JACC: CARDIOVASCULAR IMAGING
VOL. 4, NO. 10, 2011
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ISSN 1936-878X/$36.00
PUBLISHED BY ELSEVIER INC.
DOI:10.1016/j.jcmg.2011.08.004

EDITORIAL VIEWPOINT

Avoiding Patient–Prosthesis Mismatch

Is TAVI a New Solution?*

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Conservation of mass is the principle behind the continuity equation (1–3), used commonly for calculation of aortic valve area (AVA) in native aortic stenosis and prosthetic valves. Utilizing 2-dimensional echocardiographic and Doppler data, this equation is the preferred technique to evaluate native and prosthetic valve stenosis. Although there is a body of literature regarding surgically implanted aortic valve replacements (sAVR), data on the hemodynamic profile of the new transcatheter aortic valve implantation (TAVI) technique are still scarce. The structure of these valves differs significantly from sAVR, and may offer hydrodynamic advantages for a subgroup of patients.

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Following nicely in the Hatle legacy (1), the interesting study by Clavel et al. (4) in this issue of *iJACC* used velocity and imaging data to calculate the effective valve orifice area by Doppler echocardiography in patients after TAVI. They compared 2 methods of calculating AVA and found it to be preferable to measure the left ventricular outflow tract (LVOT) diameter proximal to, rather than within, the prosthesis stent. This method was superior because it correlated better with the gradient data (based on the simplified Bernoulli equation) and had lower interobserver and intraobserver variation.

The methodology may seem self-evident. It makes sense to measure the annular diameter in the same location where the pulsed Doppler velocity was measured, with the sample volume 0.5 to 1.0 cm below the leaflets of the TAVI. However, their paper underlines the importance of exacting methodology and also illustrates again the hemodynamic advantages of TAVI.

Four questions arise from the data presented by Clavel et al. (4):

1. Is it accurate to measure AVA with Doppler echocardiography in patients with TAVI?
2. Does the size of the prosthesis make a difference in outcome?
3. Do aortic valve area index (AVAI) measurements differ between TAVI and AVR?
4. How should the AVAI calculations after TAVI or AVR affect our decisions in management of patients presenting with native aortic stenosis?

Methods of measuring AVAI in prosthetic valves, a tale of apples and oranges. Continuous-wave Doppler can be used to derive prosthetic valve gradients, but the results are often higher than invasively derived gradients. Because normal and stenotic prostheses are difficult or dangerous to cross, with some perceived risk of valve damage, catheter gradients in prosthetic valves are difficult to record optimally. Invasive aortic valve gradients (AVG) in most catheterization laboratories are peak-to-peak gradients recorded from pullback of 1 catheter across the aortic valve (5), a far different entity than the peak instantaneous gradient, which is the one to which the peak velocity obtained by continuous-wave Doppler is equivalent. In addition, the "pressure recovery" phenomenon, also called the "airplane wing" effect (6,7), causes the aortic pressure to rise within a few centimeters downstream of its low point immediately above the valve. Doppler, therefore, records a higher valvular velocity and derives a higher maximum gradient than would be obtained by the ideal invasive pressure

*Editorials published in *JACC: Cardiovascular Imaging* reflect the views of the authors and do not necessarily represent the views of *JACC: Cardiovascular Imaging* or the American College of Cardiology.

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JACC: CARDIOVASCULAR IMAGING, VOL. 4, NO. 10, 2011
OCTOBER 2011:1063–6

recording, which would be a dual transducer set-up, with a multiholed catheter in the left ventricle (LV) derived by a trans-septal approach, and another in the aorta very close to the aortic side of the prosthesis. Discrepancies based on pressure recovery are more pronounced in smaller prosthetic valves with high flow (8). Calculation of AVA in prosthetic valves by the continuity equation takes into consideration the upstream velocity and diameter measurements, the site of which are of critical importance, as demonstrated by Clavel et al. (4).

Doppler-derived measurements are plainly the method of choice because of their noninvasive nature, reproducibility, and clinical importance. Though changes in cardiac output and heart rate still cause some variability, Doppler-derived AVA measurements are useful for comparing the function of a patient's prosthesis with others of the same type and size, and in comparison with the patient's own baseline recordings done on earlier visits.

Prosthetic AVA in sAVR is easy to calculate by Doppler and is reproducible. However, it has been underutilized, partly because the data obtained, even in a normal newly implanted AVR, are often unsettling. Although it has long been recognized that prosthetic valves are inherently stenotic, the degree of this stenosis is often surprising. The high maximum velocities often cause a low calculated AVA. Particularly in the case of small-size (19 or 21 mm) prostheses, the AVA is often not much higher and AVG is not much lower than that obtained on the patient's native stenotic valve prior to surgery. Thus, many echocardiographic laboratories have been reluctant to report AVA in patients with sAVR. Reproducibility of measurements, of practical importance when AVA is used for serial follow-up, is shown to be good in the current study from Clavel et al. (4).

In prosthetic valves, size matters. Numerous published series of patients with sAVR have found a substantial effect on outcome of valve area indexed by body surface area (BSA), abbreviated as AVAI. In particular, adverse clinical outcomes have been found for patients with small aortic annular diameter, large body surface area, poor LV function, and higher cardiac output requirements. Patients with sAVR whose post-operative AVAI is <0.65 cm^2/m^2 have been considered to have severe "patient–prosthesis mismatch" (PPM), which is associated with decreased survival, increased complications, and less regression in LV hypertrophy, compared with those with higher AVAI (9–15). The American Society of Echocardiography recommends predicting the risk of PPM pre-operatively (16). Based on the patient's annular size, reference data on AVA for whichever type of surgical prosthesis is anticipated, and the patient's BSA, the expected AVAI can be easily predicted. When that predicted AVAI is low, alternative options should be considered, though each has advantages and disadvantages (Table 1).

Table 1. Alternatives to a Stented Aortic Prosthesis in Patients at Risk for PPM

Procedure	Potential Disadvantages
Stentless bioprosthesis	Increased surgical difficulty and periop risk Involves root surgery + coronary reimplantation
AVR homograft	Increased surgical difficulty and periop risk Involves root surgery + coronary re-implantation Calcified aortic root hinders reop surgery later
Stented AVR with an aortic root widening procedure at initial operation	Increased surgical difficulty and periop risk More heart block, pacemakers
TAVI	Increased regurgitation, strokes Uncertain long-term durability

AVR = aortic valve replacement; periop = perioperative; PPM = patient–prosthesis mismatch; reop = reoperative; TAVI = transcatheter aortic valve implantation.

Some research concludes that prosthesis size after sAVR does not affect outcome significantly. Using the manufacturer's stated size, and following large groups of patients with various valve sizes over time, Blackstone et al. (17) and Koch et al. (18) found no differences in outcome between prosthetic valve sizes.

The hemodynamics of TAVI are better than sAVR. In Clavel et al. (4), the average effective AVA (not indexed) for a patient with an aortic annulus of 19-mm diameter having TAVI was 1.37 cm^2, whereas the average post-operative effective AVA of 19-mm sAVR valves, according to previous publications, averages 1.1 cm^2 (13). In a sample patient with a BSA of 1.7 m^2, the AVAI after sAVR with a 19-mm stented bioprosthesis would likely be 0.65 cm^2/m^2, representing severe PPM. If the same patient was treated with TAVI, the AVAI would be 0.81 cm^2/m^2, which is in the high moderate, almost mild range of PPM, at much lower risk of adverse outcomes.

The better hemodynamics of TAVI are consistent with data from cohort A of the PARTNER (Placement of AoRTic TraNscathetER Valve) trial, recently presented by Smith et al. (19). Among all patients randomized to TAVI, including prostheses of all sizes, the AVA estimated by Doppler 1 year after the procedures averaged 1.6 cm^2, higher than the mean AVA in patients randomized to sAVR, which was 1.4 cm^2. Similarly, including prostheses of all sizes, patients randomized to TAVI had a mean AVG of 10.2 mm Hg, significantly lower

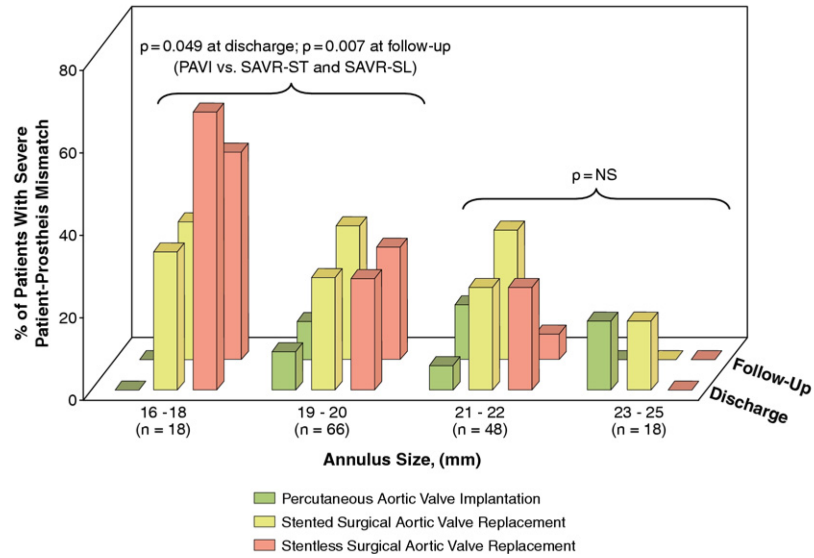

Figure 1. Incidence of Severe PPM in the 3 Aortic Bioprosthesis Groups

Prosthesis–patient mismatch (PPM) is shown at hospital discharge and at follow-up according to the aortic annulus size. Percutaneous aortic valve implantation (PAVI) is indicated by the **green bars**. Surgical aortic valve replacement–stentless valve (SAVR-SL) is indicated by the **yellow bars**. Surgical aortic valve replacement–stented valve (SAVR-ST) is indicated by the **pink bars**. Reproduced, with permission, from Clavel et al. (20).

than those randomized to sAVR, in whom the mean AVG was 11.5 mm Hg (19).

A previous article, also first authored by Clavel (20), compared the gradients and AVAI of patients with TAVI or sAVR, in groups matched for gender, aortic annulus diameter, LV ejection fraction, BSA, and body mass index. In that study, similar to the aforementioned trial, TAVI patients had better hemodynamics than sAVR, with smaller average gradients (10 mm Hg vs. 13 mm Hg) and larger AVAI (1.50 cm^2/m^2 vs. 1.33 cm^2/m^2), averaging all valve sizes.

The finding of larger AVA and lower AVG after TAVI compared with sAVR may reflect less material between the valve orifice and the patient's annulus. On the other hand, this finding is surprising, because the process of TAVI does not involve removal of the native aortic leaflets, as occurs in sAVR, which could theoretically influence AVA in the opposite direction.

Optimal management of patients with aortic stenosis and small aortic annulus diameter based on predicted AVAI. The improvement in hemodynamics of TAVI over sAVR, though small, may be sufficient to reduce the risks of adverse cardiac events, if the long-term outcome of TAVI follows what has been published comparing different sizes of sAVR.

In the article published in this issue by Clavel et al. (4), patients treated with TAVI showed a lower incidence of PPM (9%) than the 20% to 80% incidence in similar reported populations of surgical AVR with severe native aortic stenosis and similar annulus size (10–13). In the previously mentioned study of matched sAVR and TAVI groups, also by Clavel et al. (20), there was also a lower incidence of PPM (6%) compared with the sAVR group (28%) (Fig. 1).

TAVI also has some disadvantages, including a higher incidence of moderate or severe regurgitation (7.1% at 1 year vs. 1.9% for sAVR), especially periprosthetic leaks (19), which is unclear in its clinical significance (21). TAVI also had a higher risk of stroke or vascular trauma than sAVR in the PARTNER A data. On the other hand, greater bleeding and atrial fibrillation are reported in sAVR than in TAVI (19).

Conclusions

The Doppler echocardiographic methodology for measuring AVAI in percutaneous valves is able to achieve reproducible results that will help in comparing the hemodynamic effects of TAVI with various types of surgical valve prostheses. Neglected for many years, the problem of PPM is like putting a small nozzle on the end of a large-diameter fire hose. Especially in patients with small aortic annular size, there are important and avoidable risks. Though not perfect, TAVI represents a new option to solve this dilemma. Proactive decisions between the choices listed in Table 1 should be considered. Although no published data document the clinical outcome of TAVI in patients who would have PPM if treated with sAVR, future trials using the methodology of Clavel et al. (4) may help to answer these important clinical questions.

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Key Words: aortic stenosis ■ Doppler aortic valve area ■ prosthesis-patient mismatch ■ transcatheter aortic valve implantation.