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Original Article

Risk factors and predictive model for moderate to severe perivalvular leakage following transcatheter aortic valve replacement

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Abstract: Objective: To identify the risk factors associated with moderate to severe perivalvular leakage (PVL) after transcatheter aortic valve replacement (TAVR) and to construct a prediction model for this risk. Methods: A retrospective analysis was conducted on 128 patients with severe aortic stenosis who had received TAVR in The Second Hospital of Hebei Medical University from January 2019 to January 2024. The length of the aortic regurgitation bundle and annular circumference ratio were measured by transesophageal echocardiography immediately after the valve implantation. Patients with moderate to severe PVL were included in observation group, while the remaining comprised the control group. Clinical data of the patients were recorded, and univariate and multivariate Logistic regression analyses were performed on factors potentially influencing the development of moderate to severe PVL after surgery. A risk prediction model was constructed correspondingly. Results: Of the 128 patients, 51 with moderate or severe PVL served as the observation group and the remaining 77 served as the control group. The results of univariate and multivariate analyses identified LVOT coverage index, depth of valve implantation, LVEDd, aortic angulation, LVESD, and calcification volume entered as independent risk factors associated with moderate to severe PVL following TAVR (*P<0.05*). A predictive model for post-TAVR PVL was constructed by incorporating these significant factors. ROC curve analysis of the prediction model for moderate to severe PVL showed an area under the curve of 0.911. Conclusion: LVOT coverage index, depth of valve implantation, LVEDd, aortic angulation, LVESD, and calcification volume are independent risk factors for moderate to severe PVL in patients with severe aortic stenosis after TAVR. Risk prediction model constructed based on the risk factors are valuable tool for identifying patients at high risk of developing moderate or greater PVL post-surgery.

Keywords: Transcatheter aortic valve replacement, postoperative complications, perivalvular leakage, risk factors, prediction model

Introduction

With the aging of the population intensifying, degenerative aortic stenosis has become a common disease affecting the elderly, with incidence rising annually. The prevalence of degenerative aortic stenosis in people over 75 in Europe and the United States is about 4.6% [1, 2]. Surgical aortic valve replacement (SAVR) is currently an effective treatment modality for severe aortic stenosis. However, approximately 30% to 50% of patients are not suitable for SAVR due to their advanced age, poor left ventricular basic function or severe comorbidities [3-5]. Transcatheter aortic valve replacement (TAVR) is an emerging minimally invasive interventional technique that has been developed in recent years. In patients with severe aortic stenosis unsuitable for surgical intervention, TAVR is superior to conventional standard therapy (e.g., balloon dilatation angioplasty) and comparable to SAVR in effectiveness [6-9]. However, patients undergoing TAVR are more likely to develop postoperative perivalvular leakage (PVL) compared to those undergoing SAVR. Related research studies have demonstrated that over 70% of post-TAVR patients experience varying degrees of PVL [10, 11]. At the same time, the development of PVL after TAVR is recognized as an independent risk factor for both

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short- and long-term mortality, and even mild periaortic regurgitation may significantly impact patients' postoperative survival [12, 13]. Therefore, early prediction of patients at high risk for postoperative moderate to severe PVL, along with proactive preventative measures, is crucial for improving both short- and long-term outcomes of patients [14]. To date, no prediction model has been established for postoperative PVL following TAVR. To address this, this study aimed to identify risk factors for moderate and severe PVL after TAVR and to construct a risk prediction model.

Data and methods

Clinical data

A retrospective analysis was conducted on 128 patients with severe aortic stenosis who had received TAVR at The Second Hospital of Hebei Medical University from January 2019 to January 2024. The study was approved the Ethics Committee of The Second Hospital of Hebei Medical University. Specific data are shown in Supplementary Table 1.

Inclusion and exclusion criteria

Inclusion criteria: (1) Patients with severe aortic stenosis who completed TAVR [15]; (2) Patients with preoperative multi-slice spiral CT (MSCT) and transthoracic echocardiography (TTE); (3) Patients with contraindications to surgery; (4) Patients with an expected survival time of over 12 months after TAVR; (5) Patients with a New York Heart Association (NYHA) cardiac function classification of class II or higher.

Exclusion criteria: (1) Patients with acute myocardial infarction; (2) Patients with fresh thrombus in left ventricle; (3) Patients with severe obstruction of the left ventricular outflow tract; (4) Patients with a prognostic postoperative survival time of less than 12 months.

Methods

Pre-operative MSCT: Patients underwent preoperative conventional coronary CT angiography (CTA) and thoracic-abdominal aortic CTA. Using 3mensio Structural Heare software, the long and short diameters and circumferences of the annulus, aortic angle, and short diameters of the aorta and left ventricular outflow tract (LVOT), as well as the long diameter of the LVOT, were measured. Meanwhile, the calcified volume of the aortic valve was determined to classify leaflet type according to Sievers' typing criteria. The LVOT or annular ellipticity was calculated as: Ellipticity = (1 - short annular diameter/long annular diameter) × 100%; The LOVT coverage index = (1 - perimeter of the prosthetic valve/perimeter of LVOT as measured by CT) × 100%.

Pre-operative TTE: Preoperative echocardiography was conducted to record the following parameters: posterior wall thickness (PWT), left ventricular end-diastolic diameter (LVEDd), left ventricular end systolic diameter (LVESD), left ventricular ejection fraction (LVEF), left atrial diameter (LAD), and interventricular septal thickness (IVST). Additionally, relative ventricular wall thickness (RWT), left ventricular mass (LVM), and left ventricular mass index (LVMI) were also calculated: RWT = PWT × 2/LVEDd.

TAVR surgical approach: Patients received general anesthesia via transcarotid or femoral route. Following routine sterilization and draping, the right internal jugular vein was punctured, and a 5F sheath was implanted to deliver temporary pacing electrode to the right ventricular apex. Transesophageal ultrasound was applied throughout the procedure, while fluoroscopy and contrast aided in puncturing the auxiliary and main access arteries and placing arterial sheaths. Two Proglide sutures were prepositioned in the main access femoral artery, and an 18-20F femoral artery sheath was delivered under the guidance of a Lunderquist ultrarigid guidewire. Heparin (80-100 U/kg) was administered and monitored every 30 minutes. A 6F pigtail catheter was inserted into the coronary sinus or ascending aortic sinus via the lateral femoral sheath of the auxiliary access route, and aortic root angiography was performed accordingly. A straight-throw guidewire was selected for transvalvular delivery into the left ventricle, followed by a 6F pigtail catheter delivered to measure transvalvular differential pressure. The tip of the Lunderquist guidewire was pre-shaped and exchanged for delivery to the left ventricle apex, and the Numed balloon was over it to the aortic valve. Rapid pacing at 180 beats/min was induced in the right ventricle, and rapid dilatation was performed 1-2 times when systolic blood pressure (SBP) fell below 60 mmHg. The appropriate Venus-A prosthetic aortic valve was selected based on balloon inflation and preoperative CT measurements. The artificial aortic valve was positioned at the aortic annulus along Lunderquist guide wire, using the lowest point of the pigtail catheter as a reference for depth adjustment (0-6 mm). The valve was released in stages: the first third of the valve was slowly released, the middle third was quickly released under the right ventricular pacing of 140-160 times/min, and finally, the artificial valve was slowly and completely released. Transesophageal echocardiography and aortic root angiography were performed immediately after valve placement to assess patient's PVL status. Decisions for retroballoon dilation or second valve placement were based on PVL, valve shape, cross-valve pressure difference, and the opening height of coronary artery. At the end of the operation, the puncture point of the femoral artery was sutured with the pre-positioned Proglige sutures, and the patient was sent to the intensive care unit (ICU) with the temporary pacing electrodes retained for 24-48 h postoperatively. For patients without anticoagulant indications, dual antiplatelet therapy with aspirin (100 mg) and clopidogrel (75 mg) was given for 3 to 6 months, followed by long-term single antiplatelet therapy. Patients requiring anticoagulation were treated with long-term Warfarin postoperatively.

Assessment and grouping of PVL: Semi-quantitative assessment of PVL was performed using TEE after artificial valve implantation. Patients were graded for PVL according to the VARC-3 criteria published by the International Valve Society Research Consortium (VARC), which evaluates the length of the regurgitant bundle of the aortic valve and the ratio of the annular circumference to determine PVL severity. PVL was categorized into 4 grades: none/trivial, mild (<10%), moderate (10-30%), and severe (≥30%). In this study, patients with moderate to severe PVL were included in the observation group and the rest were placed in the control group.

Statistical analysis

SPSS 27.0 was used for statistical analysis. The sample size was determined according to the formula $n = z^2\sigma^2/d^2$, adjusted to the practical context of our hospital. Quantitative data were compared using *t*-test, and ranked data were analyzed with the Rank-sum test. Univariate and multivariate logistic regression analyses were performed to identify factors influencing the occurrence of moderate to severe PVL in patients. Receiver Operating Characteristic (ROC) curve was used to determine the cutoff values for statistically significant continuous variables in one-way comparisons and to analyze the predictive value of the model for moderate and severe PVL. The difference was statistically significant when $P<0.05$.

Results

Comparison of baseline information and surgical conditions

Of the 128 patients, 51 with moderate or severe PVL served as the observation group and the remaining 77 formed the control group. The difference in the depth of valve implantation between the two groups was statistically significant ($P<0.05$), and the rest of the baseline data or surgery-related conditions were not statistically significant (all $P>0.05$) (**Table 1** and Supplementary Table 1). Typical cases are shown in **Figure 1**.

Comparison of preoperative echocardiogram parameters

In terms of preoperative echocardiographic indices, the differences in LVED and LVESD were statistically significant between the two groups (all $P<0.05$). However, the differences in PWT, LVEF, LAD and RWT were not statistically significant between the two groups (all $P>0.05$) (**Table 2**).

Comparison of MSCT scanning parameters

The differences in the annular short diameter, annular long diameter, LVOT short diameter, LVOT long diameter, LVOT coverage index, aortic angulation, and calcification volume between the two groups were statistically significant (all $P<0.05$) (**Table 3**).

Determination of cutoff values of various risk factors

ROC curve was used to determine the cutoff values for statistically significant factors in the above one-way analysis, setting optimal thresholds for each variable. These thresholds were assigned to each indicator, as shown in **Figure 2** and **Tables 4**, **5**.

Multifactor logistic regression analysis

Multivariate logistic regression analysis of significant factors from the univariate analysis revealed that the LVOT coverage index, valve

Table 1. Comparison of baseline data and surgical conditions between the two groups

Parameters	Observation group (n=51)	Control group (n=77)	t/χ^2/Z	*P*
Gender				
Male	31	45	0.070	0.792
Female	20	32		
Age (years, $\bar{x}$±sd)	71.29±6.42	71.64±7.03	0.285	0.776
BMI (kg/m^2, $\bar{x}$±sd)	23.08±2.37	22.97±2.41	0.255	0.800
Classification of cardiac function by NYHA				
II	6	9	0.109	0.913
III	37	54		
IV	10	14		
Hypertension (n, %)	23 (45.10)	34 (44.16)	0.011	0.917
Diabetes mellitus	8 (15.69)	14 (18.18)	0.134	0.714
Implantation of permanent pacemaker (n, %)	4 (7.84)	7 (9.10)	0.006	0.940
Valve Size				
≤26 mm	34 (66.67)	48 (62.34)	0.250	0.617
>26 mm	17 (33.34)	29 (37.66)		
Number of in-hospital deaths	2 (3.92)	1 (12.99)	0.132	0.716
Depth of valve placement (mm, $\bar{x}$±sd)	14.05±3.97	10.25±3.10	6.063	<0.001

Notes: BMI: body mass index; NYHA Functional Classification: New York Heart Association Functional Classification.

implantation depth, LVEDd, aortic angulation, LVESD, and the calcification volume were statistically significant in the regression mode (all *P<0.05*) (**Table 6**).

Construction of predictive model

Based on the results of multivariate logistic regression analysis, a risk prediction model was constructed as follows: P = -2.978 - 2.085 × LVOT coverage index + 2.184 × valve implantation depth + 1.752 × LVEDd + 1.683 × aortic angle of formation + 1.439 × LVESD + 1.298 × calcification volume.

Predictive value of the models for moderate and severe PVL

ROC curve was used to analyze the predictive value of the model for moderate and severe PVL, and the results showed an area under the curve of 0.911, indicating high predictive accuracy (**Figure 3**).

Discussion

For patients with aortic valve disease who cannot tolerate surgery or are at high surgical risk, transcatheter aortic valve replacement (TVAR) has become the primary treatment option. Increasingly, patients with severe valve stenosis are opting for this minimally invasive and safe treatment mode; however, the occurrence of perivalvular leakage (PVL) after surgery can diminish the benefits of TVAR, adversely affecting both short- and long-term prognosis [16-18]. This study analyzed the risk factors for moderate or severe PVL after TAVR, aiming to identify high-risk patients and implement effective preventive measures to reduce the incidence of PVL.

The study showed that 51 of 128 patients (39.84%) experienced moderate to severe PVL, consistent with findings from similar studies [19, 20], highlighting the high incidence of PVL after TAVR in patients with severe valvular stenosis, which warrants clinical attention. To further analyze the risk factors for post-operative PVL in patients undergoing TAVR, we identified that LVOT coverage index, valve implantation depth, LVEDd, aortic angulation, LVESD, and calcification volume were significant factors. While previous studies have focused on LOVT in terms of its size, elliptic index, and LOVT-to-annular ratio, the present study introduced the "coverage index" for LOVT and found it to be an independent risk factor for the moderate to severe PVL after TAVR [21-23]. Excessive valve implantation depth emerged as an independent risk factor for significant PVL. In this group

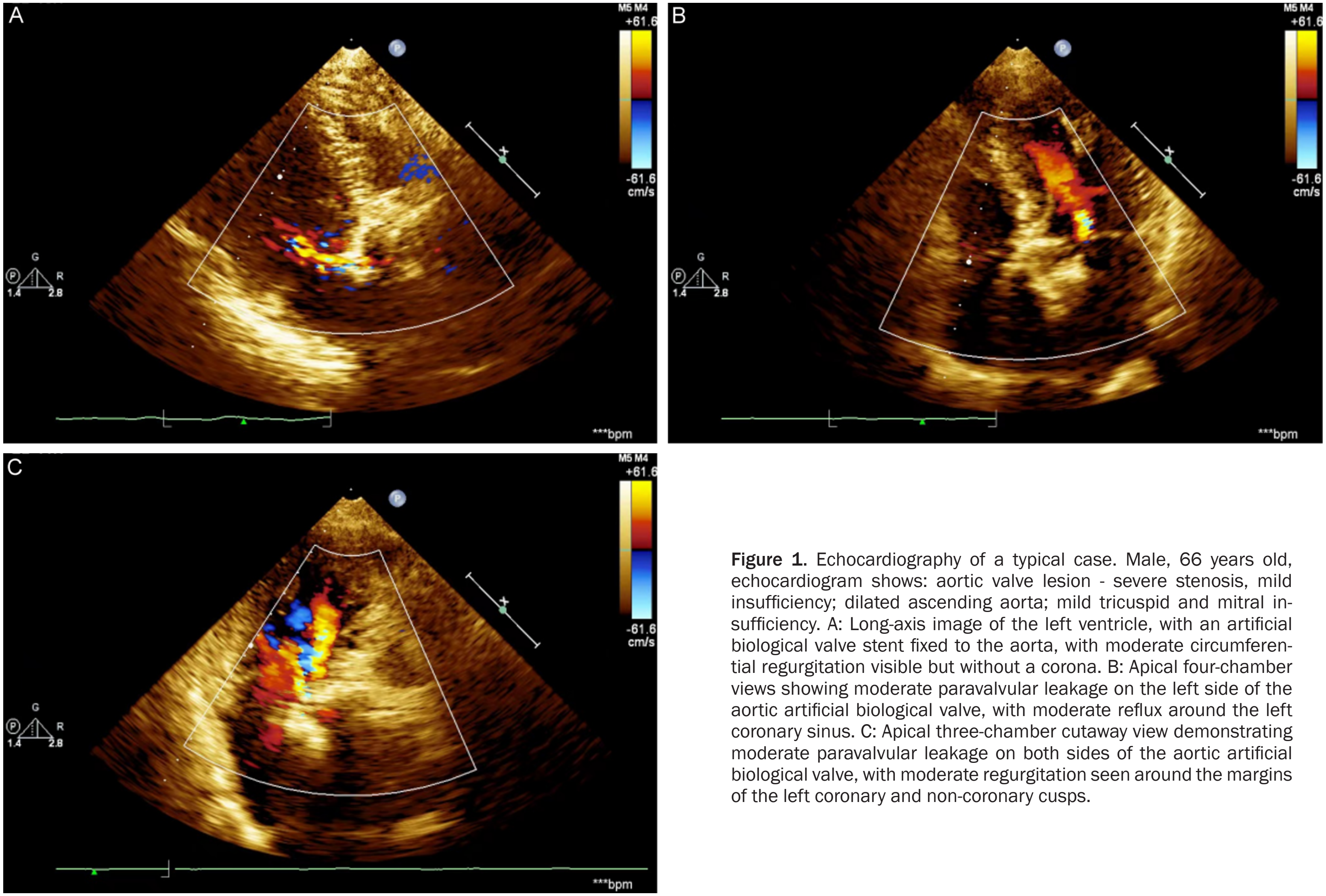

Figure 1. Echocardiography of a typical case. Male, 66 years old, echocardiogram shows: aortic valve lesion - severe stenosis, mild insufficiency; dilated ascending aorta; mild tricuspid and mitral insufficiency. A: Long-axis image of the left ventricle, with an artificial biological valve stent fixed to the aorta, with moderate circumferential regurgitation visible but without a corona. B: Apical four-chamber views showing moderate paravalvular leakage on the left side of the aortic artificial biological valve, with moderate reflux around the left coronary sinus. C: Apical three-chamber cutaway view demonstrating moderate paravalvular leakage on both sides of the aortic artificial biological valve, with moderate regurgitation seen around the margins of the left coronary and non-coronary cusps.

Table 2. Comparison of preoperative echocardiographic indices between the two groups

Echocardiography parameters	Observation group (n=51)	Control group (n=77)	t	*P*
PWT (mm, $\bar{x}$±sd)	12.02±2.81	11.97±2.15	0.114	0.910
LVEDd (mm, $\bar{x}$±sd)	55.64±7.22	49.21±5.48	5.718	<0.001
LVESD (mm, $\bar{x}$±sd)	41.28±8.56	34.79±6.45	4.884	<0.001
LVEF (%, $\bar{x}$±sd)	52.33±10.42	54.35±9.66	1.122	0.264
LAD (mm, $\bar{x}$±sd)	44.57±6.75	43.26±6.93	1.058	0.292
RWT ($\bar{x}$±sd)	0.51±0.12	0.50±0.14	0.418	0.677

Notes: PWT: posterior wall thickness; LVEDd: left ventricular end-diastolic diameter; LVESD: left ventricular end systolic diameter; LVEF: left ventricular ejection fraction; LAD: left atrial diameter; RWT: relative ventricular wall thickness.

Table 3. Comparison of preoperative MSCT scanning parameters between the two groups ($\bar{x}$±sd)

MSCT scanning parameters	Observation group (n=51)	Control group (n=77)	t	*P*
Aortic annular short diameter (mm, $\bar{x}$±sd)	23.18±2.12	20.75±2.43	5.822	<0.001
Aortic annular long diameter (mm, $\bar{x}$±sd)	29.44±3.17	26.04±2.98	6.161	<0.001
Oversize rate of implanted valves (%, $\bar{x}$±sd)	7.40±2.58	8.01±2.73	1.265	0.208
Elliptic index of the aortic annulus (%, $\bar{x}$±sd)	21.83±6.41	21.64±5.32	0.182	0.856
LVOT short diameter (mm, $\bar{x}$±sd)	24.03±3.64	20.76±2.18	6.355	<0.001
LVOT long diameter (mm, $\bar{x}$±sd)	32.12±3.67	28.96±3.33	5.046	<0.001
LVOT coverage index ($\bar{x}$±sd)	3.45±1.21	5.69±1.04	11.172	<0.001
LVOT elliptic exponent (%, $\bar{x}$±sd)	25.67±8.01	27.23±8.30	1.056	0.293
Short diameter of sinotubular junction (mm, $\bar{x}$±sd)	32.01±6.72	31.22±7.58	0.604	0.547
Long diameter of sinotubular junction (mm, $\bar{x}$±sd)	35.40±7.85	34.20±8.41	0.811	0.419
Aortic angulation (°, $\bar{x}$±sd)	59.01±7.94	51.22±6.31	6.162	<0.001
Calcifications volume (mm^3, $\bar{x}$±sd)	739.48±215.20	569.28±150.59	5.265	<0.001

Notes: LVEDd: left ventricular end-diastolic diameter; LVESD: left ventricular end systolic diameter; LVOT: left ventricular outflow tract; MSCT: multi-slice spiral CT.

of patients valve placement was generally deep, and excessive depth increased the uncovered portion of the valvular stent along the LVOT or left ventricle, raising the likelihood of moderate or greater PVL postoperatively [24-26]. The pathophysiology of aortic stenosis is characterized by progressive narrowing of the valve opening. Aortic valve stenosis can cause excessive pressure load on the left ventricle of patients, leading to myocardial thickening or changes in the geometry of the left ventricle. As a compensatory mechanism, the patient decreases ventricular wall stress and maintains cardiac output, leading to decreased exercise capacity, inadequate cardiac output, heart failure, and ultimately cardiac death [27-29]. In this study, LVEDd and LVEDSD were identified as independent risk factors for the occurrence of moderate to severe PVL after surgery, indicating that myocardial hypertrophy degree and cardiac remodeling play crucial roles in PVL development. Aortic angulation was also found to be an independent risk factor for moderate to severe PVL, aligning with existing research findings [30, 31]. This may be due to the technical difficulties associated with aortic angle and deep valve implantation. In addition, severe calcification of the aortic valve annulus was significantly associated with the degree of aortic regurgitation following TAVR, as severe calcification can hinder proper fixation and sufficient expansion of the artificial valve, thereby preventing it from fitting adequately with its own annulus and leading to the development of PVL [32-34].

Additionally, we constructed a prediction model for moderate to severe PVL in patients following TAVR surgery by incorporating the significant factors from multivariate logistic regression analysis. The model demonstrated a strong predictive value, with an area under

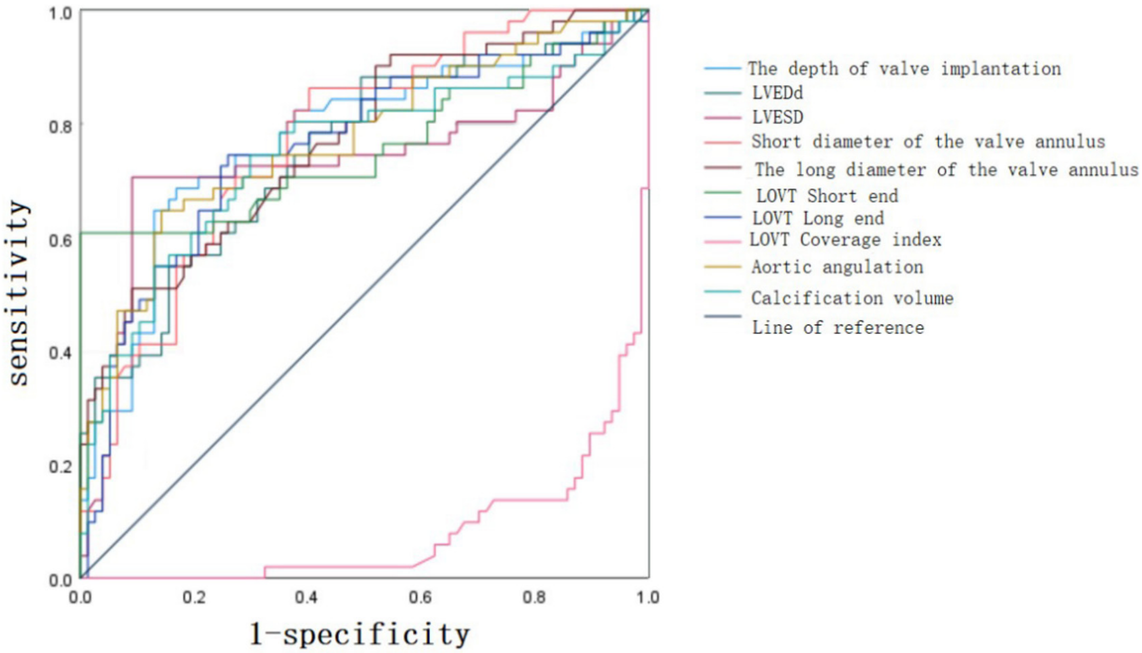

Figure 2. ROC curve analysis for significant factors in predicting moderate to severe PVL in patients undergoing TAVR. Notes: ROC: receiver operating characteristic; PVL: perivalvular leakage; TAVR: transcatheter aortic valve replacement.

Table 4. Cutoff values for various significant variables determined by ROC

Indicators	Area under the curve	Truncation value	(Level of) sensitivity	Specificity	P	95% CI
Depth of valve implantation	0.776	13.01 mm	68.60%	83.10%	<0.001	0.689-0.863
LVEDd	0.751	54.17 mm	54.90%	84.40%	<0.001	0.663-0.839
LVESD	0.738	39.0 mm	70.60%	90.90%	<0.001	0.637-0.838
Aortic annular short diameter	0.772	22.10 mm	86.30%	59.70%	<0.001	0.690-0.853
Aortic annular long diameter	0.770	27.31 mm	49.00%	90.90%	<0.001	0.687-0.853
LVOT short diameter	0.760	22.73 mm	60.80%	100%	<0.001	0.665-0.855
LVOT long diameter	0.761	30.98 mm	74.50%	74.00%	<0.001	0.672-0.849
LVOT coverage index	0.080	4.22	86.30%	85.70%	<0.001	0.033-0.126
Aortic angulation	0.771	56.40°	64.70%	85.70%	<0.001	0.685-0.857
Calcification volume	0.748	681.29 mm^3	74.50%	70.10%	<0.001	0.655-0.840

Notes: LVEDd: left ventricular end-diastolic diameter; LVESD: left ventricular end systolic diameter; LVOT: left ventricular outflow tract.

the ROC curve of 0.911, indicating its effectiveness.

Conclusion

In summary, the LVOT coverage index, valve implantation depth, LVEDd, aortic angulation, LVESD, and calcification volume are independent risk factors for moderate to severe PVL in patients with severe aortic stenosis undergoing TAVR. The risk prediction model, based on these risk factors, is highly valuable for predicting moderate to severe PVL, providing clinicians with an important tool for patient assessment and care planning post-TAVR.

Disclosure of conflict of interest

None.

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Table 5. Assignment table

Considerations	Assignment
Depth of valve placement	<13.01 mm = 0, ≥13.01 mm = 1
LVEDd	<54.17 mm = 0, ≥54.17 mm = 1
LVESD	<39.0 mm = 0, ≥39.0 mm = 1
Aortic annular short diameter	<22.10 mm = 0, ≥22.10 mm = 1
Aortic annular long diameter	<27.31 mm = 0, ≥27.31 mm = 1
LVOT short diameter	<22.73 mm = 0, ≥22.73 mm = 1
LVOT long diameter	<30.98 mm = 0, ≥30.98 mm = 1
LVOT coverage index	<4.22 = 0, ≥4.22 = 1
Aortic angulation	<56.40° = 0, ≥56.40° = 1
Calcification volume	<681.29 mm^3 = 0, ≥681.29 mm^3 = 1

Notes: LVEDd: left ventricular end-diastolic diameter; LVESD: left ventricular end systolic diameter; LVOT: left ventricular outflow tract.

Table 6. Multivariate logistic regression analysis

Factors	b	S.E	Chi-square value	P	OR	95% CI
LVOT coverage index	-2.085	0.503	17.182	<0.001	0.124	0.046-0.333
Depth of valve implantation	2.184	0.629	12.056	0.001	8.882	2.589-30.473
LVEDd	1.752	0.711	6.072	0.014	5.766	1.431-23.233
Aortic angulation	1.683	0.739	5.187	0.023	5.382	1.264-22.907
LVESD	1.439	0.635	5.135	0.023	4.216	1.215-14.638
Calcification volume	1.298	0.603	4.634	0.031	3.662	1.123-11.940

Note: LVEDd: Left ventricular end-diastolic diameter; LVESD: left ventricular end systolic diameter.

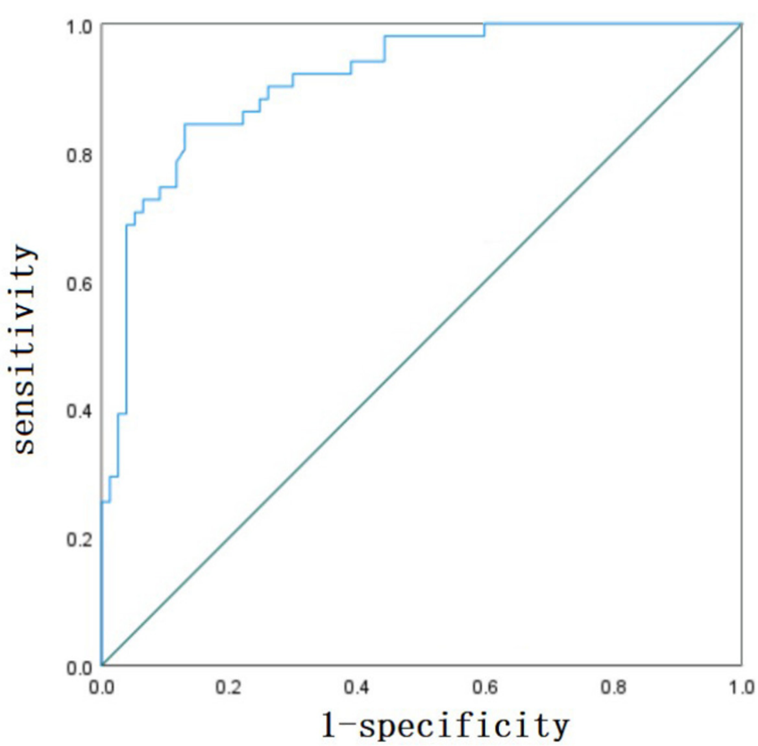

Figure 3. The predictive value of the constructed predictive model for moderate to severe PVL by ROC curve. Notes: ROC: receiver operating characteristic; PVL: perivalvular leakage.

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References

[1] Mazur P, Marin-Cuartas M, Arghami A, Noack T, Crestanello JA and Borger MA. Operative management after transcatheter aortic valve replacement. Kardiol Pol 2023; 81: 107-114.

[2] Sánchez-Ceña J, Asmarats L, Li CHP, Millán X, Fernández-Peregrina E, Menduiña I, Massó van Roessel A and Arzamendi D. Redo transcatheter aortic valve replacement in degenerated transcatheter bioprosthesis (TAV-in-TAV). Expert Rev Cardiovasc Ther 2023; 21: 703-712.

[3] Madhavan MV, Kodali SK, Thourani VH, Makkar R, Mack MJ, Kapadia S, Webb JG, Cohen DJ, Herrmann HC, Williams M, Greason K,

Pibarot P, Hahn RT, Jaber W, Xu K, Alu M, Smith CR and Leon MB. Outcomes of SAPIEN 3 transcatheter aortic valve replacement compared with surgical valve replacement in intermediate-risk patients. J Am Coll Cardiol 2023 11; 82: 109-123.
[4] Fukuhara S, Wu X, Hawkins R, Ailawadi G and Deeb GM. Prosthetic valve endocarditis after transcatheter and surgical aortic valve replacement. Ann Thorac Surg 2023; 116: 314-321.
[5] Kramer B, Vekstein AM, Bishop PD, Lowry A, Johnston DR, Kapadia S, Krishnaswamy A, Blackstone EH and Roselli EE. Choosing transcatheter aortic valve replacement in porcelain aorta: outcomes versus surgical replacement. Eur J Cardiothorac Surg 2023; 63: ezad057.
[6] Rouleau SG, Brady WJ, Koyfman A and Long B. Transcatheter aortic valve replacement complications: a narrative review for emergency clinicians. Am J Emerg Med 2022; 56: 77-86.
[7] Rivera FB, Al-Abcha A, Ansay MFM, Magalong JVU, Tang VAS, Ona HM, Miralles KA, Sausa R, Uy RAF, Lerma EV, Collado FMS, McCullough PA and Volgman AS. Transcatheter aortic valve replacement-associated acute kidney injury: an update. Cardiorenal Med 2023; 13: 143-157.
[8] Butala NM, Wood DA, Li H, Chinnakondepalli K, Lauck SB, Sathananthan J, Cairns JA, Magnuson EA, Barker M, Webb JG, Welsh R, Cheung A, Ye J, Velianou JL, Wijeysundera HC, Asgar A, Kodali S, Thourani VH and Cohen DJ; 3M-TAVR Investigators. Economics of minimalist transcatheter aortic valve replacement: results from the 3M-TAVR economic study. Circ Cardiovasc Interv 2022; 15: e012168.
[9] Jawitz OK, Raman V and Chen EP. Reoperation after transcatheter aortic valve replacement: the future is here. Eur J Cardiothorac Surg 2021; 60: 1156-1157.
[10] Nagasaka T, Patel V, Koren O, Shechter A, Chakravarty T, Cheng W, Ishii H, Jilaihawi H, Nakamura M and Makkar RR. TAVR-in-TAVR with a balloon-expandable valve for paravalvular leak. Front Cardiovasc Med 2024; 11: 1374078.
[11] Welle GA, El-Sabawi B, Thaden JJ, Greason KL, Klarich KW, Nkomo VT, Alkhouli MA, Guerrero ME, Crestanello JA, Gulati R, Rihal CS and Eleid MF. Effect of eliminating pre-discharge transthoracic echocardiogram on outcomes after TAVR. Catheter Cardiovasc Interv 2022; 99: 861-866.
[12] Gourav KP, Aspari A, Amburu V, Thingnam SS and Negi S. Iatrogenic aortic regurgitation following primary closure of ventricular septal defect: role of transesophageal echocardiography. Ann Card Anaesth 2020; 23: 103-105.
[13] Hu G, Lv Z, Ding J and Zhu X. Application of echocardiography in transcatheter aortic valve replacement in patients with severe aortic regurgitation and correlation analysis of post-procedural complications. Echocardiography 2024; 41: e15783.
[14] Li YL, Ye JC, Yancu H, Liu B, Wang YZ, Wang WJ, Wang W, Li D and Chang HY. Thoracic endovascular aortic repair for type B aortic dissection associated with retrograde type A intramural hematoma. J Vasc Interv Radiol 2020; 31: 1334-1341.
[15] Goel H, Kumar A, Garg N and Mills JD. Men are from mars, women are from venus: factors responsible for gender differences in outcomes after surgical and trans-catheter aortic valve replacement. Trends Cardiovasc Med 2021; 31: 34-46.
[16] Nishimura K, Iida M and Shimokawa T. Prosthetic valve replacement for aortic leaflet tear secondary to Impella device placement. J Artif Organs 2020; 23: 383-387.
[17] Patel P, Krishnan K, Saha S and Trohman RG. Novel implantable cardioverter-defibrillator lead placement in a patient with a prosthetic tricuspid valve. J Innov Card Rhythm Manag 2017; 8: 2894-2897.
[18] Nazir S, Elgin E, Loynd R, Zaman M and Donato A. ST-elevation myocardial infarction associated with infective endocarditis. Am J Cardiol 2019; 123: 1239-1243.
[19] Ramos-Maqueda J, Cabrera-Ramos M, Southard N, Riaño-Ondiviela A, Casasnovas-Lenguas JA and Ruiz-Arroyo JR. His-bundle pacing in a patient with tricuspid and mitral prosthetic valves without suitable coronary veins for lead placement. CJC Open 2021; 3: 1082-1084.
[20] Wei S, Ren T, Zhang L, He X, Li L and Jiang S. Thoracoscopic-assisted repair of perivalvular leakage of prosthetic mitral valve. Ann Thorac Surg 2021; 112: e431-e433.
[21] Chen YC, Hsing SC, Chao YP, Cheng YW, Lin CS, Lin C and Fang WH. Clinical relevance of the LVEDD and LVESD trajectories in HF patients with LVEF < 35. Front Med (Lausanne) 2022; 9: 846361.
[22] Cubeddu RJ, Sarkar A, Navas V and Navia JL. 'Minimalist approach' for transcatheter mitral valve replacement using intracardiac echocardiography and conscious sedation: a case series. Eur Heart J Case Rep 2020; 4: 1-5.
[23] Wan L, Tang J, Xiao Y, Li H, Peng Z, Xu DY and Shen L. Improvement of hemodynamic parameters in aortic stenosis patients with transcatheter valve replacement by using impedance cardiography. Front Cardiovasc Med 2022; 9: 950437.
[24] Liu K, Shen J, Wu K, Meng F, Wang S, Zheng S and Zhang H. Transapical mitral valve-in-valve

implantation for failed bioprosthetic valve using the J-valve system with locator device: early and mid-term outcomes. Ann Transl Med 2022; 10: 21.
[25] Papa A, Serban T, Strebel I, Knecht S, Isenegger C, Nestelberger T, Kaiser C, Leibundgut G, Haaf P, Schaer B, Krisai P, Osswald S, Sticherling C, Kühne M and Badertscher P. Impact of implantation depth and calcium burden on infranodal conduction delay after transcatheter aortic valve replacement. Heart Rhythm O2 2023; 5: 113-121.
[26] Li L, Liu Y, Jin P, Tang J, Lu L, Zhu G, Xu C, Ma Y and Yang J. Effect of eccentric calcification of an aortic valve on the implant depth of a venus-a prosthesis during transcatheter aortic valve replacement: a retrospective study. Front Physiol 2021; 12: 718065.
[27] Zheng KH, Tzolos E and Dweck MR. Pathophysiology of aortic stenosis and future perspectives for medical therapy. Cardiol Clin 2020; 38: 1-12.
[28] Parikh PB. Predicting futility in aortic stenosis: what's the holdup? J Am Coll Cardiol 2022; 80: 801-803.
[29] Shah BN and Senior R. Discordant moderate aortic stenosis: is it clinically important? Open Heart 2021; 8: e001749.
[30] Wei X, Mao Y, Chen Z, Kang L, Xu B and Wang K. Exercise-induced myocardial hypertrophy preconditioning promotes fibroblast senescence and improves myocardial fibrosis through Nrf2 signaling pathway. Cell Cycle 2023; 22: 1529-1543.
[31] Wu XC, Yuan CF, He YM, Zhou ZY, Luo Y, Yang MT, Li XX and Liu CQ. Chikusetsu saponin IVa ameliorates myocardial hypertrophy of rats through regulating expression of miR199a-5p/Atg5. Zhongguo Zhong Yao Za Zhi 2021; 46: 5064-5071.
[32] Eng MH and Zahr F. When should early discharge post-transcatheter aortic valve replacement be blocked? Catheter Cardiovasc Interv 2022; 100: 254-255.
[33] Eerdekens R, Anderson HVS and Johnson NP. How do the flow components of coronary flow reserve change after aortic valve replacement? Am J Cardiol 2024; 216: 105-107.
[34] Wolfrum M, Moccetti F, Loretz L, Bossard M, Attiger A, Cuculi F and Toggweiler S. Cerebral embolic protection during transcatheter aortic valve replacement: insights from a consecutive series with the Sentinel cerebral protection device. Catheter Cardiovasc Interv 2023; 102: 339-347.