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Influence of Type of Aortic Valve Prosthesis on Coronary Blood Flow Velocity

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ABSTRACT

Background: Severe aortic valve stenosis is associated with high resting and reduced hyperemic coronary blood flow. Coronary blood flow increases after aortic valve replacement (AVR); however, the increase depends on the type of prosthesis used. The present study investigates the influence of type of aortic valve prosthesis on coronary blood flow velocity.

Methods: The blood flow velocity in the left anterior descending coronary artery (LAD) and the right coronary artery (RCA) was measured intraoperatively before and after AVR with a stentless bioprosthesis (Sorin Freedom Solo; n = 11) or a bileaflet mechanical prosthesis (St. Jude Medical Regent; n = 11). Measurements were made with an X-Plore epicardial Doppler probe (Medistim, Oslo, Norway) following induction of hyperemia with an adenosine infusion. Preoperative and postoperative echocardiography evaluations were used to assess valvular and ventricular function. Velocity time integrals (VTI) were measured from the Doppler signals and used to calculate the proportion of systolic VTI (SF), diastolic VTI (DF), and normalized systolic coronary blood flow velocities (NSF) and normalized diastolic coronary blood flow velocities (NDF).

Results: The systolic proportion of the LAD VTI increased after AVR with the St. Jude Medical Regent prosthesis, which produced higher LAD SF and NSF values than the Sorin Freedom Solo prosthesis (SF, 0.41 ± 0.09 versus 0.29 ± 0.13 [*P* = .04]; NSF, 0.88 ± 0.24 versus 0.55 ± 0.17 [*P* = .01]). No significant changes in the LAD velocity profile were noted after valve replacement with the Sorin Freedom Solo, despite a significant reduction in transvalvular gradient and an increase in the effective orifice area. AVR had no effect on the RCA flow velocity profile.

Conclusion: The coronary flow velocity profile in the LAD was significantly influenced by the type of aortic valve prosthesis used. The differences in the LAD velocity profile probably reflect differences in valve design and the systolic transvalvular flow pattern.

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INTRODUCTION

Aortic stenosis is associated with a higher resting coronary blood flow (CBF), a reduced hyperemic CBF, and a reduced coronary flow reserve (CFR), which is defined as the ratio of the hyperemic CBF to the resting CBF. The degree of CFR impairment is proportional to the severity of aortic stenosis [Hildick-Smith 2000; Nemes 2002; Garcia 2008].

Aortic stenosis increases the resting CBF by increasing oxygen consumption by the left ventricle [Suga 2003]. CBF is tightly coupled to oxygen consumption, because the rate of oxygen extraction is high even at a resting blood flow [Duncker 2008]. Aortic stenosis also limits hyperemic CBF by decreasing the systolic and diastolic CBF. Systolic blood flow in severe aortic stenosis is decreased or even negative [Duncker 2008; Garcia 2008]. The decrease in diastolic CBF is associated with a reduction in the diastolic perfusion time [Rajappan 2003].

Although the effects of aortic stenosis on CBF are relatively predictable, owing to a common pathologic pattern in most aortic stenosis cases with immobile leaflets and a central opening, the different designs of various valve prostheses can have very different effects that influence systolic flow patterns and diastolic closure. With bioprostheses, the opening is central and similar to the native aortic valve. Therefore, stented bioprostheses with a smaller effective orifice area (EOA) are associated with a lower CFR, compared with stentless bioprostheses with a larger EOA [Bakhtiary 2006]. Mechanical prostheses, on the other hand, have a flow pattern very different from that of the native aortic valve, and simply rotating a tilting disc or a bileaflet mechanical valve has a large effect on CBF [Kleine 2002].

In our study, we compared intraoperative CBF velocity in the left anterior descending coronary artery (LAD) and the right coronary artery (RCA) before and after aortic valve replacement (AVR) with a stentless bioprosthesis (Sorin Freedom Solo [SFS]; Sorin, Milan, Italy) or a bileaflet mechanical prosthesis (St. Jude Medical Regent [SR]; St. Jude Medical, St. Paul, MN, USA). Both prostheses have relatively large and comparable EOA, but they have different flow patterns [Bach 2001; Repossini 2005].

MATERIALS AND METHODS

Between October 2007 and July 2010, 22 patients (mean ± SD age, 70 ± 12 years) with isolated severe aortic valve stenosis

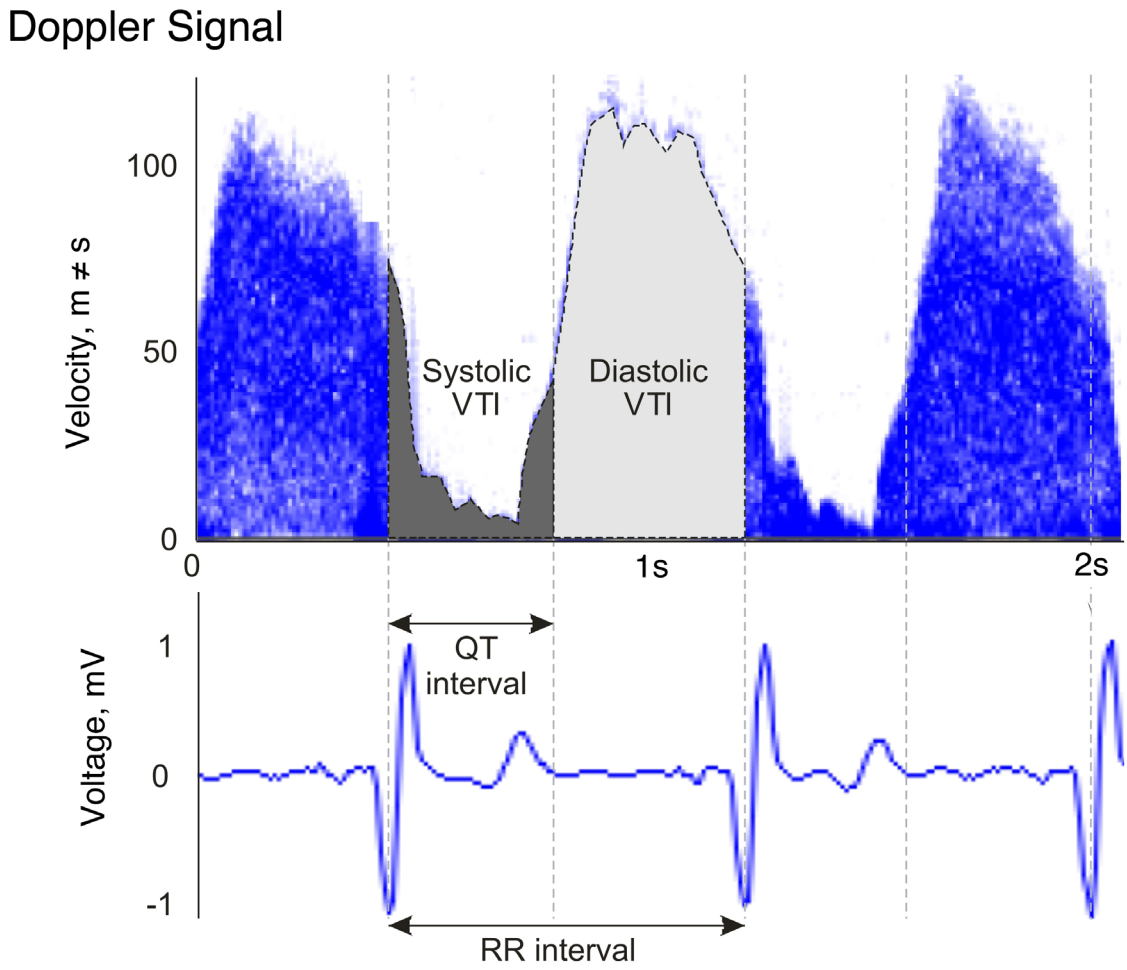

Figure 1. Measurements performed intraoperatively on the left anterior descending coronary artery before aortic valve replacement. Each measurement included the systolic and diastolic velocity time integrals (VTI) calculated from the Doppler signal, the QT interval, and the RR interval obtained from the electrocardiographic recording and the arterial pressure.

requiring AVR were included in the study. The exclusion criteria were endocarditis, emergency operation, an ejection fraction <35%, hypertrophic cardiomyopathy, reoperation, more than mild aortic regurgitation, coronary artery disease, and other valve pathology. All patients provided written informed consent. The study and the consent form were approved by the local ethics committee. All patients underwent AVR, 11 patients with the SFS stentless bioprosthesis (SFS group) and 11 with the SR mechanical prosthesis (SR group). The type of valve was chosen according to the patient's age, lifestyle, comorbidities, and patient preference.

Surgical Technique

Six surgeons performed the operations. The approach was via a full median sternotomy. We used antegrade cold blood cardioplegia followed by retrograde cold blood cardioplegia, with "hot-shot" used before removing the aortic cross-clamp. After a transverse aortotomy and resection of the native aortic valve with debridement of the aortic annulus, sizing was carried out with SFS or SR sizers. SFS valves were implanted in the supraannular position with a single suture line of three 4-0 Prolene sutures [Repossini 2005]. SR mechanical valves were implanted in the supraannular position by means of pledgeted U stitches with Tycron 2-0 sutures. Bites were taken from the ventricular side to the aortic side of the annulus. The mechanical valves were oriented with one of the pivot guards facing the left-to-right commissure and the valve leaflets facing both coronary ostia for optimal hemodynamics [Kleine 1998, 2000, 2002; Laas 1999].

Intraoperative Measurements

Doppler CBF velocity was measured epicardially in the LAD and the RCA with the Doppler X-Plore 7.5-MHz Probe (Medistim, Oslo, Norway). Measurements included Doppler signals from the LAD and the RCA, electrocardiograms (ECG) with heart rate, and arterial pressure. After opening of the sternum and pericardium, heparin was administered.

Then, the distal ascending aorta and the right atrium were cannulated for cardiopulmonary bypass. With cannulas in place but before cardiopulmonary bypass, a continuous intravenous infusion of adenosine (140 µg/kg per minute) was started to induce coronary vasodilation. The measurements were performed after 5 minutes. The patient was then placed on cardiopulmonary bypass, and the aortic valve was replaced as described above. After AVR and weaning of the patient from cardiopulmonary bypass (but with the aortic and right atrial cannulas still in place), an adenosine infusion was started again. After 5 minutes, the second set of measurements was performed. The cannulas were then removed, and the chest was closed in the usual fashion.

The Doppler signals were analyzed with CorelDRAW X3 graphics software (Corel Corporation, Ottawa, Ontario, Canada) and the GetArea plug-in to measure and calculate the velocity time integrals (VTI). The length of systole was determined by ECG and was defined as the QT interval (Figure 1). The mean value of 3 heart cycles for patients in sinus rhythm and the mean of at least 5 heart cycles for patients in atrial fibrillation were used for the statistical analysis. The measurements obtained were the systolic VTI, the diastolic VTI, the negative-flow VTI, systole length, diastole length, heart rate, and mean arterial pressure. From these measurements, we calculated the following indices: the proportion of systolic VTI (SF), where SF = Systolic VTI/(Systolic VTI + Diastolic VTI); the proportion of diastolic VTI (DF), where DF = Diastolic VTI/(Systolic VTI + Diastolic VTI); the normalized systolic VTI (NSF) (the ratio of the mean systolic velocity to the mean velocity during 1 heart cycle), where NSF = (Systolic VTI/QT Interval)/[(Systolic VTI + Diastolic VTI)/Heart Cycle Length]; and the normalized diastolic VTI (NDF) (the ratio of the mean diastolic velocity to the mean velocity during 1 heart cycle), where NDF = [Systolic VTI/(Heart Cycle Length – QT Interval)]/[(Systolic VTI + Diastolic VTI)/Heart Cycle Length].

These indices were used to estimate the relative contributions of systolic and diastolic flows and to minimize the effect of heart rate, which predominantly changes the duration of diastole [Boudoulas 1981; Occhetta 2010].

Echocardiography

Echocardiography was performed according to the American College of Cardiology/American Heart Association/American Society of Echocardiography guidelines with a Vivid S5 cardiovascular ultrasound system (GE Healthcare, Fairfield, CT, USA) 1 day before surgery and postoperatively before discharge of the patient.

Statistical Methods

Data were compiled and analyzed with Microsoft Access 2007 (Microsoft; Redmond, WA, USA) and SPSS Statistics 17.0 (SPSS/IBM, Chicago, IL, USA). Because of the small sample sizes, continuous variables were compared with the Mann-Whitney U test or the Wilcoxon signed rank test when related data were compared. Categorical variables were compared with the χ^2 test or the Fisher exact test. Results for continuous variables are reported as the mean ± SD in the text and tables.

RESULTS

Patient Data

Patient data, including preoperative symptoms, risk factors, comorbidities, and preoperative rhythm, are summarized in Table 1. One half of the patients complained of angina when performing mild to moderate exercise. Most of the patients in the 2 groups experienced dyspnea and were being treated for hypercholesterolemia and arterial hypertension.

Table 1. Patient Data*

	SFS (n = 11)	SR (n = 11)	*P*
Age, y	72.2 ± 12.2	66.9 ± 12.3	NS
Female sex, n	2	4	NS
Body mass index, kg/m^2	25.9 ± 3.5	28.3 ± 3.7	NS
Body surface area, m^2	1.85 ± 0.22	1.89 ± 0.16	NS
EuroSCORE, %	6.5 ± 5.7	4.7 ± 3.4	NS
Symptoms, n			
Dyspnea	8	8	NS
Angina	5	6	NS
Syncope	4	2	NS
Asymptomatic	1	1	NS
NYHA class, n			
I	2	4	
II	7	8	
III	1	0	
CCS class, n			
I	0	2	
II	2	4	
III	3	0	
Risk factors and comorbidities, n			
Smoking	1	2	NS
Hypercholesterolemia	7	10	NS
Diabetes	4	1	NS
Arterial hypertension	9	8	NS
COPD	0	0	
Peripheral arterial disease	0	0	
Preoperative rhythm, n			NS
Sinus	7	10	
Paroxysmal AF	2	1	
Longstanding persistent AF	2	0	

*Data are presented as the mean ± SD where indicated. SFS indicates Sorin Freedom Solo; SR, St. Jude Medical Regent; NS, nonsignificant; NYHA, New York Heart Association; CCS, Canadian Cardiovascular Society; COPD, chronic obstructive pulmonary disease; AF, atrial fibrillation.

Table 2. Echocardiographic Data with Valve and Coronary Anatomy*

	SFS (n = 11)	SR (n = 11)	*P*
Anatomy and valve disease, n			
Bicuspid aortic valve	1	3	NS
Right coronary dominance	9	10	NS
Mild aortic regurgitation	8	8	NS
Preoperative measurements			
Peak velocity, m/s	4.1 ± 0.5	4.9 ± 0.6	<.01
Peak gradient, mm Hg	70 ± 18	98 ± 24	<.01
Mean gradient, mm Hg	42 ± 13	63 ± 17	<.01
EOA, cm^2	0.77 ± 0.10	0.68 ± 0.09	NS
LVMI, g/m^2	146 ± 52	132 ± 28	NS
Ejection fraction, %	63 ± 12	69 ± 15	NS
Postoperative measurements			
Peak velocity, m/s	2.1 ± 0.3	2.7 ± 0.4	<.01
Peak gradient, mm Hg	17 ± 6	29 ± 9	<.01
Mean gradient, mm Hg	11 ± 4	15 ± 7	NS
EOA, cm^2	1.85 ± 0.26	1.77 ± 0.29	NS
LVMI, g/m^2	118 ± 19	134 ± 36	NS
Ejection fraction, %	66 ± 12	73 ± 8	NS

*Data are presented as the mean ± SD where indicated. SFS indicates Sorin Freedom Solo; SR, St. Jude Medical Regent; NS, nonsignificant; EOA, effective orifice area; LVMI, left ventricular mass index.

Echocardiography

Echocardiographic data for the patients are presented in Table 2, along with their valve and coronary anatomy. Preoperatively, the patients in the SR group had a higher degree of aortic stenosis with a significantly higher transvalvular peak velocity and higher mean and peak gradients. Postoperatively, the peak gradient and velocity were higher in the SR group; however, there were no differences with respect to the mean gradient and the EOA.

LAD versus RCA

The proportion of flow during systole was significantly higher in the RCA, before and after AVR. The mean values for all measurements (LAD versus RCA) were as follows: systolic VTI, 9.7 ± 7.7 cm versus 16.3 ± 11.0 cm ($P < .001$); diastolic VTI, 27.2 ± 15.3 cm versus 21.1 ± 16.2 cm ($P = .019$); SF, 0.25 ± 0.18 versus 0.45 ± 0.13 ($P < .001$); NSF, 0.49 ± 0.34 versus 0.85 ± 0.22 ($P < .001$); NDF, 1.57 ± 0.39 versus 1.16 ± 0.24 ($P < .001$). Negative systolic flow in the LAD was present in 10 (46%) of the 22 cases before AVR and in 2 (17%) of the 22 cases after valve replacement ($P = .016$). No negative flow was observed in the RCA for any of the cases.

Type of Prosthetic Aortic Valve

Table 3 compares the measurements on the LAD for the SFS and SR prostheses. There were no significant differences between the 2 groups before AVR, with the exception of the systolic VTI, which was higher in the SFS group. After AVR, the SF and NSF values were higher in SR group, and the DF and NDF values were lower (Figure 2).

In comparisons of measurements made on the LAD before and after AVR, there were no significant differences in any of the measurements before and after implantation of the SFS prosthesis, but patients in the SR group showed significant increases

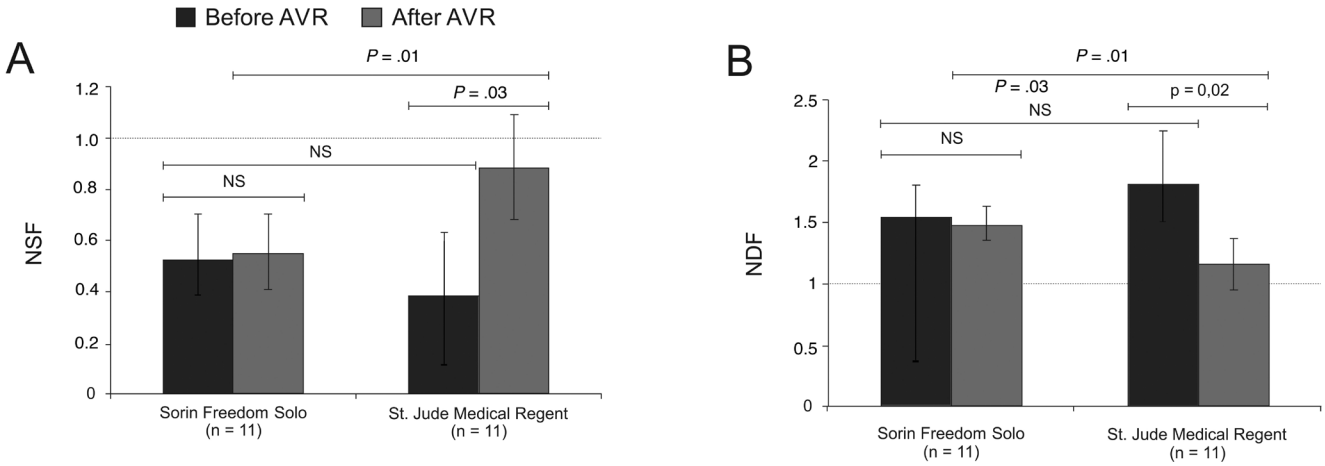

Figure 2. A, Normalized systolic VTI (NSF) before and after aortic valve replacement (AVR) for the Sorin Freedom Solo stentless bioprosthesis and the St. Jude Medical Regent mechanical prosthesis. B, Normalized diastolic VTI (NDF) before and after AVR for the Sorin Freedom Solo stentless bioprosthesis and the St. Jude Medical Regent mechanical prosthesis. Data are presented as the mean SD. NS indicates nonsignificant.

Table 3. Measurements on the Left Anterior Descending Coronary Artery*

	Before AVR			After AVR		
	SFS (n = 11)	SR (n = 11)	*P*	SFS (n = 11)	SR (n = 11)	*P*
Systolic VTI, cm	12.0 ± 5.7	6.2 ± 4.8	.04	13.0 ± 7.2	17.6 ± 8.4	NS
Diastolic VTI, cm	33.0 ± 17.8	25.3 ± 9.7	NS	31.3 ± 16.6	27.4 ± 18.9	NS
Negative-flow VTI, cm	0.4 ± 0.9	2.9 ± 3.1	NS	0.3 ± 0.9	0.5 ± 1.0	NS
SF	0.28 ± 0.13	0.21 ± 0.16	NS	0.29 ± 0.13	0.41 ± 0.09	.04
DF	0.72 ± 0.13	0.79 ± 0.16	NS	0.71 ± 0.13	0.59 ± 0.09	.04
NSF	0.52 ± 0.18	0.38 ± 0.28	NS	0.55 ± 0.17	0.88 ± 0.24	.01
NDF	1.54 ± 0.26	1.81 ± 0.43	NS	1.47 ± 0.15	1.16 ± 0.25	.01
Heart rate, beats/min	72.6 ± 12.1	80.5 ± 16.4	NS	78.5 ± 10.3	73.5 ± 17.8	NS
Mean arterial pressure, mm Hg	57.4 ± 12.1	57.9 ± 8.8	NS	61.2 ± 8.9	52.1 ± 16.7	NS

*Data are presented as the mean ± SD where indicated. AVR indicates aortic valve replacement; SFS indicates Sorin Freedom Solo; SR, St. Jude Medical Regent; NS, nonsignificant; VTI, velocity time integral; SF, systolic proportion of VTI; DF, diastolic proportion of VTI; NSF, normalized systolic VTI; NDF, normalized diastolic VTI.

in systolic VTI, SF, and NSF, and significant decreases in DF, NDF, and negative-flow VTI. AVR and type of prosthetic valve had no significant effect on the RCA velocity profile.

Table 4. Operative and Postoperative Data*

	SFS (n = 11)	SR (n = 11)	*P*
Cardiopulmonary bypass time, min	76 ± 26	76 ± 18	NS
Cross-clamp time, min	49 ± 12	61 ± 14	.04
Valve size, n			
21	4	8	
23	3	2	
25	2	1	
27	2	0	
Mean valve size	23.3 ± 2.3	21.7 ± 1.3	NS
Concomitant procedure, n			
Radiofrequency ablation	3	0	NS
Carotid endarterectomy	1	0	NS
Postoperative data			
Mechanical ventilation, h	8.6 ± 5.7	5.2 ± 2.6	NS
Chest tube drainage in first 12 h, mL	628 ± 434	340 ± 174	.01
Inotropic support, h	13 ± 13	6 ± 6	NS
ICU stay, d	2.7 ± 1.5	2.7 ± 1.2	NS
Discharge postoperative day	7.5 ± 1.4	7.4 ± 2.0	NS
Postoperative atrial fibrillation, n	2†	2	NS
Pacemaker implantation, n	0	2	NS
Pleural effusion, n	2	1	NS

*Data are presented as the mean ± SD where indicated. SFS indicates Sorin Freedom Solo; SR, St. Jude Medical Regent; NS, nonsignificant; ICU, intensive care unit.

†One of the patients had longstanding atrial fibrillation preoperatively.

Operative and Postoperative Data

There was no operative or 30-day mortality. Operative and postoperative data are presented in Table 4. The mean cross-clamp time was significantly shorter in the SFS group. Valves of size 21 were the most frequently implanted in the 2 groups. Chest tube drainage in the first 12 hours was higher in the SFS group; however, none of the patients required operative revision for bleeding. Two patients in the SR group required implantation of a permanent pacemaker.

DISCUSSION

There was a significant increase in the systolic component of the LAD flow velocity in the SR group after AVR; however, no change in the velocity profile was noted in the SFS group. The higher postoperative systolic component of LAD flow after AVR with a mechanical valve can be a consequence of either an impaired systolic LAD flow in the SFS valve or an impaired diastolic LAD flow in the SR valve. The new generation of pericardial stentless prostheses (the SFS prosthesis and the 3f Aortic Bioprosthesis [Medtronic, Minneapolis, MN, USA]) has redundant leaflet tissue to accommodate a larger coaptation length, which allows better adaptability to different ratios of annular to sinotubular dimensions and to dilatation of the sinotubular junction that may occur with time [Scharfschwerdt 2010]. This redundance in leaflet tissue, together with supraannular implantation, increases leaflet height, and the leaflets are more likely to cover the coronary ostia during systole, in contrast to native aortic valve leaflets, in which leaflet height is normally less or equal to the distance from the basal attachment of a leaflet to the corresponding coronary ostium [Cavalcanti 2003, Piazza 2008]. Compared with a bileaflet mechanical prosthesis, this redundant leaflet tissue may produce the impaired systolic flow that was observed in our study. The absence of change in the CBF velocity profile in the LAD after AVR with the SFS bioprosthesis seems contrary to the fact that impaired hyperemic flow and CFR correlate better with the hemodynamic indices of aortic stenosis

severity, such as the EOA and the transvalvular pressure gradient (which are corrected immediately after AVR), than with the left ventricular mass (which regresses over several months [Rajappan 2002]) and implies that there may be some local hemodynamic factors specific to SFS or SR aortic valve prostheses. Severe CBF impairment in a stentless bioprosthesis is unlikely. In a randomized controlled study of patients with aortic stenosis that compared 2 mechanical prostheses and 2 bioprostheses, the CFR normalized by 6 months after AVR only in patients with a stentless valve implanted [Bakhtiary 2007]. Stentless valves also had the lowest values for pressure gradient and left ventricular mass index after 6 months.

During the postoperative course, 2 patients in the SR group required implantation of a permanent pacemaker owing to atrioventricular block. The SFS valve has a potential advantage for avoiding this complication, because the sutures are placed supraannularly in the aortic wall, rather than in the aortic annulus; however, injury to the conduction system can also occur during removal and debridement of the calcified leaflets. In a study by Oses et al [2011], 3% of patients who underwent AVR with an SFS valve had a permanent pacemaker implanted in the immediate postoperative period; however, some of the patients had concomitant mitral valve surgery. The mean amount of chest tube drainage in the first 12 postoperative hours was significantly higher in the SFS group. This finding could be explained by the higher rate of radiofrequency ablation in the SFS group and by transient postoperative thrombocytopenia, which is known to be more pronounced after SFS bioprosthesis implantation. This was also observed in our study [Geršak 2011].

Study Limitations

The patients were not randomized because a mechanical aortic valve prosthesis and a bioprosthesis were compared. It would be unethical and contrary to current guidelines to randomly assign patients to either of the 2 groups.

Intraoperative Doppler measurement shows only the velocity of the blood flow in the coronary artery, not the actual flow. Conclusions drawn from velocity measurements can apply only to relative changes in the shape of velocity profile and the relationship between the systolic and diastolic flows.

CONCLUSIONS

The type of aortic valve prosthesis that was used significantly influenced the flow velocity profile in the LAD, but not in the RCA. The main difference between SFS and SR prostheses was the increase in the systolic proportion of VTI in the SR group, whereas no significant change in the LAD CBF velocity profile was noted in the SFS group, compared with preoperative measurements, even though both prostheses significantly reduced transvalvular pressure gradients and increased the EOA. The differences in the LAD velocity profile probably reflect differences in valve design and the systolic transvalvular flow pattern. The low systolic component of LAD flow is unlikely to have any clinical consequences, because only stentless bioprostheses have been shown to normalize CFR after AVR.

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