How to improve patient outcomes following TAVI in 2024? Recent advances

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ABSTRACT

Transcatheter aortic valve implantation (TAVI) has revolutionized the treatment of aortic stenosis, particularly among elderly patients. The world's first TAVI procedure was performed in 2002 by Professor Cribier. It was approved for clinical use in Europe in 2007, followed by approval in the United States in 2011. It has since been introduced into clinical practice throughout Europe, and there has been a remarkable increase both in the number of procedures and in the number of centers performing TAVI. Recent findings endorse its additional application in lower-risk populations, suggesting a transformative shift in the field of interventional cardiology.

This review article thoroughly explores the recent advances and key considerations aimed at enhancing patient outcomes following TAVI. Key areas of focus include valve durability, paravalvular leak management, valve-in-valve procedures, and the implications and management of coronary artery disease in these patients. We highlight the importance of selecting valves with favorable hemodynamics, minimal coronary risk, and optimal durability, especially for younger, lower-risk patients. Paravalvular leak remains a significant concern; thus, pre-procedural planning and immediate corrective measures are crucial to mitigate its impact. The increasing need for valve-in-valve interventions underscores the importance of the strategic initial valve choice with a forward-looking perspective. Additionally, emerging strategies such as transcatheter leaflet laceration to prevent coronary obstruction during reinterventions, are examined. This review synthesizes current research and clinical practice, providing a roadmap for enhancing TAVI outcomes through technological advances and strategic procedural planning. The findings and recommendations presented aim to optimize long-term patient prognosis, ensuring that TAVI remains a leading solution for aortic stenosis in an increasing variety of patients.

Key words: aortic stenosis, coronary access, durability, TAVI, valve-in-valve

INTRODUCTION

Aortic stenosis is the most common valvular heart disease. In the current valvular ESC guidelines, transcatheter aortic valve implantation (TAVI) is recommended in older patients (≥75 years), and in those who are high-risk or unsuitable for surgery [1]. The American Heart Association guidelines recommend as a class 1 indication either transfemoral TAVI or surgical aortic valve replacement (SAVR) for patients aged 65 or older [2]. Marzec et al. [3] analyzed outcomes and predictors of long-term mortality in patients undergoing TAVI and SAVR. They performed a retrospective analysis of patients with advanced aortic stenosis, and found no significant differences regarding prognosis between TAVI and SAVR at 2-year follow-up.

However, due to the increasing scientific evidence supporting TAVI, there has been a significant shift in the management of these patients in recent years. Surgery is being bypassed as the best option, with percutaneous treatment now the preferred choice, even for low-risk patients [4]. Several aspects must be considered when generalizing these procedures to younger patients to address their long-term prognosis: durability, the risk of atrioventricular block, the need for future percutaneous procedures, and coronary access. We must address these questions now, as the seeds we plant today are the trees of tomorrow.

The purpose of this review was to summarize the aspects that must be considered to improve the prognosis and future of patients undergoing TAVI.

DURABILITY AND HEMODYNAMICS

If we consider extending TAVI to low-risk patients, the first procedure must be performed with a lifetime strategy plan. A young patient undergoing TAVI should ideally receive a valve with a low coronary risk plane, large upper cells, commissural alignment, and optimal valve hemodynamics.

One of the most important concerns is durability.

Severe structural valve deterioration is defined as:

- Transprosthetic gradient of 30 mm Hg or more and an increase in transprosthetic gradient of 20 mm Hg or more
- Severe new intraprosthetic regurgitation.

Bioprosthetic valve failure is defined as the composite rate of death from a valve-related cause or an unexplained death following the diagnosis of bioprosthetic valve dysfunction, aortic valve re-intervention, or severe structural valve deterioration [5].

Interactions between the TAVI stent frame and valve leaflets that occur during crimping and deployment may also accelerate structural valve degeneration [6].

The NOTION trial [7] was the first to randomize patients at lower surgical risk to TAVI CoreValve (Medtronic Inc.) or SAVR. The primary composite outcome (all-cause mortality, stroke, or myocardial infarction) showed no differences 10 years after treatment. The risk of severe bioprosthesis structural valve deterioration was lower after TAVI compared to SAVR, while the risk of bioprosthetic valve dysfunction was similar.

The PARTNER 3 trial [8] demonstrated that, among low-risk patients with aortic stenosis, TAVI (balloon expandable) was superior to SAVR at preventing death, stroke, or rehospitalization at 1 year. This benefit was sustained to 5 years. Valve durability indicators were also stable over time, with no differences in the incidence of bioprosthetic valve failure related to structural valve deterioration (1.4% vs. 2.0%) or reintervention rates (2.6% vs. 3.0%) between TAVI and SAVR at 5-year follow-up.

Technology continues to advance in pursuit of improved durability. The valve SAPIEN 3 Ultra RESILIA has an advanced calcium-blocking technology that promises to improve durability, inspired by the surgical valve INSPIRIS RESILIA [9]. When comparing Sapien 3/Sapien 3 Ultra to Sapien 3 Ultra RESILIA, echo-derived mean gradients are lower with RESILIA, with larger effective orifice areas and fewer paravalvular leaks. The Japanese Ocean-TAVI Registry has published similar results in this regard [10].

The Evolut Low Risk trial [4] showed that, at 4-year follow-up, TAVI patients had sustained improvements in hemodynamics as measured by echocardiography, with significantly lower aortic valve mean gradients and greater effective orifice areas compared to SAVR.

How to improve durability

Several new polymer technologies have been developed in recent years with the goal of creating an ideal polymeric heart valve substitute that overcomes the limited durability of bioprosthetic valves [11]. It may be worthwhile focusing on the material of the TAVI or the possibility of new designs with removable leaflets sewed to a stent, as previously suggested for SAVR [12].

TAVI IN TAVI

The number of TAVI in TAVI implantations will increase significantly in the future, due to the expansion of the technique to young patients and its limited durability. There are some risks, such as impaired coronary access and residual gradients, as well as the durability. Sizing and positioning need to be standardized based on the prosthesis failure mechanism. The choice of the first prosthesis is crucial when planning the lifetime management of a patient, as it has a significant impact on treatment options in the future. The first valve implantation impacts significantly the second redo, both TAVI in TAVI and TAVI explant.

In the EXPLANTORREDO-TAVR registry [13], the authors sought to determine outcomes of TAVI surgical explant vs redo-TAVI. In this registry, TAVI explant had a shorter median time to reintervention, with less structural valve degeneration, more prosthesis-patient mismatch, and similar paravalvular leak (PVL) rates compared to redo-TAVI. TAVI explant also had higher mortality at 30 days and at 12 months.

Several aspects must be carefully examined *via* cardiac tomography (CT) to prevent coronary obstruction in TAVI in TAVI procedures [14], i.e.:

- The risk plane;
- The distance from the valve to the coronary artery;
- The commissural orientation of the first TAVI;
- The possibility of sinus sequestration.

New factors to bear in mind are emerging with the increasing need for valve-in-valve (VIV) procedures, such as the height of the newskirt, the possibility of leaflet overhang (acceptable in cases of regurgitation as the main mechanism of degeneration), and the expansion of the first TAVI.

PARAVALVULAR LEAK

PVL after TAVI is prevalent and brings with it higher risks of all-cause mortality, rehospitalization, and cardiovascular mortality following TAVI [15].

The incidence of moderate-to-severe PVL has declined with improvements in valve design, implantation technique, and operator experience, but the latest generation devices implanted in low-risk populations still show moderate-to-severe PVL in 0.8% for balloon-expandable devices and in 3.4% for self-expanding devices at 30 days. The incidence of mild PVL is high after TAVI: 29% in balloon-expandable vs. 36% in self-expanding devices

at 30 days [8, 16]. Mild PVL is usually asymptomatic and there have been contradictory results regarding its association with mortality. The negative impact of PVL on outcomes after TAVI has been attributed to remodeling of the left ventricle in patients with aortic stenosis, resulting in a pressure-overloaded ventricle, in combination with an acute volume overload [17].

Predictors of PVL are annular eccentricity, severe calcification of the aortic valve, bicuspid aortic valves, and type of prosthesis, with balloon-expandable devices associated with less PVL. PVL can be the consequence of an undersizing of the implanted device or an incomplete expansion of the prosthesis stent frame.

The use of CT for sizing the annulus reduces PVL compared to transesophageal echocardiogram [18]. Therefore, 3D measurements using multi-slice CT are considered the gold standard for sizing the annulus.

The aortic annulus is typically oval, while TAVI frames are circular, which can hinder full frame apposition. The eccentricity index (1 — minimal/maximal annular diameter) measures annular shape. In first-generation self-expanding devices, an eccentricity index of >0.35 has been associated with significant PVL [19], though other studies did not confirm this finding. In balloon-expandable devices, annular and left ventricular outflow tract eccentricity predicted PVL due to heterogeneous sealing zones. Additionally, an increased left ventricular outflow tract and ascending aorta angle influenced stent radial force, impacting PVL [20].

Procedural strategies to prevent PVL are needed. Accurate assessment of the aortic valve annulus before TAVI is mandatory to select the optimal valve size. Too deep, and too shallow, implantation have both been associated with relevant PVL.

How can we reduce PVL?

In patients considered to have moderate or greater PVL after TAVI, an immediate corrective procedure should be considered. The management should be individualized, considering the balance between the vulnerability factors to aortic regurgitation (including absence of preexistent native aortic regurgitation, severe left ventricular concentric hypertrophy with small cavity, and advanced diastolic function) versus the risk factors (bulky calcific nodules) for complications (stroke, aortic annulus injury, coronary artery obstruction).

The optimal treatment of PVL is prevention. However, when prevention is unsuccessful, some treatment options can be considered. These include balloon postdilation, placement of a second valve, and percutaneous PVL closure by a vascular plug.

The first-line procedure to correct PVL is an additional postdilation [21]. A slightly oversized balloon (equal to or >95% of the mean annulus diameter) is recommended to achieve further expansion of the prosthesis. Studies have shown that postdilation correction can be performed safely, with decreased PVL in most patients. However, balloon postdilation correction has been associated with an increased risk of stroke, which is at least partly attributable to the worse baseline risk profile of patients with PVL. It is important to carefully size the postdilation balloon according to the size and geometry of the transcatheter valve, and to consider lower deployment of the balloon to prevent leaflet injury [22].

A VIV procedure may be necessary in some cases of moderate-to-severe PVL in which postdilation correction has failed, if the anatomical conditions allow the implantation of a second prosthesis [23]. This is successful in 90% of cases, either through lengthening of the sealing skirt in cases of inadequate position, or through further expansion of the index device. This procedure is used when the PVL is primarily related to a malposition of the first valve (in particular where it is too high).

In the rare cases of significant PVL persisting after postdilation and/or a valve-in-valve correction, transcatheter closure of the PVL using vascular plugs may be an option in experienced centers to reduce mortality [24].

A comprehensive echocardiographic examination should be performed before discharge. If PVL is greater than a mild grade, or if the grading is doubtful, a cardiac magnetic resonance examination may be considered: a regurgitant fraction of 30% or more should prompt additional corrective procedures.

CORONARY ARTERY DISEASE IN TAVI

The prevalence of coronary artery disease in patients with severe aortic stenosis varies widely, from 80% in high-risk trials to only 15% in more recent low-risk trials [4, 25]. Guidelines suggest that revascularization with coronary artery bypass grafting should be considered in patients undergoing SAVR [1]. Therefore, it is not surprising that the early trials of TAVI required coronary angiography before the procedure, and percutaneous coronary intervention of proximal and mid lesions in major coronary arteries was strongly recommended. Percutaneous revascularization has been shown to be safe to perform [26], but whether it offers a clinical benefit remains unclear. To date, there have been no randomized trials addressing this issue.

Pre-TAVI CT has a high negative prognostic value for high-grade proximal stenosis of each coronary artery. As a result, CT could be used as a screening tool to rule out significant proximal coronary artery disease in patients undergoing TAVI [27].

Coronary obstruction in TAVI

Performing TAVI on a young person might have important implications on future interventions. Irrespective of valve durability, a young patient will likely receive one or more percutaneous interventions over the decades following the index procedure. The most serious complication in redo-TAVI is represented by coronary obstruction [28].

Coronary height <10 mm, sinus of Valsalva width <30 mm, leaflet tips extending above the coronary ostia

or the sinotubular junction, and distance between a virtual valve and coronary ostium <4 mm and/or at the sinotubular junction <2 mm, have all been identified as risk factors for coronary obstruction post TAVI [29–32].

In VIV cases, only a distance from the virtual valve to the coronary ostium of <4 mm and valve type (stented with externally mounted leaflets or stentless), but not coronary height, have been identified as predictors of coronary obstruction [30].

Coronary access after TAVI

Techniques to improve the success of cannulating coronary ostia and interventions have been refined recently, including the use of guide catheters with smaller curves (engaging the left coronary artery with a JL3 or EBU 3 from a radial approach or JL3.5/EBU 3.5 from a femoral approach), remote wiring, using guide extension catheters, and using the appropriate cells within the prosthesis to access the coronary ostia [33].

How to minimize risk of coronary obstruction

A careful analysis of the CT will help to predict patients at high risk of coronary obstruction. Commissural alignment is becoming an important parameter for procedure optimization in younger patients undergoing TAVI, and is essential so as to be able to engage the coronary ostium in the future [34].

Transcatheter leaflet laceration has emerged as a preventive technique to avoid coronary obstruction during TAVI procedures. A study by Kitamura et al. [32] confirmed the efficacy and safety of this technique in a real-world setting, and provided further support for its extended application at experienced centers. Bailout strategies, such as chimney stenting, might also be helpful in reducing this risk.

RISK OF PACEMAKER

This risk differs in balloon-expandable vs. self-expanding valves, in general being higher in the self-expanding [35], although different for each type of valve. Preexisting right bundle branch block, first-degree atrioventricular block, and low implantation depth have all been identified as predictors of pacemaker following TAVI [36]. However, it is highly variable and depends on the electrocardiogram at baseline and the height of implantation (the higher this is, the lower the risk of disturbances) [37]. The need for a pacemaker implies a worse prognosis in patients after TAVI [38].

RISK OF STROKE

TAVI to treat aortic stenosis can lead to embolization of debris. Capture of debris by devices that provide cerebral embolic protection can reduce the risk of stroke.

The overall evidence confirms a similar or lower rate of stroke in TAVI versus SAVR. Risk predictors for acute stroke after TAVI are generally related to procedural factors, whereas late stroke is mainly associated with patient characteristics, with a variable impact on cognitive function. The optimal choice for an antithrombotic treatment in TAVI for stroke prevention is yet to be determined. Current data does not support the routine use of cerebral embolic protection devices during TAVI [39, 40]. Richter et al. [41] produced an overview of the available literature on cerebral embolic protection devices in patients undergoing TAVI, and outlined recent advances in this field.

There are two main categories of cerebral embolic protection device: filter devices, which capture embolic debris, and deflector devices, which redirect debris away from the cerebral circulation.

Sentinel (Boston Scientific): The most studied filter device, approved in the United States and Europe, uses two filters placed in the brachiocephalic trunk and left common carotid artery. Despite showing debris capture in 99% of procedures, clinical trials such as SENTINEL and CLEAN-TAVI have yielded mixed results regarding reductions in stroke or lesion volume.

TriGuard (Keystone Heart): A deflector device covering three cerebral vessels, inserted via the femoral artery. Although showing promise in trials such as DEFLECT III and REFLECT II, its efficacy in reducing stroke and new lesions remains unproven.

Embol-X (Edwards Lifesciences): A deflector device that demonstrated smaller lesion volumes in a randomized trial.

Other devices such as Emblok, Embrella, and PointGuard are in various stages of clinical evaluation, aiming to provide more comprehensive brain protection with novel designs and mechanisms.

Overall, while cerebral embolic protection devices show potential in reducing silent brain lesions, their impact on clinical stroke outcomes and long-term neurocognitive function requires further validation through larger, standardized trials.

CONCLUSIONS

Medicine is making continuous advances to mitigate the negative aspects associated with TAVI, specifically addressing valve durability, prosthetic degeneration, PVL, coronary access, conduction disorders, and the risk of stroke.

The key areas of research and development include:

- Valve durability: Innovations aimed at enhancing the durability of TAVI prosthesis, including the use of advanced materials and designs. Strategies to prevent calcification and other forms of degeneration, potentially involving biocompatible coatings and improved manufacturing techniques.
- PVL: Development of sealing mechanisms and skirt designs to minimize PVL.
- Coronary access: Designing valves with large cells to ensure unobstructed coronary access post-implantation.

- Conduction disorders: Reducing the impact on the cardiac conduction system through refined deployment techniques and valve positioning.
- Stroke risk reduction: Implementing procedural refinements and embolic protection devices to reduce incidence of stroke during and after TAVI.

These advances are collectively contributing to the evolution of TAVI, aiming to create an ideal valve that combines optimal hemodynamics, minimal risk of coronary occlusion, effective sealing against PVL, and reduced impact on the conduction system. Improving patient prognosis with TAVI involves taking a holistic approach, and considering all the reviewed factors in order to select the valve best suited to the individual patient's characteristics.

Article information

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REFERENCES

1. Vahanian A, Beyersdorf F, Praz F, et al. 2021 ESC/EACTS Guidelines for the management of valvular heart disease. Eur Heart J. 2022; 43(7): 561–632, doi: 10.1093/eurheartj/ehab395, indexed in Pubmed: 34453165.
2. Otto CM, Nishimura RA, Bonow RO, et al. 2020 ACC/AHA Guideline for the Management of Patients With Valvular Heart Disease: Executive Summary: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Circulation. 2021; 143(5): e35–e71, doi: 10.1161/CIR.0000000000000932, indexed in Pubmed: 33332149.
3. Marzec K, Jaworska-Wilczyńska M, Kowalik I, et al. Comparison of long-term outcomes and risk factors of aortic stenosis treatment in patients undergoing transcatheter aortic valve implantation and surgical aortic valve replacement. Kardiol Pol. 2022; 80(7-8): 792–798, doi: 10.33963/KP.a2022.0122, indexed in Pubmed: 35521716.
4. Forrest JK, Deeb GM, Yakubov SJ, et al. Evolut Low Risk Trial Investigators. 4-year outcomes of patients with aortic stenosis in the Evolut Low Risk Trial. J Am Coll Cardiol. 2023; 82(22): 2163–2165, doi: 10.1016/j.jacc.2023.09.813, indexed in Pubmed: 37877907.
5. Capodanno D, Petronio AS, Prendergast B, et al. Standardized definitions of structural deterioration and valve failure in assessing long-term durability of transcatheter and surgical aortic bioprosthetic valves: a consensus statement from the European Association of Percutaneous Cardiovascular Interventions (EAPCI) endorsed by the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). Eur J Cardiothorac Surg. 2017; 52(3): 408–417, doi: 10.1093/ejcts/ezx244, indexed in Pubmed: 28874031.
6. Zareian R, Tseng JC, Fraser R, et al. Effect of stent crimping on calcification of transcatheter aortic valves. Interact Cardiovasc Thorac Surg. 2019; 29(1): 64–73, doi: 10.1093/icvts/ivz024, indexed in Pubmed: 30793744.
7. Thyregod HG, Jørgensen TH, Ihlemann N, et al. Transcatheter or surgical aortic valve implantation: 10-year outcomes of the NOTION trial. Eur Heart J. 2024; 45(13): 1116–1124, doi: 10.1093/eurheartj/ehae043, indexed in Pubmed: 38321820.
8. Mack MJ, Leon MB, Thourani VH, et al. Transcatheter aortic-valve replacement in low-risk patients at five years. N Engl J Med. 2023; 389(21): 1949–1960, doi: 10.1056/NEJMoa2307447, indexed in Pubmed: 37874020.
9. Stinis CT, Abbas AE, Teirstein P, et al. Real-world outcomes for the fifth-generation balloon expandable transcatheter heart valve in the United States. JACC Cardiovasc Interv. 2024; 17(8): 1032–1044, doi: 10.1016/j.jcin.2024.02.015, indexed in Pubmed: 38456883.
10. Yamamoto M, Yashima F, Shirai S, et al. Performance and outcomes of the SAPIEN 3 Ultra RESILIA transcatheter heart valve in the OCEAN-TAVI registry. EuroIntervention. 2024; 20(9): 579–590, doi: 10.4244/eij-d-23-00996.
11. Sun M, Elkhodiry M, Shi L, et al. A biomimetic multilayered polymeric material designed for heart valve repair and replacement. Biomaterials. 2022; 288: 121756, doi: 10.1016/j.biomaterials.2022.121756, indexed in Pubmed: 36041938.
12. Taghizadeh B, Ghavami L, Derakhshankhah H, et al. Biomaterials in valvular heart diseases. Front Bioeng Biotechnol. 2020; 8: 529244, doi: 10.3389/fbioe.2020.529244, indexed in Pubmed: 33425862.
13. Tang GHL, Zaid S, Kleiman NS, et al. Explant vs redo-TAVR after transcatheter valve failure: Mid-term outcomes from the EXPLANTORREDO-TAVR international registry. JACC Cardiovasc Interv. 2023; 16(8): 927–941, doi: 10.1016/j.jcin.2023.01.376, indexed in Pubmed: 37100556.
14. Tarantini G, Sathananthan J, Fabris T, et al. Transcatheter aortic valve replacement in failed transcatheter bioprosthetic valves. JACC Cardiovasc Interv. 2022; 15(18): 1777–1793, doi: 10.1016/j.jcin.2022.07.035, indexed in Pubmed: 36137681.
15. Sá MP, Jacquemyn X, Van den Eynde J, et al. Impact of paravalvular leak on outcomes after transcatheter aortic valve implantation: Meta-analysis of Kaplan-Meier-derived individual patient data. Struct Heart. 2023; 7(2): 100118, doi: 10.1016/j.shj.2022.100118, indexed in Pubmed: 37275584.
16. Popma JJ, Deeb GM, Yakubov SJ, et al. Transcatheter aortic-valve replacement with a self-expanding valve in low-risk patients. N Engl J Med. 2019; 380(18): 1706–1715, doi: 10.1056/NEJMoa1816885, indexed in Pubmed: 30883053.
17. Carabello BA, Puskas JD. Transcatheter aortic valve replacement. JACC: Cardiovascular Interventions. 2014; 7(9): 1033–1035, doi: 10.1016/j.jcin.2014.05.013.
18. Jilaihawi H, Kashif M, Fontana G, et al. Cross-sectional computed tomographic assessment improves accuracy of aortic annular sizing for transcatheter aortic valve replacement and reduces the incidence of paravalvular aortic regurgitation. J Am Coll Cardiol. 2012; 59(14): 1275–1286, doi: 10.1016/j.jacc.2011.11.045, indexed in Pubmed: 22365424.
19. Wong DTL, Bertaso AG, Liew GYH, et al. Relationship of aortic annular eccentricity and paravalvular regurgitation post transcatheter aortic valve implantation with CoreValve. J Invasive Cardiol. 2013; 25(4): 190–195, indexed in Pubmed: 23549493.
20. Hagar A, Li Y, Wei X, et al. Incidence, predictors, and outcome of paravalvular leak after transcatheter aortic valve implantation. J Interv Cardiol. 2020; 2020: 8249497, doi: 10.1155/2020/8249497, indexed in Pubmed: 32523474.
21. Ong G, Annabi MS, Clavel MA, et al. Paravalvular regurgitation after transcatheter aortic valve replacement: Is the problem solved? Interv Cardiol Clin. 2018; 7(4): 445–458, doi: 10.1016/j.iccl.2018.06.005, indexed in Pubmed: 30274611.
22. Patel J, Weissman G, Rogers T, et al. A word of caution regarding postdilatation of self-expanding valves for paravalvular leak. JACC Cardiovasc Interv. 2024; 17(5): 696–698, doi: 10.1016/j.jcin.2023.11.037, indexed in Pubmed: 38244002.
23. Stundl A, Rademacher MC, Descoups C, et al. Balloon post-dilation and valve-in-valve implantation for the reduction of paravalvular leakage with use of the self-expanding CoreValve prosthesis. EuroIntervention. 2016; 11(10): 1140–1147, doi: 10.4244/EIJY15M11_04, indexed in Pubmed: 26561518.
24. Wely Mv, Rooijakkers M, Stens N, et al. Paravalvular regurgitation after transcatheter aortic valve replacement: Incidence, quantification, and prognostic impact. Eur Heart J Imaging Methods and Practice. 2024; 2(2): qyae040, doi: 10.1093/ehjimp/qyae040.
25. Faroux L, Guimaraes L, Wintzer-Wehekind J, et al. Coronary artery disease and transcatheter aortic valve replacement: JACC State-of-the-Art review. J Am Coll Cardiol. 2019; 74(3): 362–372, doi: 10.1016/j.jacc.2019.06.012, indexed in Pubmed: 31319919.
26. Faroux L, Campelo-Parada F, Munoz-Garcia E, et al. Procedural characteristics and late outcomes of percutaneous coronary intervention in the workup pre-TAVR. JACC Cardiovasc Interv. 2020; 13(22): 2601–2613, doi: 10.1016/j.jcin.2020.07.009, indexed in Pubmed: 33069647.

27. Kondoleon NP, Layoun H, Spilias N, et al. Effectiveness of pre-TAVR CTA as a screening tool for significant CAD before TAVR. JACC Cardiovasc Interv. 2023; 16(16): 1990–2000, doi: 10.1016/j.jcin.2023.05.030, indexed in Pubmed: 37648347.
28. Nai Fovino L, Scotti A, Massussi M, et al. Coronary angiography after transcatheter aortic valve replacement (TAVR) to evaluate the risk of coronary access impairment after TAVR-in-TAVR. J Am Heart Assoc. 2020; 9(13): e016446, doi: 10.1161/JAHA.120.016446, indexed in Pubmed: 32578484.
29. Ribeiro HB, Webb JG, Makkar RR, et al. Predictive factors, management, and clinical outcomes of coronary obstruction following transcatheter aortic valve implantation: Insights from a large multicenter registry. J Am Coll Cardiol. 2013; 62(17): 1552–1562, doi: 10.1016/j.jacc.2013.07.040, indexed in Pubmed: 23954337.
30. Ribeiro HB, Rodés-Cabau J, Blanke P, et al. Incidence, predictors, and clinical outcomes of coronary obstruction following transcatheter aortic valve replacement for degenerative bioprosthetic surgical valves: Insights from the VIVID registry. Eur Heart J. 2018; 39(8): 687–695, doi: 10.1093/eurheartj/ehx455, indexed in Pubmed: 29020413.
31. Khan JM, Greenbaum AB, Babaliaros VC, et al. The BASILICA trial: Prospective multicenter investigation of intentional leaflet laceration to prevent TAVR coronary obstruction. JACC Cardiovasc Interv. 2019; 12(13): 1240–1252, doi: 10.1016/j.jcin.2019.03.035, indexed in Pubmed: 31202947.
32. Kitamura M, Majunke N, Holzhey D, et al. Systematic use of intentional leaflet laceration to prevent TAVI-induced coronary obstruction: feasibility and early clinical outcomes of the BASILICA technique. EuroIntervention. 2020; 16(8): 682–690, doi: 10.4244/EIJ-D-20-00386, indexed in Pubmed: 32597392.
33. Yudi MB, Sharma SK, Tang GHL, et al. Coronary angiography and percutaneous coronary intervention after transcatheter aortic valve replacement. J Am Coll Cardiol. 2018; 71(12): 1360–1378, doi: 10.1016/j.jacc.2018.01.057, indexed in Pubmed: 29566822.
34. Akodad M, Lounes Y, Meier D, et al. Transcatheter heart valve commissural alignment: an updated review. Front Cardiovasc Med. 2023; 10: 1154556, doi: 10.3389/fcvm.2023.1154556, indexed in Pubmed: 37153454.
35. Hosseinpour A, Gupta R, Kamalpour J, et al. Balloon-expandable versus self-expanding transcatheter aortic valve implantation in patients with small aortic annulus: A meta-analysis. Am J Cardiol. 2023; 204: 257–267, doi: 10.1016/j.amjcard.2023.07.100, indexed in Pubmed: 37562191.
36. Kim WK, Möllmann H, Walther T, et al. Predictors of permanent pacemaker implantation after ACURATE neo transcatheter heart valve implantation. Pacing Clin Electrophysiol. 2021; 44(2): 410–415, doi: 10.1111/pace.14155, indexed in Pubmed: 33373045.
37. Badertscher P, Knecht S, Zeljković I, et al. Management of conduction disorders after transcatheter aortic valve implantation: Results of the EHRA survey. Europace. 2022; 24(7): 1179–1185, doi: 10.1093/europace/euac027, indexed in Pubmed: 35348646.
38. Pagnesi M, Kim WK, Baggio S, et al. Incidence, predictors, and prognostic impact of new permanent pacemaker implantation after TAVR with self-expanding valves. JACC Cardiovasc Interv. 2023; 16(16): 2004–2017, doi: 10.1016/j.jcin.2023.05.020, indexed in Pubmed: 37480891.
39. Ciobanu AO, Gherasim L, Vinereanu D. Risk of stroke after transcatheter aortic valve implantation: epidemiology, mechanism, and management. Am J Ther. 2021; 28(5): e560–e572, doi: 10.1097/MJT.0000000000001413, indexed in Pubmed: 34491954.
40. Kapadia SR, Makkar R, Leon M, et al. Cerebral embolic protection during transcatheter aortic-valve replacement. N Engl J Med. 2022; 387(14): 1253–1263, doi: 10.1056/NEJMoa2204961, indexed in Pubmed: 36121045.
41. Richter I, Abdel-Wahab M, Desch S, et al. Cerebral embolic protection in patients undergoing transcatheter aortic valve implantation: Recent advances. Kardiol Pol. 2022; 80(6): 644–650, doi: 10.33963/KP.a2022.0118, indexed in Pubmed: 35521720.