

# Influence of normal to high stroke volume on congestive heart failure development after transcatheter aortic valve implantation: case series

Tomoko Tomioka<sup>✉</sup>, Tomohiro Ito, Ryokichi Takahasi, Shuhei Tanaka

Department of Cardiology, South Miyagi Medical Center, Shibata, Japan

✉ Correspondence to: [tomoko.t@southmiyagi-mc.jp](mailto:tomoko.t@southmiyagi-mc.jp)

<https://doi.org/10.11909/j.issn.1671-5411.2021.01.010>

**A**ortic stenosis (AS) is the most common valvular disease in the older adults' population, and its prevalence will likely continue to increase with the aging society.<sup>[1]</sup> Surgical aortic valve replacement (SAVR) for elderly patients is known as a high-risk procedure.<sup>[2–4]</sup> Transcatheter aortic valve implantation (TAVI) is a reasonable alternative to SAVR for older and inoperable patients with AS, and TAVI significantly improves outcomes in elderly patients with severe AS and serious comorbidities,<sup>[5,6]</sup> TAVI achieves a 20% relative reduction in mortality compared with SAVR,<sup>[7]</sup> although complications, such as cardiovascular events, stroke, and other procedural complications, are possible. It is reported that low ejection fraction (EF < 40%) and low stroke volume index (SVI < 35 mL/m<sup>2</sup>) in patients with AS before TAVI are risk factors for a poor prognosis after TAVI.<sup>[8–10]</sup>

On the other hand, in real-world clinical practice, we sometimes encounter patients with chronic heart failure (CHF) after TAVI with mid-range or preserved EF and normal or high SVI. Thus, we investigated patients with CHF whose SVI was  $\geq 35$  mL/m<sup>2</sup> before TAVI.

In this study, two EF measurements based on echocardiography, i.e., Teichholz formula or Simpson's rule,<sup>[11]</sup> were performed with case-by-case selections, and the measurements were sometimes inconsistency, resulting in sizable deviation of EF. While stroke volume (SV) was calculated based on Doppler velocimetry using the velocity-time integral of the left ventricular (LV) outflow tract, which followed normal standard distribution. Therefore,

we selected the SVI as the indicator and enrolled patients with a SVI of  $\geq 35$  mL/m<sup>2</sup>.

Twenty-six patients who were diagnosed with severe AS at our facility (South Miyagi Medical Center, Miyagi, Japan) and who underwent TAVI from April 2014 to August 2018 were enrolled. Diagnosis of severe AS was defined as an aortic valve area (AVA) of < 1 m<sup>2</sup> and a mean pressure gradient (MPG) of > 40 mmHg according to European Society of Cardiology guidelines.<sup>[12]</sup> TAVI was performed at two collaborative facilities because our facility did not have certification to perform TAVI. We selected 25 patients with before-TAVI SVI of  $\geq 35$  mL/m<sup>2</sup>, and retrospectively analyzed these patients. Data were obtained from an electronic database at our hospital before and after TAVI, and the data of echocardiography immediately after TAVI were obtained from the referral documents from the two collaborative facilities at which patients underwent TAVI. This study approved by our institutional research ethics committee. All procedures were in accordance with the 1964 Helsinki Declaration. All patients gave informed consent, and all patients had available follow-up information after TAVI for at least one year.

We divided patients into CHF and non-CHF groups according to their history of CHF development within 1 year after TAVI. The CHF and non-CHF groups included 11 patients (42%) and 14 patients (58%), respectively, and were compared according to their background, TAVI procedure, and preoperative and postoperative cardiac function obtained from echocardiography. Statistical analyses

were performed using the *t*-test and the  $\chi^2$  test. Multivariate Cox regression analyses were not possible because of the small sample size.

Patients' baseline characteristics are shown in Table 1. Patients' background information was not significantly different between groups. The mean age of patients was  $85 \pm 34$  years, and patients were classified as elderly. We did not observe a significant difference between the groups in terms of comorbidities, such as cerebrocardiovascular disease, conventional cardiac risk factors,<sup>[6,13]</sup> and medications before TAVI, while laboratory data showed that brain natriuretic peptide concentration before TAVI tended to be higher in the CHF group compared with the non-CHF group ( $984 \pm 774$  vs.  $743 \pm 525$  pg/mL, respectively;  $P = 0.3$ ). Furthermore, a pressure study before TAVI using a Swan-Ganz catheter showed that precapillary wedge pressure was significantly higher in the CHF group compared with the non-CHF group ( $14 \pm 8$  vs.  $9 \pm 4$  mmHg, respectively;  $P = 0.03$ ). LV end-diastolic pressure, which indicates LV overload, was also higher in the CHF group compared with the non-CHF group ( $22 \pm 7$  vs.  $18 \pm 2$  mmHg, respectively), although this difference was non-significant ( $P = 0.1$ ). These findings implicate LV pressure overload before TAVI, but this did not correlate with CHF development after TAVI.

As shown in Table 2, perioperative complications, such as moderate perivalvular leakage, annulus destruction, acute aortic regurgitation and/or mitral valve regurgitation, coronary events, and major vascular events, rarely occurred in either group. Chronically, three patients required pacemaker implantation (PMI) in the CHF group because of atrioventricular block, and one patient in the non-CHF group required PMI because of bradycardic atrial fibrillation (AF).

Echocardiography findings before TAVI are shown in Table 3A. Aortic valve area (AVA) was  $0.51 \pm 0.03$  vs.  $0.45 \pm 0.02$  cm<sup>2</sup>/m<sup>2</sup> ( $P = 0.2$ ), MPG was  $56 \pm 21$  vs.  $50 \pm 18$  mmHg ( $P = 0.2$ ), and peak aortic velocity was  $5.1 \pm 0.3$  m/s vs.  $4.8 \pm 0.2$  m/s ( $P = 0.3$ ) in the CHF and non-CHF groups, respectively. Thus, there were no significant differences between the groups in terms of AS severity. On the contrary, LVEF and SVI were significantly higher in the CHF group compared with the non-CHF group (LVEF:  $69\% \pm 8\%$  vs.  $56\% \pm 4\%$ , respectively,  $P = 0.05$ ; SVI:

$61 \pm 11$  mL/m<sup>2</sup> vs.  $49 \pm 14$  mL/m<sup>2</sup>, respectively,  $P = 0.03$ ). The prevalence of LV hypertrophy, left atrial dimension index, early (E) to late (A) ventricular filling velocity ratio (E/A), deceleration time (DecT), tricuspid valve regurgitation pressure gradient (TRPG), and inferior vena cava (IVC) diameter, which indicate LV overload, were nearly at the upper limit in the CHF group, although no statistically significant difference was observed when compared with the non-CHF group.

As shown in Table 3B, with echocardiography immediately after TAVI, AVA was appropriate with the selected prosthesis size and was not significantly different between the two groups ( $1.34 \pm 0.55$  cm<sup>2</sup> vs.  $1.69 \pm 0.13$  cm<sup>2</sup>, respectively;  $P = 0.1$ ). However, the Ratio of AVAI before and after TAVI (Ratio of AVAI) was higher in the CHF group compared with the non-CHF group ( $0.42 \pm 0.18$  vs.  $0.30 \pm 0.10$ , respectively;  $P = 0.03$ ), which suggests that TAVI was less effective in the CHF group compared with the non-CHF group. PV and MPG were higher in the CHF group compared with the non-CHF group (PV:  $2.7 \pm 0.3$  vs.  $2.1 \pm 0.5$  m/s, respectively;  $P = 0.02$ ; MPG:  $30 \pm 8$  vs.  $19 \pm 9$  mmHg, respectively;  $P = 0.02$ ). Furthermore, indicators of LV overload were significantly higher in the CHF group compared with the non-CHF group (E/e':  $16.1 \pm 3.4$  vs.  $12.3 \pm 3.2$ , respectively,  $P = 0.02$ ; E/A:  $0.98 \pm 0.27$  vs.  $0.60 \pm 0.13$ , respectively,  $P = 0.001$ ). In addition, TRPG was higher ( $32 \pm 5$  vs.  $24 \pm 8$  mmHg, respectively) and the IVC was more expanded ( $19 \pm 5$  mm vs.  $13 \pm 4$  mm, respectively;  $P = 0.05$ ) in the CHF group compared with the non-CHF group after TAVI.

These results highlight an imbalance between AVAI after TAVI and LV intracardiac pressure, resulting in LV pressure overload. It is possible that aortic valve resistance (AVR)<sup>[14]</sup> is not sufficiently mitigated even after TAVI; thus, CHF developed in the chronic phase. It is reasonable to suggest that AS patients with a high SVI are at a higher risk of CHF development, because AVR may increase in parallel with SVI. In fact, after-TAVI MPG, which is a substitute for AVR, and before-TAVI SVI were positively correlated in this study (data not shown).

This speculated story is similar to prosthesis-patient mismatch (PPM), which is a potentially modifiable risk factor leading to cardiac events.<sup>[15]</sup> It is re-



Table 1 Clinical characteristics of patients prior to TAVI.

Variable	All (n = 25)	CHF (n = 11)	Non-CHF (n = 14)	P-value
Age, yrs	85 ± 4	85 ± 3	85 ± 4	0.7
Male	9 (36%)	5 (50%)	4 (28%)	0.2
BMI, kg/m <sup>2</sup>	20.8 ± 3.5	20.5 ± 3.7	21.2 ± 3.8	0.8
BSA, m <sup>2</sup>	1.4 ± 0.2	1.4 ± 0.2	1.4 ± 0.1	0.3
Mean follow-up period, days	861 ± 625	1005 ± 196	754 ± 116	0.2
Presence of cardiac decompensation on admission	18 (72%)	8 (80%)	10 (71%)	0.6
NYHA class III/IV	8 (42%)	2 (20%)	6 (66%)	0.03
<b>Cerebrocardiovascular disease</b>				
Ischemic heart disease	2 (8%)	2 (20%)	0 (0%)	0.3
History of CHF	9 (36%)	5 (45%)	4 (28%)	0.4
Atrial fibrillation	8 (32%)	5 (50%)	3 (21%)	0.07
Conduction disorder	11 (44%)	6 (60%)	5 (33%)	0.2
Previous stroke	1 (4%)	1 (10%)	0 (0%)	0.2
PM/ICD	0 (0%)	0 (0%)	0 (0%)	N/A
Peripheral artery disease	0 (0%)	0 (0%)	0 (0%)	N/A
<b>Cardiac risk factor before TAVI</b>				
Hypertension	21 (84%)	10 (100%)	11 (78%)	0.06
Diabetes mellitus	9 (36%)	5 (50%)	4 (28%)	0.2
Dyslipidemia	9 (36%)	4 (40%)	5 (35%)	0.8
COPD	4 (16%)	2 (20%)	2 (14%)	0.7
CKD	5 (20%)	2 (20%)	3 (21%)	0.9
Hemodialysis	0	0	0	N/A
Immune deficiency	2 (8%)	1 (10%)	1 (7%)	0.8
Cancer within 5 years	0 (0%)	0 (0%)	0 (0%)	N/A
Current smoker	7 (28%)	4 (49%)	3 (21%)	0.3
<b>Laboratory data</b>				
eGFR, mL/min per 1.73 m <sup>2</sup>	59 ± 16	60 ± 17	58 ± 15	0.7
BNP, pg/mL	846 ± 619	984 ± 774	743 ± 525	0.3
<b>Cardiac catheterization</b>				
PCWP, mmHg	11 ± 6	14 ± 8	9 ± 4	0.03
Mean PAP, mmHg	18 ± 7	20 ± 2	18 ± 2	0.5
LVEDP, mmHg	19 ± 8	22 ± 7	18 ± 2	0.1
AVA, cm <sup>2</sup> /m <sup>2</sup>	0.47 ± 0.12	0.51 ± 0.15	0.45 ± 0.08	0.2
<b>Medication</b>				
Antiplatelet	8 (32%)	3 (27%)	5 (33%)	0.6
Anticoagulant	8 (32%)	4 (36%)	4 (27%)	0.4
ACE/ARB	17 (71%)	9 (90%)	8 (57%)	0.08
Loop diuretics	13 (52%)	4 (36%)	9 (64%)	0.2
CCB	9 (36%)	3 (27%)	6 (40%)	0.4
Beta blocker	5 (20%)	2 (18%)	3 (20%)	0.8
V2 receptor inhibitor	1 (4%)	1 (9%)	0 (0%)	0.2
Anti-aldosterone agent	10 (40%)	5 (45%)	5 (33%)	0.6
Statin	12 (48%)	3 (27%)	9 (64%)	0.06

Data are presented as mean ± SD or n (%). ACE: angiotensin-converting enzyme; ARB: angiotensin II receptor blocker; AVA: aortic valve area; BMI: body mass index; BNP: brain natriuretic peptide; BSA: body surface area; CCB: calcium channel blocker; CHF: congestive heart failure; CKD: chronic kidney disease; COPD: chronic obstructive pulmonary disease; eGFR: estimated glomerular filtration rate; ICD: implantable cardioverter defibrillator; LVEDP: left ventricular end-diastolic pressure; N/A: not available; PAP: pulmonary artery pressure; PCWP: precapillary wedge pressure; PM: pacemaker; TAVI: transcatheter aortic valve implantation; V2: vasopressin receptor 2.



**Table 2** Procedural characteristics and periprocedural outcomes in patients in the CHF and non-CHF groups after TAVI.

Variable	CHF group before TAVI (n = 11)	Non-CHF group after TAVI (n = 14)	P-value
<b>Balloon diameter</b>			
23 mm	6 (55%)	4 (27%)	0.4
26 mm	3 (27%)	6 (42%)	0.4
29 mm	2 (18%)	4 (28%)	0.4
<b>Balloon type</b>			
Balloon-expandable valve	11 (100%)	9 (64%)	0.02
Self-expandable valve	0	5 (36%)	0.02
<b>Access route</b>			
Transfemoral approach	10 (91%)	14 (100%)	0.2
Transapical approach	1 (9%)	0 (0%)	0.2
<b>Periprocedural complication</b>			
<sup>†</sup> Severe perivalvular leakage	0	0	N/A
Coronary event	0	0	N/A
*Requiring PMI	3 (27%)	0	0.03
Annulus destruction	0	0	N/A
Mitral regurgitation	2 (18%)	3 (23%)	0.8
Aortic regurgitation	3 (27%)	4 (28%)	0.9
Major vascular complication	1 (10%)	0	0.2
Acute kidney injury	0	0	N/A
Stroke	0	0	N/A
Death	0	0	N/A

CHF: congestive heart failure; PMI: pacemaker implantation; TAVI: transcatheter aortic valve implantation.

**Table 3** Comparison of echocardiographic findings between the CHF group and the non-CHF after TAVI.**Table 3A: Findings before TAVI.**

Variables	CHF group after TAVI (n = 11)	Non-CHF group after TAVI (n = 14)	P-value
AVA, cm <sup>2</sup> /m <sup>2</sup>	1.32 ± 0.49	1.66 ± 0.47	NS
Before-AVA/after-AVA	0.42 ± 0.18	0.30 ± 0.10	0.04
Aortic MPG, mmHg	30 ± 8	19 ± 9	0.006
Peak velocity, m/s	2.7 ± 0.3	2.1 ± 0.5	0.006
IVST + PWT, mm	18.1 ± 7.4	20 ± 2.4	NS
LVDd, mm	49 ± 4	46 ± 7	NS
LVDs, mm	29 ± 5	29 ± 7	NS
EF	65% ± 5%	64% ± 11%	NS
LVMI, g/m <sup>2</sup>	161 ± 41	144 ± 33	NS
SVI, mL/m <sup>2</sup>	51 ± 13	45 ± 12	NS
LADI, mm/m <sup>2</sup>	33 ± 6	33 ± 6	NS
E/A	0.91 ± 0.29	0.58 ± 0.14	0.003
E/e'	15.9 ± 3.2	12.2 ± 3.0	0.02
DecT, ms	229 ± 49	237 ± 78	NS
TRPG, mmHg	33 ± 5	26 ± 9	0.04
IVC, mm	19 ± 5	13 ± 4	0.05
MR > 2	2 (22%)	4 (23%)	NS
AR > 2	1 (11%)	0 (0%)	NS



**Table 3B. Findings after TAVI.**

Variable (mean ± SD)	CHF group before TAVI (n =11)	Non-CHF group after TAVI (n =15)	P-value
AVA, cm <sup>2</sup> /m <sup>2</sup>	1.32 ± 0.49	1.66 ± 0.47	NS
before-AVA/after-AVA	0.42 ± 0.18	0.30 ± 0.10	0.04
Aortic MPG, mmHg	30 ± 8	19 ± 9	0.006
Peak velocity, m/s	2.7 ± 0.3	2.1 ± 0.5	0.006
IVST + PWT, mm	18.1 ± 7.4	20 ± 2.4	NS
LVDd, mm	49 ± 4	46 ± 7	NS
LVDs, mm	29 ± 5	29 ± 7	NS
EF	65% ± 5%	64% ± 11%	NS
LVMI, g/m <sup>2</sup>	161 ± 41	144 ± 33	NS
SVI, mL/m <sup>2</sup>	51 ± 13	45 ± 12	NS
LADI, mm/m <sup>2</sup>	33 ± 6	33 ± 6	NS
E/A	0.91 ± 0.29	0.58 ± 0.14	0.003
E/e'	15.9 ± 3.2	12.2 ± 3.0	0.02
DecT (msec)	229 ± 49	237 ± 78	NS
TRPG (mmHg)	33 ± 5	26 ± 9	0.04
IVC (mm)	19 ± 5	13 ± 4	0.05
MR > 2	2 (22%)	4 (23%)	NS
AR > 2	1 (11%)	0 (0%)	NS

Data are presented as mean ± SD or n (%). AR: aortic regurgitation; AVA: aortic valve area; Before-AVA/after-AVA: ratio of before-TAVI AVA to after-TAVI AVA; CHF: congestive heart failure; DecT: deceleration time; E/A: early (E) to atrial (A) diastolic filling velocity ratio; E/e': ratio between early mitral inflow velocity and mitral annular early diastolic velocity; EF: ejection fraction; IVC: inferior vena cava; IVST: interventricular septum thickness; LVDd: left ventricular internal dimension in diastole; LADI: left atrial dimension index; LVDs: left ventricular internal dimension in systole; LVMI: left ventricular mass index; MPG: mean pressure gradient; MR: mitral regurgitation; NS: not significant; PWT: posterior left ventricular wall thickness; SVI: stroke volume index; TAVI: transcatheter aortic valve implantation; TRPG: tricuspid valve regurgitation pressure gradient.

ported that an effective orifice area index (EOAI) of < 0.64 cm<sup>2</sup>/m<sup>2</sup> suggests severe PPM, and an EOAI of 0.65–0.85 cm<sup>2</sup>/m<sup>2</sup> suggests moderate PPM.<sup>[15–16]</sup> In our study, EOAI (i.e., AVAI) after TAVI was > 0.85 cm<sup>2</sup>/m<sup>2</sup> in both groups, and AVAI after TAVI was comparable between groups (Table 3B). However, the ratio of AVAI in the CHF group was statistically higher than that in the non-CHF group (Table 3B). This result showed that AVA expansion was not sufficient in the CHF group even though obtained AVA were usually agreement after TAVI, resulting in leaving the patients in the CHF group in similar status to PPM, which consequently induced development of decompensated CHF. Additionally, inter-quartile calculation between the Ratio of AVAI and before-TAVI SVI demonstrated a positive correlation (data not shown), which implies a relationship between PPM and high SVI.

These results suggest that obtaining a large enough AVA both anatomically and physiologically using TAVI is desirable, especially for patients

with a hyperdynamic heart<sup>[17]</sup>; that is, a high SVI, although this may be technically difficult in patients with a small body surface area and/or aortic annulus calcification.

This study included a small sample size and possibly contained selection and/or information bias. Even so, we should identify the relationship between low SV and normal to high SV to expand our perspective in the future. This understanding would lead to improvements in clinical practice for patients undergoing TAVI.

We conclude that patients with a normal to high SVI before TAVI are prone to decompensated CHF after TAVI.

## ACKNOWLEDGMENTS

The authors thank the medical staff at our center for their cooperation in this study. We thank Emily Woodhouse, PhD, from Edanz Group (<https://en-author-services.edanz.com/ac>) for editing a draft of

this manuscript. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## REFERENCES

- [1] Domenech B, Pomar JL, Gonzales PS, *et al.* Valvular Heart Disease Epidemics. *J Heart valve Dis* 2016; 25: 1–7.
- [2] Lindman BR, Patel J. Multimorbidity in older adults with aortic stenosis. *Clin Geriatr Med* 2016; 32: 305–314.
- [3] Lee DH, Buth KJ, Martin BJ, *et al.* Frail patients are at increased risk for mortality and prolonged institutional care after cardiac surgery. *Circulation* 2010; 121: 973–978.
- [4] Murad K, Goff DC, Morgan TM, *et al.* Burden of comorbidities and functional and cognitive impairments in elderly patients at the initial diagnosis of heart failure and their impact on total mortality: the cardiovascular health study. *JACC Heart Fail* 2015; 3: 542–550.
- [5] Leon MB, Smith CR, Mack M, *et al.* Transcatheter aortic-valve implantation for aortic stenosis in patients who cannot undergo surgery. *N Engl J Med* 2010; 363: 1597–1607.
- [6] Rosa VEE, Lopes A, Accorsi T, *et al.* Euro SCORE II and STS as mortality predictors in patients undergoing TAVI. *Rev Assoc Med Bras* 2016; 62: 32–37.
- [7] Siontis G CM, Praz F, Pilgrim T. Transcatheter aortic valve implantation vs. surgical aortic valve replacement for treatment of severe aortic stenosis: a meta-analysis of randomized trial. *Eur Heart J* 2016; 37: 3503–3512.
- [8] Maes F, Lerakis S, Barbosa RH, *et al.* Low-flow, low-gradient AS with reduced LVEF (TOPAS-TAVI). *JAMA Cardiol* 2019; 4: 64–70.
- [9] Pilgrim T, Wenaweser P, Meuli F. Clinical outcome of high-risk patients with severe aortic stenosis and reduced left ventricular ejection fraction undergoing medical treatment or TAVI. *PLoS One* 2011; 6: e27556.
- [10] Conrotto F, D'Ascenzo F, Stella P, *et al.* Transcatheter aortic valve implantation in low ejection fraction/low transvalvular gradient patients: the rule of 40. *J Cardiovasc Med* 2017; 18: 103–108.
- [11] Blanco P. Echocardiographic assessment of ejection fraction in left ventricular hypertrophy. *The Ultrasound J* 2020; 12: 21.
- [12] Michalski B, Dweck MR, Marsan NA, *et al.* The evaluation of aortic stenosis, how the new guidelines are implemented across Europe: a survey by EACVI. *Eur Heart J Cardiovasc Imaging* 2020; 21: 357–362.
- [13] Arnett DK, Blumenthal RS, Albert MA, *et al.* 2019 ACC/AHA Guideline on the Primary Prevention of Cardiovascular Disease: Executive Summary: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Circulation* 2019; 140: e593–e595.
- [14] Antonini-Canterin F, Faggiano P, Zanuttini D, *et al.* Is aortic valve resistance more clinically meaningful than valve area in aortic stenosis? *Heart* 1999; 82: 9–10.
- [15] Pibarot P and Dumesnil JG. Prosthesis-patient mismatch: definition, clinical impact, and prevention. *Heart* 2006; 92: 1022–1029.
- [16] Herrmann HC, Daneshvar SA, Fonarow GC, *et al.* Prosthesis-patient mismatch in patients undergoing transcatheter aortic valve replacement. From the STS/ACC TVT Registry. *J Am Coll Cardiol* 2018; 72: 2701–2011.
- [17] Fowler NO. *Hyperdynamic States. Diagnosis of Heart Disease.* Springer-Verlag New York Inc 1991; 389-399.

**Please cite this article as:** Tomioka T, Ito T, Takahasi R, Tanaka S. Influence of normal to high stroke volume on congestive heart failure development after transcatheter aortic valve implantation: case series. *J Geriatr Cardiol* 2021; 18(1): 83–88. DOI: 10.11909/j.issn.1671-5411.2021.01.010

