Evaluation and Management of Paravalvular Aortic Regurgitation After Transcatheter Aortic Valve Replacement

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Paravalvular aortic regurgitation (PAR) negatively affects the prognosis after transcatheter aortic valve replacement (TAVR) with dramatically increased morbidity and mortality in patients with more than mild PAR. Because transcatheter heart valves are implanted in a sutureless fashion using oversizing to anchor the prosthesis stent frame at the level of the virtual aortic annulus, stent frame underexpansion due to heavily calcified cusps, suboptimal placement of the prosthesis, and/or annulus-prosthesis-size mismatch due to malsizing can contribute to paravalvular leakage. In contrast to open heart surgery, TAVR does not offer the opportunity to measure the aortic annulus under direct vision during the procedure. Therefore, the dilemma before each TAVR procedure is the appropriate sizing of the dimensions of the aortic annulus and to choose not only the size but also the transcatheter heart valve type (self-expanding vs. balloon-expandable) that fits the given anatomy best. Because precise echocardiographic quantification of PAR in patients with TAVR remains challenging especially in the acute implantation situation, a multimodal approach for the evaluation of PAR with the use of hemodynamic measurements and imaging modalities is imperative to precisely quantify the severity of aortic regurgitation immediately after valve implantation and to identify patients who will benefit from corrective measures such as post-dilation or valve-in-valve implantation. Every measure has to be taken to prevent or reduce PAR to provide a satisfying long-term clinical outcome.

Transcatheter aortic valve replacement (TAVR) has become an alternative to surgical aortic valve replacement for inoperable or surgical high-risk patients with severe aortic stenosis and prohibitive surgical risk (1,2). Transcatheter heart valves (THVs) are implanted in a sutureless fashion using oversizing to anchor the prosthesis stent frame at the level of the aortic annulus. Therefore, incomplete circumferential apposition of the prosthesis with the annulus might lead to paravalvular aortic regurgitation (PAR). Because PAR negatively affects the prognosis after TAVR with dramatically increased morbidity and mortality in patients with more than mild PAR (3–16), this procedure-related issue has to be addressed to further improve the outcome of patients after TAVR (3–5).

This paper reviews the evaluation of significant PAR in patients with TAVR with a focus on precise quantification and therapeutic options to manage PAR after TAVR.

Background

Anatomy of the aortic valve. Precise assessment of the dimensions of the aortic valvular complex is fundamental before each TAVR procedure. Although the concept of an annulus is ingrained in the surgical vocabulary, the aortic root is not constructed on the basis of a ring-like structure supporting the leaflets of the aortic valve. The true histological ventricular–aortic junction, which is circular but crossed by the semilunar attachments of the leaflets of the aortic valve in a crown-like fashion (the “surgical” annulus) within the cylindrical aortic root, cannot be seen on multi-slice computed tomography or other noninvasive imaging modalities (17,18). Therefore, the so-called aortic annulus is defined as a virtual ring that has three anchor points at the nadir of each of the attachments of the aortic cusps (Fig. 1). This virtual aortic annulus is mostly noncircular and often may have an oval or elliptical shape (17–22).
Paravalvular Aortic Regurgitation

PAR results from incomplete circumferential apposition of the prosthesis with the annulus. Discordance in the orthogonal diameters of oval-shaped annuli with the circular prosthesis leads to prosthetic undersizing or oversizing, a cause of significant PAR or annular rupture (21). Degenerative calcification of the native aortic valve (e.g., severely calcified cusp) causes PAR through mal-apposition of the skirt with the annulus or displacement of the prosthesis into a high or low position within the aortic root (6,22). It may hamper proper positioning of the THV and contribute to the occurrence of significant PAR after TAVR (23).

Another risk factor for PAR is a functional bicuspid aortic valve, which is predominantly caused by fusion of the commissures as a consequence of heavy calcification that may preclude the expansion of the prosthesis and full apposition of the THV with the annulus. On a compassionate off-label basis, early results of TAVR for bicuspid aortic valve stenosis seem promising, and most cases of PAR are mild (24–26). However, the long-term impact of noncircular prosthesis expansion on hemodynamics and durability of the THV has to be elucidated before TAVR can be recommended in patients with bicuspid aortic stenosis.

Clinically significant acute AR is characterized by a considerable diastolic runoff into the left ventricle (LV) leading to acute volume overload, which has a disastrous effect, especially in patients with severely impaired left ventricular function: The noncompliant, hypertrophic LV, which has been adapted to chronic pressure overload, is unable to increase the end-diastolic volume, so that the left ventricular end-diastolic pressure (LVEDP) increases rapidly with consecutive decrease of cardiac output leading to hemodynamic deterioration (27,28).

Several studies have shown that up to 70% of all patients with TAVR have PAR after the procedure, graded as moderate or severe in approximately 15% of the patients (Table 1). Meanwhile, it is well recognized that the occurrence of more than mild PAR has a significant impact on prognosis after TAVR with a two- to four-fold increased 1-year mortality risk compared with patients without clinically significant PAR (6–16). In 3,195 patients of the prospective FRANCE-2 (French Aortic National Core-Valve and Edwards Registry 2) TAVR registry, the investigators observed that patients with a more than mild PAR had a 2.5-fold increased mortality risk compared with patients without PAR or with only mild PAR (11). The 2-year results of the PARTNER (Placement of Aortic Transcatheter Valves) Trial cohort A (10) even suggested that a lesser extent of PAR may be harmful for patients with TAVR. Therefore, the precise quantification of the severity of AR immediately after valve implantation (within the catheterization laboratory) is paramount to identify patients with clinically significant PAR.

Imaging Before and After TAVR

In contrast to open heart surgery, TAVR does not offer the opportunity to measure the aortic annulus under direct vision during the procedure. Therefore, the dilemma before each TAVR procedure is the appropriate sizing of the dimensions of the aortic annulus and to choose not only the size but also the THV type (self-expanding vs. balloon-expandable) that fits the given anatomy best.
Table 1: Incidence of Moderate/Severe PAR After TAVR

<table>
<thead>
<tr>
<th>First Author (Ref. #)</th>
<th>Patients</th>
<th>EuroSCORE</th>
<th>Access Route</th>
<th>THV Type</th>
<th>PAR Rate</th>
<th>Assessed by</th>
<th>Mortality for More Than Mild PAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdel-Wahab et al. (8)</td>
<td>690</td>
<td>20.4 ± 13.1</td>
<td>92.4% TF, 3.5% TA</td>
<td>84.3% CV (Medtronic Inc., Minneapolis, Minnesota), 15.7% ES (Edwards Lifesciences Corporation, Irvine, California)</td>
<td>17.2%</td>
<td>Angiography</td>
<td>NA</td>
</tr>
<tr>
<td>Leon et al. (1)</td>
<td>179</td>
<td>26.4 ± 17.2</td>
<td>100% TF</td>
<td>100% ES</td>
<td>15.2%</td>
<td>Echocardiography</td>
<td>NA</td>
</tr>
<tr>
<td>Tamburino et al. (9)</td>
<td>663</td>
<td>23.0 ± 13.7</td>
<td>90.3% TF, 9.7% TS</td>
<td>100% CV</td>
<td>21.0%</td>
<td>Echocardiography</td>
<td>NA</td>
</tr>
<tr>
<td>Smith et al. (2)</td>
<td>348</td>
<td>29.3 ± 16.5</td>
<td>70.1% TF, 29.9% TA</td>
<td>100% ES</td>
<td>13.1%</td>
<td>Echocardiography</td>
<td>NA</td>
</tr>
<tr>
<td>Moat et al. (12)</td>
<td>870</td>
<td>18.5 (11.7-27.9)</td>
<td>68.9% TF, 26.4% TA</td>
<td>52.0% CV, 48.0% ES</td>
<td>13.6%</td>
<td>Angiography</td>
<td>NA</td>
</tr>
<tr>
<td>Sinning et al. (6)</td>
<td>146</td>
<td>30.2 ± 18.0</td>
<td>91.8% TF, 8.2% ES</td>
<td>100% CV</td>
<td>15.1%</td>
<td>Echocardiography, angiography, hemodynamics</td>
<td>30-day: 22.7%, 1-yr: 63.6%</td>
</tr>
<tr>
<td>Gilad et al. (11)</td>
<td>1,915*</td>
<td>21.9 ± 14.3</td>
<td>73.9% TF, 17.7% TA</td>
<td>66.9% ES, 33.1% CV</td>
<td>16.5%</td>
<td>Echocardiography</td>
<td>NA</td>
</tr>
<tr>
<td>Gotzmann et al. (16)</td>
<td>198</td>
<td>22.0 ± 16.0</td>
<td>97.5% TF, 2.5% TS</td>
<td>100% CV</td>
<td>14.1%</td>
<td>Echocardiography, hemodynamics</td>
<td>30-day: 21.0%, 1-yr: 57.0%</td>
</tr>
<tr>
<td>Vasa-Nicloreta et al. (34)</td>
<td>122</td>
<td>22.4 ± 13.0</td>
<td>97.5% TF, 1.7% TA</td>
<td>79.5% CV, 20.5% ES</td>
<td>16.4%</td>
<td>Echocardiography, angiography, hemodynamics</td>
<td>30-day: 30.0%, 1-yr: 60.0%</td>
</tr>
<tr>
<td>Hayashi et al. (15)</td>
<td>400</td>
<td>22.3 (17.1-30.3)</td>
<td>NA</td>
<td>86.8% ES, 13.2% CV</td>
<td>3.0%</td>
<td>Echocardiography</td>
<td>NA</td>
</tr>
</tbody>
</table>

*In 1,915/3,195 patients, PAR was assessed after the TAVR procedure.

euroSCORE = European System for Cardiac Operative Risk Evaluation; CV = CoreValve; ES = Edwards SAPIEN; NA = not available; PAR = paravalvular aortic regurgitation; TA = transapical; TF = transfemoral; THV = transcatheter heart valve; TS = trans-subclavian.
reasons: 1) the acute hemodynamic changes that occur during TAVR affect Doppler and color flow assessment; 2) semiquantitative parameters of AR severity, such as jet width, vena contracta, or pressure half-time, are best applied in central jets and thus are not ideal for quantification of the eccentric, circumferential PAR jets seen in patients with TAVR; and 3) acoustic shadowing by the prosthesis and native calcification also may obscure PAR jets. Given these quantitative limitations, TEE screening criteria include a jet depth extending beyond the left ventricular outflow tract (LVOT), multiple PAR jets, and holodiastolic flow reversal in the descending aorta (37). Prominent holodiastolic flow reversal in the descending aorta identifies patients with more than mild PAR with a sensitivity of up to 86% and rules out significant PAR with a specificity of up to 92% (p < 0.001) (6,13). In addition, it is desirable to measure the circumferential extent of the jet in the short-axis view in patients with clinically significant PAR (<10%: mild, 10% to 29%: moderate, and ≥30%: severe PAR) (37). However, it is important to realize that at this time, the body of evidence supporting these criteria for the assessment of paravalvular AR may be limited and requires further validation in patients with THV as our experience continues to expand.

 Nonetheless, TEE has an essential role in defining the origin and mechanism of PAR. The jets of transvalvular AR are easy to differentiate from PAR, lying within the circumference of the prosthetic stent frame (Fig. 2A, Online Video 1). The valve leaflets should be assessed to determine whether there is structural damage causing transleaflet AR, intact leaflets with insufficient diastolic pressure to close them, or central leaflet malapposition related to the prosthetic design or tissue. Malapposition paravalvular AR jets occur outside the circumference of the prosthetic stent frame. These jets are caused by incomplete apposition between the prosthesis and the annulus because of heavy calcification or underexpansion of the prosthesis (Fig. 2B, Online Video 2). TEE assessment of prosthetic geometry (circular or noncircular) (Fig. 2C) and in vivo diameter may be required to guide treatment (Fig. 2D).

 Furthermore, malposition PAR jets may occur across the stent frame, when the prosthesis is implanted in too low or too high a position relative to the native annulus. In the low implant (“too ventricular”), the prosthesis is deployed at a depth that exceeds the height of its tissue skirt; the PAR jet passes above the skirt (“supra-skirt” PAR), from within the aortic portion of the stent frame into the paravalvular space and the LVOT (Fig. 2E, Online Video 3). In the high implant (“too aortic”), the prosthesis is deployed partially above the native annulus; the PAR jet passes from the paravalvular space across the irregular inflow edge of the

Figure 2 Origin and Mechanism of Paravalvular Aortic Regurgitation (PAR)

Transesophageal echocardiography (TEE) long-axis view of Edwards SAPIEN (Edwards Lifesciences Corporation, Irvine, California) 23-mm prosthesis with both transvalvular AR and PAR (A, Online Video 1). PAR after deployment of an Edwards SAPIEN XT 26-mm prosthesis because of malapposition with the left annulus. The device was not co-axial to the root (B, Online Video 2). TEE short-axis view of underexpanded oval-shaped waist of a Medtronic CoreValve 29-mm prosthesis (Medtronic Inc., Minneapolis, Minnesota) (C). TEE long-axis view of an Edwards SAPIEN XT 26-mm prosthesis with diameters of 24 to 26 mm indicating reasonable expansion in the presence of PAR (D). Color 3-dimensional TEE of malposition PAR after low implantation of a Medtronic CoreValve prosthesis. The PAR jet passes from within the aortic portion of the stent frame above the tissue skirt (“supra-skirt” PAR) into the paravalvular space and LVOT (E, Online Video 3). TEE of malposition PAR after the high implantation of a Medtronic CoreValve 29-mm prosthesis. The posterior PAR jet passes from the aortic sinus below the tissue skirt (“infra-skirt” PAR) into the LVOT where the irregular inflow edge rises above the native annulus (F, Online Video 4). AR = aortic regurgitation.
prosthesis into the LVOT (“infra-skirt” PAR) (Fig. 2F, Online Video 4).

**Hemodynamic Assessment During TAVR**

Because an objective and quantitative parameter for the direct assessment of the severity of PAR during the procedure would be invaluable in patients with TAVR to apply effective measures to reduce the severity of PAR, the use of hemodynamic parameters for a quantitative evaluation of PAR seems to be useful. The so-called aortic regurgitation index (ARI) is the ratio of the transvalvular gradient between diastolic blood pressure ($R_{dia}$) in the aorta and LVEDP to systolic blood pressure ($R_{sys}$) in the aorta: \[\frac{(R_{dia} - LVEDP)}{R_{sys}} \times 100\] (Figs. 3A and 3B) (6). The ARI was developed in a cohort of TAVR patients from Bonn, Germany, and was validated in an independent TAVR cohort from Leicester, United Kingdom (6,13). The ARI shows an inverse correlation to the severity of PAR; differentiates between patients with mild, moderate, or severe PAR; and independently predicts the associated 1-year mortality risk. In both cohorts, an ARI cutoff value of 25 was calculated by receiver operating curve analysis as the optimal predictor of the 1-year mortality risk after TAVR.

In addition, this ARI cutoff value had a negative predictive value of 95% to 100% for the occurrence of more than mild PAR, when used complementary to the angiographically or echocardiographically assessed PAR severity (6,13). Although the ARI does not consider the severity of pre-procedural AR and concomitant mitral regurgitation, it is a helpful tool to identify patients after TAVR with the need to take effective corrective measures to decrease the severity of PAR. Another study on the impact of PAR on long-term outcome recently confirmed that the ARI significantly differed between patients with moderate/severe PAR compared to patients with no or mild PAR (16). However, the ARI still has to be validated in a larger and controlled study population.

When evaluating hemodynamics after TAVR with the dimensionless ARI, it is recommended to perform the measurements approximately 10 min after valve deployment to prevent confounding by an increased LVEDP due to myocardial ischemia and/or diastolic dysfunction after rapid pacing and balloon valvuloplasty. The determination of the ARI should be performed as mean value over several cardiac cycles (especially in patients with atrial fibrillation) with a heart rate of 60 to 80 beats/min and without extrasystolic beats, because with increasing heart rate and shortened duration of the diastole, the diastolic pressure in the aorta also increases and thereby might lead to a false-negative ARI above the cutoff of 25.

**Treatment Options to Reduce PAR**

Several corrective measures have been proposed to overcome significant residual PAR after TAVR. However, data on these measures predominantly originate from small series or case reports, and the impact of corrective measures for the reduction of PAR on long-term outcome and especially valve durability still has to be clarified in future studies (39–45).

A standardized algorithm with a multimodal approach might be helpful for the evaluation of PAR after TAVR to: 1) quantify the severity of AR immediately after valve implantation (within the catheterization laboratory); 2) evaluate the hemodynamic tolerability of PAR with regard to the prognosis after TAVR, and 3) identify patients who will benefit from corrective measures, such as post-dilation or valve-in-valve implantation to reduce PAR and improve outcome (Fig. 4). After valve deployment, the degree of PAR can be assessed by aortic root angiography or echocardiography. If no PAR is present, no measures have to be taken. In all other cases with mild to severe PAR, the determination of the ARI is helpful to more precisely quantify the extent of PAR and to have a point of reference before corrective measures are taken. In patients with more-than-mild PAR and/or an ARI <25, the evaluation of PAR by echocardiography, preferably TEE, is recommended to elucidate the cause of PAR and its mechanism. When corrective measures have been taken in patients with...
Figure 4 - Treatment Algorithm for PAR After TAVR

Treatment algorithm using a multimodal approach with the use of hemodynamic measurements and imaging modalities to quantify the severity of PAR during the TAVR procedure and to identify patients who will benefit from corrective measures. AR = aortic regurgitation; TEE = transesophageal echocardiography; TTE = transthoracic echocardiography.

Figure 5 - Balloon Post-Dilation

Underexpansion of a CoreValve 29-mm prosthesis frame caused by a severely calcified cusp (A) resulted in moderate PAR with an eccentric jet near the left coronary cusp in aortic root angiography (B, arrows show eccentric AR jet) and an ARI of 20.8 (C). Post-dilation with a straight 28-mm valvuloplasty balloon (D) led to a satisfying procedural result with only mild PAR (E) and increased the ARI to 31.8 (F). AR = aortic regurgitation.
Deep ("too ventricular") implantation of a CoreValve 31-mm prosthesis (A) led to severe PAR in aortic root angiography (B, arrows show supra-skirt PAR) and an ARI of 14.3, reflecting unfavorable hemodynamics (C). After implantation of a second CoreValve 31-mm prosthesis in valve-in-valve-technique, which was delivered 5 mm higher than the first CoreValve under TEE control (D), only trivial PAR was left in angiography (E), and the ARI increased from 14.3 to 45.8, indicating a good procedural result (F). Abbreviation as in Figure 5.

Deep implantation of a CoreValve prosthesis (left coronary cusp: 13.2 mm; noncoronary cusp: 12.3 mm) resulted in severe "supra-skirt" PAR (A, B) with beginning equalization between the diastolic blood pressure in the aorta and the left ventricular end-diastolic pressure (LVEDP), resulting in an ARI of 16.0 (C). TEE showed the circumferential extent of massive paravalvular leakage (D). Via left-sided transbrachial access, the CoreValve prosthesis was pulled into a more favorable position (left coronary cusp: 4.2 mm; non-coronary cusp: 2.6 mm) with use of an Amplatz (AGA Medical Corp., Plymouth, Minnesota) gooseneck snare catheter (E), resulting in an ARI of 32.1 (F) without evidence of residual PAR (E). Abbreviation as in Figure 5.
clinically significant PAR, the severity of PAR can be re-evaluated by imaging modalities and the AR index.

**Balloon Post-Dilation**

The presence of severely calcified cusps of the native aortic valve might prevent complete apposition of the prosthesis with the annulus leading to a typical eccentric AR jet (Fig. 5). Several studies identified a higher degree of native aortic valve calcification as a predictor of more than mild PAR (22,46). Balloon post-dilation is an option to reduce the degree of PAR by obtaining a better expansion of the prosthesis stent frame and a better sealing of the paravalvular space if the THV has been deployed at the correct implantation depth (6,26,40–43,45,47). Post-dilation is also the treatment option of choice for patients with frame underexpansion as the reason for severe PAR that can occur in rare cases—despite predilation of the native aortic valve—with the use of self-expanding THVs (48).

The size of the balloon for post-dilation should conform to the aortic annulus dimension and not exceed the maximum diameter of the native aortic valve. For the Medtronic CoreValve prosthesis (Medtronic Inc., Minneapolis, Minnesota), a straight valvuloplasty balloon with a maximum diameter of 22, 25, 28, and 29 mm is recommended for the 23-, 26-, 29-, and 31-mm CoreValve, respectively (6). For the Edwards SAPIEN prosthesis (Edwards Lifesciences Corporation, Irvine, California), balloon post-dilation should be performed with the same balloon as used for delivery of the valve prosthesis stepwise adding 1 ml saline to the total volume to increase its diameter (43). In a recent study, THV oversizing after deployment by post-dilation did not lead to leaflet malapposition with consecutive central AR (15,43).

**Valve-in-Valve Implantation**

Accurate positioning of the THV with respect to the native aortic annulus is critical to ensure a successful procedure, whereas suboptimal deployment can result in incomplete apposition of the valve and annulus or even worse in incomplete sealing by the pericardial skirt of the stent frame allowing a considerable diastolic backflow into the LV. For malpositioned THVs with too shallow (“too aortic”) or too deep (“too ventricular”) implantation of the prosthesis, valve-in-valve implantation is a viable treatment strategy to reduce significant PAR and to prevent bailout cardiac surgery (Fig. 6). The second valve can be deployed in a way that the sealing pericardial skirts of both valves overlap and that the second valve ensures sealing with the native valve annulus (44). Thus, initial procedural failure can be converted into procedural success in up to 90% of the attempts, and valve-in-valve implantation results in comparable hemodynamic

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**Figure 8 Interventional Closure of Paravalvular Leakage**

Despite balloon post-dilation and oversizing with a straight 22-mm valvuloplasty balloon, moderate AR due to incomplete circumferential apposition of an Edwards SAPIEN 23-mm prosthesis with the annulus caused by a severely calcified cusp (A, B) remained 2 months after implantation of this accurately sized prosthesis with proper implantation depth and showed an unfavorable ARI of 21.7 (C). TEE was used to identify the PAR pathomechanism and identified the localized paravalvular leak (D). Passage of the paravalvular defect was obtained with use of a straight hydrophilic wire over a diagnostic 4F Judkins right coronary catheter, avoiding crossing through the stent struts of the Edwards SAPIEN prosthesis. Before insertion of the 9F delivery sheath, the THV was secured by transvalvular insertion of an Amplatz Super Stiff wire via a 5F pigtail catheter placed in the LV to control the Edwards SAPIEN prosthesis in case of dislodgement or embolization. After deployment of an Amplatz Vascular Plug III under guidance with real-time 3-dimensional TEE and successful leak closure with only trace PAR left in angiography (E), the ARI increased to 30.8 (F) (51,52). Abbreviation as in Figure 5.
results with satisfactory short-term and midterm outcomes (42,44,49). In addition, the valve-in-valve technique is a viable treatment option for significant transvalvular AR due to severe prosthetic leaflet dysfunction and has important implications for patients who develop late failure of THVs, also in case of restenosis as a “re-do” procedure (50). However, one major drawback of THV-in-THV implantation with the Medtronic CoreValve is the restricted access to the coronary ostia. In the near future, repositionability and retrievability of THVs will be addressed by the next-generation devices and help to reduce the occurrence of malpositioning (4).

Snare Technique

The Snare technique represents an option worth considering for a too deeply implanted Medtronic CoreValve (too “ventricular” placement of the prosthesis) (Fig. 7). In this case, correction of the device position may be achieved by engaging one of the anchoring hooks and pulling with a snare catheter (39). To increase the leverage effect, the snaring maneuver can be performed via transbrachial access. However, this corrective maneuver is not without hazards (e.g., aortic dissection) and bears the potential risk of THV embolization into the ascending aorta (6,40,45). If the attempt to reposition a Medtronic CoreValve with the snare technique fails, valve-in-valve implantation can be considered to prevent conversion to emergency open heart surgery.

Interventional Closure

Interventional closure of paravalvular leaks after TAVR has been described for the Edwards SAPIEN prosthesis (51,52) (Fig. 8). If the implantation depth of a THV is appropriate and the THV is not undersized, balloon post-dilation can be the first step to obtain a better expansion of the prosthesis stent frame with improved sealing of the paravalvular space. However, if significant PAR remains because of heavy calcifications of the native aortic valve and a localized AR jet can be identified, transcatheter device closure with use of the Amplatzer Vascular Plug III (AVP III, AGA Medical Corp., Plymouth, Minnesota) can be attempted analogous to paravalvular leak closure in surgical heart valves (53). However, potential risks associated with transcatheter device closure of paravalvular leaks after TAVR include stroke, THV dislodgment, and embolization of the closure device (52).

Future Developments

The reduction in the incidence and severity of PAR represents an obvious target for technical improvements in the design of upcoming “next-generation” THVs and of implantation techniques (4): sealing mechanisms at the lower part of the prosthesis skirt that help to conform to irregular surfaces of the native anatomy or full repositionability and retrievability to achieve an optimal procedural result with proper placement of the prosthesis and a lesser extent of PAR.

Conclusions

For the evaluation of PAR after TAVR, a multimodal approach with the use of hemodynamic measurements and imaging modalities is imperative to precisely quantify the severity of AR immediately after valve implantation and to identify patients who will benefit from corrective measures, such as post-dilation or valve-in-valve implantation. Every measure has to be taken to prevent or reduce PAR to provide a satisfying long-term clinical outcome.

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REFERENCES


17. Anderson RH, Devine WA, Ho SY, Smith A, McKay R. The myth of
the aortic annulus: The anatomy of the subaortic outflow tract. Ann

tions for transcatheter implantation of the aortic valve. Circ Cardiovasc

tion of the aortic annulus using multislice computer tomography: are
manufacturer’s guidelines for sizing for percutaneous aortic valve


tomographic assessment improves accuracy of aortic annular sizing
for transcatheter aortic valve replacement and reduces the incidence

22. Buellesfeld L, Grube E. A permanent solution for a temporary

zone calcification and acute procedural success in patients undergoing
transcatheter aortic valve implantation with the self-expanding Cor-

24. Roberts WC, Janning KG, Ko JM, Filardo G, Matter GJ. Frequency of
congenitally bicuspid aortic valves in patients ≥80 years of age
undergoing aortic valve replacement for aortic stenosis (with or without
aortic regurgitation) and implications for transcatheter aortic valve

implantation in patients with bicuspid aortic valve stenosis. J Am Coll

term outcomes of transcatheter aortic valve implantation in high-risk patients

27. Gotzmann M, Lindstaedt M, Mügge A. From pressure overload to

paravalvular leakage on outcome in patients after transcatheter aortic

speckle-tracking analysis of left ventricular function after transcatheter

valve implantation on aortic annular calcification severity with the degree of aortic regurgitation after


34. Whisenant B, Jones K, Horton KD, Horton S. Device closure of

35. Rihal CS, Sorajja P, Booker JD, Hagler DJ, Cabalka AK. Principles of

Key Words: ARI • paravalvular aortic regurgitation • periprosthetic
regurgitation • TAVI • TAVR.

APPENDIX

For supplemental videos and their legends, please see the online version of
this article.