures : 3 pts
- Aortic dissection : 2 pts
- Endocarditis : 1 pt

Le Polain de Waroux et al., J Am Coll Cardiol Imag 2009;2:931-939
Functional Anatomy of Aortic Regurgitation
Immediate post-operative measurements

- Annulus
- Sinuses
- ST junction
- Tubular aorta
- Height of the sinuses
- Coaptation length
- Symmetry of the coaptation
- Tips to annulus
- Cusp’s belly to annulus
- Eccentric Jet
- Vena contracta width

Le Polain de Waroux et al., J Am Coll Cardiol Imag 2009;2:931-939
## Functional Anatomy of Aortic Regurgitation

### Multivariate analysis

<table>
<thead>
<tr>
<th></th>
<th>HR</th>
<th>Cox P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coaptation length</td>
<td>0.82</td>
<td>0.54</td>
</tr>
<tr>
<td>Tips - annulus</td>
<td>4.72</td>
<td>0.08</td>
</tr>
<tr>
<td>Tips below the annulus</td>
<td>7.9</td>
<td>0.003</td>
</tr>
<tr>
<td>Annulus size</td>
<td>1.18</td>
<td>0.012</td>
</tr>
<tr>
<td>Residual AR</td>
<td>5.3</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Le Polain de Waroux et al., *J Am Coll Cardiol Imag* 2009;2:931-939
Functional Anatomy of Aortic Regurgitation

Representative example
Functional Anatomy of Aortic Regurgitation

Coaptation tips below the annulus?

Yes
- Recurrence rate 20/28 (71%)
- Redo rate 12/28 (48%)

No

Residual AR?

Yes

Coaptation length?

< 4 mm
- Recurrence rate 17/77 (22%)
- Redo rate 2/77 (3%)

> 4 mm
- Recurrence rate 2/77 (2%)
- Redo rate 2/77 (1%)

No

Recurrence rate 2/81 (2%)
Redo rate 1/81 (1%)

Le Polain de Waroux et al., J Am Coll Cardiol Imag 2009;2:931-939
Functional Anatomy of Aortic Regurgitation

AR repair: freedom 3+ AR recurrence

Coaptation above the annulus
No residual AR

Coaptation above the annulus
Residual AR
Coaptation length > 4 mm

Coaptation above the annulus
Residual AR
Coaptation length < 4 mm

Coaptation below the annulus

log rank  \( p = 0.0001 \)

Le Polain de Waroux et al., *J Am Coll Cardiol Imag* 2009;2:931-939
Transesophageal echocardiography allows for accurate delineation of the mechanisms of aortic regurgitation when compared to surgery.

In both Type 1 and Type 2 dysfunction by TEE, the likelihood of successful and durable repair is > 90%.

In Type 3 dysfunction by TEE, the likelihood of repair does not exceed 50%. More than 40% of attempted repairs in Type 3 dysfunction fail over the next 4 years.

Transesophageal echocardiography also allows for the intra-operative evaluation of repair results and can be used to decide whether further surgery is needed.