Structural Heart 8 (2024) 100278

Articles and Issues Available at ScienceDirect

Structural Heart

journal homepage: www.structuralheartjournal.org

Original Research

Intentional Oversizing of Valve in Transcatheter Aortic Valve Replacement: Is Bigger Better? A Large, Single-Center Experience

Khawaja Afzal Ammar, MD[a,b,1,*], Alexandria Graeber, BS[a,1], Abdur Rahman Ahmad, MD[a], Jodi Zilinski, MD[a,b], Daniel P. O'Hair, MD[c], Renuka Jain, MD[a,b], Suhail Q. Allaqaband, MD[a,b], Tanvir Bajwa, MD[a,b]

[a] Aurora Cardiovascular and Thoracic Services, Aurora Sinai/Aurora St. Luke's Medical Centers, Advocate Aurora Health, Milwaukee, Wisconsin, USA
[b] Division of Cardiovascular Medicine, University of Wisconsin School of Medicine and Public Health, Milwaukee Clinical Campus, Milwaukee, Wisconsin, USA
[c] Boulder Heart at Boulder Community Health, Boulder, Colorado, USA

ARTICLE INFO

Article history:
Submitted 2 August 2023
Revised 18 December 2023
Accepted 21 December 2023
Available online 6 February 2024

Keywords:
Complications
Outcomes
Pacemaker implantation
Paravalvular leak
Transcatheter aortic valve replacement

ABSTRACT

Background: The current clinical practice standard is 10% to 20% oversizing of self-expanding valves in transcatheter aortic valve replacement. We aimed to determine whether >20% oversizing of self-expanding valves (Medtronic Evolut) would lead to better valve performance with similar or better outcomes.
Methods: From October 2011 to December 2016, we approached all transcatheter aortic valve replacement patients with a conscious attempt at large oversizing (>20%). The most common valve used, excluding those used in valve-in-valve patients, was the 29-mm Evolut R (29%). We used a retrospective chart review to compare moderate oversizing (group 1; 10% to 20%) with large oversizing (group 2; >20%).
Results: Of 556 patients, 45% were male; the overall mean Society of Thoracic Surgeons risk score was 5.8 ± 3.8. Eighty-five (15%) patients needed a pacemaker, and 21 (3.8%) developed significant paravalvular leak. Mean oversizing was 20.3% ± 6.0%, with 41.4% of patients included in group 1 and 54.5% in group 2. Incidences of complications in group 2 vs. group 1 were as follows: a) paravalvular leak (2.0 vs. 6.1%; odds ratio = 0.31, p = 0.01), b) pacemaker (15 vs. 14%), c) gastrointestinal bleed (n = 4 vs. 0; 1.3 vs. 0.0%; p = 0.03), d) annular dissection (n = 1 vs. 0; 0.3 vs. 0%; p = 0.29), e) mortality (n = 5 vs. 4; 1.6 vs. 1.7%). Incidence of paravalvular leak was higher in those who died than survivors (13 vs. 1.3%; $p \leq 0.0001$).
Conclusions: These data suggest that, in current self-expanding valves, >20% oversizing delivers a significantly lower prevalence of paravalvular leak without an increase in other complications. Since paravalvular leak is associated with increased mortality, >20% oversizing may represent a superior prosthesis choice.

ABBREVIATIONS

CT, computed tomography; GI, gastrointestinal; OR, odds ratio; PPM, permanent pacemaker; PVL, paravalvular leak; STS, Society of Thoracic Surgeons; TAVR, transcatheter aortic valve replacement.

Introduction

Optimal sizing of the valve in patients undergoing transcatheter aortic valve replacement (TAVR) continues to be a challenge, as oversizing leads to an increased incidence of permanent pacemaker (PPM) implantation and undersizing results in paravalvular leak (PVL), both major determinants of postprocedure prognosis.[1] For self-expanding, nitinol-based valves (Medtronic CoreValve, Evolut R, and Evolut PRO, Minneapolis, Minn.), the current industry guidelines call for the use of a prosthetic valve that is 10% to 20% larger than the patient's valve, with a recommended range of 13% to 31% (personal communication; Medtronic). Multiple prior studies suggested that this oversizing in balloon-expandable valves (Edwards, Irvine, Calif.) led to annular rupture, which was not seen in self-expanding valves, as mentioned in a review article on this topic.[2] The PPM implantation rate was quite high, approximately 30%, for both types of valves. The incidence of PVL was

[1] KAA and AG share first authorship.

* Address correspondence to: Khawaja Afzal Ammar, MD, Aurora Cardiovascular and Thoracic Services, Aurora St. Luke's Medical Center, 2801 W. Kinnickinnic River Parkway, Ste. 130, Milwaukee, WI 53215.
E-mail address: wi.publishing28@aah.org (K.A. Ammar).

https://doi.org/10.1016/j.shj.2023.100278

Table 1
Demographic and clinical characteristics of population

Characteristic	Overall	0%-10%	Moderate oversizing (10%-20%)	Large oversizing (>20%)	*p* value of 10%-20% vs. >20% oversizing
Age (y)	82.6 ± 7.4	79.7 ± 7.7	83.2 ± 7.0	82.4 ± 7.6	0.13
Male sex	250 (45.0)	21 (91.3)	89 (38.7)	140 (46.2)	0.08
Height (cm)	164.7 ± 10.9	172.6 ± 7.9	163.5 ± 11.0	165.0 ± 10.9	0.10
Weight (kg)	81.6 ± 31.3	89.3 ± 20.0	79.9 ± 23.3	82.3 ± 36.8	0.51
Diabetes mellitus	216 (38.8)	10 (43.5)	101 (43.9)	105 (34.6)	0.03*
Hypertension	522 (93.9)	23 (100)	216 (93.9)	283 (93.4)	0.81
Caucasian	543 (97.7)	23 (100)	225 (97.8)	295 (97.4)	0.72
Pacemaker	76 (13.7)	5 (21.7)	40 (17.4)	31 (10.2)	0.02*
RBBB	73 (13.5)	4 (18)	29 (13.2)	40 (13.2)	0.80
Incomplete RBBB	16 (3)	1 (4.6)	9 (4.1)	6 (2)	0.30
LBBB	31 (5.7)	0	11 (5)	20 (6.7)	0.18
Percutaneous coronary intervention	145 (26.1)	6 (26.1)	58 (25.2)	81 (26.8)	0.68
Stroke	55 (9.9)	4 (17.4)	23 (10.0)	28 (9.2)	0.77
Peripheral artery disease	133 (23.9)	6 (26.1)	67 (29.1)	60 (19.8)	0.01*
Smoker	30 (5.4)	1 (4.3)	14 (6.1)	15 (4.9)	0.57
Current dialysis	22 (4.0)	3 (13.0)	6 (2.6)	13 (4.3)	0.29
Myocardial infarction	103 (18.6)	5 (21.7)	46 (20.0)	52 (17.3)	0.42
Porcelain aorta	4 (0.7)	1 (4.3)	1 (0.4)	2 (0.7)	0.73
Atrial fibrillation/flutter	208 (37.4)	12 (52.17)	86 (37.4)	110 (36.3)	0.80
Forced expiratory volume	72.0 ± 21.9	65.8 ± 1.1	73.5 ± 19.9	71.5 ± 23.9	0.31
STS risk score	5.8 ± 3.8	5.0 ± 2.6	6.1 ± 3.3	5.6 ± 4.2	0.01*

Notes. Data are presented as mean ± SD or n (%).
Abbreviations: LBBB, left bundle branch block; RBBB, right bundle branch block; STS, Society of Thoracic Surgeons.
* 10%-20% vs. >20%, $p < 0.05$.

similar irrespective of valve type or size. The limitations of these studies included the use of an older version of self-expanding valve (CoreValve) and smaller sample sizes (n = 412 with 283 CoreValve and 129 Edwards SAPIEN valves), thus limiting their generalizability to more modern (Evolut and Evolut PRO) valves.[3]

We hypothesized that even greater oversizing (>20%) would be associated with a lesser incidence of PVL without an increase in the rate of PPM implantation or other complications and intentionally followed this hypothesis as a policy at our institution over the last several years. This study was carried out to gauge the impact of our large oversizing policy on outcomes.

Methods

Study Setting

From October 2011 to December 2016, all TAVR patients at our large, urban tertiary-care center were approached with a conscious attempt at large oversizing (>20%) with either the Evolut R or Evolut PRO valve. Demographics, echocardiographic data, computed tomographic (CT) data, procedural characteristics, and clinical outcomes were collected from electronic medical records. Critical aortic valve stenosis was defined as an aortic valve area of <0.6 cm^2. Aortic valve annular calcification was qualitatively categorized as present if read as moderate or severe by the interpreting radiologist. Discharge status was determined at the moment each patient left the hospital grounds. Death rate was calculated based on patient discharge status. Post-TAVR aortic insufficiency[4] was classified as none, trace/trivial, mild, moderate, or severe by transthoracic echocardiogram read on the first postoperative day by a TAVR-dedicated level III echocardiologist. Only a moderate or severe classification was deemed significant.

Each patient received a pre- and post-TAVR echocardiogram so valve function and performance could be examined. Pre-TAVR 3-dimensional multidetector (≥64 slice) CT imaging was performed on all patients in order to examine valve and artery morphology. Oversizing was calculated in reference to the patient's native aortic annulus perimeter. Relative oversizing by perimeter (%) is equal to the device diameter minus the patient's CT-scan-measured aortic annulus perimeter, divided by the patient's CT-scan-measured aortic annulus perimeter, and then multiplied by 100 (personal communication; Medtronic).

Authorization from the Aurora Health Care Institutional Review Board was obtained (IRB #18-22ET) to perform a retrospective review of data, and the requirement for informed consent was waived.

Table 2
Echocardiographic characteristics of population

Characteristic	Overall	0%-10%	Moderate oversizing (10%-20%)	Large oversizing (>20%)	*p* value of 10%-20% vs. >20% oversizing
Left ventricular ejection fraction (%)	57.4 ± 13.1	53.4 ± 10.4	57.2 ± 13.7	57.9 ± 12.7	0.72
Right ventricular systolic pressure (mmHg)	42.7 ± 15.1	43.5 ± 11.5	43.9 ± 15.6	41.6 ± 14.9	0.15
Left atrial volume index (mL/m^2)	47.2 ± 19.2	50.0 ± 15.3	47.5 ± 18.3	46.8 ± 20.3	0.63
Left ventricular internal diastolic dimension (cm)	4.6 ± 0.7	5.0 ± 0.6	4.6 ± 0.05	4.6 ± 0.04	0.46
Septal wall (cm)	1.3 ± 0.2	1.3 ± 0.3	1.2 ± 0.3	1.3 ± 0.2	0.86
Posterior wall (cm)	1.2 ± 0.2	1.3 ± 0.3	1.2 ± 0.2	1.1 ± 0.2	0.75
Aortic valve area (cm^2)	0.7 ± 0.2	0.77 ± 0.17	0.72 ± 0.18	0.76 ± 0.19	0.01*
Critical aortic valve stenosis†	94 (17.3)	2 (8.7)	43 (19.3)	49 (16.5)	0.41
Aortic valve peak gradient (mmHg)	68.4 ± 22.1	60.9 ± 18.7	69.9 ± 24.2	67.7 ± 20.4	0.26

Notes. Data are presented as mean ± SD or n (%).
* 10%-20% vs. >20%, $p < 0.05$.
† Critical aortic valve stenosis = aortic valve area <0.6 cm^2.

Table 3
Computed tomography characteristics of population

Characteristic	Overall	0%-10%	Moderate oversizing (10%-20%)	Large oversizing (>20%)	*p* value of 10%-20% oversizing vs. >20% oversizing
Perimeter (mm)	76.3 ± 7.3	87.9 ± 3.2	76.1 ± 6.8	75.4 ± 7.1	0.25
% of oversizing	20.3 ± 6.0	6.5 ± 2.4	16.0 ± 2.2	24.6 ± 3.9	<0.0001*
Aortic valve annulus size (mm)	23.9 ± 2.4	27.4 ± 1.8	24.0 ± 2.3	23.6 ± 2.3	0.04*
Sinus of Valsalva left coronary cusp diameter (mm)	31.9 ± 3.8	37.3 ± 2.9	31.6 ± 3.7	31.9 ± 3.6	0.39
Sinus of Valsalva right coronary cusp diameter (mm)	30.6 ± 3.7	36.2 ± 3.4	30.3 ± 3.5	30.5 ± 3.6	0.68
Sinus of Valsalva noncoronary cusp diameter (mm)	31.8 ± 4.0	37.4 ± 3.1	31.6 ± 4.2	31.6 ± 3.6	0.99
Mean sinus of Valsalva diameter (mm)	31.2 ± 4.7	33.8 ± 11.0	30.9 ± 4.6	31.2 ± 3.9	0.46
Left coronary cusp sinus of Valsalva height (mm)	24.0 ± 3.5	29.9 ± 3.6	23.8 ± 3.3	23.7 ± 3.3	0.63
Right coronary cusp sinus of Valsalva height (mm)	24.1 ± 9.9	28.8 ± 4.1	23.6 ± 3.0	24.1 ± 13.0	0.62
Noncoronary cusp sinus of Valsalva height (mm)	22.4 ± 3.5	27.3 ± 4.5	22.3 ± 3.4	22.1 ± 3.3	0.65
Mean sinus of Valsalva height (mm)	23.3 ± 4.9	26.1 ± 9.0	23.0 ± 3.5	23.2 ± 5.3	0.67
Right common iliac mean (mm)	8.4 ± 2.1	9.9 ± 2.4	8.3 ± 2.2	8.4 ± 1.9	0.62
Right external iliac mean (mm)	7.2 ± 1.6	8.0 ± 1.4	7.0 ± 1.7	7.2 ± 1.5	0.23
Right common femoral mean (mm)	6.9 ± 1.5	7.8 ± 1.6	6.8 ± 1.6	7.0 ± 1.5	0.27
Left common iliac mean (mm)	8.4 ± 2.0	9.4 ± 1.6	8.4 ± 2.1	8.3 ± 1.9	0.36
Left external iliac mean (mm)	7.2 ± 1.5	8.2 ± 1.2	7.1 ± 1.6	7.3 ± 1.5	0.15
Left common femoral mean (mm)	6.9 ± 1.5	7.9 ± 1.2	6.8 ± 1.5	6.9 ± 1.5	0.32
Aortic valve annular calcification[†]	179 (37.5)	0 (0)	56 (29.6)	123 (46.4)	0.0003*
Aortic valve calcium score (n = 216)	2451.4 ± 1450.9	N/A	2354.3 ± 1530.3	2503.1 ± 1409.7	0.47

Notes. Data are presented as mean ± SD or n (%).
* 10%-20% vs. >20%, $p < 0.05$.
† Classified as present if qualitatively categorized as moderate or severe by the interpreting radiologist.

Oversizing Degrees

Patients were divided into 3 groups based on the degree of oversizing of their prosthetic heart valve compared to their annulus size: 0% to 10%, 10% to 20% (moderate), >20% (large).

Definitions of Different Complications

Gastrointestinal (GI) bleed was defined as a patient experiencing GI bleeding associated with any of the following documented in the electronic medical record: hemoglobin drop of ≥3 g/dL, transfusion of whole blood or packed red blood cells, or procedural intervention/surgery at the bleeding site to reverse/stop or correct the bleeding (such as endoscopy with cautery of a GI bleed).

Annular dissection was defined as the indication that there was disruption or tearing of the valve annulus extending to the aorta caused by mechanical injury from oversizing a balloon or the valve device itself.

An unplanned other cardiac surgery or intervention was defined as the patient having subsequently undergone cardiac surgery or a catheterization laboratory intervention that was unplanned. This does not include an intervention or procedure already identified as an adverse event in the STS/ACC TVT Registry (Society of Thoracic Surgeons/American College of Cardiology Transcatheter Valve Therapy Registry).

An event labeled "other bleed" was defined as the patient experiencing bleeding from a site not otherwise specified, such as pulmonary bleeding. To qualify, the bleeding had to be associated with any of the following documented in the medical record: hemoglobin drop of ≥3 g/dL, transfusion of whole blood or packed red blood cells, or procedural intervention/surgery at the bleeding site to reverse/stop or correct the bleeding.

An unplanned vascular surgery or intervention was defined as the patient having required unplanned vascular surgery or intervention to correct a bleeding complication or vascular access site-related complication.

Major vascular complications were defined as any of the following: (a) any aortic dissection, aortic rupture, annulus rupture, left ventricle perforation, or new apical aneurysm/pseudoaneurysm; (b) access site or access-related vascular injury (dissection, stenosis, perforation, rupture, arteriovenous fistula, pseudoaneurysm, hematoma, irreversible nerve injury, compartment syndrome, percutaneous closure device failure) leading to death, life-threatening or major bleeding,[4] visceral ischemia, or neurological impairment; (c) distal embolization (noncerebral) from a vascular source requiring surgery or resulting in amputation or irreversible end-organ damage; (d) the use of unplanned endovascular or surgical intervention associated with death, major bleeding, visceral ischemia, or neurological impairment; (e) any new ipsilateral lower extremity ischemia documented by patient symptoms, physical examination, and/or decreased or absent blood flow on lower extremity angiogram; (f) surgery for access site-related nerve injury; and (g) permanent access site-related nerve injury.

Minor vascular complications were defined as any of the following: (a) access site or access-related vascular injury (dissection, stenosis, perforation, rupture, arteriovenous fistula, pseudoaneurysms, hematomas, percutaneous closure device failure) not leading to death, life-threatening or major bleeding,[4] visceral ischemia, or neurological impairment; (b) distal embolization treated with embolectomy and/or thrombectomy and not resulting in amputation or irreversible end-organ damage; (c) any unplanned endovascular stenting or unplanned surgical intervention not meeting the criteria for a major vascular complication;

Table 4
Procedural characteristics

Characteristic	Overall	0%-10%	Moderate oversizing (10%-20%)	Large oversizing (>20%)	*p* value of 10%-20% vs. >20% oversizing
Evolut PRO	141 (25.4)	0 (0)	60 (26.1)	81 (26.7)	0.87
Anesthesia type (MAC)	497 (89.4)	22 (95.6)	198 (86.1)	277 (91.4)	0.05
Contrast volume (mL)	52.6 ± 28.7	55.0 ± 14.6	55.0 ± 28.8	50.7 ± 29.3	0.01*
Fluoroscopy time (min)	10.4 ± 4.5	12.4 ± 4.5	10.4 ± 4.6	10.2 ± 4.4	0.67

Notes. Data are presented as mean ± SD or n (%).
Abbreviation: MAC, monitored anesthesia care.
* 10%-20% vs. >20%, $p < 0.05$.

Table 5
Post-TAVR valve performance

Variable	Overall	0%-10%	Moderate oversizing (10%-20%)	Large oversizing (>20%)	p value of 10%-20% vs. >20% oversizing*
Peak velocity (m/s)	2.0 ± 0.5	2.0 ± 0.4	2.0 ± 0.6	2.0 ± 0.4	0.13
Aortic valve mean gradient (mmHg)	7.7 ± 3.4	8.5 ± 3.7	7.8 ± 3.5	7.5 ± 3.3	0.29
Aortic valve area (cm^2)	2.2 ± 0.6	2.3 ± 0.8	2.2 ± 0.7	2.3 ± 0.6	0.14

Notes. Data are presented as mean ± SD or n (%).
Abbreviation: TAVR, transcatheter aortic valve replacement.
* 10%-20% vs. >20%, $p < 0.05$.

or (d) vascular repair or the need for vascular repair (via surgery, ultrasound-guided compression, transcatheter embolization, or stent-graft).

All definitions used were those recorded in the STS/ACC TVT Registry Adverse Event Definitions v2.1 and VARC-2 criteria.[4]

Statistical Analysis

Patient data were collected from the electronic medical record and organized into one dataset. Continuous variable data were represented as mean ± SD. Variables were compared using one-way analysis of variance or Student's t-test. Nominal data were represented as n (%). Variables were compared using the chi-square test.

Demographics, echocardiographic characteristics, CT characteristics, and clinical outcomes were compared and analyzed across all groups with a focus on the moderate oversizing group and large oversizing group. If any continuous variable had a skewed distribution, a Wilcoxon/Kruskal-Wallis test was performed, or the variable was converted to nominal and a one-way chi-square approximation test was performed.

Bivariate and stratum-specific analyses were performed in order to determine potential confounding variables. A meaningful change in odds ratio (OR) was defined as a >20% change in unadjusted OR, as this is considered a norm in clinical epidemiology circles.[5] An alpha value of 0.05 was used to determine the statistical significance of data. All statistical analyses were performed using JMP software (SAS Institute, Cary, North Carolina).

Results

A total of 556 TAVR patients were included in this study (age 82.6 ± 7.4 years, 45% men) after the exclusion of valve-in-valve patients. The mean oversizing was 20.3% ± 6.0% with 4.1% of the patients in the 0% to 10% oversizing group, 41.4% in the 10% to 20% oversizing group, and 54.5% in the >20% oversizing group. The oversizing policy led to the Evolut R 29 mm being the valve most commonly deployed (n = 159; 29%), followed by the Evolut R 34 mm (n = 118; 21.2%), Evolut R 26 mm (n = 107; 19.2%), and Evolut PRO 29 mm (n = 100; 18%). Other sizes were utilized in <10% of patients.

Demographic and clinical characteristics of the patient population are presented in Table 1. The patients who received large oversizing had a statistically significant lower prevalence of diabetes (34.6 vs. 43.9%; $p = 0.03$), prior PPM (10.2 vs. 17.4%; $p = 0.02$), and peripheral artery disease (19.8 vs. 29.1%; $p = 0.01$), as well as a lower STS risk score (5.6 vs. 6.1; $p = 0.01$).

Of all the echocardiographic characteristics presented in Table 2, all were statistically similar between groups except aortic valve area, which was significantly larger in the large oversizing group (0.76 vs. 0.72 cm^2; $p = 0.01$).

CT characteristics of the patient population, shown in Table 3, were similar between the moderate and large oversizing groups, except for a slightly smaller aortic valve annulus size (23.6 vs. 24.0 mm; $p = 0.04$) and a significantly higher prevalence of significant aortic valve annular calcification (46.4 vs. 29.6%; $p = 0.0003$), a subjective and qualitative measurement by the radiologist, in the large oversizing group. Calcium

Table 6
Post-TAVR complications

Complication	Overall	0%-10%	Moderate oversizing (10%-20%)	Large oversizing (>20%)	p value of 10%-20% vs. >20% oversizing*
Pacemaker	85 (15.3)	7 (30.4)	33 (14.3)	45 (14.8)	0.87
Paravalvular leak (moderate or severe)	21 (3.8)	1 (4.5)	14 (6.1)	6 (2.0)	0.01*
Ischemic stroke	9 (1.6)	0 (0)	3 (1.3)	6 (2.0)	0.54
Unplanned vascular surgery or intervention	6 (1.1)	1 (4.3)	3 (1.3)	2 (0.6)	0.45
Unplanned other cardiac surgery or intervention	5 (0.9)	0 (0)	4 (1.7)	1 (0.3)	0.09
Transient ischemic attack	2 (0.4)	0 (0)	0 (0)	2 (0.7)	0.13
Perforation with or without tamponade	3 (0.5)	0 (0)	1 (0.4)	2 (0.7)	0.73
Percutaneous coronary intervention	1 (0.2)	0 (0)	1 (0.4)	0 (0)	0.19
Other bleed	13 (2.3)	1 (4.3)	6 (2.6)	6 (2.0)	0.63
Any vascular complication	14 (2.5)	0 (0)	3 (1.3)	11 (3.6)	0.08
Minor vascular complications	13 (2.3)	0 (0)	3 (1.3)	10 (3.3)	0.13
Major vascular complications	2 (0.4)	0 (0)	0 (0)	2 (0.7)	0.13
Genitourinary bleed	1 (0.2)	0 (0)	0 (0)	1 (0.3)	0.29
Gastrointestinal bleed	4 (0.7)	0 (0)	0 (0)	4 (1.3)	0.03*
Device migration	1 (0.2)	0 (0)	1 (0.4)	0 (0)	0.19
Cardiac arrest	11 (2.0)	3 (13.0)	4 (1.7)	4 (1.3)	0.69
Annular dissection	1 (0.2)	0 (0)	0 (0)	1 (0.3)	0.29
Atrial fibrillation	15 (2.7)	0 (0)	6 (2.6)	9 (3.0)	0.80
Coronary occlusion rate	0 (0)	0 (0)	0 (0)	0 (0)	N/A
Electrocardiographic abnormalities	168 (30.3)	6 (26.1)	74 (32.2)	88 (29.1)	0.45
Left bundle branch block	168 (30.3)	6 (26.1)	74 (32.2)	88 (29.1)	0.45
Death rate	10 (1.8)	1 (4.3)	4 (1.7)	5 (1.6)	0.94

Notes. Data are presented as n (%).
Notes. One patient had a major and minor vascular complication.
Abbreviation: TAVR, transcatheter aortic valve replacement.
* 10%-20% vs. >20%, $p < 0.05$.

Table 7
Bivariate analysis of the association between post-TAVR paravalvular leak and demographic variables

Model	Odds ratio	95% Confidence interval	*p* value
Unadjusted model			
Large vs. moderate oversizing	0.31	0.12-0.83	0.02
Model adjusted for age			
Large oversizing	0.32	0.12-0.86	0.02
Age	1.09	1.00-1.18	0.05
Model adjusted for sex			
Large oversizing	0.32	0.12-0.84	0.02
Sex	0.77	0.3-2.0	0.59
Model adjusted for height			
Large oversizing	0.31	0.11-0.81	0.02
Height	1.02	0.97-1.06	0.44
Model adjusted for weight			
Large oversizing	0.32	0.12-0.84	0.02
Weight	0.99	0.97-1.01	0.39
Model adjusted for diabetes			
Large oversizing	0.29	0.11-0.78	0.01
Diabetes	0.46	0.16-1.31	0.15
Model adjusted for hypertension			
Large oversizing	0.33	0.12-0.88	0.03
Hypertension	0.28	0.08-1.05	0.06
Model adjusted for pacemaker			
Large oversizing	0.31	0.12-0.83	0.02
Pacemaker	0.97	0.27-3.45	0.97
Model adjusted for percutaneous coronary intervention			
Large oversizing	0.31	0.12-0.83	0.02
Percutaneous coronary intervention	0.71	0.23-2.16	0.54
Model adjusted for smoker			
Large oversizing	0.31	0.12-0.81	0.02
Smoker	7.86e-7[†]	Too few patients to calculate	0.99
Model adjusted for stroke			
Large oversizing	0.31	0.12-0.82	0.02
Stroke	0.47	0.06-3.61	0.47
Model adjusted for peripheral artery disease			
Large oversizing	0.31	0.12-0.82	0.02
Peripheral artery disease	0.92	0.32-2.62	0.88
Model adjusted for current dialysis			
Large oversizing	0.31	0.12-0.82	0.02
Current dialysis	1.68	0.21-13.55	0.63
Model adjusted for myocardial infarction			
Large oversizing	0.31	0.12-0.83	0.02
Myocardial infarction	1.06	0.34-3.26	0.92
Model adjusted for porcelain aorta			
Large oversizing	0.31	0.12-0.83	0.02
Porcelain aorta	7.32e-6[†]	Too few patients to calculate	0.99
Model adjusted for atrial fibrillation/flutter			
Large oversizing	0.31	0.12-0.83	0.02
Atrial fibrillation/flutter	2.67	1.07-6.68	0.04*
Model adjusted for STS risk score			
Large oversizing	0.31	0.12-0.82	0.02
STS risk score	0.98	0.86-1.12	0.79

Notes. Meaningful change in odds ratio was defined as >20% change in unadjusted odds ratio (<0.248 or >0.372).
Abbreviations: STS, Society of Thoracic Surgeons; TAVR, transcatheter aortic valve replacement.
* $p < 0.05$.
† Too few patients to calculate.

scores were higher in the large oversizing group (2503 vs. 2354); however, scoring was only performed for 216 out of 556 patients owing to the lack of availability of noncontrast CT studies.

Of the procedural characteristics shown in Table 4, contrast volume was significantly less in the large oversizing group (50.7 vs. 55.0 mL; $p = 0.01$). All other variables were similar.

Large oversizing had slightly better post-TAVR valve performance (Table 5), consisting of a lower mean gradient (7.5 vs. 7.8 mmHg), larger aortic valve area (2.3 vs. 2.2 cm^2), and a similar peak velocity (2.0 vs. 2.0 m/s), but all failed to reach statistical significance.

Regarding post-TAVR complications, shown in Table 6, there was a significantly lower prevalence of moderate or severe PVL in the large oversizing group (2.0 vs. 6.1%; $p = 0.01$). The difference in the incidence of post-TAVR PPM implantation between the moderate and large oversizing groups was insignificant (14.8 vs. 14.3%; $p = 0.87$). Of all the other possible complications, the occurrence of annular dissection was meaningful (n = 1 vs. 0; 0.3 vs. 0%; $p = 0.29$). Additionally, the large oversizing group had a statistically significant higher prevalence of GI bleed than the moderate oversizing group (n = 4 vs. 0; 1.3 vs. 0.0%; $p = 0.03$). At the time of discharge, the mortality rate was similar between groups (n = 5 [large] vs. 4 [moderate]; 1.6 vs. 1.7%; $p = 0.94$). Since post-TAVR PVL was the only complication that had a statistically significant and clinically meaningful difference in occurrence, this was the only outcome that was converted into an odds ratio and subjected to logistic regression.

Bivariate analysis was performed on post-TAVR PVL comparing large oversizing to moderate oversizing; the results are presented in Table 7. Large oversizing continued to be associated with reduced PVL, irrespective of confounding by 16 demographic and clinical variables with 69% lower odds (OR = 0.31, 95% CI 0.12-0.83; $p = 0.02$). These

Table 8
Stratum-specific analysis of the association between post-TAVR PVL as a function of large vs. moderate oversizing, stratified for demographic variables and clinical variables, shows that the relationship stands in most strata

Model	Odds ratio	95% Confidence interval	*p* value
Unadjusted model			
Large vs. moderate oversizing	0.31	0.12-0.83	0.02
Model adjusted for age			
Age >80	0.29	0.10-0.85	0.02*
Age <80	0.62	0.04-10.15	0.74
Model adjusted for sex			
Female	0.74	0.24-2.24	0.59
Male (n = 250)	5.29E-8†	Too few patients to calculate	0.99
Model adjusted for height			
Tall	0.32	0.03-3.82	0.37
Not tall	0.31	0.11-0.89	0.03*
Model adjusted for obesity (BMI >30)			
BMI >30	0.41	0.10-1.78	0.24
BMI <30	0.25	0.07-0.96	0.04*
Model adjusted for diabetes			
Diabetes	0.23	0.03-2.12	0.20
No diabetes	0.31	0.1-9.3	0.04*
Model adjusted for hypertension			
Hypertention	0.24	0.08-0.77	0.02*
No hypertension	1.37	0.11-17.10	0.80
Model adjusted for pacemaker			
Pacemaker (n = 76)	Too few patients to calculate		0.99
No pacemaker	0.37	0.13-1.01	0.05
Model adjusted for percutaneous coronary intervention			
Percutaneous coronary intervention (n = 145)	Too few patients to calculate		
No percutaneous coronary intervention	0.45	0.16-1.27	0.13
Model adjusted for smoking			
Smoker (n = 30)			
Nonsmoker	0.31	0.12-0.81	0.02*
Model adjusted for stroke			
Stroke (n = 51)	Too few patients to calculate		0.99
No stroke	0.33	0.12-0.89	0.03
Model adjusted for peripheral artery disease			
Peripheral artery disease	0.27	0.03-2.46	0.24
No peripheral artery disease	0.32	0.11-0.96	0.04*
Model adjusted for current dialysis			
Current dialysis (n = 22)	Too few patients to calculate		0.99
No current dialysis	0.34	0.13-0.92	0.03*
Model adjusted for myocardial infarction			
Myocardial infarction	0.90	0.12-6.65	0.92
No myocardial infarction	0.23	0.07-0.74	0.01*
Model adjusted for porcelain aorta			
Porcelain aorta (n = 4)			
No porcelain aorta	0.31	0.12-0.83	0.02
Model adjusted for atrial fibrillation/flutter			
Atrial fibrillation/flutter	0.37	0.11-1.28	0.12
No atrial fibrillation/flutter	0.24	0.05-1.21	0.08
Model adjusted for STS risk score			
STS risk score >6%	0.43	0.08-2.27	0.32
STS risk score <6%	0.26	0.08-0.87	0.03*

Notes. Height criteria for identifying as tall was defined as ≥168.16 cm for females and ≥181.6 cm for males.
Abbreviations: PVL, paravalvular leak; STS, Society of Thoracic Surgeons; TAVR, transcatheter aortic valve replacement.
* $p < 0.05$.
† Too few patients to calculate.

variables included the STS risk score. Of all these variables, only atrial fibrillation/flutter was significantly associated with PVL (OR = 2.67, *p* = 0.04), independent of the effect of large oversizing.

Stratum-specific analyses were performed for the association between post-TAVR PVL in different strata of clinical variables (Table 8). Large oversizing was associated with reduced odds of PVL only in octogenarians (age >80 years; OR = 0.29, *p* = 0.02), those of short stature (males <181.6 cm, females <168.16 cm; OR = 0.31, *p* = 0.03), the nonobese (body mass index <30; OR = 0.25, *p* = 0.04), nondiabetics (OR = 0.31, *p* = 0.04), hypertensives (OR = 0.24, *p* = 0.02), nonsmokers (OR = 0.31, *p* = 0.02), those without peripheral artery disease (OR = 0.32, *p* = 0.04), nondialysis patients (OR = 0.34, *p* = 0.03), patients with no prior myocardial infarction (OR = 0.23, *p* = 0.01), and those with an STS risk score <6% (OR = 0.26, *p* = 0.03).

Mortality Data

Of the 556 TAVR patients, 10 died while in the hospital (Table 9). One death occurred in the 0% to 10% oversizing group, 4 in the 10% to 20% oversizing group, and 5 in the >20% oversizing group, with no significant difference between the large and moderate oversizing groups. There were different causes of death in patients, including PVL (n = 3), PPM implantation (n = 2), stroke (n = 1), sepsis (n = 1), hemothorax (n = 1), severe left ventricular systolic function reduction (n = 1), and multifactorial death consisting of pericardial effusion, superficial femoral artery occlusion needing a stent, atrial fibrillation, and GI bleed (n = 1). The incidence of significant PVL was much higher in those who died than in survivors (13 vs. 1.3%; $p \leq 0.0001$).

Table 9
Mortality data

Pt	Age (y)	Sex	% Of oversizing	STS risk score (%)	Cause of death	Rescue SAVR	Other complications	PVL
1	90	M	8	5.26	PVL	No	Cardiac arrest	Yes
2	87	F	14	12.5	PPM lead perforation and tamponade	No	None	No
3	85	M	12	4.3	Stroke	No	Aspiration pneumonia, respiratory failure	No
4	81	M	11	5.4	PVL	No	Cardiac arrest, cardiogenic shock, family refused emergent SAVR	Yes
5	84	F	19	6.63	Hemothorax from direct aortic approach	No	Intermittent CHB	No
6	68	M	30	2.6	PPM	No	CHB, ventricular fibrillation during RV lead insertion	No
7	84	F	24	11	Severe left ventricular systolic function reduction, pulmonary edema, cardiogenic shock	No	Other bleed, ischemia of right brachial artery	No
8	85	F	23	4.2	Multifactorial: pericardial effusion, stent, atrial fibrillation, GI bleed	No	None	No
9	72	F	20	14.8	Sepsis	No	Thrombocytopenia, excessive bleeding, INR too high because of disseminated intravascular coagulation, GI bleed, ischemic hepatitis, hypotension due to shock	No
10	85	M	20	8.9	PVL and annular dissection	Yes	Ventricular septal defect, stroke, left common carotid dissection	Yes

Abbreviations: CHB, complete heart block; F, female; GI, gastrointestinal; INR, international normalized ratio; M, male; PPM, pacemaker; Pt, patient; PVL, paravalvular leak; RV, right ventricular; SAVR, surgical aortic valve replacement; STS, Society of Thoracic Surgeons.

Discussion

The current data represent the largest study to date evaluating the hypothesis that bigger self-expanding valves are associated with better outcomes in TAVR patients. The essential findings from this study are that large oversizing significantly reduced the occurrence of PVL and had no significant effect on the postprocedure PPM implantation rate or mortality rate.

Clinical Demographic, Echocardiographic, and Computed Tomographic Variables

Regarding clinical variables, lower prevalence of peripheral artery disease in the large oversizing group is likely indicative that the operator chose a larger valve because the patient was able to receive a 16 Fr sheath.

The STS risk score was significantly lower for the large oversizing group than the moderate oversizing group, which likely suggests that the operator chose healthier patients with larger vessels for a more oversized valve. Previously, Fadahunsi et al.[6] found that patients with an increased STS risk score had higher odds of PPM. However, our data did not reveal any difference between the oversizing groups, even when our data were analyzed as in his study (data available on reasonable request to the corresponding author).

With regard to CT characteristics, aortic valve annulus size was smaller in the large oversizing group than the moderate oversizing group, but this difference was not clinically meaningful (23.6 vs. 24.0 mm). The prevalence of moderate or severe aortic valve annular calcification was much greater in the large oversizing group than the moderate oversizing group (Table 3, 46 vs. 29). The presence of greater calcification in the large oversizing group theoretically could have resulted in difficulty in delivery and expansion of the valve. However, this theoretical concern was not supported by our data.

All procedural characteristics were similar between the large and moderate oversizing groups except for contrast volume. Contrast volume was significantly less (50.7 vs. 55.0 mL) in the large oversizing group than the moderate oversizing group. Although, in theory, placement of a larger valve would require more imaging and more use of contrast, our data did not support this theoretical concern. This suggests that the risk of contrast-induced nephropathy would not be increased with large oversizing.

Complications of Large Oversizing vs. Moderate Oversizing in TAVR

Among postprocedure complications, there was no difference in PPM incidence between the large and moderate oversizing groups. However, the incidence of PVL was significantly lower (2 vs. 6%; $p = 0.01$) in the large oversizing group than in the moderate oversizing group.

The current study is in consonance with other studies in that oversizing reduced post-TAVR PVL (Table 10). All of these studies had a much smaller sample size than our study, with the largest sample size being 202—less than half of our sample size. Similarly, our data are in agreement with four other studies on self-expanding valves, evaluating the mean oversizing and its association with the incidence of PPM

Table 10
Previous studies evaluating % oversizing and PVL rate

Study	Sample size (n)	Valve type	Age group (mean ± SD)	% OS	Post-TAVR PVL (moderate/severe)
Abdel-Wahab et al.[7]	120	CoreValve	79.6 ± 15.8 y	14.8%	5.8%
Debry et al.[8]	201	CoreValve	80.6 ± 7.2 y	Moderate OS: 2.1-2.5 Severe OS: 2.6-4	Moderate OS: 2% Severe OS: 0%
Dvir et al.[9]	202	CoreValve	81.5 ± 6.7 y	Moderate OS: 2.5%-9.5% Large OS: 9.6%-16.2%	Moderate OS: 9.8% Large OS: 16.7%
Schultz et al.[10]	56	CoreValve	80 ± 6 y	1.38	25%*
Ammar et al.	556	Evolut	82.6 ± 7.4 y	Moderate OS: 10%-20% Large OS: >20%	Moderate OS: 6.1% Large OS: 2.0%

Notes. Oversizing criteria varied between studies, making it harder to compare. Abdel-Wahab et al. oversized by perimeter (%), Debry et al. by ratio between prosthesis area and annulus area indexed and measured on multislice computed tomography, Dvir et al. by perimeter (%), Schultz et al. by mean ratio of nominal prosthesis cross-sectional surface area at inflow to cross-sectional surface area of the native annulus, and our study by perimeter (%).
Abbreviations: OS, oversizing; PVL, paravalvular leak; TAVR, transcatheter aortic valve replacement.
* Mild PVL.

Table 11
Previous studies evaluating % oversizing and PPM rate showing the impact of oversizing on PPM incidence

Study	Sample size (n)	Valve type	Mean % oversizing in patients needing a PPM	Mean % oversizing in patients who did not need a PPM	*p* value
Fadahunsi et al.[6]	1096	CoreValve	31.8%	27.8%	<0.001
Schroeter et al.[11]	88	CoreValve	4.19 mm	3.56 mm	0.10
Ammar et al.	556	Evolut	19.56%	20.48%	0.20

Notes. Oversizing criteria varied among studies, making it harder to compare. Fadahunsi et al. oversized by area (%), Schroeter et al. by the difference between the actual implanted valve size and the annular diameter as measured by transesophageal echocardiography (mm), and our study by perimeter (%). Our study extends the findings of Schroeter's study but is in contradiction with Fadahunsi's study.

implantation (Table 11). The mean oversizing was similar for those who needed post-TAVR PPM implantation and those who did not need it. Our study extends these findings from prior studies, all of which solely utilized an outdated Medtronic CoreValve; our study represents current clinical practice by evaluating the Evolut valve, the current standard of care in self-expanding valves.

The oversizing criteria varied among studies, making it harder to compare post-TAVR PVL and PPM implantation (Tables 10 and 12).[6] Fadahunsi et al. oversized by area (%),[6] Schroeter et al. by the difference between the actual implanted valve size and the annular diameter as measured by transesophageal echocardiography (mm),[11] Schultz et al. by mean ratio of nominal prosthesis cross-sectional surface area at inflow to cross-sectional surface area of the native annulus,[10] Debry et al. by the ratio between the prosthesis area and the annulus area indexed and measured on multislice CT,[8] and our study by perimeter (%). Our study extends the findings of Schroeter's study, but it is in contradiction with Fadahunsi's study (Table 11).

The incidence of GI bleed was 1.3 vs. 0% in the large vs. moderate oversizing groups, but this number was driven by only 1 GI bleed.

The incidence of any post-TAVR vascular complication for our large oversizing group was much lesser than that reported in prior studies (3.6% in our study vs. 12.8% in Abdel-Wahab et al.[7]) despite the fact that our study oversized the valves by a greater amount (mean overall oversizing by perimeter was 20.3% in our study vs. 14.8% in the study by Abdel-Wahab et al.).

The incidence of major vascular complications was not significantly different between our large oversizing patients and moderate oversizing patients (0.66 vs. 0%; $p = 0.13$) and was much lower than that reported by Dvir et al. (10% in large oversizing vs. 7.1% in moderate oversizing; 0.07).[9] The incidence of vascular complications in TAVR has decreased from 34% in the early-generation TAVR era (2008; owing to 24 Fr sheaths), to 9% in 2012 with a 16 Fr sheath, to even lower in our study (2.5%), which likely also reflects greater operator experience as well as most of our patients having undergone surgical cutdown.

The one patient who experienced annular dissection had severe calcification of the aortic valve, with a calcification score of 7174. This patient also had severe subaortic calcification that interfered with optimal delivery of the valve. During valve delivery, the first two valves were placed too deep below the aortic annulus, leading to severe PVL. A third valve was placed that had less PVL, but the patient developed further hemodynamic compromise. The patient underwent emergency thoracotomy and was found to have an annular rupture and a ventricular septal defect, likely secondary to balloon valvuloplasty of the prior valve. This patient expired on the surgeon's table. Although this patient belonged to the large oversizing group, the mortality was more related to aortic valve annulus calcification and subaortic calcification, which made it difficult to deliver the valve at optimal position. In our opinion, this annular dissection does not provide evidence against our practice of oversizing, which is based on the premise that self-expanding valves can be oversized and still may not cause rupture as they do not need active balloon dilation/valvuloplasty, which is needed by balloon-expandable valves. It, in fact, provides evidence that balloon dilation/valvuloplasty predisposes the patient to annular rupture.

Confounding and Effect Modification in the Relationship Between Large Oversizing and PVL

Bivariate analysis to evaluate the relationship between large oversizing and PVL demonstrated that the beneficial association persisted irrespective of any of the confounding variables (Table 7). Stratum-specific analyses revealed that in many strata, the beneficial association between large oversizing and PVL persisted (Table 8). There was significant biological interaction, with persistence of the beneficial relationship only in the following strata of patients: octogenarians, those who were short of stature, those who were not obese, those who were not diabetic, hypertensives, nonsmokers, those without peripheral artery disease, nondialysis patients, patients with no prior myocardial infarction, and those with an STS risk score <6%.

To illustrate these findings, we displayed the individual findings from two cases comparing two otherwise similar patients, one of whom received moderate oversizing and the other large oversizing. Figure 1 shows that these 2 patients had similar aortic valve calcium scores, perimeter, and mean sinus of Valsalva diameter. Figure 2 shows each patient's post-TAVR electrocardiogram and echocardiogram results: the patient with moderate oversizing had severe PVL and PPM implantation immediately post-TAVR, whereas the patient with large oversizing had trace PVL and no immediate PPM implantation.

Clinical Implications

Data generated in this study support the possibility that oversizing >20% may be beneficial for reducing PVL without the cost of increased PPM incidence but at the cost of other procedural complications.

Strengths and Limitations

All the patient data collected for this study were from one institution. It suffers from selection bias as it represents the institutional clinical policy of preferring large oversizing over moderate oversizing. STS risk

Table 12
Patients with post-TAVR vascular complications (n = 14)

Vascular complication	Number of incidents	Major or minor
Rupture of aortic annulus and ascending aorta, left common carotid artery repair	2	Major
Femoral (n = 2) and iliac (n = 2) artery dissection or femoral artery occlusion (n = 4) and repair with stent	7	Minor
Hematoma at access site or pseudoaneurysm	6	Minor

Abbreviation: TAVR, transcatheter aortic valve replacement.

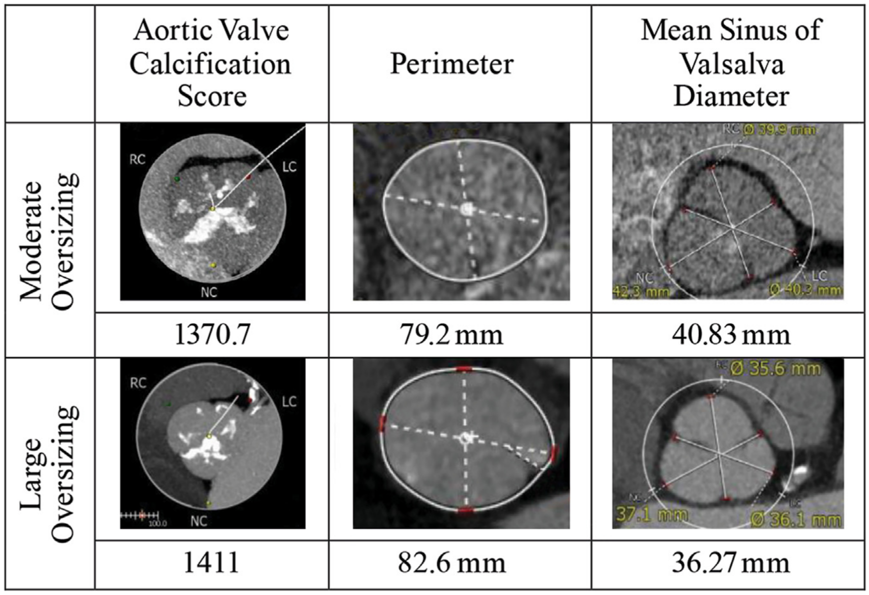

Figure 1. Illustrative cases of 2 transcatheter aortic valve replacement patients. The patients had similar calcification score, perimeter, and sinus of Valsalva diameter; one received a valve with moderate oversizing, the other a valve with large oversizing.

score was significantly lower in the large oversizing group, likely suggesting that the operator selected healthier patients with larger vessels for the more oversized valves. This selection bias could partially explain the reduced complications seen in the large oversizing group. However, the strength of this study is that the data were collected prospectively, which reduces the recall bias.

Conclusions

This study suggests that in self-expanding valves, a policy of large oversizing (>20%) is superior to standard clinical practice. Large oversizing leads to significantly lesser PVL post-TAVR without the cost of an increased incidence of PPM or major

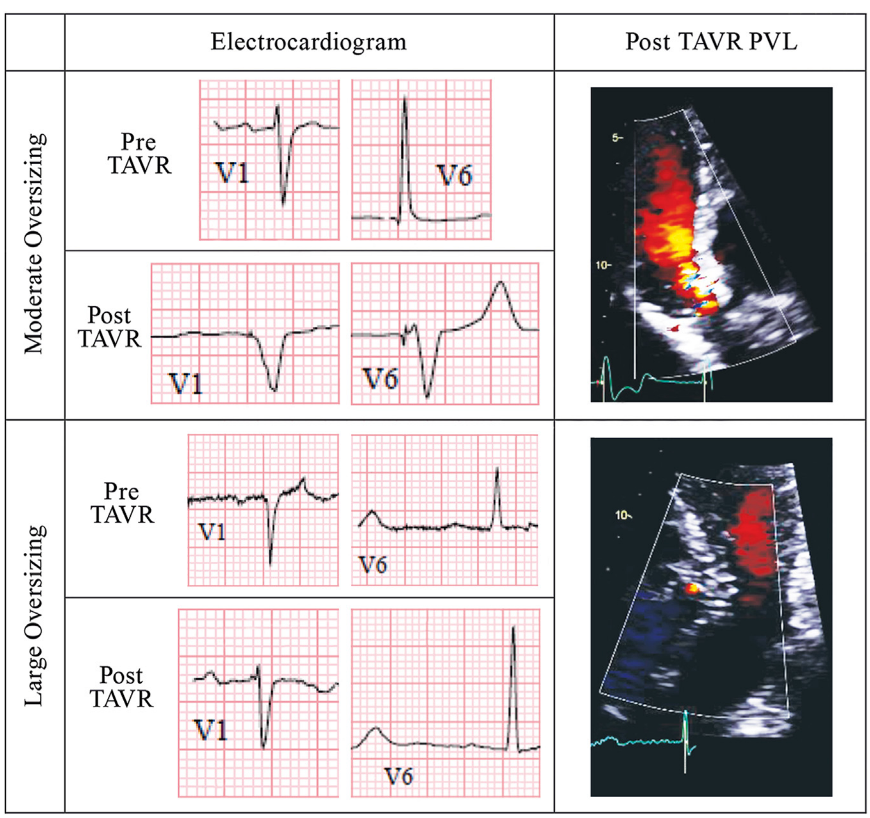

Figure 2. Outcomes of the 2 patients from Figure 1. The patient with moderate oversizing (15% oversizing; Evolut R 29 mm) suffered from severe PVL and needed immediate PPM implantation, whereas the patient with large oversizing (30% oversizing; Evolut R 34 mm) did not have either complication.
Abbreviations: PVL, paravalvular leak; TAVR, transcatheter aortic valve replacement.

vascular complications. That large oversizing was associated with PVL reduction irrespective of confounding variables suggests that this reduction was a direct result of the larger oversizing. Stratum-specific analyses indicated that the benefit of large oversizing is more evident in specific subgroups, making it likely that the recommendation for >20% oversizing may need to be tailored to the individual patient's profile.

CRediT Authorship Contributions

Khawaja Afzal Ammar (Study conception and design, Data analysis and interpretation, Drafting the manuscript, Critical revision). Jodi Zilinski (Study conception and design, Data analysis and interpretation, Critical revision). Daniel P. O'Hair (Study conception and design, Data analysis and interpretation, Critical revision). Renuka Jain (Study conception and design, Data analysis and interpretation, Critical revision). Suhail Q. Allaqaband (Study conception and design, Data analysis and interpretation, Critical revision). Tanvir Bajwa (Study conception and design, Data analysis and interpretation, Critical revision). Alexandria Graeber (Data acquisition, Data analysis and interpretation, Drafting the manuscript). Abdur Rahman Ahmad (Data acquisition, Data analysis and interpretation, Drafting the manuscript). All authors reviewed and approved the final manuscript.

ORCIDs

Khawaja Afzal Ammar https://orcid.org/0000-0001-7216-7051
Jodi Zilinski https://orcid.org/0000-0002-0183-1063
Renuka Jain https://orcid.org/0000-0002-5792-4963
Suhail Q. Allaqaband https://orcid.org/0000-0002-6067-0212
Tanvir Bajwa https://orcid.org/0000-0002-0720-0879

Ethics Statement

Authorization from the Aurora Health Care Institutional Review Board was obtained (IRB #18-22ET) to perform a retrospective review of data, and the requirement for informed consent was waived.

Funding

The authors have no funding to report.

Prior Presentation

An earlier version of this research was presented at the American College of Cardiology Scientific Sessions, 2019, in New Orleans, LA.

Disclosure Statement

T. Bajwa, R. Jain, and D. P. O'Hair are consultants for Medtronic. The other authors had no conflicts to declare.

References

1 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: 1200-1254. https://doi.org/10.1016/j.jacc.2012.01.001
2 Pasic M, Unbehaun A, Buz S, et al. Annular rupture during transcatheter aortic valve replacement: classification, pathophysiology, diagnostics, treatment approaches, and prevention. *JACC Cardiovasc Interv*. 2015;8:1-9. https://doi.org/10.1016/j.jcin.2014.07.020
3 Lange R, Bleiziffer S, Piazza N, et al. Incidence and treatment of procedural cardiovascular complications associated with trans-arterial and trans-apical interventional aortic valve implantation in 412 consecutive patients. *Eur J Cardio Thorac Surg*. 2011;40:1105-1113. https://doi.org/10.1016/j.ejcts.2011.03.022
4 Kappetein AP, Head SJ, Généreux P, et al. Updated standardized endpoint definitions for transcatheter aortic valve implantation: the Valve Academic Research Consortium-2 consensus document. *J Am Coll Cardiol*. 2012;60:1438-1454. https://doi.org/10.1016/j.jacc.2012.09.001
5 Kleinbaum DG, Sullivan KM, Barker ND. *ActivEpi Companion Textbook*. 2nd ed. New York: Springer-Verlag New York; 2013.
6 Fadahunsi OO, Olowoyeye A, Ukaigwe A, et al. Incidence, predictors, and outcomes of permanent pacemaker implantation following transcatheter aortic valve replacement: analysis from the U.S. Society of Thoracic Surgeons/American College of Cardiology TVT Registry. *JACC Cardiovasc Interv*. 2016;9:2189-2199. https://doi.org/10.1016/j.jcin.2016.07.026
7 Abdel-Wahab M, Mehilli J, Frerker C, et al. Comparison of balloon-expandable vs self-expandable valves in patients undergoing transcatheter aortic valve replacement: the CHOICE randomized clinical trial. *JAMA*. 2014;311:1503-1514. https://doi.org/10.1001/jama.2014.3316
8 Debry N, Sudre A, Elquodeimat I, et al. Prognostic value of the ratio between prosthesis area and indexed annulus area measured by MultiSlice-CT for transcatheter aortic valve implantation procedures. *J Geriatr Cardiol*. 2016;13:483-488. https://doi.org/10.11909/j.issn.1671-5411.2016.06.004
9 Dvir D, Webb JG, Piazza N, et al. Multicenter evaluation of transcatheter aortic valve replacement using either SAPIEN XT or CoreValve: degree of device oversizing by computed-tomography and clinical outcomes. *Catheter Cardiovasc Interv*. 2015;86: 508-515. https://doi.org/10.1002/ccd.25823
10 Schultz CJ, Tzikas A, Moelker A, et al. Correlates on MSCT of paravalvular aortic regurgitation after transcatheter aortic valve implantation using the Medtronic CoreValve prosthesis. *Catheter Cardiovasc Interv*. 2011;78:446-455. https://doi.org/10.1002/ccd.22993
11 Schroeter T, Linke A, Haensig M, et al. Predictors of permanent pacemaker implantation after Medtronic CoreValve bioprosthesis implantation. *Europace*. 2012; 14:1759-1763. https://doi.org/10.1093/europace/eus191