Usefulness of the Cryolife O’Brien Stentless Suprannular Aortic Valve to Prevent Prosthesis-Patient Mismatch in the Small Aortic Root

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OBJECTIVES
This study evaluated the occurrence of prosthesis-patient mismatch (PPM) after Cryolife O’Brien (CLOB) suprannular stentless valve replacement in patients with a small aortic root and its repercussions on the patient’s hemodynamic status and left ventricular mass regression.

BACKGROUND
The correct management of the small aortic annulus is still controversial. Small aortic prostheses can lead to a PPM, which results in high gradients with important repercussions on the hemodynamic status.

METHODS
Seventy-two patients (mean age: 72.5 ± 6.2 years, 73.6% women) with a small aortic root (≤21 mm intraoperatively measured aortic annulus) had a CLOB valve implanted in the aortic position between November 1993 and July 2001 at our institution. Mean prosthesis size was 22.0 ± 0.8 mm. Patients underwent echocardiography preoperatively, at discharge, six months, one year and yearly thereafter.

RESULTS
The incidence of PPM at discharge was 22.2% (16/72); 18.7% were severe (effective orifice area index [EOAI] ≤ 0.65 cm/m²), 43.7% were moderate (EOAI 0.66 to 0.75 cm/m²) and 37.6% were mild (0.76 to 0.85 cm²). At multivariable analysis, gender (p = 0.001), age (p = 0.015), body surface area (p = 0.001) and patient’s annulus index (p = 0.001) were significant factors influencing the occurrence of “transient” PPM. At one year the incidence of PPM was 0%.

CONCLUSIONS
Suprannular CLOB valve yielded excellent hemodynamic results in patients with small aortic roots. This study demonstrates that PPM can be completely avoided when using the CLOB valve. The superior hemodynamics of this stentless valve are likely to be related to its suprannular design. (J Am Coll Cardiol 2002;39:1845–51) © 2002 by the American College of Cardiology Foundation

Patients with small aortic roots undergoing aortic valve replacement (AVR) present a special challenge to the surgeon regarding operative technique and selection of prosthesis. Small aortic annular size has been reported to be associated with increased operative mortality (1,2). However, the effects of small aortic prostheses on long-term survival still remain controversial (3,4). Nevertheless, it is widely accepted that a discrepancy between the prosthesis effective orifice area and the patient’s body surface area (BSA) (prosthesis-patient mismatch [PPM]) (5) results in abnormally high residual gradients, worsening of the patient’s hemodynamic status (6,7) and impaired regression of left ventricular hypertrophy (8). Thus, this condition might require a reoperation (9).

As conventional stented valves have been demonstrated to be obstructive and the stent to be a stress factor on the tissue components (10), stentless valves have no prosthetic sewing ring and no prosthetic struts and result in larger effective orifice area (EOA) and lower transvalvular gradients after AVR (11). The Cryolife O’Brien bioprosthesis (CLOB) (Cryolife International, Atlanta, Georgia) is a composite suprannular stentless valve, which, in our previous reports, yielded good hemodynamics and significant left ventricular mass (LVM) regression (12).

The present study was aimed toward evaluating the occurrence of PPM after CLOB suprannular stentless valve replacement in patients with a small aortic root and its repercussions on the patient’s hemodynamic status and LVM regression.

METHODS
Patients. Between November 1993 and July 2001, 72 consecutive patients with small aortic roots (≤21 mm intraoperatively measured aortic annulus) received a CLOB valve in the aortic position. Mean age was 72.5 ± 6.2 years (range: 50 to 87 years). Forty patients (55.5%) were over 65 years of age. Nineteen patients (26.4%) were men and 53 (73.6%) women; mean BSA was 1.68 ± 0.8 m² (range: 1.3 to 2.1 m²); 21 patients (29.2%) were in New York Heart Association (NYHA) functional class IV, 46 (63.9%) were in class III and 5 patients (6.9%) were in class II. Mean preoperative NYHA was 3.2 ± 0.3. Valve pathology con-
Abbreviations and Acronyms

ANOVA = analysis of variance  
AV = aortic valve  
AVR = aortic valve replacement  
BSA = body surface area  
CI = confidence interval  
CLOB = Cryolife O’Brien  
CSA = cross-sectional area  
EOAI = effective orifice area index  
LVMI = left ventricular mass index  
LVOT = left ventricular outflow tract  
MG = mean gradient  
NYHA = New York Heart Association  
PAI = patient annulus index  
PPM = prosthesis-patient mismatch  
PPM = prosthesis-patient mismatch  
RR = relative risk  
RWT = relative wall thickness  
VTI = velocity-time integral

sisted of aortic stenosis in 45 (62.5%) patients, insufficiency in 8 (11.1%) patients and mixed lesions in 19 (26.4%) patients. Etiology was degenerative calcific disease in 52 (72.2%) patients, congenital bicuspid valve in 12 (6.7%) patients, rheumatic disease in 2 (2.8%) patients, endocarditis in 4 (5.6%) patients and bioprosthetic failure in 4 (5.6%) patients.

Associated procedures were: coronary artery bypass grafting (n = 22, 30.5%), mitral valve replacement (n = 7, 9.7%), mitral valve repair (n = 1, 1.4%) and tricuspid annuloplasty (n = 1, 1.4%). Patients undergoing concomitant coronary artery bypass grafting had an average of 1.5 ± 0.2 grafts, and 59% (13/22) had a bypass with the left internal mammary artery. The host annulus was measured in all patients with a Hegar probe; mean measured annulus size was 19.7 ± 0.4 mm; diameter of annulus was then indexed by patient BSA to obtain the patient annulus index (PAI) (13); in our cohort PAI was 11.7 ± 0.2 mm. Mean valve size implanted was 22.0 ± 0.8 mm and mean labeled valve size/BSA was 1.2 ± 0.2 cm²/m²; for instance, 35 (48.6%) patients received a 21-mm valve and 37 (51.4%) patients received a 23-mm valve. The implants were performed as widely described (14). Contraindications for using the stentless valve were extensive calcification of the sinus aortic wall or an extremely thin aortic wall. The average time on cardiopulmonary bypass was 118 ± 72.1 min with a mean of 98 ± 42.8 of aortic cross clamping.

All patients started, from the first postoperative day, a regimen of a three-month treatment with warfarin sodium (Coumadin, Du Pont Pharmaceuticals, Wilmington, Delaware). The target international normalized ratio was 2.0 to 2.5.

Follow-up information was obtained from outpatient clinic appointments; mean follow-up time was 41 ± 14 months (range: 2 to 92 months). No patient was lost at follow-up, which was 100% complete.

All data were collected according to the Society of Thoracic Surgeons and the American Association for Thoracic Surgery guidelines for reporting mortality and morbidity after aortic valve surgery (15).

The investigational review board approved the study protocol, and written informed consent was obtained from all patients before enrollment. 

Echocardiography. Echocardiographic imaging was performed with a Hewlett Packard Sonos 5500 ultrasound system with a 2.5 MHz transducer (Hewlett Packard, Andover, Massachusetts) and recorded on VHS videotape for subsequent review. The same technician (M. L. M.) performed all exams with the supervision of a cardiologist (G. M.). Imaging was performed in the early postoperative period (before hospital discharge), six months after operation, one year after operation and yearly thereafter. M-mode, two-dimensional, continuous pulsed-wave and color Doppler were carried out, and standard views were employed. Measurements of end systolic diameter, end diastolic diameter, posterior wall thickness and septum thickness were first made according to the recommendations of the American Society of Echocardiography using a leading-edge-to-leading-edge convention (16). The presence of aortic regurgitation was quantified using color flow Doppler (17); ratios of either percent diameter and percent area of the jet to that of the left ventricular outflow tract (LVOT) in the long- or short-axis views were calculated. Aortic regurgitation was defined as trivial (grade I), mild (grade II), moderate (grade III) or severe (grade IV) if the ratio of the jet diameter to the LVOT diameter in the long-axis view was <24%, 24% to <45%, 45% to <65% or 65%, respectively. Similarly, aortic regurgitation was defined as trivial, mild, moderate or severe if the ratio of the jet area to the LVOT area in the short-axis view was <4%, 4% to <25%, 25% to <60%, 60% respectively. Peak and mean velocities in the LVOT (V max LVOT [m/s] and V mean LVOT [m/s]) and velocity-time integral (VTI LVOT [cm]) were determined proximal to the valve using pulsed-wave Doppler. Peak and mean velocities across the valve (V max AV [m/s] and V mean AV [m/s]) and VTI (VTI LVOT [cm]) were calculated using continuous wave Doppler through the aortic valve (AV). The LVOT diameter was measured in midystole from the parasternal long-axis view. The LVOT cross-sectional area (CSA) was calculated as: CSA LVOT = 3.14·D²/4 (where D = diameter). All Doppler measurements were averaged from 3 to 10 cardiac cycles in sinus rhythm and in atrial fibrillation, respectively. Peak and mean pressure gradients were calculated by applying the modified Bernoulli equation (18); EOA was calculated according the continuity equation (19). The EOA was indexed by patient’s BSA and expressed as EOAI (cm²/m²). This index was used to detect mismatch between valve size and patient’s BSA; according to Pibarot et al. (4), an EOAI ≤0.85 cm²/m² was considered evidence of a mismatch, which was defined as severe if EOAI was ≤0.65 cm²/m², moderate if EOAI was 0.66 to 0.75 cm²/m² and mild if EOAI was 0.76 to 0.85 cm²/m². Left ventricular mass...
(LVM) was calculated employing measurements by Penn convention (20); LVM was indexed by BSA and expressed as left ventricular mass index (LVMI) (g/m²). End diastolic wall thickness above the normal range of 0.6 to 1.1 cm (mean: 0.9 cm) was considered hypertrophied (21). Left ventricular ejection fraction was calculated by use of the apical four-chamber view and the application of the modified Simpson rule method (22).

### Statistical analysis.

All data were analyzed with the SPSS for Windows, release 8.0 (SPSS, Inc., Chicago, Illinois) statistical package. Continuous data were presented as mean ± SD; discrete variables were given as percentages. Repeated analysis of variance (ANOVA) measures were used to test the significance of changes of data at various points of the study and the Sheffe post-hoc test was utilized for multiple comparisons. The chi-square analysis or Fisher exact test was used to compare categorical data. Death and event-free survival estimates were calculated by the product-limit method of Kaplan and Meier and reported with 95% confidence limit; the Mantel-Cox (log-rank) test was used to test the hypothesis that there was no difference in survival among groups.

Variables entered into a univariate model; significant and borderline (p ≤ 0.1) factors were then reintroduced in a multivariable model examining predictors of mismatch. Results were expressed with the relative risk (RR) and 95% confidence limit; the Mantel-Cox (log-rank) test was used to test the hypothesis that there was no difference in survival among groups.

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### RESULTS

#### Mortality, morbidity and functional status.

There were two early (30-day) deaths (2.7%); no death was directly valve related as demonstrated by the postmortem examination. Nonfatal complications occurred in 4.1% of cases: these comprised one postoperative bleeding requiring re-exploration, one sternal infection and one respiratory failure. One patient died during follow-up. Seven-year actuarial survival was 94.9 ± 2.8% (0.8 patients/year; 95% CI, 0.4 to 1.2). Actuarial seven-year freedom from events was as follows: reoperation (90.1 ± 6.7%), structural valve deterioration (96.1 ± 3.4%), thromboembolism (100%), anticoagulant-related hemorrhage (100%), and endocarditis (97.5 ± 1.7%); all events (76.8 ± 4.4%). At recent follow-up all patients showed an improvement in functional status; among 69 survivors, mean NYHA was 1.27 ± 0.3 (p < 0.001 vs. preoperatively). For instance, 50 (72.4%) patients were in NYHA class I, 19 (27.6%) patients were in class II and 0 patients were in class III or IV.

#### Echocardiographic/hemodynamic assessments.

Hemodynamic data are shown in Table 1. Mean transprosthetic systolic gradient reduced significantly over time (p < 0.001). It showed at discharge a decrement of 47.1 mm Hg from preoperative values (p < 0.001); it reduced again at subsequent controls but without statistical significance. At discharge, LVMI decreased by 26.5% (−53 g/cm² [p < 0.001]) from the baseline value. It reduced from 147 ± 39 g/cm² to 119 ± 26 g/cm² (p = 0.03) from discharge to six months. At late control, LVMI was 97 ± 14 g/cm² (p = 0.01 from the six-month value). Relative wall thickness (RWT) decreased from 0.52 ± 0.12 preoperatively to 0.47 ± 0.1 at discharge (p = 0.001), and it did not show further significant changes. Basically, 6.1% (4/65), 6% (3/50), 4.1% (1/24) and 0% (0/10) of patients still presented further significant changes. Basically, 6.1% (4/65), 6% (3/50), 4.1% (1/24) and 0% (0/10) of patients still presented features of concentric hypertrophy (RWT and LVMI both elevated) at one-, three-, five- and seven-year controls, respectively.

#### Incidence and impact of PPM.

Patients also showed statistically significant increase in EOAI (p < 0.001). On average, increases were 0.61 ± 0.1 cm/m² from baseline to discharge (p < 0.001), 0.33 ± 0.1 cm/m² from discharge to six-month control (p = 0.04) and 0.2 ± 0.1 cm/m² (p = 0.3) from six-month study to the subsequent control. At discharge, mean labeled size/BSA was 1.2 ± 0.04 and EOAI was 0.9 ± 0.1 cm/m² (p = 0.001); this difference was not significant up to the six-month control (p = NS). The incidence of PPM at discharge was 22.2% (16/72); three patients (18.7%) had a severe (EOAI ≤ 0.65 cm/m²), seven

### Table 1. Echocardiographic Results

<table>
<thead>
<tr>
<th></th>
<th>Preoperative (n = 72)</th>
<th>Discharge (n = 70)</th>
<th>6 Months (n = 69)</th>
<th>1 Year (n = 65)</th>
<th>3 Years (n = 50)</th>
<th>5 Years (n = 24)</th>
<th>7 Years (n = 10)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{es}, m/s</td>
<td>4.9 ± 0.3</td>
<td>2.1 ± 0.3†</td>
<td>1.8 ± 0.3‡</td>
<td>1.7 ± 0.4</td>
<td>1.6 ± 0.3</td>
<td>1.5 ± 0.2§</td>
<td>1.5 ± 0.2§</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>MG, mm Hg</td>
<td>57 ± 12</td>
<td>10 ± 3.3†</td>
<td>8 ± 2.3</td>
<td>7 ± 3.3</td>
<td>6 ± 2.4</td>
<td>6 ± 1.9</td>
<td>5 ± 1.1</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>EOAI, cm²/m²</td>
<td>0.3 ± 0.1</td>
<td>0.91 ± 0.1†</td>
<td>1.11 ± 0.1‡</td>
<td>1.13 ± 0.2</td>
<td>1.11 ± 0.2</td>
<td>1.14 ± 0.2</td>
<td>1.18 ± 0.2</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>ESD, cm</td>
<td>4.0 ± 1.1</td>
<td>3.9 ± 0.1†</td>
<td>3.5 ± 0.1‡</td>
<td>3.4 ± 0.6</td>
<td>3.4 ± 0.8</td>
<td>3.4 ± 0.6</td>
<td>3.2 ± 0.5</td>
<td>0.01</td>
</tr>
<tr>
<td>EDD, cm</td>
<td>5.3 ± 1.2</td>
<td>5.0 ± 0.2‡</td>
<td>4.9 ± 0.2</td>
<td>4.6 ± 0.8</td>
<td>4.6 ± 1.1</td>
<td>4.7 ± 0.7</td>
<td>4.5 ± 0.5</td>
<td>0.01</td>
</tr>
<tr>
<td>LVMI, g/m³</td>
<td>200 ± 54</td>
<td>147 ± 39†</td>
<td>119 ± 26‡</td>
<td>114 ± 19</td>
<td>108 ± 22</td>
<td>104 ± 18§</td>
<td>97 ± 14§</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>RWT, %</td>
<td>0.52 ± 0.12</td>
<td>0.41 ± 0.1†</td>
<td>0.44 ± 0.1‡</td>
<td>0.47 ± 0.1</td>
<td>0.47 ± 0.1</td>
<td>0.44 ± 0.1</td>
<td>0.42 ± 0.08</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>FS, %</td>
<td>0.23 ± 0.06</td>
<td>0.23 ± 0.05</td>
<td>0.28 ± 0.02</td>
<td>0.26 ± 0.02</td>
<td>0.26 ± 0.1</td>
<td>0.27 ± 0.1</td>
<td>0.28 ± 0.1</td>
<td>NS</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>48 ± 16.4</td>
<td>44 ± 12.2</td>
<td>55 ± 18.3</td>
<td>51 ± 21.1</td>
<td>52 ± 20.3</td>
<td>54 ± 19.7</td>
<td>56 ± 22.3</td>
<td>NS</td>
</tr>
</tbody>
</table>

*p = results of analysis of variance over time. †‡§Indicate a significant but different value from preoperatively, discharge and 6 months, respectively, at repeated analysis of variance measures.

EDD = end diastolic diameter; EOAI = effective orifice area index; ESD = end systolic diameter; FS = fractional shortening; LVEF = left ventricular ejection fraction; LVMI = left ventricular mass index; MG = mean transvalvular gradient; RWT = relative wall thickness; V_{es} = peak transprosthetic velocity.
having a moderate (EOAI = 0.65 to 0.75 cm²/m²) and six (37.6%) had a mild (0.76 to 0.85 cm²/m²) mismatch. Table 2 shows preoperative characteristics of patients with or without mismatch; patients with mismatch were older, prevalently women, received a smaller valve size, had a smaller BSA and a smaller PAI; furthermore, they had higher baseline mean gradient (MG) and LVMI. Determinants of mismatch at univariate analysis (Table 3) resulted in not being significant. At six months two patients (16.6%) belonging to the 21-mm group and one to the 23-mm group (1.7%) still showed echocardiographic evidence of mismatch. The incidence of mismatch was 0% at subsequent controls. Patients with “transient” mismatch had higher mean gradients at discharge (13.3 vs. 7.1 mm Hg, p = 0.01) and six months (9.1 vs. 6.4 mm Hg, p = 0.01). At one-year (8.6 vs. 6.5 mm Hg, p = NS), three-year (6.1 vs. 5.9 mm Hg, p = NS), five-year (6.3 vs. 5.7 mm Hg, p = NS) and seven-year (6.4 vs. 5.1, p = NS) studies, no difference in MG was detected between patients with or without mismatch. The LVMI reduced over time in both groups (Table 4). It decreased by 23.4% and 34.1% at discharge (p = NS), by 11.9% and 18.9% at six months (p = NS), by 13.8% and 8.8% at one year (p = NS), by 14.8% and 0.3% at five years (p < 0.001) and by 4.5% and 9.5% at seven years (p = NS) in patients with or without mismatch, respectively. At one-way ANOVA, postoperative EOAI ≤0.85 was a borderline factor associated with a greater

### Table 2. Preoperative Data: Patients With or Without Evidence of Mismatch

<table>
<thead>
<tr>
<th>Variable</th>
<th>EOAI ≤ 0.85 cm²/m²</th>
<th>EOAI &gt; 0.85 cm²/m²</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yrs</td>
<td>77.2 ± 10</td>
<td>67.9 ± 9</td>
<td>0.01</td>
</tr>
<tr>
<td>Female gender</td>
<td>93.7% (15/16)</td>
<td>67.8% (38/56)</td>
<td>0.01</td>
</tr>
<tr>
<td>Valve size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean, mm</td>
<td>21.3 ± 0.1</td>
<td>2.2 ± 0.3</td>
<td>0.03</td>
</tr>
<tr>
<td>21 mm</td>
<td>13 (81.2%)</td>
<td>22 (39.2%)</td>
<td></td>
</tr>
<tr>
<td>23 mm</td>
<td>3 (18.8%)</td>
<td>34 (60.8%)</td>
<td></td>
</tr>
<tr>
<td>PAI, mm</td>
<td>10.7 ± 0.08</td>
<td>12.0 ± 0.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Body surface area</td>
<td>1.62 ± 0.1</td>
<td>1.74 ± 0.1</td>
<td>0.001</td>
</tr>
<tr>
<td>NYHA ≥III</td>
<td>93.7% (15/16)</td>
<td>92.8% (52/56)</td>
<td>NS</td>
</tr>
<tr>
<td>Pathology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stenosis</td>
<td>62.5% (10/16)</td>
<td>62.5% (35/56)</td>
<td></td>
</tr>
<tr>
<td>Insufficiency</td>
<td>12.5% (2/16)</td>
<td>10.8% (6/56)</td>
<td>NS</td>
</tr>
<tr>
<td>Mixed</td>
<td>25.0% (4/16)</td>
<td>26.7% (15/56)</td>
<td></td>
</tr>
<tr>
<td>CAD</td>
<td>25.0% (4/16)</td>
<td>32.1% (18/56)</td>
<td>NS</td>
</tr>
<tr>
<td>MVD</td>
<td>12.5% (2/16)</td>
<td>10.7% (6/56)</td>
<td>NS</td>
</tr>
<tr>
<td>MG, mm Hg</td>
<td>65 ± 14</td>
<td>50.2 ± 10</td>
<td>0.01</td>
</tr>
<tr>
<td>LVMI, g/m²</td>
<td>214.6 ± 62</td>
<td>186.4 ± 46</td>
<td>0.03</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>47.7 ± 14.6</td>
<td>48.7 ± 17.1</td>
<td>NS</td>
</tr>
</tbody>
</table>

**CAD** = (associated) coronary artery disease; EOAI = effective orifice area index; LVEF = left ventricular ejection fraction; LVMI = left ventricular mass index; MG = mean transvalvular gradient; MVD = (associated) mitral valve disease; NYHA = New York Heart Association functional class; PAI = patient’s annulus index.

### Table 3. Predictors of PPM at Univariate Analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Relative Risk</th>
<th>95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age &gt; 70 yrs</td>
<td>1.4</td>
<td>0.6–2.3</td>
<td>0.02</td>
</tr>
<tr>
<td>Female gender</td>
<td>7.1</td>
<td>5.3–13.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BSA ≥ 1.7 m²</td>
<td>6.3</td>
<td>5.8–11.8</td>
<td>0.01</td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>1.1</td>
<td>0.6–1.6</td>
<td>NS</td>
</tr>
<tr>
<td>NYHA class ≥ III</td>
<td>0.9</td>
<td>0.7–1.1</td>
<td>NS</td>
</tr>
<tr>
<td>Labeled valve size &lt; 23 mm</td>
<td>1.4</td>
<td>0.3–4.1</td>
<td>NS</td>
</tr>
<tr>
<td>Labeled valve size/BSA &lt; 1.3 cm²</td>
<td>1.0</td>
<td>0.9–11</td>
<td>NS</td>
</tr>
<tr>
<td>PAI &lt; 11 mm</td>
<td>7.6</td>
<td>6.2–18.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MG &gt; 40 mm Hg</td>
<td>2.3</td>
<td>1.6–3.0</td>
<td>NS</td>
</tr>
<tr>
<td>$V_{max}$ &gt; 4 m/s</td>
<td>1.8</td>
<td>1.4–2.2</td>
<td>NS</td>
</tr>
<tr>
<td>LVMI &gt; 180 g/m²</td>
<td>0.7</td>
<td>0.4–1.3</td>
<td>NS</td>
</tr>
</tbody>
</table>

BSA = body surface area; LVMI = (preoperative) left ventricular mass index; MG = (preoperative) mean transvalvular gradient; NYHA = New York Heart Association functional class; PAI = patient’s annulus index; PPM = prosthesis-patient mismatch; $V_{max}$ = (preoperative) peak transprosthetic velocity.
LVMi (p = 0.08). At multivariable analysis, reduction in LVMi was not significantly affected by the presence of PPM (RR: 1.38, 95% CI: 0.31 to 2.57, p = 0.13).

**DISCUSSION**

Aortic valve replacement in the small aortic root has been reported to be associated with obstruction of left ventricular output. It predominantly occurs in small aortic roots, which require the use of small prostheses resulting in higher transvalvular gradients (23). Since Rahimtoola (5), in 1978, stated, “mismatch can be considered to be present when the effective prosthetic area, after insertion into the patient, is less than that of a normal human valve,” PPM has been recognized by the American Society of Thoracic Surgeons, and it has been identified as a nonstructural dysfunction (13). It is still uncertain if PPM may affect postoperative mortality; previous studies (1,24) have demonstrated that mortality was higher in patients receiving a small (≤21 mm) aortic prosthesis; nonetheless, two previous reports of a relatively small number of patients failed to show a negative impact of mismatch on survival (3,4). In a recent study, Rao et al. (25) reported the in vitro calculated EOAI/BSA <0.75 cm²/m² to have a strong impact on survival. Many studies have demonstrated that all prosthetic valves are at least mildly stenotic and that they result in high postoperative transprosthetic gradients despite normal valve function (26). Particularly, stented valves lead to a non-physiological flow pattern and do not achieve complete abolition of transvalvular gradients because of the obstructive effects of the prosthetic valve stents and sewing ring (27). Moreover, allografts and autografts represent an ideal substitute, but their use is restricted because of a limited availability, and there is still no agreement about annulus enlarging techniques, considered by some as safe and by others to significantly increase morbidity and mortality after AVR (28,29). Unstented valves could represent, theoretically, a resolution to the problem (30) because they generally provide a larger EOAI in relation to the patient’s BSA, as compared with stented bioprostheses (31). Nonetheless, the EOAI of a stentless valve inserted within the patient’s aorta remains somewhat smaller than that of the corresponding native valve, and differences in valve sizing among manufacturers make comparisons between different prostheses almost impossible. Christakis et al. (32) demonstrated that internal prosthesis diameters are 4 mm smaller than external ones, which corresponds to the manufacturer’s size. Rao et al. (33) showed stentless and stented bioprostheses to have similar hemodynamic profiles when the comparison is adjusted to reflect true measured dimensions (33). We present clinical and hemodynamic results of the performance of CLOB suprannular stentless valves (34) in patients with small aortic roots. The theoretically great advantage of the CLOB over other stentless valves is the suprannular design; in its correct position the prosthetic valve is sutured to the aortic wall, above the annulus, thus allowing a larger effective flow area for any given measured host annulus. Certainly, following our prosthesis selection criteria and annulus measurement method, all patients have received a valve larger than they would receive if a stented or an intrannular stentless had been chosen. For instance, in our experience, we oversized by one in the majority of patients, by two in 10 and by three in two patients. Those two patients had a very small annulus (<19 mm), and one of them was a young man with a large BSA (>1.75) who would have been expected to have a PPM. At the latest control, both patients presented an adequate EOAI (1.12 cm²/m² and 1.11 cm²/m², respectively).

**Incidence of PPM.** In our series 16 patients had evidence of a “transient” mismatch early postoperatively; this incidence is not negligible, but it can be justified by a very small PAI in our population (11.7 ± 0.2 mm). However, in contrast with other authors who, in studies not only restricted to patients with a small aortic root, reported a 19% to 29% incidence of PPM at one year in other intrannular stentless bioprostheses (30,35), in our series no patient had evidence of “permanent” PPM at one year and at subsequent controls. These remarkable results may have important clinical implications and makes the suprannular CLOB valve an ideal substitute for patients with small aortic roots. To date, the only biological substitutes that provide comparable results in terms of PPM prevention are the pulmonary autografts (Ross operation) and the aortic homografts (35). However, how can an increment in EOAI in a fixed valve be explained? This had been previously explained with a progressive regression of perivalvular edema/hematoma occurring early postoperatively within the patient’s aortic root after stentless AVR. We can speculate that a thin-walled stentless valve, made without any prosthetic material, is associated with a more distensible aortic sinus and allows a more dynamic aortic root function than other prostheses, thus achieving a higher systolic flow and a greater EOAI, which is a function of systolic flow (36,37). Dumesnil et al.
(38) demonstrated that, for equal volume load, a hypertrophied heart has a higher ejection fraction than a normal heart and that this will translate into a higher transvalvular velocity, and Del Rizzo et al. (39) showed a strong linear relation between gradients and transvalvular velocities; in contrast, he failed to demonstrate a correlation between gradients and LVOT velocities or $CSA_{LVOT}$. Thus, hemodynamic and geometric changes of the left ventricle, and, in particular, regression of left ventricular hypertrophy, could play an important role causing a reduction in transvalvular velocity and, consequently, increasing EOA, which is inversely related to the transvalvular velocity (20).

**Hemodynamic repercussions of PPM.** In our small cohort, CLOB valve showed excellent hemodynamics with low postoperative gradients and early regression of left ventricular hypertrophy. “Transient” PPM mismatch did not have negative repercussions on the patient's hemodynamic status. Mean gradient reduced independently from an EOAI <0.85 cm$^2$. In our analysis, female gender, BSA, age and PAI resulted in significantly affecting the occurrence of postoperative mismatch. In contrast, and according to Pibarot et al. (40), labeled valve size and labeled valve size indexed to the patient's BSA did not affect the incidence of mismatch. Valve pathology (stenosis) and NYHA functional class resulted in not being significant. Moreover, differently from Del Rizzo et al. (41), we failed to show a relation between EOAI and the extent of LVM regression. Finally, left ventricular ejection fraction did not differ in patients with and without mismatch ($p = NS$).

**Study limitations.** Our study presents some strong limitations, which have to be pointed out: 1) the number of patients was rather small; 2) the limited number of events limited the strength of analysis; 3) the retrospective nature limits the significance of the study; 4) exams were performed at rest, and no information about parameters measured under stress was given; 5) in our cohort the average BSA is relatively small; it is, therefore, possible that the incidence and severity of mismatch with the CLOB valve will be more frequent in populations with larger body surface areas (i.e., North American populations); and 6) the CLOB bioprosthesis was not compared with other stented or stentless valves.

Larger studies, comparing different types of valves (stented, intranunnular stentless and supranunnular stentless) on the basis of the patient's true annulus index are necessary to confirm if the oversizing procedure really allows better hemodynamics to be achieved and, in this way, if a supranunnular stentless valves could represent an optimal choice for the management of the small aortic annulus.

**Conclusions.** Stentless AVR with a supranunnular CLOB valve in patients with small aortic roots yielded excellent hemodynamics. Although all patients had a relatively small aortic annulus, none of them had PPM one year after operation. Even with the above-mentioned limitations, this study demonstrates that PPM can be completely avoided when using the CLOB valve. The superior hemodynamics of this stentless valve is likely to be related to its supranunnular design.

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