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Effects of Two Types of Prosthetic Valves For Transcatheter Aortic Valve Implantation On Intraoperative Left Ventricular End-diastolic Pressure

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Background: Transcatheter aortic valve implantation (TAVI) is intended to reduce left ventricular afterload and the concomitant left ventricular end-diastolic pressure (LVEDP) change. Currently, two types of prosthetic valves are used in the TAVI procedures: balloon-expandable valves and self-expandable valves. The purpose of the current study was to investigate the effects of these valves on the LVEDP after valve deployment.

Methods: This retrospective study included 181 patients who underwent transfemoral TAVI. The patients were classified into one of two groups according to whether a balloon-expandable prosthetic valve (group B) or self-expandable prosthetic valve (group S) was used in the procedure. The intraoperative LVEDP, measured using an intracardiac catheter, was compared before and after valve deployment.

Results: The LVEDP decrement was significantly greater for group S than for group B (-1.3 ± 6.0 mmHg vs. 0.8 ± 5.1 mmHg). A subgroup analysis of the patients with mild or lower grade aortic regurgitation showed a significantly greater decrement of the LVEDP for subgroup S than for subgroup B (-1.8 ± 5.6 mmHg vs. 0.5 ± 4.8 mmHg).

Conclusion: Self-expandable prosthetic valves are advantageous for preventing LVEDP elevation after TAVI compared to balloon expandable prosthetic valves.

The study was registered at the University Hospital Medical Information Network Clinical Trials Registry (UMIN 000040255).

Keywords: TAVI, LVEDP, self-expandable prosthetic valve, balloon-expandable prosthetic valve

Introduction

Transcatheter aortic valve implantation (TAVI) for patients with severe aortic stenosis has spread rapidly as a less invasive alternative to surgical aortic valve replacement.[1,2] Not only is TAVI expected to improve the left ventricular (LV) systolic function by reducing the LV afterload, but it also improves the LV diastolic function. As a result, the LV end-diastolic pressure (LVEDP) is predicted to decrease after the TAVI procedure; however, we have previously reported a significant LVEDP elevation just after deployment of a balloon-expandable pros-

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thetic valve via the transfemoral approach.[3]

There are two types of prosthetic valves that have been used in the TAVI procedure since the introduction of self-expandable valves: balloon-expandable prosthetic valves and self-expandable prosthetic valves.[1] The major procedural difference between these prosthetic valves is whether or not balloon dilatation is required for valve deployment. A balloon-expandable prosthetic valve requires balloon dilatation at least once during the aortic balloon valvuloplasty (BAV) and valve deployment,[4] whereas a self-expandable prosthetic valve does not require balloon dilatation. Balloon dilatation generally requires rapid ventricular pacing (RVP), which can cause significant and sustained hemodynamic deterioration. We have hypothesized that RVP during the TAVI procedure can impact the LV diastolic function and LVEDP. Thus, in this study, we investigated whether the two types of prosthetic valves currently in use have different effects on the LVEDP.

Materials and Methods

The regional ethical committee of the Kurashiki Central Hospital Review Board provided ethical approval for this retrospective study (Reference No. 2333), and the study was registered at the University Hospital Medical Information Network Clinical Trials Registry (UMIN 000040255, registration date: April 27, 2020). For this study, we reviewed the medical records of patients who had undergone a TAVI procedure between February 2017 and January 2020, and the exclusion criteria were as follows: patients who required a percutaneous cardiopulmonary support device or intra-aortic balloon pumping perioperatively, patients who required additional surgical procedures because of intraoperative complications, patients who transitioned to emergent cardiac surgery, and patients with insufficient medical data.

Anesthesia management and TAVI procedures

All the procedures were performed in a hybrid operating suite with angiographic, fluoroscopic, and other imaging capabilities. During the procedures, the patients were managed under general anesthesia or monitored anesthetic care (MAC) at the discretion of the heart team, which included anesthesiologists. General anesthesia was routinely induced using propofol, rocuronium bromide, fentanyl, and remifentanil and maintained using desflurane, sevoflurane or propofol at the anesthesiologist's discretion. MAC was performed using a small dose of sedatives and opioids.

The TAVI procedures were performed via the transfemoral approach using either a balloon-expandable prosthetic valve (SAPIEN 3 valve, Edwards Lifesciences, Irvine, CA, USA) or a self-expandable prosthetic valve (CoreValve, Evolut R or Evolut PRO, Medtronic, Minneapolis, MN, USA). The specific type of valve to use for each patient was determined by the surgeon at the preoperative heart team conference.

After the valve was prepared for implantation, RVP at a rate of 170-180 beats/min was applied during the BAV and balloon-expandable prosthetic valve deployment to adequately reduce the cardiac output. To reduce perivalvular leakage (PVL) after the prosthetic valve was deployed, post-dilatation RVP was performed at the discretion of the heart team and based on the PVL severity. After the procedure was completed, the patients who underwent TAVI under general anesthesia were awakened and extubated in the operating theater, after which they were transferred to the intensive care unit and managed for at least one day.

Data recordings and collection process

The intraoperative LV pressure waveform was routinely recorded using the intracardiac catheter that was required for the TAVI procedure. The LVEDP was then derived from the LV pressure waveform. After the procedure was completed, experienced cardiologists used perioperative transthoracic or transesophageal echocardiography to comprehensively assess the residual aortic regurgitation (AR) severity and PVL based on the definitions developed by the Valve Academic Research Consortium-2, which include qualitative parameters, as well as semi-quantitative and quantitative measurements.[5]

The hemodynamic data and intracardiac pressures were obtained from the anesthesia and intracardiac pressure measurement records at specific time points before and after implantation. The values from the hemodynamically stable period before the first RVP were used as the pre-procedural measurements, and those from the stable period immediately after deployment of the prosthetic

valve were used as the post-procedural measurements.

Data analysis

Each patient was assigned to one of two groups. Group S consisted of patients treated with a self-expandable prosthetic valve, and group B consisted of patients treated with a balloon-expandable prosthetic valve. The continuous variables are presented as the mean ± standard deviation, unless otherwise specified. The non-parametric variables are presented as the median (25th and 75th percentiles). The continuous variables were compared using paired or non-paired Student's t-tests for the normally distributed variables. The non-normally distributed continuous variables were compared using the Mann-Whitney U test. The categorical variables were compared using the Pearson's chi-square test. The Pearson product-moment correlation coefficient was used to evaluate the relationship between the changes in the LVEDP and the intraoperative fluid balance. A subgroup analysis was performed based on the severity of the pre-operative and residual AR to avoid the effects of AR on the LVEDP. The AR severity cutoff value was determined based on the results of a previous study in which the relationship between peri-prosthetic AR and post-TAVI outcomes was investigated.[6] The subgroup analysis in that study included patients with mild or lower AR grades and/or residual PVL, both before and after the procedure. Statistical significance was set at $p < 0.05$. All the statistical analyses were performed using the R Statistical Package (R Foundation for Statistical Computing, Vienna, Austria).

Results

We reviewed the medical records of 196 patients who underwent TAVI via the transfemoral approach at our hospital during the study period. Ultimately, a total of 181 patients (61 in group S and 120 in group B) were enrolled after excluding the patients that required circulatory assist devices (2 patients), those with intraoperative complications (4 patients), and those with insufficient data (9 patients). The patient characteristics were similar between the two groups. The proportion of patients with a history of myocardial infarction was significantly higher for group B than for group S (15% vs. 4.9%, respectively). Preoperative echocardiography showed a significantly higher mean aortic valve pressure gradient for group S than for group B (55.3 ± 17.6 vs. 47.8 ± 15.9 mmHg, respectively) (**Table 1**). For both groups, high early diastolic mitral inflow velocity to early diastolic mitral annular velocity (E/e') ratios, low e' velocity values, and prolongation of the E velocity deceleration time were observed.

The procedural characteristics and anesthetic management are summarized in **Table 2**. The pre-procedural mean pressure gradient between the LV and ascending aorta was significantly higher for group S than for group B (62.8 ± 21.7 vs. 50.9 ± 16.9 mmHg, respectively, $p < 0.001$), but the total number of balloon dilatations was significantly smaller for group S than for group B (**Table 2**). The proportion of patients with mild or less residual PVL was significantly lower for group S than for group B. Although the LVEDP did not decrease significantly after the procedure for either group (from 14.1 ± 6.1 to 12.9 ± 4.8 mmHg for group S, $p = 0.11$ vs. 13.1 ± 6.1 to 13.9 ± 5.8 mmHg for group B, $p = 0.065$) (**Table 2**), the decrement of the LVEDP before and after valve deployment was significantly greater for group S than for group B (-1.3 ± 6.0 vs. 0.8 ± 5.1 mmHg, $p = 0.015$) (**Figure 1, left**).

A subgroup analysis excluding 25 patients from group S and 20 patients from group B due to moderate or severe preoperative AR grades and/or residual PVL was performed. There was no significant difference in the pre-procedural LVEDP between the two groups (14.3 ± 6.2 for subgroup S vs. 13.3 ± 6.5 mmHg for subgroup B). The LVEDP decrement was significantly greater for subgroup S than it was for subgroup B (-1.8 ± 5.6 vs. 0.5 ± 4.8 mmHg, $p = 0.025$) (**Figure 1, right**). The intraoperative fluid balance did not correlate with LVEDP changes in either subgroup (**Figure 2**).

Discussion

The results of the present study demonstrate that the LVEDP did not decrease meaningfully after deployment of the prosthetic valves, and the LVEDP decrement after the TAVI procedure for the patients treated with a self-expandable prosthetic valve was significantly greater than that of the patients treated with balloon-expandable

Table 1. Patient baseline clinical parameters.

	All (n = 181)	Group S (n = 61)	Group B (n = 120)	p-value
Male/Female	53/128	19/42	34/86	NS
Age, years	85.7 ± 5.2	84.4 ± 5.2	86.3 ± 5.0	p < 0.05
Height, cm	149.4 ± 8.9	149.7 ± 8.4	149.2 ± 9.1	NS
Weight, kg	50.5 ± 10.4	49.1 ± 10.2	51.2 ± 10.4	NS
Body surface area, m^2	1.43 ± 0.16	1.41 ± 0.17	1.44 ± 0.16	NS
Comorbidity				
Hypertension, n (%)	124 (68.5)	44 (72.1)	80 (66.7)	NS
Diabetes, n (%)	39 (21.5)	13 (21.3)	26 (21.7)	NS
Smoking, n (%)	6 (3.3)	4 (6.6)	2 (1.7)	NS
Dyslipidemia, n (%)	72 (39.8)	21 (34.4)	51 (42.5)	NS
Old myocardial infarction, n (%)	21 (11.6)	3 (4.9)	18 (15)	p < 0.05
EuroSCORE II, %, median (IQR)	3.1 [2.3, 4.2]	3.1 [2.3, 4.0]	3.1 [2.3, 4.5]	NS
Preoperative echocardiographic study, mean ± SD				
Ejection fraction, %*	61.0 ± 11.6	61.8 ± 10.9	60.6 ± 12.0	NS
Stroke volume index, mL/m^2	50.7 ± 14.7	52.2 ± 12.1	50.0 ± 15.8	NS
Mean aortic valve pressure gradient, mmHg	50.3 ± 16.8	55.3 ± 17.6	47.8 ± 15.9	p < 0.01
Aortic valve orifice area index, cm^2/m^2	0.49 ± 0.15	0.48 ± 0.16	0.49 ± 0.14	NS
Aortic valve regurgitation severity, n (%)				p < 0.05
Grade ≤ 2	153 (84.5)	47 (77.0)	106 (88.3)	
Grade > 2	28 (15.5)	14 (23.0)	14 (11.7)	
Mitral inflow E velocity, cm/s†	78.3 ± 26.8	78.7 ± 25.9	78.1 ± 27.2	NS
Mitral inflow A velocity, cm/s‡	103.4 ± 27.4	101.5 ± 28.5	104.3 ± 26.7	NS
E velocity/A velocity ratio‡	0.79 ± 0.45	0.82 ± 0.50	0.77 ± 0.42	NS
Mitral inflow E wave deceleration time, ms§	255.2 ± 111.9	264.1 ± 97.7	250.8 ± 118.0	NS
Early diastolic mitral annular velocity (e'), cm/s‖	4.0 ± 1.4	4.0 ± 1.4	4.1 ± 1.4	NS
E/e' ratio¶	21.1 ± 9.2	21.9 ± 9.8	20.7 ± 8.8	NS

*Group S, n = 61; Group B, n = 118.
†Group S, n = 58; Group B, n = 118.
‡Group S, n = 52; Group B, n = 103.
§Group S, n = 57; Group B, n = 115.
‖Group S, n = 59; Group B, n = 117.
¶Group S, n = 56; Group B, n = 116.
EuroSCORE, European System for Cardiac Operative Risk Evaluation; IQR, interquartile range; NS, not significant; SD, standard deviation.

valves.

There are several factors that affect the LVEDP, including RVP, AR, LV diastolic function, and the intraoperative fluid balance. RVP could have a negative effect on cardiac function, which did not reduce the LVEDP of the patients treated with balloon-expandable valves. The critical procedural difference between the two types of prosthetic valves is whether balloon dilatation is necessary for valve deployment. BAV and deployment of balloon-expandable devices generally require RVP. Our results show that the total number of balloon dilatations was significantly higher for the patients using balloon-expandable prosthetic valves than for those using self-expandable prosthetic valves, which may induce sustained hemodynamic deterioration.[7,8] A previous study reported that RVP induced a time-dependent decrement in microvascular blood perfusion and was associated with microcirculatory arrest and delayed microflow recovery.[9] The demographic data showed a significantly high ratio of patients with balloon-expandable prosthetic valves who had a history of myocardial infarction. Coronary perfusion deterioration induced by RVP may have been partly responsible for the LVEDP changes, especially for patients with myocardial ischemia.

Preoperative AR or residual PVL after TAVI deployment could directly affect LVEDP elevation. Therefore, we conducted a subgroup analysis in which the patients with moderate or higher preoperative AR grades and/or residual PVL after deployment were excluded. However, the results of this analysis were the same as those of the

Table 2. Procedural characteristics.

	All (n = 181)	Group S (n = 61)	Group B (n = 120)	p-value
Prosthetic valve, n		Corevalve 1 Evolut R 40 Evolut PRO 20	SAPIEN 3 120	
Total number of BAV procedures, n (%)				p < 0.001
0	15 (8.3)	15 (24.6)	0 (0)	
1	32 (17.7)	28 (45.9)	4 (3.3)	
2	111 (61.3)	9 (14.8)	102 (85.0)	
3	19 (10.5)	7 (11.5)	12 (10.0)	
4 ≤	4 (2.2)	2 (3.3)	2 (1.7)	
Mean aortic valve pressure gradient, mmHg				
Before the deployment	54.9 ± 19.4	62.8 ± 21.7	50.9 ± 16.9	p < 0.001
After the deployment	8.6 ± 4.9	9.1 ± 5.2	8.3 ± 4.7	NS
LVEDP, mmHg				
Before the deployment	13.4 ± 6.1	14.1 ± 6.1	13.1 ± 6.1	NS
After the deployment	13.5 ± 5.5	12.9 ± 4.8	13.9 ± 5.8	NS
LVEDP decrement, mmHg	0.1 ± 5.5	-1.3 ± 6.0	0.8 ± 5.1	p < 0.05
Residual PVL severity, n (%)				p < 0.001
Grade ≤ 2	158 (87.3)	44 (72.1)	114 (95.0)	
Grade > 2	23 (12.7)	17 (27.9)	6 (5.0)	
Anesthetic time, min	111 ± 52	117 ± 26	108 ± 21	p < 0.05
Surgical time, min	53 ± 19	58 ± 19	50 ± 18	p < 0.001
Anesthesia, n (%)				NS
GA	53 (29.3)	14 (23.0)	39 (32.5)	
MAC	128 (70.7)	47 (77.0)	81 (67.5)	
Intraoperative fluid balance, mL	469 ± 333	491 ± 337	459 ± 329	NS
Intraoperative use of cardiovascular agents, n (%)				
Ephedrine	77 (42.5)	26 (42.6)	51 (42.5)	NS
Phenylephrine	49 (27.1)	11 (18.0)	38 (31.7)	NS
Noradrenaline	113 (62.4)	43 (70.5)	70 (58.3)	NS
Nicardipine	80 (44.2)	25 (41.0)	55 (45.8)	NS
Nicorandil	15 (8.3)	1 (1.6)	14 (11.7)	p < 0.05

The data are presented as the mean ± standard deviation or n (%).
BAV, aortic balloon valvuloplasty; GA, general anesthesia; LVEDP, left ventricular end-diastolic pressure; MAC, monitored anesthetic care; NS, not significant; PVL, perivalvular leakage.

overall analysis. Previously, we demonstrated a significant increase in the LVEDP immediately after deployment of an older balloon-expandable valve model (SAPIEN XT, Edwards Lifesciences, Irvine, CA, USA).[3] However, all the patients in group B in the present study were treated with a SAPIEN 3 balloon-expandable prosthetic valve, which is a newly developed valve equipped with an outer skirt designed to minimize PVL. The differences in these devices may have contributed to the different magnitudes of the LVEDP increase and the ratios of the patients with moderate or higher PVL grades in both studies (5% in the present study, 32% in our previous study).

LV diastolic function can affect the LVEDP. Severe aortic stenosis is associated with LV hypertrophy and subsequent diastolic dysfunction, which causes LV filling pressure elevation. Severe LV diastolic dysfunction and ventricular filling pressure elevation were reported to be associated with poor outcomes after the TAVI procedure.[10] Gonçalves et al. investigated the intraoperative acute diastolic function change induced by the TAVI procedure[11] and reported an improvement in the diastolic function implied by an elongation of the transmitral E wave deceleration time, isovolumetric relaxation time, and decrement of the LVEDP after valve deployment. They also showed that patients with severe diastolic dys-

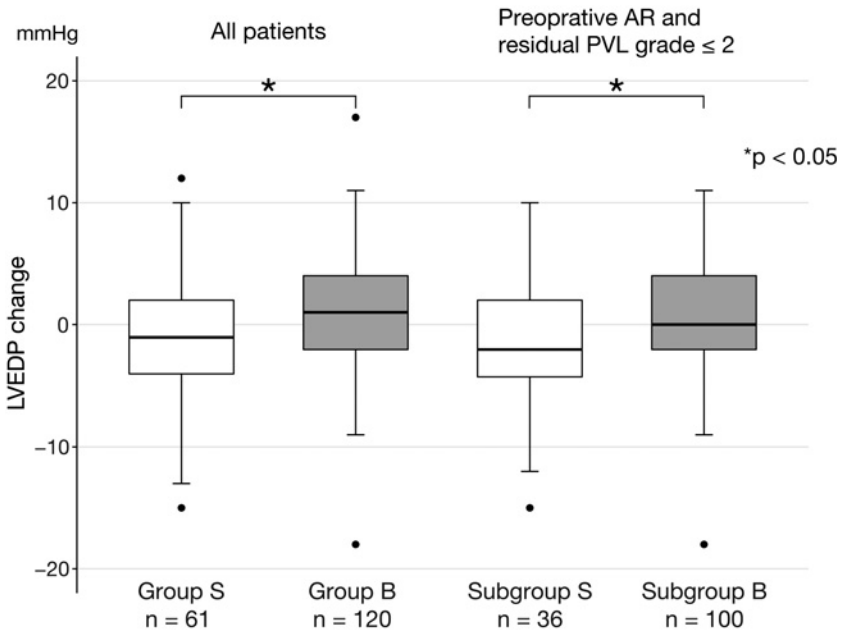

Figure 1. The LVEDP change before and after the prosthetic value deployment for all the patients and patient subgroups with preoperative AR and a PVL grade ≤2.
AR, aortic regurgitation; LVEDP, left ventricular end-diastolic pressure; PVL, perivalvular leakage.

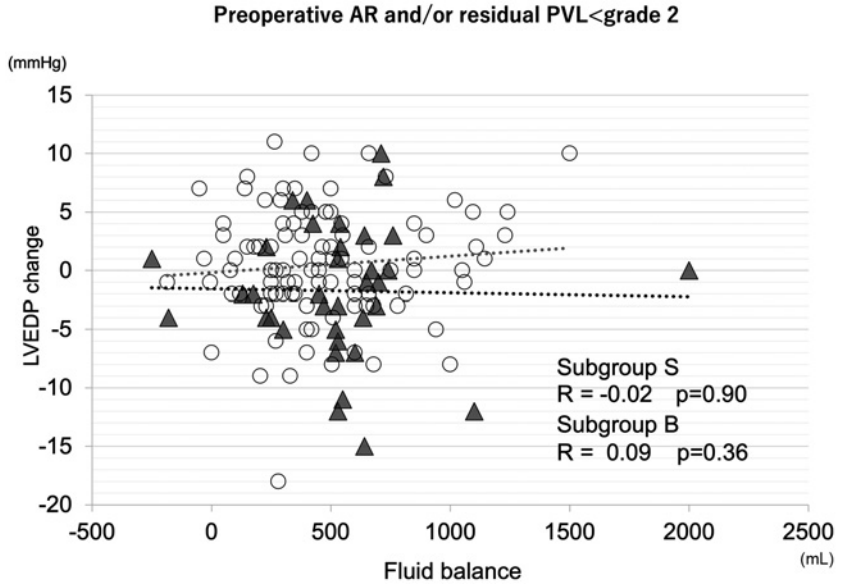

Figure 2. The correlation between fluid balance and LVEDP change for the patients with a mild or lower grade preoperative AR and/or residual PVL.
The closed triangles and open circles indicate Subgroup S and Subgroup B, respectively.
AR, aortic regurgitation; LVEDP, left ventricular end-diastolic pressure; PVL, perivalvular leakage.

function exhibited a smaller decrease in the LVEDP than those with milder diastolic dysfunction. Since the preoperative echocardiographic parameters of the diastolic function were abnormal in the present study, diastolic dysfunction may have contributed to the small decrement of the LVEDP.

Because the fluid volume status could also affect the LVEDP, the effect of the intraoperative fluid administration volume on LVEDP changes was analyzed. Although rapid fluid administration during the TAVI procedure might lead to a significant increase in the LVEDP,[3] intraoperative fluid administration was not related to the

LVEDP in this study. However, excessive fluid administration should be avoided to prevent filling pressure elevation and subsequent coronary perfusion disturbance. In addition, the pulse pressure increment that increases ventricular wall stress should also be avoided to prevent a cardiac workload increment and early diastolic filling impairment.[12] These precautions are required to improve the perioperative myocardial oxygen supply and demand for high-risk patients, including TAVI candidates. Understanding the characteristics of the specific TAVI valve used and the hemodynamic management practices necessary to prevent an increase in the LVEDP may improve the early prognosis of TAVI patients.

Our study had some limitations. First, this was a retrospective, observational, single-center study. Therefore, the number of patients was limited, and the patients' characteristics were not completely analogous between the two groups. In addition, the management of anesthetic, including the anesthetic method and fluid administration, was performed at the discretion of the heart team and anesthetist. Thus, the influence of the fluid infusion speed and the depth of anesthesia on the results is unclear, and arterial pressure, which could affect LVEDP, was not obtained at the time of measurements. Second, the measurement periods were limited to immediately before and after the deployment of the prosthetic valve. Therefore, an LVEDP time-course change after the prosthetic valve deployment could not be observed. Continuous measurement of the LV pressure is not practical, as LV intracardiac catheter insertion is an invasive technique. Third, this retrospective study did not provide a simple comparison between the two groups because the valves used in group S included three types of self-expanding prosthetic valves: Corevalve, Evolut R, and Evolut PRO. Evolut R and Evolut PRO, which were launched as an improved version of Corevalve, have improved sealing performance to reduce PVL and their delivery systems for accurate deployment and avoiding vascular complications. Since these three self-expanding prosthetic valves were developed with the same design concept, patients in whom each valve was used were included in group S. Fourth, although the clinical significance and impact on the outcomes of the difference in the LVEDP decrement between self-expandable and balloon-expandable valves are critical, they could not be clarified due to the design of this study.

Conclusion

The results of our study show that the LVEDP decrement immediately after the TAVI procedure was significantly greater for the patients treated with self-expandable prosthetic valves than for those treated with balloon-expandable prosthetic valves. However, the LVEDP did not decrease meaningfully after the TAVI procedure, regardless of which prosthetic valve was used. Although TAVI is generally expected to reduce afterload and LVEDP and improve cardiac function, anesthesiologists should be aware that the procedure does not always result in an LVEDP decrease. However, compared to balloon expandable prosthetic valves, self-expandable prosthetic valves are advantageous for preventing post-TAVI LVEDP elevation.

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References

1. Hamm CW, Arsalan M, Mack MJ. The future of transcatheter aortic valve implantation. Eur Heart J. 2016;37(10):803−10.

2. Perrin N, Frei A, Noble S. Transcatheter aortic valve implantation: Update in 2018. Eur J Intern Med. 2018;55: 12−9.
3. Toyota K, Ota T, Nagamine K, et al. Effect of transcatheter aortic valve implantation on intraoperative left ventricular end-diastolic pressure. J Anesth. 2016;30(6): 1051−5.
4. Ahn HC, Nielsen NE, Baranowski J. Can predilatation in transcatheter aortic valve implantation be omitted? - a prospective randomized study. J Cardiothorac Surg. 2016;11(1):124.
5. Kappetein AP, Head SJ, Généreux P, et al. Valve Academic Research Consortium-2. Updated standardized endpoint definitions for transcatheter aortic valve implantation: the Valve Academic Research Consortium-2 consensus document. J Thorac Cardiovasc Surg. 2013; 145(1):6−23.
6. Sinning JM, Hammerstingl C, Vasa-Nicotera M, et al. Aortic regurgitation index defines severity of peri-prosthetic regurgitation and predicts outcome in patients after transcatheter aortic valve implantation. J Am Coll Cardiol. 2012;59(13):1134−41.
7. Holmes Jr DR, Mack MJ, Kaul S, et al. 2012 ACCF/AATS/SCAI/STS expert consensus document on transcatheter aortic valve replacement. J Am Coll Cardiol. 2012;59(13):1200−54.
8. Witzke C, Don CW, Cubeddu RJ, et al. Impact of rapid ventricular pacing during percutaneous balloon aortic valvuloplasty in patients with critical aortic stenosis: should we be using it? Catheter Cardiovasc Interv. 2010; 75(3):444−52.
9. Selle A, Figulla HR, Ferrari M, et al. Impact of rapid ventricular pacing during TAVI on microvascular tissue perfusion. Clin Res Cardiol. 2014;103(11):902−11.
10. Kampaktsis PN, Vavuranakis M, Choi DY, et al. Prognostic role of diastolic dysfunction in patients undergoing transcatheter aortic valve replacement. Catheter Cardiovasc Interv. 2020;95(5):1024−31.
11. Gonçalves A, Marcos-Alberca P, Almeria C, et al. Acute left ventricle diastolic function improvement after transcatheter aortic valve implantation. Eur J Echocardiogr. 2011;12(10):790−7.
12. Ryu T, Song S-Y. Perioperative management of left ventricular diastolic dysfunction and heart failure: an anesthesiologist's perspective. Korean J Anesthesiol. 2017; 70(1):3−12.