Work in progress report - Valves

Influence of orientation of bi-leaflet valve prostheses on coronary perfusion pressure in humans

Marcel van 't Veer, Bart van Straten, Frans van de Vosse, Nico Pijls

Abstract

Orientation of a bi-leaflet prosthesis (BLP) might influence coronary perfusion. The aim of this study was to investigate the influence of the orientation on coronary perfusion pressure during hyperemia and adrenergic stimulation. During hyperemia perfusion pressure determines coronary blood flow. Fourteen patients with normal coronary angiogram underwent aortic valve replacement (AVR) by a BLP, and seven received a bio-prosthesis. Patients receiving a BLP were randomized to either orientation A (hinge mechanism perpendicular to a line drawn between the coronary ostia) or B (hinge mechanism parallel to the line between the ostia). Six months after surgery all patients underwent cardiac catheterization. Pressures were measured during resting conditions, during maximum hyperemia, and during maximum adrenergic stimulation with a guiding catheter in the aortic arch (P_cor) and in the aortic root (P_min), P_cor - P_min described a flow-induced pressure drop in the aortic root (Venturi effect) and the gradient P_cor - P_min described coronary ostium abnormalities. Only small non-significant differences in myocardial perfusion pressure were found between different orientations of a bi-leaflet prosthesis or between bi-leaflet prostheses and bio-prostheses in P_cor - P_min and P_cor - P_min.

Keywords: Physiological measurements; Coronary arteries; Heart valve prostheses

1. Introduction

After aortic valve replacement (AVR) the pressure gradient over the valve decreases significantly with a favorable effect on the relation between intraventricular compressive forces, coronary perfusion pressure, and left ventricular cavity pressure [1], reflected by increase of coronary flow reserve [2, 3].

It has been suggested that different types and orientations of aortic valve prostheses could affect coronary blood flow in a different way [4, 5]. Kleine et al. and Bakhtiar et al. hypothesized that this should be ascribed to a disturbed flow pattern in the proximal part of the aorta distal of the valve [6].

Coronary flow is regulated by a complex interaction of neural and humoral responses, depending on oxygen demand and affecting myocardial resistance. The resistance can be minimized (and, therefore, kept constant) by pharmacological stimuli like adenosine and dobutamine, reflecting maximum exercise in true life. Under such circumstances coronary blood flow has been shown to be directly proportional to coronary perfusion pressure [7–9].

When blood is forced through the orifice of the valve prosthesis, the blood flow velocity increases thereby increasing the kinetic energy at the cost of the hydraulic energy, the pressure. Maximum velocity and, therefore, minimum pressure (Venturi effect) is observed just distal to the prosthetic valve at the position of the coronary ostia [10]. We hypothesized that differences in coronary perfusion pressure caused by a Venturi-like effect, in different orientations of a mechanical bi-leaflet prosthesis (BLP) during hyperemia and adrenergic stimulation, could influence coronary blood flow.

2. Materials and methods

The study was approved by the Medical Ethics Committee of the Catharina Hospital in Eindhoven and written informed consent was obtained from each patient.

2.1. Study population

Twenty-one patients accepted for isolated AVR and a normal coronary angiogram were selected from the total population referred to our hospital. Exclusion criteria were: previous valve surgery in any position; concomitant surgical procedures; left ventricle dilatation; aortic regurgitation grade 2; history of myocardial infarction; preoperative creatine level > 150 μmol·l⁻¹; or age over 75 years at time of surgery.
Fourteen patients were selected to receive a BLP (SJM®, St. Jude Medical Inc., St. Paul, MN) and seven patients received a bio-prosthesis (Medtronic Mosaic, Medtronic Inc., Minneapolis, MN). Prior to surgery patients receiving a BLP were randomized to different orientations of the valve, defined as A and B, as in previous studies [5, 6]. In orientation A (orthotopic position) the hinge mechanism was placed perpendicular to a line drawn between the coronary ostia, in orientation B (heterotopic position) the hinging mechanism was placed parallel to a line drawn between the two coronary ostia.

2.2. Surgical procedure

Anesthesia was performed according to routine in our hospital. All patients underwent a sternotomy, followed by arterial cannulation in the ascending aorta and single venous cannulation in the right atrium. Operations were performed under normothermic extra-corpooreal circulation and the heart was arrested by antegrade administration of cardioplegia. The native aortic valve was removed and the annulus was decalcified. The valve prosthesis was implanted using running or separate sutures according to the surgeons preference. Mechanical prostheses were implanted with an orientation according to randomization. Most patients were extubated within a few hours and left the ICU the same day.

2.3. Catheterization at follow-up

Follow-up catheterization was performed six months after surgery. Forty-eight hours prior to the procedure, patients were asked to stop beta-blockers in order to avoid inhibition of the maximal adrenergic stimulation by dobutamine. Catheterization was performed by the Judkins approach using 6F guiding catheters with side holes at a distance of 10 cm from the tip, enabling pressure recording at the level of the ostium of the coronary artery again and dobutamine i.v. was started at a rate of 10 μg/kg-min and stepwise increased with 10 μg/kg-min every two minutes until the maximum dosage of 40 μg/kg-min was reached. It has been shown previously that dobutamine in this dosage not only stimulates contractility and ejection velocity of blood across the aortic valve, but also induces maximum hyperemia [12].

At first, pressure measurements were performed under resting conditions. The pressure wire was advanced until the pressure-sensor was at the location of the side holes. At that position equilibration with the fluid-filled catheter was performed \( P_{ao} = P_{ao,pw} \). Thereafter, the two pressure signals were recorded simultaneously throughout the procedure. The wire was advanced into the proximal part of the coronary artery to record \( P_{root} \) and further advanced to record \( P_{cor} \). Under normal circumstances all these pressures should be equal [11].

Next, steady state maximum coronary hyperemia was induced by intra-venous infusion of adenosine in a dosage of 140 μg/kg-min as described before [8]. During hyperemia, the pressure wire was slowly pulled back to the aortic root. In the case of a coronary artery ostial stenosis, whether iatrogenic by the preceding AVR or atherosclerotic, a gradient is expected between \( P_{cor} \) and \( P_{root} \) [7]. Next, the sensor was pulled back to the level of the side holes of the guiding catheter to ensure equal pressures again. After the adenosine administration was stopped, its effect vanishes within a couple of minutes.

Thereafter, the pressure wire was advanced into the coronary artery again and dobutamine i.v. was started at a rate of 10 μg/kg-min and stepwise increased with 10 μg/kg-min every two minutes until the maximum dosage of 40 μg/kg-min was reached. It has been shown previously that dobutamine in this dosage not only stimulates contractility and ejection velocity of blood across the aortic valve, but also induces maximum hyperemia [12].

At maximum adrenergic stimulation, the pressure guide wire was pulled back again in a similar way as during maximum hyperemia by adenosine. The difference between the root and the arch \( P_{ao} - P_{root} \) indicates presence of a Venturi pressure drop due to artificial valve induced high ejection velocities across the valve.
2.5. Data analysis and statistical analysis

When studying pressure gradients across the coronary ostium it should be kept in mind that this pressure gradient is proportional to aortic pressure during maximal coronary hyperemia. Therefore, gradients were normalized by taking changes in aortic pressure into account. It has been shown that such pressure measurements are highly reproducible [13].

The comparison of the groups was performed by the non-parametric Mann–Whitney test with no Gaussian distribution assumed. Data are expressed as mean with the interquartile range (IQR) and box-and-whisker plots are used for the representation of the perfusion pressure measurements. A P-value of 0.05 is considered statistically significant. Baseline patient data are expressed as mean ± S.D.

3. Results

3.1. Procedural results

Out of our 21 patients, seven patients had a BLP in position A (BLP_A), seven in position B (BLP_B), and seven had a bio-prosthesis (Bio). The preoperative baseline characteristics of these patients are mentioned in Table 1.

Average diameter of the prostheses for the different groups are presented in Fig. 2. Panels a and b describe the characteristics of these patients are mentioned in Table 1. Average diameter of the prostheses for the different groups were 23.6 mm, 22.9 mm, and 23.9 mm, respectively, for the BLP_A, BLP_B, and Bio.

The comparison of the groups was performed by the non-parametric Mann–Whitney test with no Gaussian distribution assumed. Data are expressed as mean with the interquartile range (IQR) and box-and-whisker plots are used for the representation of the perfusion pressure measurements. A P-value of 0.05 is considered statistically significant. Baseline patient data are expressed as mean ± S.D.

Two patients refused angiographic follow-up (1 BLP_B and 1 Bio). The six-month follow-up catheterization with hemodynamic measurements could be performed without problems in all the remaining 19 patients.

3.2. Pressure measurements

The values of blood pressure and heart frequency during the catheterization are shown in Table 2. A slight overall decrease in mean aortic pressure was observed for all patients with increasing dosages of dobutamine (101 (23) mmHg–87 (25) mmHg, P=0.021). The heart frequency on the other hand increased from 77 (19) to 125 (25) beats per minute (P<0.0001) as expected.

The results of the coronary perfusion pressure measurements are presented in Fig. 2. Panels a and b describe the pressure gradients \( P_{\text{rest}} - P_{\text{sys}} \) in resting conditions and during adenosine induced hyperemia. No severe proximal coronary or ostial disease was present in any of the groups. Panels c and d express the Venturi-related pressure drop \( (P_{\text{rest}} - P_{\text{sys}}) \) under resting conditions and during sympathetic stimulation by dobutamine infusion. Although a small pressure drop is present at the level of the coronary ostium, no significant differences between the different valve orientations or between the different prostheses were observed.

4. Discussion

In this pilot study in 21 patients undergoing aortic valve replacement, only a negligible influence of different orientations of the BLP on coronary perfusion pressure was found. Moreover, coronary perfusion pressure was not different between mechanical and biological prostheses.

In our protocol we differentiated between resting conditions, maximal pharmacological coronary hyperemia, and maximal adrenergic stimulation in combination with maximal coronary hyperemia (to mimic maximum exercise in true life). Therefore, we measured pressures in the coronary artery and in the aortic root simultaneously with the pressure in the aortic arch. We are not aware of another way to measure coronary perfusion pressures more accurately.

Recently it has been suggested in acute animal experiments that coronary blood flow is affected by the orienta-

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Table 1: Preoperative patient characteristics

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>21</td>
</tr>
<tr>
<td>Male/Female</td>
<td>13/8</td>
</tr>
<tr>
<td>Age, years</td>
<td>63.7±8.4</td>
</tr>
<tr>
<td>Risk factors</td>
<td></td>
</tr>
<tr>
<td>Diabetes</td>
<td>3</td>
</tr>
<tr>
<td>Systemic hyperten.</td>
<td>10</td>
</tr>
<tr>
<td>Smoking</td>
<td>5</td>
</tr>
<tr>
<td>Cardiac rhythm</td>
<td></td>
</tr>
<tr>
<td>Sinus</td>
<td>19</td>
</tr>
<tr>
<td>Paced</td>
<td>1</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>1</td>
</tr>
<tr>
<td>Statins</td>
<td>9</td>
</tr>
<tr>
<td>ACE-inhibitors</td>
<td>7</td>
</tr>
<tr>
<td>Diuretics</td>
<td>10</td>
</tr>
</tbody>
</table>

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Table 2: Physiologic data during the measurements

<table>
<thead>
<tr>
<th>Category</th>
<th>BLP_A</th>
<th>BLP_B</th>
<th>Bio</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_{\text{ref}} ) (mmHg)</td>
<td>HR</td>
<td>( P_{\text{ref}} ) (mmHg)</td>
<td>HR</td>
</tr>
<tr>
<td>Rest</td>
<td>97 (25)</td>
<td>78 (26)</td>
<td>100 (19)</td>
<td>79 (23)</td>
</tr>
<tr>
<td>Adeno</td>
<td>89 (29)</td>
<td>84 (28)</td>
<td>92 (18)</td>
<td>89 (23)</td>
</tr>
<tr>
<td>10 dobu</td>
<td>99 (9)</td>
<td>77 (21)</td>
<td>95 (15)</td>
<td>83 (27)</td>
</tr>
<tr>
<td>20 dobu</td>
<td>100 (7)</td>
<td>90 (64)</td>
<td>94 (21)</td>
<td>104 (24)</td>
</tr>
<tr>
<td>30 dobu</td>
<td>95 (17)</td>
<td>106 (50)</td>
<td>85 (24)</td>
<td>122 (24)</td>
</tr>
<tr>
<td>40 dobu</td>
<td>98 (24)</td>
<td>124 (39)</td>
<td>82 (27)</td>
<td>129 (22)</td>
</tr>
</tbody>
</table>

Values are mean ± S.D.; APA, aortic valve area.
Fig. 2. Box-and-whisker plots for the pressure gradients representing ostial abnormalities ($P_{\text{ost}} - P_{\text{cur}}$) during resting conditions and during adenosine induced hyperemia (panel a and b). Box-and-whisker plots for the pressure gradients representing the velocity induced Venturi effect ($P_{\text{ao}} - P_{\text{root}}$) during resting conditions and during dobutamine induced adrenergic stimulus (panel c and d). BLP_A and BLP_B represent bi-leaflet prosthesis in orientation A and B; Bio represents bio-prosthesis.

4.1. Limitations

In this study we did not measure transvalvular pressure drop and the accompanying intra-myocardial compressive forces or microvascular resistance. To do so, simultaneous intra-ventricular pressure measurement would also have been mandatory, which for obvious reasons could not be performed. Furthermore, because accurate absolute flow measurement in coronary arteries is not possible in conscious humans neither invasively or non-invasively with MRI, we used coronary perfusion pressure as a surrogate of flow. This is justified because at maximum hyperemia resistance in the coronary circulation is minimal and constant and blood flow is directly proportional to perfusion pressure [7–9].
Finally, the number of patients in our study was small, but since the protocol was extensive we consider the number of patients in this pathophysiologic study sufficient, especially since the pressure differences we observed were small and clinically irrelevant.

5. Conclusion

In this study in 21 patients undergoing aortic valve replacement, only small non-significant differences in myocardial perfusion pressure were found between different orientations of a bi-leaflet prosthesis or between bi-leaflet prostheses and bio-prostheses.

References

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