doi:10.1510/icvts.2011.283218

INTERACTIVE CARDIOVASCULAR AND THORACIC SURGERY

Interactive CardioVascular and Thoracic Surgery 13 (2011) 606-610

www.icvts.org

Follow-up papers - Valves

Valve prosthesis-patient mismatch: hemodynamic, echocardiographic and clinical consequences☆

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Received 12 July 2011; received in revised form 9 August 2011; accepted 11 August 2011

Abstract

Objectives: The purpose is to evaluate in vivo at rest and under stress conditions hemodynamic performance of the small size St. Jude Medical Regent (SJMR) prosthetic valve in patients with a body surface area (BSA) of 1.8±0.11 m^2 and to define the role of valve prosthesis-patient mismatch on left ventricular mass regression following aortic valve replacement. **Methods:** We evaluated 25 cases (12 males and 13 females, mean age 65.2±8 years) of aortic valve replacement (17 mm SJMR in three cases and 19 mm SJMR in 22 cases). All the patients underwent at rest Doppler echocardiography before and after surgery and both basal and dobutamine stress echocardiography (DSE) at follow-up. The mean duration of follow-up was 41.3±24 months. **Results**: A significant reduction in mean and peak transaortic gradients and peak transaortic velocity over time following valve replacement has been identified. After surgery, there was a significant increase of ejection fraction. DSE significantly increased heart rate, ejection fraction, peak transaortic gradient and peak transaortic velocity. All patients passed DSE without complication. Even if a significant mismatch was present in 76% of cases, the left ventricular mass decreased significantly from preoperative value of 278.7±51.1 g to 181.5±52.73 g, respectively. **Conclusion**: Aortic valve replacement with 17 mm SJMR or 19 mm SJMR prostheses appear to provide satisfactory clinical and hemodynamic results at rest and under DSE, even in those patients with BSA of 1.8±0.11 m^2 where it was not possible to enlarge the aortic annulus. Prosthesis-patient mismatch is not associated with lesser regression of left ventricular mass. Dobutamine stress echocardiography should be a useful and effective means for evaluating prosthesis hemodynamic aspects.

Keywords: Prosthesis-patient mismatch; Left ventricular mass; Effective orifice area; Dobutamine

1. Introduction

Aortic valve replacement (AVR) is the standard therapy for patients with severe aortic stenosis; there has been persistent improvement in hemodynamic status results. With the aging population, greater numbers of patients are exhibiting aortic stenosis; thus, the number of patients undergoing AVR is increasing. However, AVR in small aortic root patients is still a challenge for the cardiac surgeon with regard to operative technique and prosthesis selection. Since the introduction of the concept of prosthesis-patient mismatch (PPM) by Rahimtoola [1], implantation of a small prosthesis in the aortic position has been blamed for residual gradients, that are responsible for poor left ventricular mass regression, increased long-term mortality and more valve-related complications [2, 3]. Various strategies to increase the effective orifice area (EOA) of the implanted valve have been described, such as the aortic enlargement or replacement with a larger prosthesis, like a stentless bioprosthesis or a new generation supraannular mechanical prosthesis. Some of those techniques are more difficult, for instance they require longer cross-clamp times, and they are associated with higher hospital mortality rates than isolated AVR, with no increase in long-term survival [4, 5].

The St. Jude Medical Regent (St. Paul, MN, USA) is a new bileaflet aortic valve that represents a design evolution of SJM Hemodynamic Plus Series (HP) valve [6, 7]. Its modified outer profile, along with a larger inside lumen area of the prosthesis, should improve hemodynamic by increasing the EOA of the valve.

The purpose is the evaluation in vivo at rest and in a stress condition, by performing dobutamine stress echocardiography (DSE) [8], hemodynamic performance of this prosthetic valve in patients with body surface area (BSA) of 1.8±0.11 m^2 but with a small annulus. Besides, we want to define the role of valve prosthesis-patient mismatch on left ventricular mass regression following aortic valve replacement.

☆Presented as a poster at the XXV SICCH Congress, 6–9 November 2010, Rome, Italy.

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2. Materials and methods

2.1. Patient population

The study population consisted of 25 patients with a mean age of 65.2±8 years (12 males and 13 females); it was 41.3±24 months before they had received a 17 mm SJMR in three cases and in 22 cases a 19 mm SJMR aortic valve, after sizing the aortic annulus. All patients presented important annulus and aortic root calcification at the time of operation. In none of the cases has it been possible to attempt the enlargement of the aortic annulus. All demographic and clinical data are summarized in Table 1.

2.2. Operative technique

Aortic valve surgery was performed through a standard median sternotomy. Cardiopulmonary bypass was initiated after cannulation of the ascending aorta, superior and inferior vena cava. A left ventricular vent was inserted by means of the right upper pulmonary vein. Anterograde crystalloide cardioplegia (St. Thomas II) was administered to maintain cardiac arrest. Moderate hypothermia was applied. After complete excision of the diseased aortic valve, the diameter of the aortic annulus was measured with sizers (St. Jude Medical, St. Paul, Minnesota, USA) for selection of the appropriate prosthesis size. Prostheses were implanted supraannularly with interrupted sutures reinforced by Gore-Tex pledget in all patients. Warfarin sodium was started on the day of surgery and continued thereafter so that the international normalized ratio of prothrombin time was maintained between 2.0 and 2.5.

Table 1. Demographic and clinical patient characteristics

Clinical variable	Median	Mean	S.D.
Follow-up (months)	40	41.3	24
Age	68	65.2	8
Body surface area (BSA) (m^2)	1.8	1.8	0.11
Body mass index (BMI)	28	28.7	3.93
Size LVOT (cm)	1.9	1.92	0.17
Preoperative ejection fraction (EF) (%)	59	56.7	6.72
	Number of patients		%
Male	12		48
Female	13		52
Aortic valve stenosis	24		96
Aortic valve incontinence	5		20
Ischemic heart disease	6		24
Diabetes	6		24
Broncopneumapatia	2		8
Cronic renal failure	0		0
Smoke	10		40
Hypertension	12		48
Preoperative NYHA			
grade I	0		0
grade II	2		8
grade III	20		80
grade IV	3		12
Aortic valve replacement			
St. Jude 17 (mm)	3		12
St. Jude 19 (mm)	22		88
Aortocoronary bypass	6		24

NYHA, New York Heart Association; S.D., standard deviation.

2.3. Protocol study

All patients underwent basal echocardiography before cardiac surgery and one month after surgery. Preoperative and perioperative data were obtained by retrospective review of clinical and surgical records. At mean distance of 41.3±24 months after surgery patients were enrolled in the study and underwent rest echocardiography and DSE. β-Blockers were discontinued in all patients 24 h before the test, whilst patients on ace-inhibitors and calcium antagonists continued their medication. Informed written consent was obtained from all patients. Dobutamine was infused intravenously starting at 5 μg/kg/min and increased by 5 μg/kg/min at five minute intervals up to 25 μg/kg/min. During the study, patients underwent continuous electrocardiographic monitoring, and blood pressure was recorded at five minute intervals with an automated cuff. Criteria for stopping the dobutamine infusion included: (1) hypotension (systolic blood pressure <100 mmHg); (2) dyspnea; (3) significant ventricular and supraventricular arrhythmias. Repeat (stress) Doppler measurements were obtained before each incremental increase in the infusion rate. Following the completion of the final assessment at a dose of 25 μg/kg/min (maximum stress), dobutamine infusion was discontinued, and the patient was monitored for a minimum of 20 min, or until heart rate (HR) had returned to pre-stress values.

2.4. Echocardiographic measurements and calculations

Examinations included M-mode, two-dimensional (2D), continuous wave and pulsed Doppler, and color Doppler analysis. Left parasternal, apical and periapical, subcostal, and suprasternal standard views were employed.

Standard M-mode dimensions were obtained according to the American Society of Echocardiography criteria. The mean of three measures of two different cardiac cycles was taken. The following variables were obtained: end-diastolic septal thickness, left ventricular end-diastolic diameter and left ventricular end-systolic diameter. All Doppler measurements were averaged from more than three cycles in sinus rhythm patients and more than five cycles in the atrial fibrillation ones. The peak and the mean transprosthetic gradients were calculated using the modified Bernoulli equation. Left ventricular mass was calculated according to the Devereux formula [9]. The in vivo EOA was calculated using continuity equation method [10]: EAO=(LV outflow cross-section area)×(subvalvular flow/supravalvular flow). The EOA index (EAOi) was calculated by dividing EOA by BSA. The criteria are an EOAi of <0.85 cm^2/m^2 for moderate PPM and <0.65 cm^2/m^2 for severe PPM [11]. Left ventricular ejection fraction (EF) was calculated using the apical four-chamber view and the application of the modified Simpson rule method [12].

2.5. Statistical methods

Value is expressed as the mean±standard deviation (S.D.). Simple comparison was performed using a standard χ^2-test or non-paired *t*-test. A $P<0.05$ value was considered significant.

3. Results

Preoperative and postoperative echocardiographic data are reported in Table 2. A significant increasing of ejection fraction was observed after surgery (56.72±6.72% vs. 62.6±5.2%, $P<0.00001$). The basal transaortic maximal flow velocity passed from 4.89±0.59 m/s to 2.7±0.5 m/s ($P<0.00001$), as a result mean and peak transprosthetic gradient decreased, respectively, from 57.56±17.75 mmHg to 17.12±5.98 mmHg ($P<0.00001$) and from 91.12±21.52 mmHg to 32.12±11.35 mmHg ($P<0.00001$). We observed a significant decreasing of left ventricular dimensions and of the interventriculae septum thickness. Left ventricular mass decreased from preoperative values of 278.7±51.1 g to 181.5±52.73 g ($P<0.00001$).

After surgery EOAi was 0.78±0.3 cm^2/m^2. According to Pibarot definitions, 76% of patients had significant PPM (Fig. 1).

All patients completed DSE without complications. Three patients had occasional premature atrial and/or ventricular beats, which did not preclude them from completing the test. Echocardiographic data at rest and under DSE at follow-up are reported in Table 3.

With dobutamine heart rate increased from baseline of 76±13 beats/min to 118±11 beats/min ($P<0.00001$); ejection fraction increased from baseline of 62.6±5.2% to 67.92±4.8% ($P<0.00001$). Basal systolic and diastolic blood pressure did not change significantly during the test. At peak dobutamine, the maximal transprosthetic flow velocity increased from baseline to 2.7±0.5 m/s to 4.3±0.93 m/s ($P<0.00001$); the mean and the peak transprosthetic gradients increased significantly from baseline, by achieving, respectively, 42.76±18.23 mmHg and 71.36±30.54 mmHg ($P<0.00001$ and $P<0.00001$). EAO and EAOi changed during the test but there was an insignificant increase. The mean NYHA class did not change significantly during or after the test.

4. Discussion

Pibarot and colleagues [11] defined PPM as being present if the EOAi was <0.85 cm^2/m^2. Furthermore, PPM was considered as moderate if the EOAi was between 0.65 cm^2/m^2 and 0.85 cm^2/m^2 and severe if it was <0.65 cm^2/m^2. PPM can result in persistent left ventricular outflow obstruction, which increases left ventricular work and reduces left ventricular mass regression, with a presumed shortening of lifespan. Authors proposed a three-step algorithm for its prevention, as follows: (1) calculate the patient's BSA; (2) determine the minimal valve EOA required to ensure an EOAi >0.85 cm^2/m^2, given the patient's BSA as calculated in step 1; and (3) select the type and size of prosthesis that has reference values for EOA≥the minimal EOA value obtained in step 2. Nevertheless, in those patients with a large BSA and relatively small aortic annulus requiring AVR, the native annulus may not fit the size of the prosthesis required and so the surgeon faces the problem of whether to perform an annular enlargement procedure or to possibly compromise the surgical result by accepting PPM. Sometimes, this procedure is technically difficult and it requires an increase in cross-clamp time. This variable has been suggested to be associated with increased mortality following AVR. The use of a small size St. Jude Medical Regent mechanical valve [13, 14] has been proposed in patients with small annulus when aortic enlargement is not attempted. Its modified outer profile, along with a larger inside lumen area of the prosthesis, should improve hemodynamic by increasing the EOA of the valve. To confirm this speculation, we study, in vivo at rest and in a stress condition (DSE), the hemodynamic performance of 17 mm and 19 mm SJM Regent (SJMR) mechanical valve implanted in a study population of 25 patients with mean BSA was 1.8±0.11 m^2 and a small aortic annulus. In none of the cases has the enlargement of the aortic annulus has been possible because it appeared technically difficult. We analyzed several anatomical, hemodynamic and clinical parameters, such as left ventricular mass, resting and stressed heart rate, ejection fraction, transvalvular gradient and velocity, as well as clinical well-being.

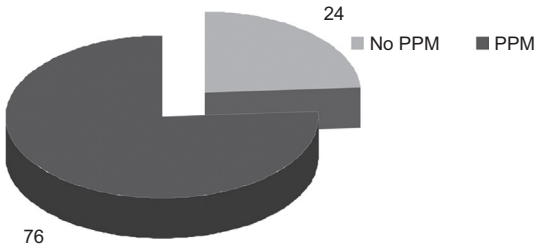

Fig. 1. Percentage of patients that presented prosthesis-patient mismatch according Pibarot definition. Pibarot and colleagues defined PPM as being present if the effective orifice area index was <0.85 cm^2/m^2. Furthermore, PPM was considered as moderate if the EOAi was between 0.65 cm^2/m^2 and 0.85 cm^2/m^2 and severe if it was <0.65 cm^2/m^2. EOAi, effective orifice area index; PPM, prosthesis-patient mismatch.

Table 2. Preoperative and postoperative echocardiographic data

Variable	Preoperative mean value	S.D.	Postoperative mean value	S.D.	*P*-value
Ejection fraction (%)	56.72	6.72	62.6	5.2	<0.00001
Peak transaortic velocity (m/s)	4.89	0.59	2.7	0.5	<0.00001
Mean gradient (mmHg)	57.56	17.75	17.12	5.98	<0.00001
Peak gradient (mmHg)	91.12	21.52	32.12	11.35	<0.00001
End-systolic diameter (cm)	35.42	6.38	31.16	5.41	<0.00001
End-diastolic diameter (cm)	48.36	5.44	42.36	5.2	<0.00001
Interventriculae septum (cm)	12.96	1.45	11.04	1.69	<0.00001
End-systolic volume (ml)	42.4	15.56	29.48	8.76	<0.00001
End-diastolic volume (ml)	97.12	25.75	78.84	18.97	<0.00001
Left ventricular mass (g)	278.7	51.1	181.5	52.73	<0.00001

S.D., standard deviation.

Table 3. Echocardiographic data at rest and under DSE at follow-up

Variable	Rest mean	ds pre	Stress mean	ds post	*P*-value
Ejection fraction (%)	62.6	5.2	67.92	4.8	<0.00001
Peak transprosthetic velocity (m/s)	2.7	0.5	4.3	0.93	<0.00001
Mean gradient (mmHg)	17.12	5.98	42.76	18.23	<0.00001
Peak gradient (mmHg)	32.12	11.35	71.36	30.54	<0.00001
Transvalvular velocity time integral	54.44	15.57	66.04	16.71	<0.00001
Left ventricular outflow tract velocity time integral	24.6	5.26	32.12	6	<0.00001
End-systolic diameter (cm)	31.16	5.41	25.88	4.41	<0.00001
End-diastolic diameter (cm)	42.36	5.2	37.88	6	<0.00001
Interventriculae septum (cm)	11.04	1.69	11.41	1.26	0.35
End-systolic volume (ml)	29.48	8.76	21.92	5.29	<0.00001
End-diastolic volume (ml)	78.84	18.97	68.76	14.79	<0.00001
Effective orifice area (EAO)	1.35	0.5	1.46	0.41	0.07
Effective orifice area index (EAOi)	0.78	0.3	0.81	0.24	0.28
Heart rate	76	13	118	11	<0.00001
Systolic blood pressure (mmHg)	151	20.46	147	19.89	0.24
Diastolic blood pressure (mmHg)	73	11.61	68	13.77	0.08

DSE, dobutamine stress echocardiography; S.D., standard deviation.

Even if significant PPM was present in 76% of cases, there was indeed a decrease in left ventricular mass, satisfactory clinical well-being of the patient, and normal resting hemodynamic parameters. The appreciable increase of the gradient and the strain associated with these undersized valves under stressed conditions was evidently necessary for the heart to provide (otherwise) normal hemodynamics. Considering the regression of the ventricular mass and the satisfactory clinical state of the patients, this strain, if applied only during occasional exercise, might not influence the patient's well-being and might be a reasonable 'price' to avoid complex aorto-plastic procedures in most, if not all, cases of small aortic annuli. All patients, in fact, passed DSE without complication and they lived a normal lifestyle. In particular, all of the females were housewives and performed all normal daily activities without any difficulty, and even with less effort than before the surgery. Most of males reported they went for long walks and some train on an exercise bicycle, even if only a light workout. Thus, none of them had a sedentary life.

According to us, the influence of the PPM on left ventricular modeling and quality of life may be less than previously hypothesized. Alternatively, while some researchers have defended the hypothesis that PPM affect survival and/or functional class [15, 16], others consider it a phenomenon with no clinical importance or that only affects the prognosis in young patients and in patients of any age with ventricular dysfunction [17, 18].

5. Study limitations

This study has some limitations. First of all, the total number of patients was too small to allow us come to any definite conclusions. Secondly, we calculated EAOi from echocardiographic data. As well-known, there are technical errors with respect to obtaining data among operating physicians. In order to minimize the possibility of this type of error, only one physician (T.D.) reviewed all of the echocardiographic data. In the end, the data was collected retrospectively.

6. Conclusions

Aortic valve replacement with 17 mm SJMR or 19 mm SJMR prostheses appears to provide satisfactory clinical and hemodynamic results at rest and under DSE, even in patients with BSA of 1.8±0.11 m^2 and a small aortic annulus. The appreciable increase of the gradient and the strain associated with undersized valves under stressed conditions is evidently necessary for the heart to provide (otherwise) normal hemodynamics.

Prosthesis-patient mismatch is not associated with lesser regression of left ventricular mass.

Acknowledgments

All statistical analyses in this manuscript were elaborated by Torretta Federico.

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eComment: Valve prosthesis-patient mismatch: hemodynamic, echocardiographic and clinical consequences

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doi:10.1510/icvts.2011.283218A

Pisano et al. [1] describe a difficult group of patients requiring a mechanical valve, but having a small calcified aortic root, making a root enlarging procedure potentially hazardous. Their methods and conclusions raise a number of issues.

The effective orifice area (EOA) was calculated using the continuity equation method [2]: EOA = (LV outflow cross-section area)×(subvalvular flow/supravalvular flow). This means that the cardiac output is an important factor. With no documentation of cardiac output assessment pre- and post-dobutamine stress testing, interpretation of the EOA is difficult. The use of heart rate, although useful, does not directly correlate with increased cardiac output due to the shortening of diastole, and the diastolic dysfunction that is virtually universal in patients with aortic valve disease.

Doppler is notoriously inaccurate in patients with atrial fibrillation. The number of patients that had this pre- and postoperatively at the time of investigation was unspecified in the manuscript. Atrial fibrillation is associated with left ventricular hypertrophy, making it a potentially important confounding factor [3], as the effects on regression are unknown.

Left ventricular mass regression is not just dependent on aortic stenosis, but also the presence of systemic hypertension, and the stage of valve disease that is being operated on. As half the patients were hypertensive, were these the ones that had LV regression due to their hypertension being adequately managed postoperatively?

Even in the presence of patient-prosthesis mismatch, patients with normal left ventricular function will have left ventricular mass regression as the ventricle is being off-loaded, even if not adequately.

Patient-prosthesis mismatch in the small annulus is potentially critical in patients with poor ventricular function, and suggesting such extrapolation of data from patients with good ventricular function may be premature.

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