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Original Research

Large Field-of-View Intravascular Ultrasound for Mitral and Tricuspid Valve-in-Valve Guidance: A Pilot Study

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ABSTRACT

Background: Actual expansion of a transcatheter heart valve (THV) might differ from nominal, particularly during nonaortic valve-in-valve for a degenerated bioprosthetic surgical heart valve (SHV). This pilot study compared THV expansion measured using large-field-of-view intravascular ultrasound (IVUS) vs. multi-slice computed tomography (MSCT) and assessed the correlation between THV dimensions and transvalvular gradients.
Methods: Fourteen patients were successfully treated with mitral/tricuspid valve-in-valve SAPIEN 3 implantation sized using the true SHV inner diameter; all 14 had baseline MSCT and transvalvular gradients measured at baseline, postprocedure, and at discharge. Periprocedural IVUS (in 6 patients using a Philips 10MHz Vision PV035) was compared with postprocedural MSCT (in 9 patients) with offline measurements performed at 1-mm steps along the THV height. Overall, 190 MSCT and paired 124 IVUS cross-sections were analyzed.
Results: There was very good agreement between IVUS THV dimensions and corresponding MSCT measurements (intraclass correlation coefficient $\geq$0.986 and $p < 0.001$). IVUS measured THV expansion (percent of the nominal cross-sectional area) was smaller within the inflow and middle of the THV overlapping the ring (85.9% $\pm$ 11.3%, 83.8% $\pm$ 11.8%) than within the outflow (98.8% $\pm$ 12.7%). The residual mean transvalvular gradient increased from periprocedural to predischarge (3.5 $\pm$ 2.0 vs. 6.3 $\pm$ 1.7 mmHg, $p < 0.001$). The only independent predictor of predischarge maximal transvalvular gradient was the smallest minimal inner THV frame diameter ($r^2 = 0.67$), predicted by true SHV internal diameter (Beta = 0.066, 95% CI = 0.015-0.117, $r^2 = 0.49$, $p = 0.037$).
Conclusions: This pilot study is the first to report the feasibility of a large field-of-view IVUS for periprocedural measurement of actual THV expansion when deployed valve-in-valve. Minimal inner THV stent frame dimensions correlate with increased postprocedural transvalvular gradients.

ABBREVIATIONS

ID, inner diameter; IVUS, intravascular ultrasound; LV, left ventricular; MSCT, multi-slice computed tomography; SHV, surgical heart valve; TEE, transoesophageal echocardiography; THV, transcatheter heart valve; TMVR, transcatheter mitral valve replacement; TTE, transthoracic echocardiography; TTVR, transcatheter tricuspid valve replacement; VIV, valve-in-valve.

Introduction

In 60% to 80% of patients treated successfully with valve-in-valve (VIV) transcatheter heart valve (THV) replacement for a failed bioprosthetic surgical heart valve (SHV) in a mitral or tricuspid position, abnormally increased residual transvalvular gradients are measured by transthoracic echocardiography (TTE) before discharge, despite being within normal limits in a routine periprocedural transoesophageal echo (TEE). Importantly, abnormally increased residual transvalvular gradients are associated with a worse subsequent outcome.[1-5] A few in vitro

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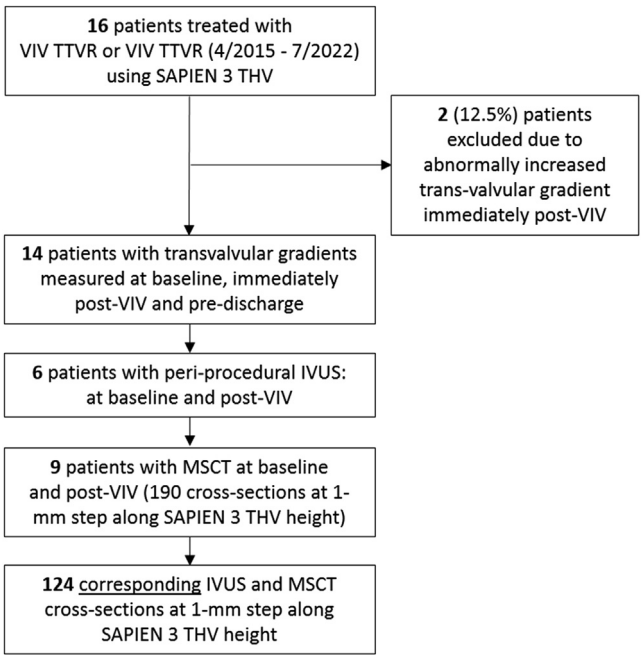

Figure 1. Flow chart illustrating patient selection.
Abbreviations: IVUS, intravascular ultrasound; MSCT, multi-slice computed tomography; THV, transcatheter heart valve; TTVR, transcatheter tricuspid valve replacement; VIV, valve-in-valve.

studies reported a substantial impact of actual THV frame geometry (eccentricity/nonround shape and under-expansion) on the altered trans-valvular flow characteristics.[6-10] Large field-of-view intravascular ultrasound (IVUS) offers a unique tomographic perspective for a direct periprocedural measure of THV stent frame and leaflet geometry.[11-15] We compared the periprocedural IVUS assessment of SAPIEN 3 THV expansion deployed during VIV transcatheter mitral valve replacement (TMVR) or transcatheter tricuspid valve replacement (TTVR) vs. the postprocedural multi-slice computed tomography (MSCT) and assessed the correlation between THV dimensions in MSCT and predischarge transvalvular gradients.

Methods

Population

We analyzed consecutive patients undergoing successful VIV TTVR or VIV TMVR due to symptomatic bioprosthetic SHV structural deterioration from April 2015 to July 2022, using fluoroscopy for implant depth and stent geometry and TEE for hydrodynamic performance of the deployed SAPIEN 3 THV (Edwards Lifesciences Corp., Irvine, California, USA). Out of 16 consecutive patients, 2 (12.5%) were excluded from the study due to an unsuccessful VIV implantation, defined as a residual transvalvular gradient >3 mmHg for TTVR and >5 mmHg for TMVR. All VIV TMVR/TTVR utilized Edwards SAPIEN 3 THVs sized upon the failed bioprosthetic SHV stent true inner diameter (ID) with a rule that selected THV nominal diameter was ≥2 mm bigger than the corresponding stent true ID.[16] Exceptionally, single operators, at their individual discretion, overfilled the delivery balloon volume. Since July 2021, six patients have had novel periprocedural imaging using a Vision PV035 10 MHz IVUS. This system offered a 60 mm imaging field with an axial resolution of 160μm to 240μm and tracking over a standard 0.035" guidewire (Philips North America Corporation, Andover, MA, USA) as a part of a research protocol (4.44/VI/21), and all attempts were successful. Overall, 9

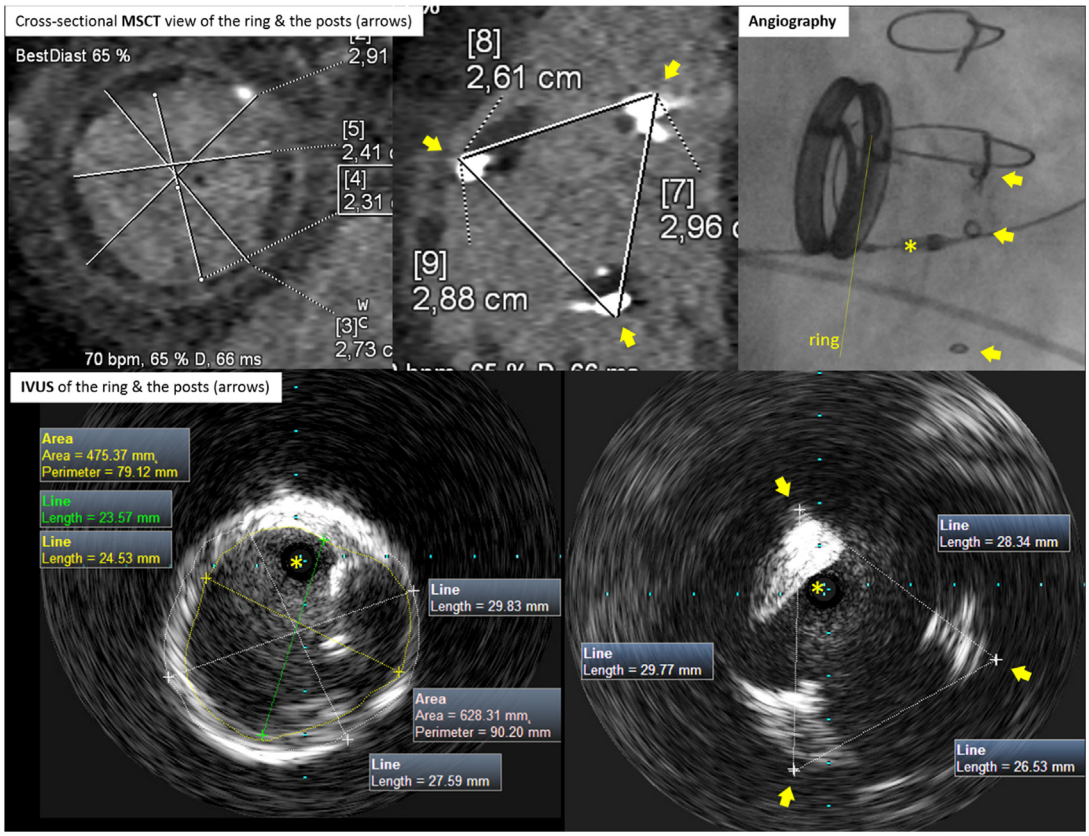

Figure 2. Corresponding preprocedural MSCT, periprocedural angiography, and IVUS (transducer location is marked with an asterisk), showing the sites of the failed bioprosthetic SHV ring and the posts. Relevant and corresponding measurements are shown in IVUS and MSCT.
Abbreviations: IVUS, intravascular ultrasound; MSCT, multi-slice computed tomography; SHV, surgical heart valve.

Table 1
Baseline clinical, echocardiographic, and MSCT characteristics

Variables	All patients (n = 14)
Demographics and clinical characteristics	
Age, y	62.0 ± 18.5
Female, n (%)	10 (71.4)
Body mass index, kg/m^2	27.1 ± 5.9
EuroSCORE II, %	10.6 ± 5.6
EuroSCORE II >4%	13 (92.9)
Permanent pacemaker, n (%)	4 (28.6)
Atrial fibrillation, n (%)	10 (71.4)
Previous myocardial infarction, n (%)	2 (14.3)
Previous percutaneous coronary intervention, n (%)	1 (7.1)
Previous coronary bypass surgery, n (%)	0 (0)
Previous stroke/TIA, n (%)	1 (7.1)
Diabetes mellitus, n (%)	6 (42.8)
Hypertension, n (%)	5 (35.7)
Dyslipidemia, n (%)	5 (35.7)
Chronic renal disease, n (%)	9 (64.3)
Chronic obstructive lung disease, n (%)	0 (0)
Dysfunctional bioprosthesis	
Dysfunctional bioprosthesis in mitral position	6 (42.9)
Dysfunctional bioprosthesis in tricuspid position	8 (57.1)
Standard 3rd generation Carpentier-Edwards stented bovine valve	2 (14.3)
Carpentier-Edwards PERIMOUNT Plus stented bovine valve	1 (7.1)
Carpentier-Edwards PERIMOUNT Magna Ease stented bovine valve	1 (7.1)
Medtronic Mosaic bioprosthesis	3 (21.4)
Medtronic Hancock II porcine bioprosthesis	4 (28.6)
St Jude Medical Biocor valve	2 (14.3%)
Abbott Epic heart valve	1 (7.1)
Nominal outer bioprosthesis diameter 27 mm	3 (21.4)
Nominal outer bioprosthesis diameter 29 mm	4 (28.6)
Nominal outer bioprosthesis diameter 31 mm	7 (50.0)
Mean nominal outer bioprosthesis diameter, mm	27.4 ± 2.1
Mean bioprosthesis stent true ID, mm	25.4 ± 2.1
Duration since surgical insertion, y	10.5 (9.0-19.5)
Baseline echocardiography	
Transvalvular bioprosthetic gradient (peak), mmHg	20.5 ± 7.5
Transvalvular bioprosthetic gradient (mean), mmHg	10.1 ± 9.2
Bioprosthetic dominant stenosis	3 (21.4)
Bioprosthetic dominant regurgitation	4 (28.6)
Bioprosthetic mixed stenosis and regurgitation	7 (50.0)
LV ejection fraction, %	55.1 ± 10.8
TAPSE, mm	12.9 ± 3.7
Baseline MSCT findings	
Minimal bioprosthetic SHV stent ID, mm	26.3 ± 1.4
Maximal bioprosthetic SHV stent ID, mm	27.5 ± 1.8
Minimal lumen ID at the site of the bioprosthetic ring, mm	22.4 ± 3.4
Maximal lumen ID at the site of the bioprosthetic ring, mm	23.6 ± 3.1

Abbreviations: ID, inner diameter; LV, left ventricular; MSCT, multi-slice computed tomography; SHV, surgical heart valve; TAPSE, tricuspid annular plane systolic excursion; TIA, transient ischaemic attack.

patients had predischarge electrocardiogram-gated cardiac MSCT using 384-slice SOMATOM Definition Flash Dual Source (Siemens Healthcare GmbH). In every patient with periprocedural IVUS, MSCT was done as a part of the scientific protocol, and in the remaining subjects, it was performed for clinical reasons (Figure 1). All patients were Heart Team-qualified, and the study complied with the Declaration of Helsinki, with all patients signing informed consent. The study was approved by the local ethics committee.

Baseline demographic and clinical characteristics and procedural details were prospectively gathered and made available from the hospital database. In-hospital outcomes were prospectively collected in accordance with the standardized end-point definitions by the Mitral Valve Academic Research Consortium.[17]

Imaging

Patients underwent preprocedural 2D TTE (GE Vivid E95, General Electric, Boston, Massachusetts, USA) and 2D TEE (GE Vivid E95) as required with an evaluation of: (1) peak and mean transvalvular bioprosthetic gradients; (2) peri- and trans-valvular regurgitation; (3) left ventricular (LV) ejection fraction; and (4) tricuspid annular plane systolic excursion. All had preprocedural contrast-enhanced electrocardiogram-gated cardiac MSCT to assess: (1) risk for iatrogenic LV outflow tract obstruction and (2) baseline SHV anatomy. The procedures were guided with 2D TEE (GE Vivid E95) with measurement of: (1) residual peak and mean transvalvular gradient, (2) peri- and trans-valvular regurgitation, and (3) gradient across the LV outflow tract. IVUS was performed at baseline (preprocedural) and after successful THV deployment, with manual pullback parallel to the long axis of the SHV (baseline) or the THV (postprocedural). All MSCT images were recorded and available for offline analysis using syngo.via (Siemens Healthcare GmbH). Before discharge, all patients underwent 2D TTE evaluations (GE Vivid E95A) with measured peak and mean transvalvular gradients and assessments of peri- and trans-valvular regurgitation.

Table 2
Procedural data

Variables	All patients (n = 14)
General anesthesia with intubation	13 (92.9)
Conscious sedation and local anesthesia	1 (7.1)
Transseptal access in TMVR	6 (100)
Cerebral protection device (sentinel)	1 (7.1)
SAPIEN 3 THV 23 mm	1 (7.1)
SAPIEN 3 THV 26 mm	4 (28.6)
SAPIEN 3 THV 29 mm	9 (64.3)
Nominal delivery balloon volume	8 (57.1)
Overfilling delivery balloon volume*	3 (21.4%)
Preceding valvuloplasty	1 (7.1)
True inner SHV ring area oversizing, %	19.7 ± 10.2
Residual peak transvalvular gradient, mmHg	6.7 ± 1.7
Residual mean transvalvular gradient, mmHg	3.5 ± 2.0
Minor paravalvular leak (trace/mild)	6 (42.9)
Residual transvalvular minor (trace/mild) regurgitation	5 (35.7)
Minor paravalvular and minor transvalvular leak/regurgitation	3 (21.4)
Contrast agent volume, ml	50 (22.5-90.0)
Fluoroscopy time, min	20.7 (17.2-44.1)
Radiation, mGy	767.0 (401.5-2081.5)

Abbreviations: SHV, surgical heart valve; THV, transcatheter heart valve; TMVR, transcatheter mitral valve replacement.
* Using an extra fluid ≥10% of the nominal inflation volume.

Volumetric IVUS and MSCT Qualitative Analysis

Using the double-oblique multiplanar reconstructions with the vertical oblique plane parallel with the failed bioprosthetic SHV long axis and the transverse plane oriented at the visualized perimeter of the bioprosthetic SHV ring, preprocedural MSCT measurements included: (1) minimal and maximal lumen IDs and cross-sectional areas; and (2) inner stent (ring) minimal and maximal diameters and cross-sectional areas. Similarly, IVUS recordings were analyzed at the site of the SHV ring with the least image distortion (Figure 2).

The postprocedure MSCT was assessed by using a vertical oblique plane parallel to the THV long axis with a transverse plane oriented at the nondistorted THV stent frame perimeter. At 1mm steps along the entire THV height, measurements included inner and outer THV stent frame minimal and maximal diameters and cross-sectional areas. As a result, there were 18, 20, and 22 independent cross-sections for SAPIEN 3 THV 23, 26, and 29 mm, respectively (Supplementary Figure 1). We identified the IVUS loop with the best image quality after successful VIV deployment (not distorted) for THV stent frame visualization. Then we counted the total number of the following THV cross-sections recorded consistently within the known THV height and identified 18, 20, or 22 evenly spaced and nondistorted images that were measured the same way as MSCT images (Supplementary Figure 2).

Table 3
Comparison of the corresponding results of IVUS and MSCT measurements, obtained at baseline at the site of failed SHV ring and after the VIV procedure at 1-mm step along the entire SAPIEN 3 THV height with assessed outer stent frame dimensions (the paired-samples T-test with computed Pearson correlation coefficients)

Variables	IVUS	MSCT	Correlation	*p*-value
Baseline				
Planar measurements at the site of failed SHV ring (n = 6)				
Min lumen diameter, mm	21.1 ± 3.4	21.1 ± 3.4	0.995	<0.001
Max lumen diameter, mm	22.2 ± 3.1	22.1 ± 3.1	0.985	<0.001
Lumen area, cm^2	3.78 ± 0.92	3.83 ± 0.96	0.997	<0.001
Stent minimal ID, mm	25.9 ± 1.3	26.1 ± 1.0	0.978	0.004
Stent maximal ID, mm	27.1 ± 1.8	27.0 ± 2.1	0.962	0.009
Stent inner area, cm^2	5.37 ± 0.57	5.39 ± 0.53	0.998	<0.001
Post-VIV THV replacement				
(immediately in IVUS and subsequently in MSCT)				
Entire SAPIEN 3 THV height (n = 6)				
Minimal diameter, cm	2.55 ± 0.24	2.58 ± 0.24	0.992	<0.001
Maximal diameter, cm	2.79 ± 0.27	2.73 ± 0.29	0.992	<0.001
Outer frame stent volume, cm^3	5.61 ± 1.06	5.57 ± 1.08	0.999	<0.001
Expansion, %	91.9 ± 11.6	91.2 ± 11.4	0.998	<0.001
THV eccentricity	1.09 ± 0.03	1.06 ± 0.03	0.676	0.141
SAPIEN 3 THV inflow (n = 6)				
Minimal diameter, cm	2.45 ± 0.23	2.50 ± 0.23	0.992	<0.001
Maximal diameter, cm	2.72 ± 0.28	2.64 ± 0.32	0.976	0.001
Outer frame stent volume, cm^3	5.25 ± 1.01	5.20 ± 1.02	0.998	<0.001
Expansion, %	86.2 ± 11.9	85.2 ± 11.5	0.997	<0.001
THV eccentricity	1.11 ± 0.03	1.05 ± 0.05	0.626	0.184
SAPIEN 3 THV mid-segment (n = 6)				
Minimal diameter, cm	2.48 ± 0.27	2.46 ± 0.27	0.965	0.002
Maximal diameter, cm	2.67 ± 0.26	2.61 ± 0.28	0.964	0.002
Outer frame stent volume, cm^3	5.11 ± 1.03	5.10 ± 1.07	0.995	<0.001
Expansion, %	83.8 ± 12.4	83.5 ± 12.7	0.995	<0.001
THV eccentricity	1.08 ± 0.05	1.06 ± 0.01	0.020	0.969
SAPIEN 3 THV outflow (n = 6)				
Minimal diameter, cm	2.65 ± 0.25	2.68 ± 0.25	0.991	<0.001
Maximal diameter, cm	2.90 ± 0.27	2.84 ± 0.28	0.990	<0.001
Outer frame stent volume, cm^3	6.04 ± 1.12	6.01 ± 1.13	0.998	<0.001
Expansion, %	98.8 ± 12.8	98.3 ± 12.4	0.991	<0.001
THV eccentricity	1.09 ± 0.04	1.06 ± 0.03	0.736	0.096

Abbreviations: IVUS, intravascular ultrasound; MSCT, multi-slice computed tomography; SHV, surgical heart valve; THV, transcatheter heart valve; VIV, valve-in-valve.

Applying Simpson's Rule and using the measured outer stent frame dimensions (diameters and cross-sectional areas) from MSCT and IVUS studies, we calculated: (1) average THV outer stent frame volume (cm^3) and (2) minimal and maximal diameters (mm). These calculations were made per the entire THV height and independently per its inflow, mid (coaptation region), and outflow. The valve inflow height was equal to the outer skirt height (6.0, 7.0, and 8.1 mm for 23, 26, and 29 mm valves, respectively), and the valve mid-height was considered as the difference between the corresponding outer and inner skirt heights (inner skirt heights: 9.3, 10.2, and 11.6 mm for 23, 26, and 29 mm valves, respectively). The THV outflow height was the overall stent frame height minus the inner skirt height.[18]

The average/minimal percentage (%) expansion of the THV stent frame in relation to nominal THV dimensions was calculated as the actually measured average/minimal outer stent frame volume/cross-sectional area divided by the corresponding nominal outer stent frame average volume/cross-sectional area x 100%. The nominal SAPIEN 3 THV outer stent frame cross-sectional area was derived from published studies that measured it with microCT after the valve expansion on air using the transfemoral Edwards Commander delivery system (Edwards Lifesciences) filled with a nominal volume of fluid.[19,20] The average % expansion was calculated for the entire THV height and separately for its inflow, mid, and outflow. Additionally calculated was % oversizing of the THV stent frame in relation to SHV (nominal THV outer stent frame area/SHV inner ring true area × 100%–100%).[16] THV eccentricity was calculated as max/min outer stent frame diameters.

Statistical Analysis

Categorical data are presented as numbers and frequencies and compared with the Pearson chi-square statistics. The one-sample Kolmogorov-Smirnov test was used to verify the distribution (normal vs. nonuniform) of continuous parameters. Normally distributed variables were presented as means ± standard deviation and compared using the paired-samples T-test with computed Pearson correlation coefficients. Continuous variables with non-normal distributions are presented as medians with an interquartile range. Multivariate linear regression was used to search for independent correlates of (1) minimal THV inner stent frame area (measured using MSCT), (2) maximal transvalvular gradient measured predischarge, and (3) the smallest minimal inner THV stent frame diameter measured using postprocedural MSCT, with computed parameter estimate and corresponding 95% confidence interval (Beta and 95% CI). Interobserver and intraobserver variability in IVUS measurements were assessed with intraclass correlation coefficients. The reproducibility of the corresponding IVUS vs. MSCT measurements was analyzed using the Bland-Altman plot analysis and calculated intraclass correlation coefficients. The limits of agreement were defined as mean ±1.96 SD of absolute difference; $p < 0.05$ was considered significant. Statistical analysis was performed using the PASW Statistics 18 (IBM Corporation, Armonk, New York, USA).

Results

Demographics and Baseline Clinical Data

In the current cohort (n = 14) of consecutive patients treated with mitral/tricuspid VIV SAPIEN 3 THV implantation, the patient age was 62.0 ± 18.5 years, most were female (71.4%), and most (92.9%) were categorized as surgically high-risk. The degenerated bioprosthesis was mitral in 42.9% and tricuspid in 57.1% (Table 1). In 50% of patients, the dominant bioprosthesis failure

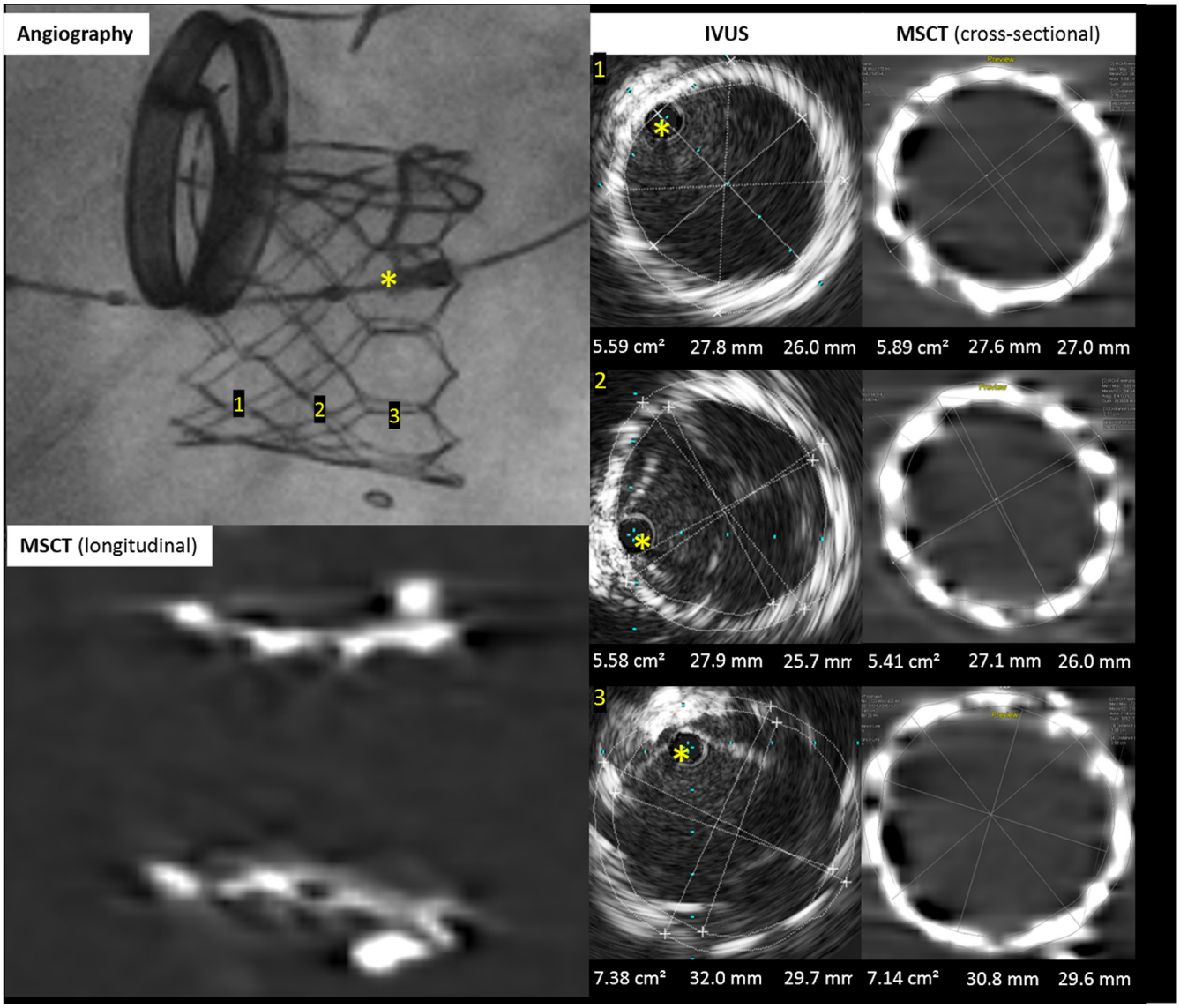

Figure 3. An example of the corresponding IVUS and MSCT SAPIEN 3 THV inner and outer frame measurements (IVUS transducer location is marked with an asterisk).
Abbreviations: IVUS, intravascular ultrasound; MSCT, multi-slice computed tomography; THV, transcatheter heart valve.

mode was mixed stenosis and regurgitation with nominal bioprosthesis size being ≥29mm in 78.6%. Bioprostheses type distribution is shown in Table 1.

Procedural Data

There was a significant correlation between SHV stent true ID and nominal THV diameter (r = 0.865 and $p < 0.001$) with a nominal THV diameter that was oversized compared to the corresponding stent true ID (27.7 ± 1.9 vs. 25.4 ± 2.1 mm, $p < 0.001$). SAPIEN 3 THVs were mostly (64.3%) 29mm nominal size, with a nominal diameter that was >2mm bigger than the corresponding SHV stent true ID and >20% inner ring area oversizing in 6 patients (42.9%). SAPIEN 3 THV was deployed with nominal delivery balloon volume except for three patients (21.4%), in whom operators at their own discretion overfilled it by 10%, mostly without preceding valvuloplasty (92.9%) and without postdilation. Minor paravalvular leak and minor residual trans-valvular regurgitation were observed in 6 (42.9%) and 5 (35.7%) patients, respectively, with 3 (21.4%) having both. The in-hospital course of all patients was uneventful, except for one case of extensive bleeding associated with vascular access requiring surgical intervention. In all patients, predischarge transvalvular gradients were bigger than periprocedural measures with their maximal values of 14.9 ± 3.7 mmHg and 7.5 ± 2.4 mmHg, respectively (Table 2).

Baseline MSCT and IVUS Results

Minimal and maximal bioprosthetic SHV stent (ring) ID measured using baseline MSCT (n = 14) were similar to the nominal ($p = 0.114$ and $p = 0.864$, respectively), whereas minimal and maximal lumen ID measured at the site of the bioprosthetic SHV ring were smaller than the corresponding stent true ID ($p = 0.005$ and $p = 0.056$, respectively). The nominal THV diameter was larger than the corresponding minimal and maximal lumen ID ($p < 0.001$ for both), but was similar to the measured in baseline MSCT nominal and maximal bioprosthetic SHV stent ID ($p = 0.239$ and $p = 0.774$, respectively) (Table 1). Baseline IVUS measurements (n = 6) corresponded well with the respective MSCT dimensions (Table 3).

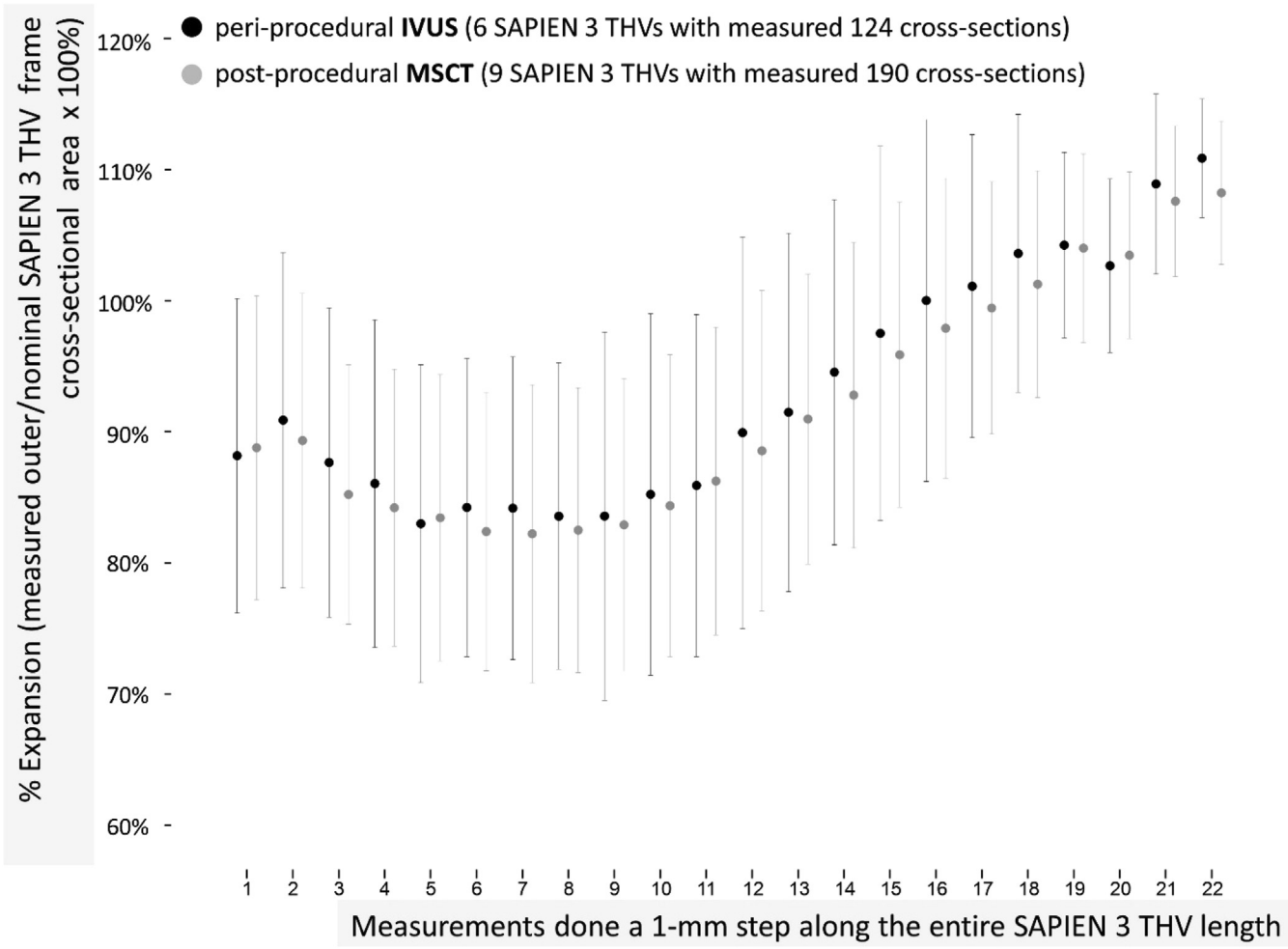

Figure 4. % Expansion of SAPIEN 3 THVs measured in IVUS and MSCT.
Abbreviations: IVUS, intravascular ultrasound; MSCT, multi-slice computed tomography; THV, transcatheter heart valve.

Postprocedural MSCT, Periprocedural IVUS, and Predischarge TTE Results

Overall, 190 THV cross-sections were analyzed in MSCT and 124 in IVUS. There was a good correlation between all the volumetric THV outer frame dimensions measured by IVUS vs. MSCT (Table 3, Figure 3). The actual outer-frame expansion was smaller within the lengths of inflow and mid-THV height (overlapping the ring) than in the outflow, being substantially smaller than nominal (83.3% ± 12.1% and 81.8% ± 11.8% and 95.7% ± 12.1% in MSCT vs. 85.9% ± 11.3% and 83.8% ± 11.8% and 98.8% ± 12.7% in IVUS, respectively, Figure 4). There was high interobserver and intraobserver agreement in IVUS measurements (Supplementary Table 1). Comparing 248 corresponding pairs of inner and outer-stent frame THV cross-sectional measurements (minimal and maximal diameters and cross-sectional areas) made using IVUS and MSCT, there was a good agreement (intraclass correlation coefficient from 0.990 to 0.999, Figure 5, Supplementary Table 2).

The minimal percentage of THV expansion measured using MSCT and IVUS were 80.1% ± 10.0% and 79.0% ± 11.1%, respectively, with corresponding minimal inner SAPIEN 3 THV frame area of 3.47 ± 0.78 cm^2 and 3.22 ± 0.62 cm^2. The degree of the % THV oversizing in relation to SHV correlated inversely with a minimal % THV expansion in relation to nominal size measured in both IVUS and MSCT ($r = -0.876$, $p = 0.002$ and $r = -0.86$, $p = 0.026$; respectively), but minimal inner THV stent frame area was independently predicted only by stent true ID (Beta = 0.313, 95% CI = 0.183-0.442, $r^2 = 0.823$, $p = 0.001$). The only independent predictor of the maximal transvalvular gradient measured predischarge was the smallest minimal inner THV frame diameter ($r^2 = 0.67$, Table 4), which was predicted by the true bioprosthetic SHV stent ID (Beta = 0.066, 95%CI = 0.015-0.117, $r^2 = 0.49$, $p = 0.037$).

Discussion

Optimal THV leaflet function requires the stent frame to be fully expanded (100% nominal) and circular.[7,21,22] Periprocedural angiographic guidance of THV stent frame expansion, including rotational 3D angiography,[15] has limitations due to visual resolution and projection angles (the short axis of the valve is often unattainable with fluoroscopy). TEE visual resolution is also limited; it is used less and less ("minimalist THV deployment") and is hampered by acoustic shadows and poor imaging windows. Periprocedural Doppler measurements, including those with TEE, are often biased, with subsequent values frequently higher.[1] With this background, the current pilot study was the first to use IVUS to assess actual SAPIEN 3 THV stent frame expansion immediately following successful TMVR or TTVR VIV. The major findings of the current study are as follows: (1) Expansion was significantly smaller than nominal, especially where it overlapped with the bioprosthetic SHV ring, with the stent minimum expansion averaging 80%, resulting in an under-expansion of 4.6mm for the nominal 23mm diameter valve and 5.8mm for the 29mm valve. (2) IVUS findings were comparable

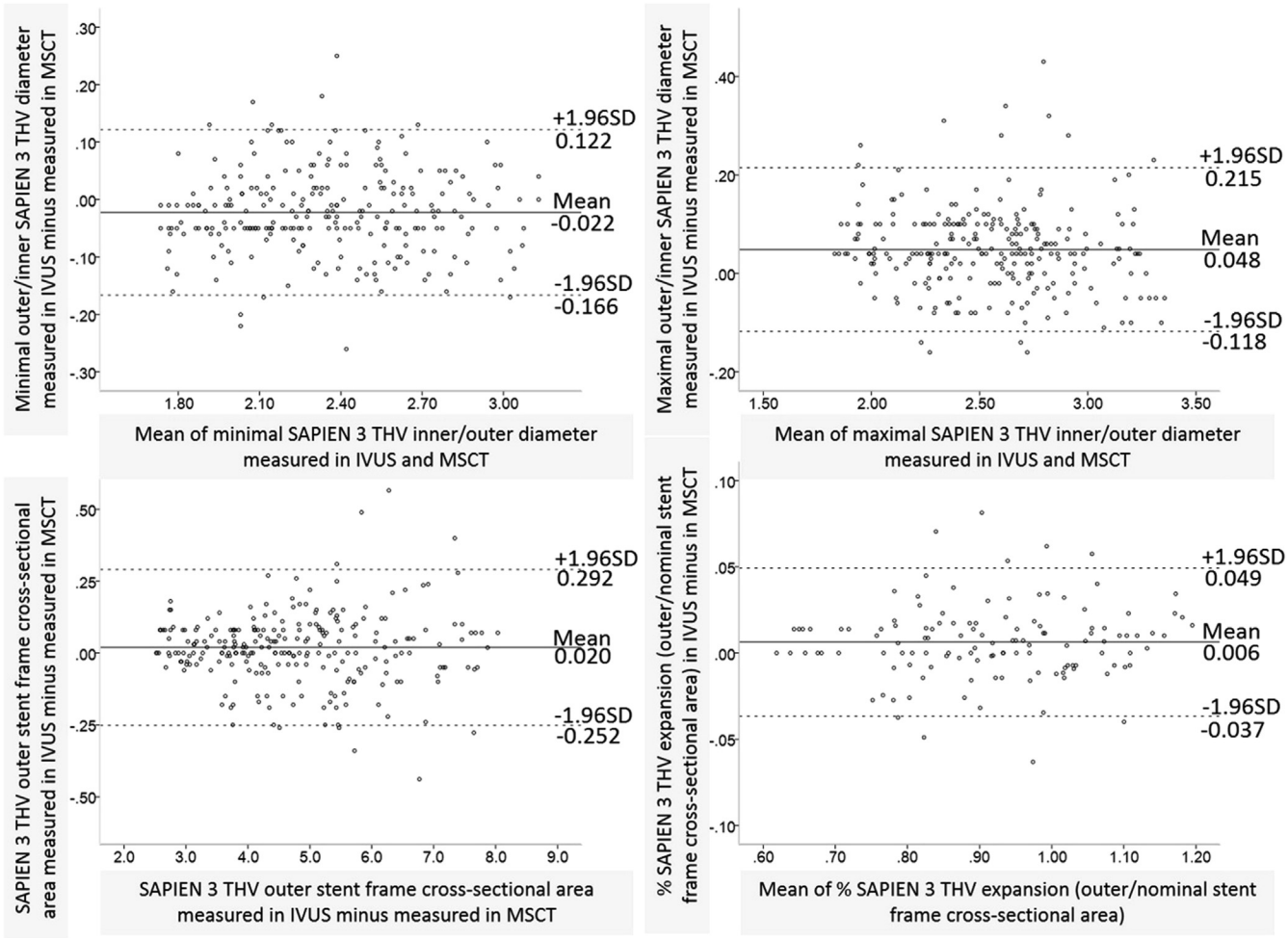

Figure 5. Plots of differences between corresponding inner and outer-frame IVUS and MSCT measurements vs. the mean of the 2 measurements (IVUS and MSCT), with marked the limits of agreement from −1.96 × SD + 1.96 × SD (dotted lines).
Abbreviations: IVUS, intravascular ultrasound; MSCT, multi-slice computed tomography; THV, transcatheter heart valve.

to the current gold standard MSCT assessment. (3) Minimal inner SAPIEN 3 THV stent frame dimensions correlated directly with increased transvalvular gradients recorded predischarge. For example, other authors using MSCT studies of early dysfunctional THVs (less than 1 year since deployment) found stent frame under-expansion in the THV inflow and midportion that was corrected with subsequent dilatations using a noncompliant tubular balloon with a diameter equal to the nominal THV size.[23] This could have been prevented with intraprocedural IVUS guidance.

In a previous pig model, the authors inserted 26mm SAPIEN 3 THVs into stented bioprosthetic SHVs with varying IDs following the VIV Mitral app's recommendation of a nominal THV diameter 2mm larger than the SHV ID.[24,25] Despite our study having a smaller THV oversizing percentage than the pig model, the actual inflow and outflow expansion percentages were larger. This underscores the importance of periprocedural insights into the actual results over the preprocedural planning. In an in vitro analysis of mitral hemodynamic performance after VIV deployment of first-generation SAPIEN THV into brand-new surgical bioprostheses, the authors found that VIV deployment was associated with increased transvalvular gradients, particularly in bioprostheses with small stent true ID and higher % oversizing, aligning with the VIVID Registry findings.[3,26] In the current analysis, only the

Table 4
Correlates of maximal transvalvular gradient measured predischarge

Variables	Univariate			Multivariable		
	Beta	95% CI	*p*-value	Beta	95% CI	*p*-value
True stent ID (n = 14)	−1.062	−1.928 to −0.195	0.020	-	-	-
Nominal SAPIEN 3 THV diameter (n = 14)	−0.873	−1.932 to 0.186	0.098	-	-	-
Minimal lumen diameter measured in baseline MSCT at the site of bioprosthetic SHV ring (n = 14)	−0.126	−0.735 to 0.486	0.694	-	-	-
% SAPIEN 3 THV outer stent frame area oversizing (n = 14)	0.153	−0.052 to 0.359	0.130	-	-	-
Minimal % expansion of SAPIEN 3 THV outer frame in MSCT (n = 9)	−2.693	−24.776 to 19.390	0.818	-	-	-
Minimal inner SAPIEN 3 THV stent frame area (n = 9)	−2.766	−5.179 to −0.353	0.030	-	-	-
The smallest minimal inner SAPIEN 3 THV stent frame diameter measured in postprocedural MSCT (n = 9)	−11.495	−18.783 to −4.207	0.007	−11.495	−18.783 to −4.207	0.007

Abbreviations: ID, inner diameter; MSCT, multi-slice computed tomography; SHV, surgical heart valve; THV, transcatheter heart valve.

bioprosthesis stent true ID remained an independent correlate of minimal inner SAPIEN 3 THV stent frame dimension. Although maximal transvalvular gradients measured predischarge in the current study were bigger for smaller bioprostheses, it was the measured minimal inner SAPIEN 3 THV stent frame diameter that independently explained 67% of its variability.

The current results suggest that in the lifelong management of THV replacements, including aortic procedures with a significant readmission rate, accurate periprocedural insights using IVUS hold great potential for guiding the process, both at the initial and redo levels. This would complement detailed preprocedural planning using baseline MSCT and bench tests results.[19,27-29] The potential for improved procedural outcomes may justify the cost of incorporating IVUS equipment. Because its integration into THV procedures may add to the overall procedural time, it would be essential to weigh the benefits of real-time guidance and precise measurements against delays.

Study Limitations

This is a proof-of-concept pilot study of a small number of patients. Two patients were excluded due to high residual gradients measured during the procedure, but we couldn't evaluate the expansion of their stent frames because we didn't do IVUS or MSCT. We expect that future multicenter investigator-initiated research will provide a more thorough analysis of our findings. The accuracy of our results might be influenced by the noncoaxial IVUS transducer location. Significant errors can occur when the transducer is angled more than 25 degrees off-center, but this can be corrected with gentle wire adjustments (e.g., right ventricle loop or pulmonary artery wire position during TTVR VIV) and use of steerable sheaths.[30] Technological advancements should automate IVUS pullback and reduce variability caused by the transducer location. The Edwards Commander Delivery System comes with a compliant balloon. If this balloon is inflated at the rigid ring with a substantially smaller inner dimension, it may unevenly distribute the inflation fluid toward areas with less resistance, affecting the actual stent frame expansion. Overfilling the balloon can enhance this issue. We didn't adjust nominal SAPIEN 3 THV dimensions to account for this overfilling.[19] Importantly, none of the valves were cracked/remodeled, but IVUS seems to be helpful for guiding these, even for nonaortic valves.[31]

Conclusions

Periprocedural use of a large field-of-view IVUS offers accurate and online measurements of actual expansion of SAPIEN 3 THVs deployed for VIV, enabling clinicians to make real-time, data-driven decisions to enhance outcomes. Measured minimal inner THV stent frame dimensions correspond with increased postprocedural transvalvular gradients, and postdilatation of the stent frame might be justified in such cases.

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Ethics Statement

The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Local Ethics Comitee.

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Disclosure Statement

The authors report no conflict of interest.

Supplementary Material

Supplemental data for this article can be accessed on the publisher's website.

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