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Impact of Patient-Prosthesis Mismatch and Aortic Valve Design on Coronary Flow Reserve After Aortic Valve Replacement

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Objectives This prospective-randomized study investigated the effect of aortic valve design and patient-prosthesis mismatch (PPM) on coronary flow reserve (CFR) after mechanical or biological aortic valve replacement (AVR) in patients with aortic stenosis (AS).

Background Coronary flow reserve may be an important parameter of long-term survival after AVR in patients with AS. Reduced CFR may contribute to more cardiovascular events and greater rates of mortality.

Methods A total of 48 patients undergoing AVR underwent magnetic resonance imaging for the measurement of coronary flow preoperatively, 5 days postoperatively, and at 6-month follow-up with measurement of CFR. Patients scheduled for mechanical AVR were randomized to a tilting disc or bileaflet prosthesis ($n = 12$ in each group). For biological AVR, patients were scheduled to receive a stented ($n = 12$) or stentless ($n = 12$) valve. Patients also underwent echocardiography with measurement of transvalvular pressure gradients and left ventricular mass regression.

Results Postoperatively, coronary flow increased significantly in all groups ($p < 0.001$). Only stentless valves demonstrated a normal CFR (3.4 ± 0.3 vs. 2.3 ± 0.1 for stented biological valves, 2.1 ± 0.2 for tilting disc, and 2.2 ± 0.3 for bileaflet mechanical valves). Patient-prosthesis mismatch with an indexed effective orifice area <0.85 cm^2/m^2 led to decreased rates of CFR in the tilting disc, stentless, and stented groups. Pressure gradients were 14 ± 3 mm Hg for tilting disc, 12 ± 4 mm Hg for bileaflet, 19 ± 6 mm Hg for stented, and 10 ± 4 mm Hg for stentless valves.

Conclusions Normalization of CFR after AVR in patients with AS was observed only for stentless valves. Coronary flow reserve might explain the excellent long-term results for stentless valves. (Impact of Patient-Prosthesis Mismatch on Coronary Flow Reserve; http://www.clinicaltrials.gov/ct/show/NCT00310947?order=1; NCT00310947)
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Impairment of coronary flow reserve (CFR) in patients with aortic stenosis and left ventricular hypertrophy is related to aortic valve area and peak transvalvular gradients rather than the degree of left ventricular hypertrophy (1). Reduced CFR has been defined to be an independent predictor of cardiovascular prognosis within the next decade (2).

Long-term mortality is increased in patients after aortic valve replacement (AVR) compared with the normal population (3,4). Findings from trials conducted in the 1970s and 1980s seemed to demonstrate that valve design did not influence long-term outcome, but recent studies observed varying mortality between different stented biological valve substitutes (5,6). Also, the impact of patient-prosthesis mismatch (PPM) with an indexed effective orifice area (iEOA) <0.85 cm^2/m^2 on survival has been the topic of controversy (7,8). However, the role of PPM on coronary perfusion and especially CFR has not been investigated, although an inadequate valve opening will cause turbulent aortic root flow and thus also might impair physiological backflow during diastole.

Chronic coronary hypoperfusion and reduced CFR might contribute to cardiac events such as sudden cardiac death or arrhythmias. Furthermore, deteriorating left ventricular

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function is common after AVR and might be related to insufficient coronary flow. Our own previous experimental studies showed that postoperative coronary flow and coronary reserve are dependent on valve design and orientation. None of the tested aortic valve prostheses allowed for physiological coronary flow rates (9–12).

The aim of this prospective, randomized study was to investigate the impact of valve design and PPM on CFR and hemodynamic performance in patients undergoing AVR for aortic stenosis. We compared 2 mechanical and 2 biological valves and evaluated the acute and chronic changes in coronary artery flow, CFR, hemodynamic outcome, and regression of left ventricular mass in patients undergoing AVR who did not have coronary artery disease.

Noninvasive measurement of coronary perfusion rates in vivo can be performed either by echocardiography or magnetic resonance imaging (MRI). Echocardiography frequently is limited by impaired postoperative conditions of analysis. Therefore, we used MRI scanning because it provides a more objective measurement of right and left coronary artery flow rates in patients without their additional exposure to X-rays (13,14).

Methods

From March 2003 to January 2005, 48 patients undergoing AVR were included in this prospective randomized study. Patients suffered from severe aortic stenosis (maximum gradient >50 mm Hg or aortic valve area <1.0 cm^2); no patient had more than minimal aortic regurgitation and, all patients, a preoperative coronary angiography demonstrated the absence of any coronary artery obstruction. Exclusion criteria included active endocarditis, emergency surgery, and a history of coronary artery disease or myocardial infarction. The hypothesis of our study was that less downstream turbulence achieved by stentless valves contributes to improved coronary flow. The study was approved by the ethics committee of the Johann Wolfgang Goethe University Hospital (Frankfurt/Main, Germany) and all patients provided written informed consent before inclusion.

Transthoracic echocardiography and MRI scanning were performed on the day of admission, before discharge, and during a 6-month follow-up visit. The MRI scan was used to measure coronary flow rates and dynamics. Additional measurement of adenosine-induced CFR (140 μg/kg/min adenosine over the course of 7 min) was performed during the follow-up MRI. Rate-pressure product (RPP) as the product of heart rate multiplied by left ventricular pressure (systolic blood pressure + systolic transvalvular gradient) was calculated as an indicator of myocardial oxygen demand. The intention was to exclude increased cardiac work load as the cause of increased coronary flow rates. We used echocardiography to evaluate the hemodynamics of the valves and left ventricular mass regression (LVMR). At the follow-up visits, additional clinical evaluation was performed.

Abbreviations and Acronyms

AVR = aortic valve replacement
CFR = coronary flow reserve
iEOA = indexed effective orifice area
LVMR = left ventricular mass regression
MRI = magnetic resonance imaging
PPM = patient-prosthesis mismatch
RPP = rate-pressure product

Echocardiography. Echocardiography was executed according to American Society of Echocardiography guidelines using a Wingmed Vivid 5 cardiac ultrasound scanner (GE Medicals, Fairfield, Connecticut). Continuous-wave Doppler was used to derive peak transvalvular pressure gradients across the aortic valve (peak aortic valve gradient). Aortic valve area was calculated according to the American College of Cardiology/American Heart Association guidelines to determine severity of aortic stenosis. Effective orifice area was calculated using the continuity equation method. The iEOA was derived by dividing EOA by the body surface area. Left ventricular ejection time was measured on the continuous-wave Doppler trace, from opening to closure of the aortic valve. The mean of 3 separate readings in case of sinus rhythm and the mean of 5 separate readings in case of atrial fibrillation were used for each parameter. All data collected were entered in a central database.

Cardiovascular magnetic resonance (cMRI scan). Patients were examined in a 1.5-T system (Magnetom Sonata, Maestro Class; Siemens, Erlangen, Germany) in a supine position using thoracic surface coils. The examination started with a set of transverse and double oblique scout images to localize the coronary arteries. Subsequently, a retrospectively ECG-gated breath hold phase-contrast flash sequence with high temporal and spatial resolution was used to acquire flow data. These sequences were oriented perpendicularly to the left (segment 5) and right (segment 1) coronary artery main stems. Resulting cMRI flow data sets included rephased, magnitude, and phase images and were segmented manually using the ARGUS flow analysis software (Houston, Texas). According to the measured velocities at every time frame, velocity and flow curves were generated and analyzed. The preoperative measured values of coronary flow for each individual patient were set as 100% values. The postoperative values were then related to these preoperative flow rates. Coronary flow reserve was calculated as the ratio between maximum and rest coronary flow rates. Additionally, the distance of the coronary flow velocity peak to the R-wave was measured representing the time of maximal coronary flow in relation to systole and diastole.

The reproducibility of the described MRI technique of coronary flow rate evaluation has been reported recently (14). Patients were either selected for mechanical or biological valve replacement depending on their age, risk of anticoagulation, and life expectancy. This selection was performed according to the institutional standards. Randomization started after this process. Patients scheduled for mechanical valve replacement (n = 24) were randomized to

Table 1 The Most Important Features of the Implanted Valves

	Hall	Advantage	Mosaic	Freestyle
Design	Mechanical		Porcine biological	
	Tilting Disc	Bileaflet	Stented	Stentless
Material	Polycarbon leaflets Titanium housing		Porcine leaflets, treated with physiological fixation and AOA	
First implant	1977	1999	1994	1992
Characteristics	Requires optimal orientation, good hemodynamics	Low profile Low thrombogenicity Easy implantation Larger central orifice	Good midterm outcome	Excellent hemodynamic performance, laminar flow

AOA = alpha-aminooleic acid (anticalcification treatment).

receive a Medtronic Hall tilting disc or Medtronic Advantage bileafleat valve. Also, in the biological group (n = 24), patients were randomized for either a porcine stented bioprostheses (Medtronic Mosaic) or a porcine stentless valve (Medtronic Freestyle; all valves by Medtronic Inc., Minneapolis, Minnesota). The most important features of the implanted valves are listed in Table 1.

Both biological valves undergo identical processing with zero pressure cusp fixation and amino-oleic acid anticalcification treatment. Intraoperatively, patients were excluded from the study if their aortic root wall had severe calcifications that could not be removed surgically and thus made the implantation of a stentless valve impossible or if their aortic root was dilated.

Surgical technique. A total of 9 surgeons performed the operations using partial upper sternotomy, standard extracorporeal circulation, retrograde cold blood cardioplegia, and carbon dioxide insufflation of the open chest to minimize organ damage caused by air embolism. Access to the aortic valve was gained via a transverse aortotomy. After complete resection of the native aortic valve and debridement of the aortic annulus, accurate sizing was conducted using the original sizers for the 4 different valves. Hall, Advantage, and Mosaic valves were implanted in a supraannular fashion using interrupted pledget-armed U stitches with Ethibond 2-O sutures (Ethicon, Inc., Cornelia, Georgia). Bites were taken from the ventricular to the aortic side of the annulus. For the 2 mechanical valves, optimum orientation was chosen according to previous publications (11). Freestyle valves were implanted in the modified subcoronary position, leaving the noncoronary prosthetic sinus intact. Single Ethibond 4-O sutures (Ethicon) for the proximal and a running Prolene 4-O suture (Ethicon) for the distal anastomoses were used. No oversizing for stentless valves was performed.

Statistical methods. As a first step of statistical analysis, Gaussian normal distributions of results obtained for hemodynamic parameters and coronary flow rates were tested using the Dallal-Wilkinson corrected, Kolmogoroff-Smirnoff test (15). Data were compiled and analyzed using Microsoft Excel (Redmond, Washington) and Statview (Cary, North Carolina). The baseline characteristics and hospital outcomes for the 4 groups were compared using chi-square contingency or the Fisher exact test for categorical data and Mann-Whitney *U* test or Kruskal-Wallis test for continuous variables. Results are reported as the mean ± SD in text and tables. Statistical significance was defined as a $p < 0.05$.

Results

Preoperative coronary artery flow and also other clinical characteristics, including gender, body surface area, ejection fraction (EF), New York Heart Association functional class, and cardiovascular risk factors were comparable in the 4 groups (Table 2); the only significant difference was observed with respect to lower age in the 2 mechanical groups. Coronary flow rates varied distinctly between individuals, but mean and median values were similar. Evaluation of the coronary perfusion pattern demonstrated a pathological early flow velocity peak (distance from the R-wave 375 ms for Hall, 390 ms for Advantage, 380 ms for Mosaic, and 390 ms for Freestyle). Flow was even partially reversed during systole: mean RPP was 19,885 ± 4,558 beats/min·mm Hg, again, with no differences between groups.

Each of the 4 valves was implanted into 12 patients, respectively. Because of the more complex implantation technique, cross-clamp times and cardiopulmonary bypass times were significantly longer in the stentless valve group. The mean valve sizes were 24 ± 1.8 mm for tilting disc, 23.5 ± 1.5 mm for bileaflet, 23 ± 1.6 mm for the stented group, and 24 ± 1.1 mm for the stentless group. Because only the stentless sizers were metric, Hall, Advantage, and Mosaic, sizes had to be converted into their metric values (16,17), which were 21.2 ± 1.4 for Hall, 21 ± 1.3 for Advantage, and 20.6 ± 1.0 mm for Mosaic. Thus, Freestyle valves demonstrated significantly greater implanted diameters ($p < 0.05$), with the remaining valve sizes comparable.

The discharge MRI evaluation of coronary flow revealed a significant increase in coronary flow for each individual patient ($p < 0.001$). The preoperative values were set as 100%. Figure 1 demonstrates that coronary artery flow increased to 185 ± 23% for Hall, 182 ± 19% for Advantage, 224 ± 37% for Mosaic, and 245 ± 28% for Freestyle

Table 2 Preoperative Patient Characteristics

	Hall (n = 12)	Advantage (n = 12)	Mosaic (n = 12)	Freestyle (n = 12)	p Value
Male	8	5	5	5	NS
Female	4	7	7	7	NS
Age (yrs)	62 ± 4.5	63 ± 5	*76 ± 6	*71 ± 7	*
BSA	1.98 ± 0.25	1.84 ± 0.2	1.90 ± 0.1	1.85 ± 0.2	NS
Angina pectoris	4	6	6	7	NS
Hypertension	8	6	7	7	NS
Valvular gradient (mm Hg)	65 ± 19	73 ± 11	69 ± 22	73 ± 14	NS
NYHA functional class	3 ± 0.5	2.8 ± 0.3	2.5 ± 0.5	2.8 ± 0.4	NS
Coronary flow RCA (ml/min)	59 ± 28	63 ± 18	65 ± 21	60 ± 30	NS
Coronary flow LCA (ml/min)	85 ± 28	100 ± 41	90 ± 33	94 ± 31	NS
Preoperative ejection fraction (echocardiography, %)	63 ± 12	59 ± 14	60 ± 10	52 ± 5	NS
Diabetes	4	4	6	5	NS
Smoking	5	6	5	7	NS

*$p < 0.05$.
BSA = body surface area; LCA = left coronary artery; NS = nonsignificant; NYHA = New York Heart Association; RCA = right coronary artery.

valves. The 2 biological valves showed a significantly greater increase (related to the preoperative values) in flow rates compared with the mechanical groups ($p < 0.01$); the difference in favor of the stentless group compared with the stented biological valve also was significant ($p < 0.05$). Both the left and right coronary artery demonstrated similar results. At the follow-up examination, coronary flow rates were lower compared with the discharge evaluation (mean 146 ± 19% of preoperative values for Hall, 156 ± 24% for Advantage, 188 ± 39% for Mosaic, and 215 ± 35% for the Freesytle group), with the difference between the valve groups being maintained. The stentless valve demonstrated significantly greater coronary flow rates compared with the other 3 valve designs. Coronary flow rates at rest were comparable 6 months postoperatively (left coronary artery flow 75 ± 11 ml/min for Hall, 81 ± 14 ml/min for Advantage, 78 ± 13 ml/min for Mosaic, and 88 ± 17 ml/min for Freestyle; RCA flow 48 ± 8 ml/min for Hall, 51 ± 11 ml/min for Advantage, 42 ± 8 ml/min for Mosaic, and 51 ± 11 ml/min for Freestyle). Coronary flow reserve (Fig. 2) induced by Adenosine was normal (>2.5) only for stentless valves (3.4 ± 0.3), whereas the remaining groups showed reduced values (2.1 ± 0.2 for Hall, 2.2 ± 0.3 for Advantage, and 2.3 ± 0.1 for Mosaic valves). Hemodynamic data at the time of CFR measurement were recorded, and no significant differences were observed among the 4 groups regarding heart rate (mean 76 beats/min for Hall, 72 beats/min for Advantage, 74 beats/min for Mosaic, and 77 beats/min for Freestyle), arterial blood pressure (mean 78 mm Hg for Hall, 75 mm Hg for Advantage, 78 mm Hg for Mosaic, and 72 mm Hg for Freestyle) and peripheral oxygen saturation (variation between 93% and 98% in all groups).

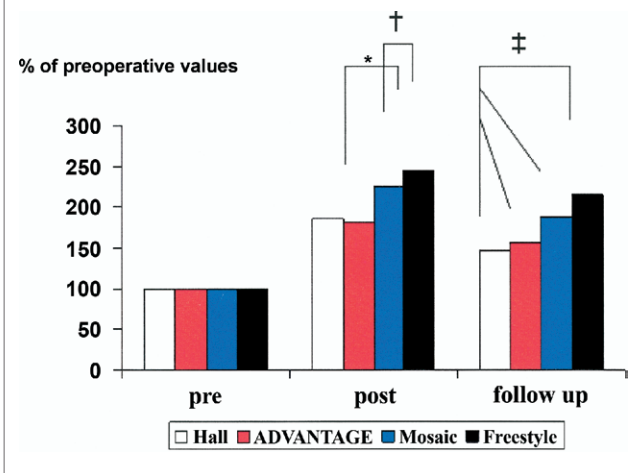

Figure 1 Comparison of Pre- With Postoperative Flow Rates for the 4 Valve Designs

Preoperative flow rates were set as 100%. A significant increase was observed for all valves postoperatively. Postoperative flow rates were significantly greater for biological valves compared with the mechanical groups (*$p < 0.01$) and within the biological group for stentless prosthesis (†$p < 0.05$). At follow-up, coronary flow was lower compared with the early postoperative phase with the Advantage in favor of the stentless valve compared with the 3 other substitutes being maintained (‡$p < 0.05$).

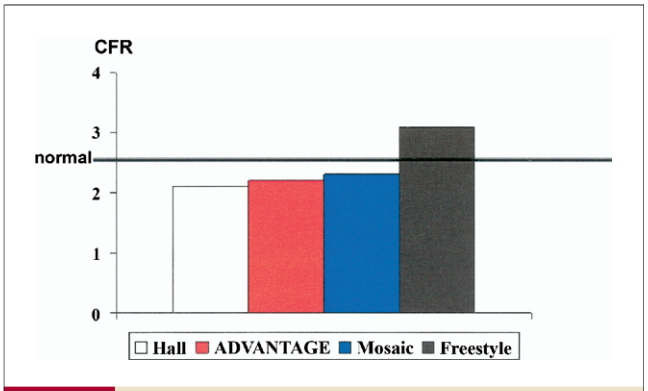

Figure 2 CFR 6 Months Postoperatively

Only the stentless Freestyle valve showed a normal coronary flow reserve (CFR) >2.5; the remaining 3 valve designs demonstrated comparable results with slightly reduced CFR.

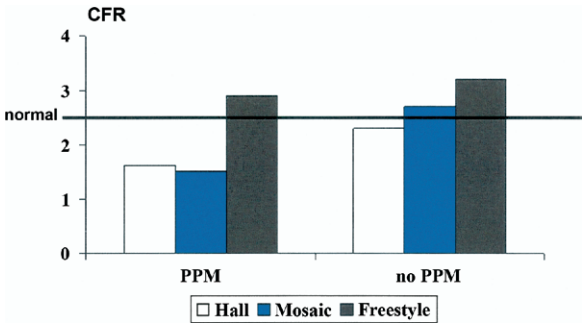

Figure 3 **Reduced CFR in Patients With PPM for Hall Tilting Disc, Mosaic Stented, and Freestyle Stentless Valves**

The results for stentless valves remained within normal ranges. Only 1 patient in the Advantage bileaflet group had patient-prosthesis-mismatch (PPM); therefore, evaluation of the results in this group was not relevant. CFR = coronary flow reserve.

Patient-prosthesis mismatch with an iEOA <0.85 cm^2/m^2 occurred in 3 Hall (25%), 1 Advantage (8.3%), 3 Freestyle (25%), and 4 Mosaic (33.3%) patients. Figure 3 summarizes the results of CFR in patients with or without PPM. Except for the Advantage group, with only 1 patient demonstrating PPM, there was a clear decrease in CFR for patients with an iEOA <0.85 cm^2/m^2. However, for the stentless valves, CFR remained within normal ranges (2.9 ± 0.3).

The coronary flow pattern changed in both groups postoperatively toward a more diastolic velocity peak of perfusion with no more reversed systolic coronary flow. The peak flow velocity distance from the R-wave increased to 550 ms for Hall, 530 ms for Advantage, 550 ms for Mosaic, and 570 ms for Freestyle. There were no significant differences between the 4 valve groups.

All echocardiographic results are summarized in Table 3. Mean gradients for the 2 mechanical valves were comparable, whereas Freestyle valves demonstrated significantly lower results at discharge and at the 6-month follow-up ($p < 0.01$). Left ventricular mass index regressed significantly in all groups over time. However, there were no significant differences in LVMR between the groups at either discharge or 6 months postoperatively, although a trend for more pronounced LVMR was observed for Freestyle valves.

Rate-pressure product decreased for all patients toward normal values without any significant differences (Hall 10,114 ± 1,102 beats/min·mm Hg; Advantage 9,166 ± 964 beats/min·mm Hg; Freestyle 9,124 ± 1,002 beats/min·mm Hg; and Mosaic 10,489 ± 1,120 beats/min·mm Hg).

The overall rate of perioperative complications was low in all groups. In the Hall group, 2 patients suffered from temporary atrial fibrillation and 1 patient from a stroke at 8 months after the operation. In the Advantage group, 1 patient required prolonged inotropic support and 1 patient developed temporary atrial fibrillation. In the stentless group, we observed a case of AV-block grade III and needed to implant a DDD pacemaker. In the stented group, there was a case of pericardial effusion, which could be treated by medication alone. There was no case of severe clinical events or death in both groups either perioperatively or at the 6-month follow-up.

New York Heart Association classification improved in all patients (mean 1.8 ± 0.5 for Hall, 1.6 ± 0.7 for Advantage, 1.5 ± 0.4 for stentless, and 1.7 ± 0.4 for stented valves at the follow-up). No patient was classified as New York Heart Association functional class IV.

Discussion

Besides other variables, coronary artery flow is determined by the diastolic flow pattern within the sinuses of Valsalva, which in native aortic valves is characterized by rounded backflow eddies enhancing aortic valve closure and forward coronary flow. This natural low-turbulent flow pattern is disturbed by any aortic valve substitute. In previous studies, downstream turbulence was dependent on valve design and valve size (11). Therefore, it was logical that also coronary flow was determined by these variables (10,11). The current study adds the variable of valve size and thus effective orifice area, as it is known that adequate valve opening will allow less turbulent flow passage.

Long-term survival after AVR is limited by so-called valve-related complications like thrombosis in mechanical and structural valve deterioration in biological substitutes. By definition, the development of heart failure and sudden cardiac deaths are not considered to be related to the implanted aortic valve, although these complications occur in as many as 24% of the AVR patients within 10 years after surgery (8,18). This incidence is significantly greater compared with the background population; therefore, a connection between AVR and the risk of development of heart failure and arrhythmias can be presumed. Both might be related to an inadequate coronary perfusion because myocardial blood flow impairment has been defined to be a

Table 3 **Echocardiographic Data**

	Hall	Advantage	Mosaic	Freestyle	p Value
Mean gradient (mm Hg) at discharge	14 ± 3	12 ± 4	17 ± 5	9 ± 4	0.001 (Freestyle vs. Mosaic)
Mean gradient (mm Hg) at follow-up	11 ± 3	11 ± 4	14.8 ± 5.2	8.0 ± 2.5	0.001 (Freestyle vs. Mosaic)
LVM (g/m^2) preoperatively	280 ± 39	227 ± 57	265 ± 56	276 ± 65	NS
LVM (g/m^2) at follow-up	174 ± 44	186 ± 51	191 ± 54	159 ± 70	NS

LVM = left ventricular mass; NS = nonsignificant.

strong independent predictor for the progression of heart failure (19).

Indisputably, patients suffering from aortic stenosis demonstrate impaired coronary perfusion; we even demonstrated reversed flow during systolic ejection. This observation can be related on the one hand to a pathological pressure relation between the left ventricle and the ascending aorta and on the other hand to Ventouri-type suction in the aortic root caused by highly turbulent flow in aortic stenosis. It was demonstrated before that AVR leads to improvement of coronary artery flow immediately but not to a complete normalization (9). In a previous animal study, we could show that no mechanical valve prosthesis could restore the physiological values of coronary perfusion measured in a control group with a native aortic valve (12). Coronary flow rates depended on valve design and orientation. Because all mechanical and biological valves are stenotic to some extent, it was not surprising that the remaining flow obstruction also impaired coronary artery flow analogous to aortic stenosis.

The current prospective randomized study was designed to investigate the clinical impact of the findings. We determined not only the impact of valve design on coronary flow, but also the role of the prosthetic aortic valve area represented by the iEOA. Coronary flow rates significantly increased after AVR in each individual patient; a pathologically reversed flow pattern could not be observed postoperatively. A more diastolic and thus physiological flow distribution was observed. The decline of coronary perfusion rates at 6 months postoperatively can be explained by LVMR and the normalization of cardiac output compared with the hyperdynamic phase immediately after the operation. We demonstrated that the 2 mechanical groups behaved rather similarly with respect to their hemodynamic performance and the coronary flow rates, including follow-up CFR. Thus, the Advantage valve matched the hemodynamic performance of the optimally orientated tilting disc prosthesis better than previously investigated bileaflet prostheses (20). This might be caused by the design improvement of a larger central orifice, which allows a more equal flow distribution of eccentric systolic outflow (9–11). Both mechanical valves could not reach the results of the 2 investigated biological valve designs. One reason might be the inherent closing volume and leakage flow during the diastolic phase, which interferes with the physiological backflow in the sinuses of Valsalva. The impact of flow dynamics in the sinuses of Valsalva on coronary flow was recently demonstrated by Markl et al. (21) for patients who had undergone aortic valve repair under the different techniques of Tirone David. Another reason might be the more physiological valve leaflet closure in biological valves, which both have 3 leaflets as the native human aortic valve.

In the biological groups, stentless valves demonstrated significantly greater perfusion rates at discharge and follow-up. Only stentless patients showed a normal flow reserve. Transvalvular gradients and RPP as marker for myocardial oxygen demand and cardiac work load also were lower for the Freestyle patients. Thus, the valve correcting the pressure difference between the left ventricle and the aortic root best provided the most physiological coronary flow as well. The maintained annulus geometry and flexibility, as well as the low resistance to transvalvular flow reducing the intraventricular pressure, might be the most important contributors to this result. Active annulus motion and its impact on flow dynamics recently has been demonstrated by Lansac et al. (22). The stentless valve imitates this natural geometry closer than the stented valve; thus, backflow and sinus turbulence is closer to normal physiology. It would be interesting to investigate the full-root technique of stentless valve implantation, a technique that is intended to preserve the geometry not only of the valve leaflets but also of the aortic root.

Patient-prosthesis mismatch occurred in all groups. Only one patient demonstrated PPM in the Advantage group; therefore, the evaluation of this group was not possible. For the remaining prostheses, there was a correlation between PPM and reduction of CFR. However, for stentless valves, this impairment did not lead to pathological results. For the remaining tilting disc and stented biological valves, PPM further reduced the previously already decreased values.

A superior hemodynamic performance in combination with increased coronary artery flow and a normal flow reserve may contribute to the observed lower midterm mortality, which has been reported for stentless valve designs, especially if PPM is absent (23).

Because a major result this study draws attention on is the influence of the type of aortic valve prosthesis on coronary perfusion, especially CFR, this property should be included in investigations regarding the hemodynamic performance of mechanical and biological valve prostheses in the future. Impaired CFR might influence left ventricular function, susceptibility for arrhythmias and, finally, exercise tolerance. However, the current study did not prove definitely any clinical relevance of impaired CFR on later outcome. It is possible that the flow obtained from all 4 valve prostheses is still adequate. Further studies with larger patient cohorts should investigate its impact on late myocardial morbidity and survival rates.

Study limitations. Regarding limitations, we included a small number of patients in this study. In part, the negative effect of postoperative arrhythmia on MRI quality postoperatively is another limitation. Atrial fibrillation at the time of discharge was present in 3 patients in the Freestyle group, 2 patients in the Mosaic group, 1 patient in the Hall group, and 1 patient in Advantage group. In all of these patients, rate control was achieved before the MRI scan by antiarrhythmic medication. Fortunately, these patients did not demonstrate arrhythmias at the follow-up examination. From a surgical perspective, longer follow-up periods and also a greater number of patients are necessary to purport any long-term advantage of better flow pattern and higher flow velocity in different valve substitutes.

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