Prosthetic-Patient Mismatch and Pressure Recovery: Clinical Implications for Aortic Valve Replacement

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Definition of Prosthetic-Patient Mismatch

Prosthesis-patient mismatch is a term used to describe the condition when the effective orifice area of a prosthetic valve is too small in relation to the size or age of an individual patient causing effective stenosis with an abnormally high transvalvular pressure gradient. This condition occurs because prosthetic heart valves are inherently stenotic relative to native cardiac valves. The diameter of the native aortic valve annulus typically limits the maximum size of the prosthetic valve that can be implanted. Prosthesis-patient mismatch is considered severe after aortic valve replacement if the $EOA_i \leq 0.65 \text{ cm}^2/\text{m}^2$, moderate if the $EOA_i$ is between 0.65 cm$^2$/m$^2$ and 0.85 cm$^2$/m$^2$, and not significant if the $EOA_i$ is $\geq 0.85 \text{ cm}^2/\text{m}^2$. Prosthesis-patient mismatch is considered significant after mitral valve replacement if the $EOA_i \leq 1.2 \text{ cm}^2/\text{m}^2$. ($EOA_i = EOA/BSA$, where $EOA_i$ is the indexed effective orifice area, $EOA$ is the effective orifice area of the prosthetic valve and $BSA$ is the body surface area of the patient in m$^2$).

Clinical Implications of Prosthetic-Patient Mismatching

Although still somewhat controversial, several clinical studies have provided evidence that implantation of a prosthetic valve that is sized too small for an individual patient with aortic stenosis has the potential to cause significant obstruction to flow. Several studies have shown that the hemodynamic consequences of flow obstruction caused prosthetic-patient mismatching increased the likelihood of mortality and cardiac complications after aortic valve replacement. Implantation of a stenotic prosthetic valve in the aortic position has also been shown to be associated with decreased ventricular mass regression after operation and an increased risk of premature bioprosthetic structural valve degeneration. Prosthesis-patient mismatch may be particularly important in patients with decreased left ventricular function because the increased load on the ventricle is less well tolerated in the presence of reduced left ventricular ejection fraction leading to an increased risk of early mortality or heart failure. In younger patients, prosthetic-patient mismatching, even if minor, may have a long term impact on ventricular function and remodeling caused by the increased load on the left ventricle over time. Because the transvalvular pressure gradient across a prosthetic valve is a function of cardiac output, prosthetic-patient mismatching may also be an important factor that determines the exercise capacity of patients who are physically active.

Intraoperative TEE provides an opportunity to measure the diameter of the native aortic valve annulus to estimate the size of a prosthetic valve that can be implanted. This information may help to predict the risk of prosthetic-patient mismatch. A limitation of
predicting prosthetic-patient mismatch is that the formula relies on accurate estimates of the effective orifice areas of each model and size of prosthetic valve. Furthermore, there is less population data (smaller sample size) on the effective orifice area for smaller prosthetic valve sizes that are more prone to prosthetic-patient mismatch. At present, the best guide to effective orifice areas for prosthetic valves come from composite values obtained from the medical literature (see Table below). The clinical evidence supporting the importance of prosthetic-patient mismatching rely on the ability to accurately determine the effective orifice areas of individual prosthetic valves of each size.

<table>
<thead>
<tr>
<th>Table 3 Normal reference values of EOAs* for prosthetic valves</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Valve type</strong></td>
</tr>
<tr>
<td>Medtronic Mosaic</td>
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<tr>
<td>Hancock II</td>
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<tr>
<td>Carpenter-Edwards Perimount</td>
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<tr>
<td>Stentless bioprosthetic valves</td>
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<tr>
<td>Medtronic Freestyle</td>
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<tr>
<td>St Jude Medical Toronto SPV</td>
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<tr>
<td>Prima Edwards</td>
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<tr>
<td><strong>Mechanical valves</strong></td>
</tr>
<tr>
<td>Medtronic-Hall</td>
</tr>
<tr>
<td>St Jude Medical Standard</td>
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<tr>
<td>St Jude Medical Regent</td>
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<tr>
<td>McGil On X</td>
</tr>
<tr>
<td>Carbomedics</td>
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<tr>
<td>Sorin Bicarbon</td>
</tr>
</tbody>
</table>

*Expressed as mean values available in the literature.

**From: Pibarot P and Dumesnil JG. Heart 2006;92:1022-1029**

If intraoperative TEE measurements detect a small aortic valve annulus prior to aortic valve replacement, operative options to decrease the risk of prosthetic-patient mismatch include supra-annular implantation of the prosthetic valve, choose a prosthetic valve model with more a favorable hemodynamic flow profile in relation to its annular dimension, perform aortic root enlargement to permit implantation of a larger prosthetic valve, or perform a root replacement.

**Definition of Pressure Recovery**

Pressure recovery is the term used to describe the variable increase in hydrostatic pressure downstream from a stenotic orifice due to the transfer of kinetic energy in the form of velocity back into potential energy in the form of static pressure. Doppler echocardiography estimates the transvalvular pressure gradient based upon the measurement of maximum blood flow velocity at the site of the vena contracta. Catheter-based measurement of the transvalvular pressure gradient obtained by cardiac catheterization is based on direct pressure measurements downstream from the site of stenosis. The phenomenon of pressure recovery predicts that Doppler-derived
transvalvular pressure gradients will be greater than catheter-based transvalvular
gradients. Therefore, quantification of aortic stenosis by Doppler echocardiographic will
be more severe compared to assessments made by cardiac catheterization.

\[
P_1 - P_2 = \text{Maximum pressure gradient} = 4(v_2^2) \quad \text{[Doppler-based]}
\]

\[
P_2 - P_3 = \text{Pressure recovery}
\]

\[
P_1 - P_3 = \text{Net pressure gradient [catheter-based]}
\]

From: Gjertsson P, et al. Am J Cardiol 2001;88:139-144

Blood flow velocity accelerates across a stenosis at the site of the vena contracta. Hydrostatic pressure decreases across a stenosis to a maximum at the site of maximum velocity, then increases downstream (pressure recovery).

**Clinical Implications of Pressure Recovery**

The severity of aortic stenosis has traditionally been graded based on the net transvalvular pressure gradient and the calculated aortic valve area (Gorlin equation) obtained from measurements during cardiac catheterization. Criteria for aortic stenosis based on cardiac catheterization defines aortic stenosis as severe when the aortic valve area is less than 1.0 cm\(^2\) and mean transvalvular pressure gradient is greater than 40 mm Hg and defines aortic stenosis as moderate when the aortic valve area is 1.0-1.5 cm\(^2\) and the mean transvalvular pressure gradient is between 25-40 mm Hg. Because of pressure
recovery, Doppler-based estimation of transvalvular pressure gradient using the Bernoulli equation may yield greater mean transvalvular pressure gradients than that measured by cardiac catheterization in the same patient leading to discrepancy in the estimation of the severity of aortic stenosis in an individual patient. Similarly, pressure recovery predicts that Doppler-based estimation of aortic valve area using the continuity equation will also yield a smaller aortic valve area compared to catheter-based measurements in the same patient. The differences between Doppler- and catheter-based quantification of aortic stenosis become important when aortic valve areas are near the classification thresholds of 1 cm\(^2\) or 1.5 cm\(^2\) or when mean transvalvular pressure gradients are near 25 mm Hg or 40 mm Hg because small differences in the value of these measurements determine whether the severity of aortic stenosis is classified as mild, moderate, or severe. For this reason, it is important to understand the factors that may affect the magnitude of pressure recovery when comparing Doppler and catheter-derived assessments of the severity of aortic stenosis.

Factors that affect the magnitude of pressure recovery in aortic stenosis include transvalvular flow, density of blood, the severity of stenosis, the diameter of the ascending aorta, and shape of the stenosis. Based on theoretical, experimental and clinical studies, the magnitude of pressure recovery has the following relationships: 1) Pressure recovery varies directly with transvalvular flow or cardiac output, i.e. higher blood flow increases pressure recovery, 2) Pressure recovery varies indirectly with the severity of aortic stenosis, i.e. pressure recovery is greater at an aortic valve area of 1 cm\(^2\) compared to an aortic valve area of 0.5 cm\(^2\), 3) Pressure recovery is less at larger aortic diameters and may be negligible when the ascending aortic diameter exceeds 3 cm, and 4) Pressure recovery is greater for long, tunnel-shaped stenoses.

Pressure recovery has also been demonstrated to explain differences in catheter-measured and Doppler-derived transvalvular pressure gradients across prosthetic heart valves. For example, the different geometric shapes of the central and side orifices of bileaflet prosthetic valves would be expected to cause different velocity patterns and degrees of pressure recovery. Doppler-derived pressure gradients were greater than catheter-based gradients across bileaflet prosthetic valves. Differences between the Doppler-derived and catheter-based pressure gradients were greatest using centerline velocity measurement through the central orifice of the bileaflet valve. For this reason, Doppler based measurements may overestimate the severity of stenosis across bileaflet prosthetic valves if based on velocity measurements through the central orifice where pressure recovery is greater.

**Conclusion**

Understanding the concept of pressure recovery and other factors that may contribute to discrepancies between Doppler-based echocardiographic and catheter-based estimation of the valve area and transvalvular pressure gradients is important for assessing and quantifying the severity of aortic stenosis for clinical decision making. In addition to quantification of aortic valve area and the transvalvular pressure gradient, it is also important to consider clinical symptoms, left ventricular function, the size of the aortic
valve annulus, patient age, and the rate of disease progression in the decision to replace a stenotic aortic valve. Because the echocardiographic criteria based on Doppler measurement of blood flow velocities alone are being used increasingly for the primary diagnosis of valve stenosis it is important to understand how these measurements compare to traditional catheter-based assessments of the severity of aortic stenosis.

Selected References: