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Procedural and Mid-Term Outcomes of Coronary Protection During Transcatheter Aortic Valve Replacement in Patients at Risk of Coronary Occlusion: Insight From a Single-Centre Retrospective Analysis

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Procedural and Mid-Term Outcomes of Coronary Protection During Transcatheter Aortic Valve Replacement in Patients at Risk of Coronary Occlusion: Insight From a Single-Centre Retrospective Analysis

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ABSTRACT

Background: Detailed procedural analysis and long-term data is limited for coronary protection (CP) during transcatheter aortic valve replacement (TAVR) for patients with high anatomical risk for coronary occlusion (CO). We aim to assess the procedural and mid-term outcomes of CP during TAVR.
Methods: We retrospectively analyzed patients who underwent TAVR at Henry Ford Hospital, USA from January 2015 to August 2019 and identified those considered at risk of CO and underwent pre-emptive CP with or without subsequent "chimney" stenting (i.e. coronary stenting with intentional protrusion into the aorta). Procedural features, immediate and mid-term clinical outcomes were reviewed.
Results: Twenty-five out of 1166 (2.1%) patients underwent TAVR with CP, including 10 (40%) valve-in-valve procedures. Twenty-eight coronary arteries (Left: n = 11, Right: n = 11; Left + Right: n = 3) were protected. Eleven coronaries (39.3%) were electively "chimney"-stented due to angiographic evidence of coronary impingement (63.6%), tactile resistance while withdrawing stent (27.3%) and electrocardiogram change (9.1%). Twenty-four patients (24/25, 96%) had successful TAVR without CO. Procedure-related complications included stent-balloon entrapment (n = 1), stent entrapment (n = 1) and occlusive distal stent edge dissection (n = 1). After a mean follow-up of 19.1 months, there was 1 cardiac death but no target vessel re-intervention or myocardial infarction.
Conclusions: Our study found that angiographic evidence of coronary impingement (63.6%) was the most common reason for stent deployment during TAVR with CP. The mid-term clinical outcome of CP with TAVR was favorable.

1. Introduction

Coronary occlusion (CO) during transcatheter aortic valve replacement (TAVR) is a rare (<1%) but life-threatening complication and is usually due to the displacement of valve leaflet over the coronary ostia [1]. With increasing experience and advancement in pre-procedural computer tomography (CT), specific anatomical factors e.g. low-lying coronary ostia (<12 mm) [1], narrow sinuses of Valsalva (<30 mm) [1], short virtual transcatheter heart valve-to-coronary distance (VTC, <4 mm) [2,3] in valve-in-valve (VIV) TAVR were found to be associated with CO. Coronary protection (CP) with a guidewire, coronary balloon or stent, positioned pre-emptively in the coronary artery was previously reported to be a feasible technique to manage CO during TAVR in at risk patients [4]. However, detailed procedural analysis and long-term data of this technique were limited. This study aimed to assess the procedural and mid-term outcome of CP technique in TAVR patients at risk of CO based on pre-procedural CT analysis.

2. Materials and methods

We retrospectively analyzed patients who underwent TAVR at Henry Ford Hospital, USA from January 2015 to August 2019 to identify those considered at risk of CO and who underwent pre-emptive CP with or without subsequent "chimney" stenting (i.e. coronary stenting with intentional protrusion into the aorta to prevent a displaced leaflet from impinging the coronary ostium). The baseline clinical and anatomical characteristics were reviewed. The procedural documentations,

Abbreviations: AS, aortic stenosis; CT, computer tomography; CO, coronary occlusion; CP, coronary protection; TAVR, transcatheter aortic valve replacement; VIV, valve-in-valve; VTC, virtual transcatheter heart valve-to-coronary distance.

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fluoroscopic images and transesophageal echocardiographic images (if any) were reviewed to analyze the procedural techniques used, indication of stent deployment and immediate procedural outcomes. Indications of stent deployment included, 1) angiographic evidence of coronary impingement e.g. TIMI 0-2 distal coronary flow, presence of "white-line" sign that represent a displaced, pinned thickened calcified aortic valve leaflets in front of the coronary ostium (Fig. 1B) [5] or definite prolapsed calcified leaflet into coronary ostium; 2) Tactile resistance when withdrawing stent/balloon if guide extension was not used or withdrawn; 3) Electrocardiographic/Echocardiographic evidence of coronary ischemia. The CT images of each patients were reviewed to obtain various aortic dimensions, comparison between those with and without final stent deployment were performed. Chart review and questionnaire-based phone interview were performed to determine the mid-term clinical outcomes. The study was approved by institutional review board and was waived the requirement for informed consent for this retrospective analysis.

The primary endpoint of the study was a composite of cardiac mortality, target vessel re-intervention or myocardial infarction related to target vessel at the latest clinical follow-up or questionnaire-based phone interview. Secondary endpoints included procedural myocardial infarction, coronary occlusion, stroke, cardiac mortality and all-cause mortality. All clinical outcomes were defined according to the Valve Academic Research Consortium-2 criteria [6].

2.1. Statistical analysis

Categorical variables were summarized as percentages. Normally distributed continuous data were expressed as mean ± SD and skewed data as median (range). Student's *t*-test was used to compare means. Survival analyses were determined using the Kaplan-Meier method. Two-sided p values <0.05 were considered to indicate statistical significance. SPSS version 24 (IBM, Armonk, New York) and Microsoft Excel 365 (Microsoft, Redmond, Washington) were used for all statistical analysis.

3. Results

From January 2015 to August 2019, 25 out of 1166 (2.1%) TAVR performed at Henry Ford Hospital underwent CP due to presence of anatomical risk factors for CO based on pre-procedural CT. The mean age was 78.8 ± 8.6 and mean STS score was 7.2 ± 5.7 (Table 1). Majority (92%) of the TAVR were performed electively and 10 (40%) were VIV TAVR. Sixty percent of patients were classified as high or inoperable risk by local Heart team. Seventy-two percent patients included did not have prior significant coronary artery disease (i.e. >70% lesion, prior coronary artery stenting or prior coronary artery bypass grafting). Transfemoral access (88%) was used most frequently (Table 2) as valve deployment access, whereas one single small contralateral femoral (36%), two small contralateral femoral (36%) and one single large contralateral femoral (28%) accesses were used for CP and radiographic pigtail. Twenty-four percent patients received Sentinel cerebral embolic protection device (Boston Scientific, Marlborough, Massachusetts), as many of these TAVR were done before Sentinel was commercially available. Balloon expandable valve was used in 96% of the cases. Balloon valve fracturing was performed in 50% (5/10) of VIV TAVR, whereas balloon post-dilatation was performed in 46.7% (7/15) of native valve TAVR. All balloon post-dilatation/valve fracturing were performed before coronary stent deployment to avoid stent crushing. Five patients also underwent concomitant aortic scallop laceration (BASILICA) procedure [7] to a mitigate the risk of CO in 7 coronary arteries (i.e. 2 were bilateral coronary BASILICA), including 5 successful BASILICA to contralateral arteries which were excluded from the analysis, and 2 failed BASILICA to subsequently protected coronary arteries which

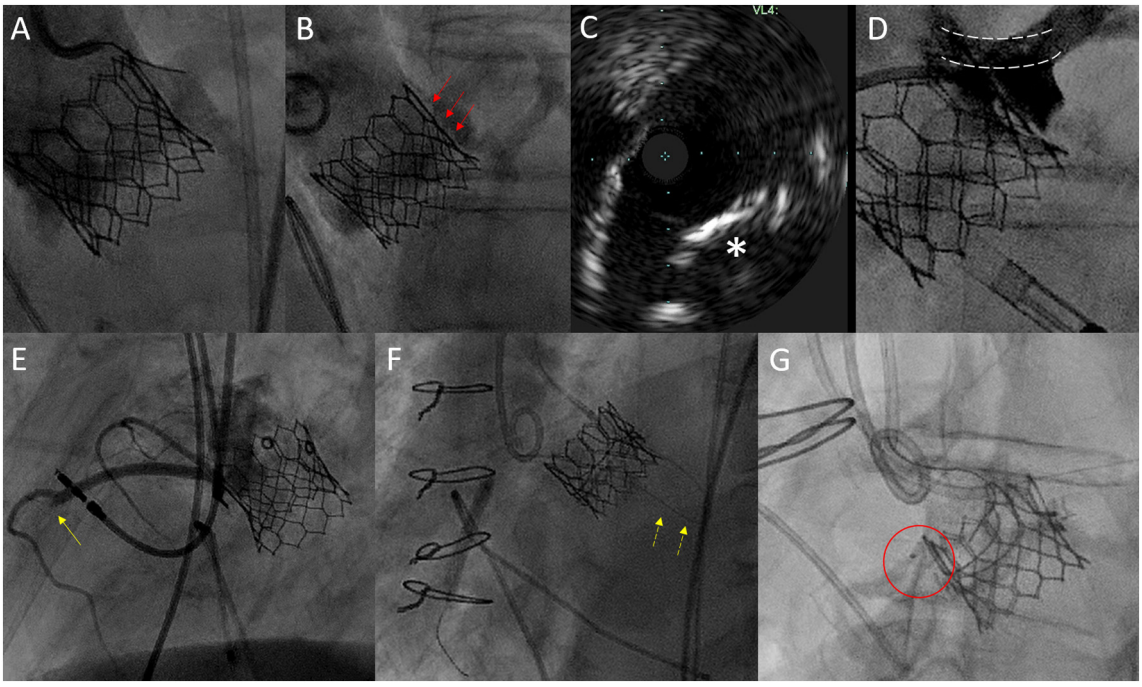

Fig. 1. Procedural images of complications of coronary protection during transcatheter aortic valve replacement. A–D showed a patient with coronary occlusion after pre-emptively placed coronary balloon and wire were removed. A: Non-selective coronary angiogram with coronary wire (soft part only) left in left main artery showed no angiographic evidence of coronary impingement. B: Soon after wire removal, patient developed hypotension with ischemic electrocardiographic change, repeated aortogram showed radiographic evidence of coronary impingement ("white-line" sign, red arrows). C: Intravascular ultrasound confirmed compromised opening into left main due to calcified aortic leaflet (*). D: The impinged coronary was rewired and stented (white dash lines). E. Angiogram showing occlusive distal stent edge dissection after "chimney" stenting. F. Fluoroscopic image showing deployment of an entrapped stent, due to coronary wire prolapse (dash yellow arrows) into the left ventricular during transcatheter valve delivery, at mid-right coronary artery. G. Fluoroscopic image showing an entrapped stent balloon (red circle) by valve stent frame after stent deployment.

Table 1
Baseline clinical characteristics of patients underwent coronary protection and transcatheter aortic valve replacement.

	N = 25
Age	78.8 ± 8.6
Female	20 (80%)
BMI (kg/m^2)	30.0 ± 4.8
Diabetes	11 (44%)
Hypertension	22 (88%)
Dialysis	0
STS score (%)	7.2 ± 5.7
Operative classification	
Low risk	1 (4%)
Intermediate risk	9 (36%)
High risk	13 (52%)
Inoperable	2 (8%)
Status of procedure	
Elective	23 (92%)
Urgent/emergency	2 (9%)
Atrial fibrillation	6 (24%)
Prior PCI	3 (12%)
Prior CABG	5 (20%)
Valve in valve procedure	10 (40%)
Magna/magna ease	4
MitroFlow	2
Mosaic	1
Trifecta	1
CarboMedics	1
Stentless	1
Prior TAVR	0
Prior Stroke/TIA	3 (12%)
Prior PAD	6 (24%)
CAD	
0	18 (72%)
1	1 (4%)
2	2 (8%)
3	4 (16%)
LM	2
Proximal LAD	5
Bicuspid	2 (8%)

STS = Society of Thoracic Surgeons; PCI = percutaneous coronary artery intervention; CABG = coronary artery bypass grafting; TAVR = transcatheter aortic valve replacement; TIA = transient ischemic attack; PAD = peripheral arterial disease; CAD = coronary artery disease; LM = left main; LAD = left anterior descending artery.

Table 2
Anatomical and procedural characteristics of coronary protection during transcatheter aortic valve replacement.

	N = 25
Annular size	356.0 ± 85.5
Coronary protected	
Left coronary artery alone	11
Right coronary artery alone	11
Bilateral coronary arteries	3
Coronary heights protected	9.0 ± 1.8
Left coronary artery	9.0 ± 1.7
Right coronary artery	8.8 ± 1.8
Sinus dimension	
Left	27.1 ± 3.3
Right	25.0 ± 2.9
Non	28.1 ± 2.8
Target sinus	27.1 ± 3.6
STJ height	18.7 ± 3/3
VTC	4.0 ± 0.9
Valve deployment access (14-16Fr)	
Transfemoral	22 (88%)
Transcaval	2 (8%)
Percutaneous axillary	1 (4%)
Non-valve deployment access (s)	
Single 6-7Fr	9 (36%)
Two 6-7Fr	9 (36%)
Single 14-16Fr	7 (28%)
Valve implanted	
SEV	1 (4%)
BEV	24 (96%)
Valve size	
20 mm	9 (36%)
23 mm	11 (44%)
26 mm	4 (16%)
29 mm	1 (4%)
Valve fracturing[a]	5/10 (50%)
Balloon post-dilatation[b]	7/15 (46.7%)
Sentinel used	6 (24%)
General anesthesia	8 (32%)
Contrast (ml)	181.2 ± 79.8
Fluoroscopy time (minutes)	58.7 ± 33.8
Fluoroscopy dose (mGy)	1455.1 ± 1025.2

STJ = sinotubular junction; VTC = virtual transcatheter valve-to-coronary distance; SEV = self-expandable valve; BEV = balloon-expandable valve.
[a] For valve-in-valve procedures only, including 1 trifecta and 1 stentless valve that cannot be fractured;
[b] For native valve procedure only.

were included for the analysis. For the two failed BASILICA attempts, one failed to transverse at the base of right coronary leaflet due to calcium; and the other, BASILICA was aborted after multiple transverse attempts at suboptimal leaflet location (bicuspid).

A total of 28 coronary arteries were protected, including 11 left coronary arteries alone, 11 right coronary arteries alone and 3 dual coronary arteries (Table 3). None of the coronaries had prior ostial stenting but 5 (17.9%) had prior target vessel significant coronary disease (either had a >70% lesion or stented). Among these 28 coronaries, 3 (10.7%) were protected using coronary wire with coronary balloon and 25 (89.3%) were protected using coronary wire with an undeployed coronary stent positioned distal to the coronary ostium. Intra-vascular ultrasound was used in 7 (25%) coronaries to assess vessel size before CP and guide extension was used in 2 (7.1%) coronaries during CP.

3.1. Acute procedural outcomes

Twenty-four (96%) patients had successful TAVR without CO and none required conversion to surgery. At the end of the CP procedure, 12 of the prior placed coronary stents were deployed, including 11/28 (39.2%) "chimney"-stented (6 right coronary arteries and 5 left coronary arteries) and 1 deployed at the middle of the coronary artery due to stent entrapment (Table 3, Fig. 1). One additional patient received coronary stenting due to coronary occlusion (n = 1, 4%), after pre-emptive wire and coronary balloon were removed, which was emergently managed with re-wiring and coronary stenting under mechanical circulatory support (Fig. 1). Among those "chimney"-stented patients (n = 11), the most common indication for stent deployment was angiographic evidence of coronary impingement after TAVR (n = 7, 63.6%), followed by tactile resistance felt by the operators while pulling back the pre-emptively placed stents across the coronary ostia/transcatheter valve frame (n = 3, 27.3%). Only 1 (9.1%) patient had electrocardiogram evidence of ischemia (Table 3).

Apart from the only CO patient, another patient had myocardial infarction (n = 2, 8%) due to distal stent edge dissection, which resulted in vessel occlusion after the pre-emptively placed coronary stent was deployed (Fig. 1) and was managed with another overlapping stent deployment. Of note, intravascular ultrasound was not used in this coronary. In addition, 1 (4%) patient had stent balloon entrapment by the transcatheter valve frame while pulling back the stent balloon after coronary stent was deployed, which was successfully snared in a staged procedure (Fig. 1). There was 1 (4%) peri-procedural stroke and 1 (4%) major vascular complication. At 30 days, there was 1 (4%) cardiovascular death. The patient underwent bilateral coronary protection with left coronary "chimney" stented but right coronary not stented. She also had concomitant severe mitral stenosis, was discharged after procedure and readmitted for refractory heart failure on day 19 and died on day 26 post-procedure. Besides, there was 1 additional non-cardiovascular

Table 3
Technical characteristics and procedural outcomes of coronary protection during transcatheter aortic valve replacement.

Technical characteristics	
	N = 28
Prior target vessel ostial stenting	0
Prior target vessel significant coronary disease (>70% lesion or stented)	5 (17.9%)
Coronary protection	
• Wire alone	0
• Wire with balloon	3 (10.7%)
• Stent	25 (89.3%)
• Stent deployed	13 (46.4%)
Reason for stent deployment (n = 13)	
• Planned	11
○ Angiographic evidence of coronary impingement	7 (63.6%)
○ Tactile feeling when withdrawing stent/balloon	3 (27.3%)
○ EKG/echo ischemic change	1 (9.1%)
• Recue for coronary occlusion	1
• Stent entrapment	1
IVUS used	7 (25%)
Guide extension used	2 (7.1%)
Type of stents deployed	
DES	9
BMS	4
Acute procedural outcomes	
	N = 25
Procedure aborted	0
Conversion to surgery	0
Myocardial infarction	2 (8%)
Coronary obstruction	1 (4%)
Cardiac arrest	0
Ischemic stroke/TIA	1 (4%)
Major vascular complication	1 (4%)
Minor vascular complication	0
Need of emergency MCS support	1 (4%)
30-day repeat revascularization	0
30-day myocardial infarction	0
30-day ischemic stroke/TIA	0
30-day device thrombosis	0
30-day CV mortality	1 (4%)
30-day all-cause mortality	2 (8%)

CO = coronary occlusion; EKG = electrocardiogram; Echo = echocardiograpm; IVUS = intravascular ultrasound; DES = drug eluting stent; BMS = bare-metal stent; TIA = transient ischemic attack; MCS = mechanical circulatory support; PCI = percutaneous coronary intervention; CV = cardiovascular.

death due to pneumonia. Detailed clinical, anatomical, procedural and outcomes of each patients were provided in Table 4.

3.2. Anatomical analysis

The mean coronary height protected was 9.0 ± 1.8 mm (left: 9.0 ± 1.7 mm, right: 8.8 ± 1.8 mm). The mean sinus dimensions measured 27.1 ± 3.3 mm, 25 ± 2.9 mm and 28.1 ± 2.8 mm for left, right and non-coronary sinus respectively; and 27.1 ± 3.6 mm for the sinus of the target coronary protected. The mean Sino-tubular height measured 18.7 ± 3.3 mm and the VTC measured 4.0 ± 0.9 mm for VIV procedures. The coronary height for those requiring final coronary "Chimney" stenting (including 11 planned and 1 rescue) was significantly lower than those not stented (8.2 ± 1.7 mm vs 9.7 ± 1.6 mm, p = 0.038). The VTC distance and target sinus dimensions were not statistically different between the two groups (4.1 ± 0.8 mm vs 3.5 ± 1.2 mm, p = 0.347; 26.9 ± 4.2 mm vs 26.8 ± 3.5, p = 0.970).

3.3. Mid-term outcome

Eighty percent of the patients had at least 1-year follow-up. With a mean of 19.1 ± 14.8 months follow-up, there were 1 cardiovascular death at 1 month, 2 non-cardiovascular death at 1 and 13 months respectively. Otherwise, there was no target vessel re-intervention or myocardial infarction related to target vessel. After excluding the patient with mid coronary stenting due to stent entrapment, there was no statistically significant difference in the survival between the stented and non-stented group (log rank = 0.279) (Fig. 2).

4. Discussion

The main findings of the study included that 1). Angiographic evidence of coronary impingement (63.6%) was the most common indication for "chimney" stenting during CP; 2). Mid-term outcome of CP for patients with high anatomical risk for CO during TAVR was promising; 3). There was no difference in the survival between patients with or without final "chimney" stenting during CP. The recently published multi-center CORPROTAVR [8] registry showed similarly a favorable mid-term result of CP in an anatomically comparable group of at-risk patients. Although our study was a single-center retrospective analysis, complete review of medical records, procedural records, fluoroscopic images ± intra-procedural echocardiogram, and with questionnaire-based phone interview were performed to verify the mid-term clinical outcomes. Our registry includes a detailed procedural review analysing the variation in CP techniques, procedural complications and the rationale of final stent deployment.

4.1. Coronary protection techniques

Choice between a balloon-expandable versus a self-expanding valve might affect the risk of CO. Owing to device availability, operators' preference and expertise and considering the technical feasibility of future coronary access, balloon-expandable valve was used in majority of cases in our cohort. However, due to small sample size and biased valve choice, the difference in feasibility of future coronary access between the two valve designs was not studied. Besides, different variations in CP techniques were identified in our study, including different approaches of vascular access, use of intravascular ultrasound and guide extension and use of drug-eluting versus bare-metal stents. The use of guide extension during CP could reduce the risk of stent entrapment by the leaflet calcium and transcatheter valve stent frame while withdrawing the initially positioned stent from mid-coronary. However, the engaged guide extension might keep potentially occlusive leaflet/calcium away from the coronary ostium and falsely reassure operators the absence of CO. On the other hand, if disengaged to assess the risk of CO, it could be difficult to reengage the guide extension to coronary ostium and eliminated its function to assist delivery and removal of coronary stent. In fact, even a 0.014 coronary wire alone pre-emptively placed across the coronary ostium could displace valve leaflet and masked the risk of CO after wire removal (Fig. 1), which might explain the only case of CO in our cohort and those identified as "delayed" coronary occlusion in the CORPROTAVR [8] registry. Therefore, it was not uncommon for operators to adopt "if in doubt, stent it" approach, which acutely would eliminate the risk of CO. As a result, operators have different thresholds to deploy the pre-emptively placed stent during CP, that accounted for the variations in the percentages of final stent deployment in different registries (60% in CORPROTAVR vs 39.2% in our cohort). We performed a detailed analysis for all "Chimney" stented coronaries, the decision to deploy the stent were based on angiographic suspicion of coronary impingement in 63.7%, tactile resistance while pulling back the stent in 27.3%, and only 9.1% had definite electrocardiogram ischemic change. In fact, we had very limited knowledge in deciding when to stent; and "chimney" a coronary stent unnecessarily could make future coronary re-access challenging, which should to be

Table 4
Clinical and anatomical features, coronary protection technique and outcomes of each individual patients.

Patient	Age	STS	Coronary protected	Coronary height (mm)	Prior SAVR	VTC (mm)	Target sinus dimension (mm)	Protection technique	Guide extension used	Stent deployed?	Size of stent(s), mm	Reason for stent deployment	Follow-up duration (months)	Clinical event	Remarks
1	77	3.97	Right	7.4	Toronto stentless	N/A	N/A	Stent	No	DES	3.0 × 23	Angiographic	58.3	No	
2	80	8.2	Right	11.8	No	N/A	22.8	Stent	No	BMS	3.5 × 23	Tactile resistance	41.5	No	
3	91	4.9	Left	8.5	Magna ease	4.3	N/A	Stent	No	DES	4.0 × 24	Angiographic	35.9	No	
4	81	20.5	Left + right	5.1; 7	Magna	4.1;4.2	N/A	Stent; Stent	No	DES; No	4.0 × 28	Angiographic	1	CV death (severe mitral stenosis)	
5	77	3.1	Right	9	Mitroflow	3	N/A	Stent	No	DES	3.0 × 24	Tactile resistance	21.6	No	Successful BASILICA to Left and failed BASILICA to Right
6	93	9.9	Left	8.3	No	N/A	33.5	Balloon	No	BMS[a]	7.0 × 15[a]	N/A	1	Coronary occlusion, non-CV death (pneumonia)	Hypotension with EKG/echocardiogram change after balloon/wiring removal, rescue stenting
7	71	3.8	Left + right	7.1; 6	Magna ease	4.2; 4.1	N/A	Stent; Stent	No	BMS; DES	5.0 × 18 3.5 × 16	Tactile resistance	14	No	Stent balloon entrapment, staged successful snaring
8	75	2.3	Right	8.4	Magna 3000	3.1	N/A	Stent	No	BMS	3.5 × 28	Stent entrapment	7.1	No	Stent deployed as ostial as possible
9	76	2.4	Left	10.1	No	N/A	27.3	Stent	No	DES	3.5 × 20	Angiographic and EKG change	11.1	No	
10	87	12.6	Left	9.1	No	N/A	23.8	Stent	Yes	DES	5.0 × 12	Angiographic	1.1	No	
11	86	9.5	Left + right	8.9; 7.3	Mosiac	4.4; 5.3	N/A	Stent; Stent	No	DES; DES	5.0 × 16 2.5 × 38	Angiographic	4	Myocardial infarction due to stent edge dissection	
12	88	6.7	Left	13	No	N/A	32.7	Balloon	No	No	N/A	N/A	50.3	No	
13	75	19.5	Right	9.9	Carbomediacs	2.4	N/A	Stent	No	No	N/A	N/A	30.5	No	Successful BASILICA to left
14	68	1.9	Right	11	Mitroflow	2.3	N/A	Stent	No	No	N/A	N/A	29.3	No	Successful BASILICA to left
15	76	2.1	Left	10.4	No	N/A	27.6	Stent	No	No	N/A	N/A	25.7	No	
16	94	9.8	Left	9.2	No	N/A	31.3	Stent	No	No	N/A	N/A	25.5	No	
17	70	2.86	Left	10.4	No	N/A	26.8	Stent	No	No	N/A	N/A	25.3	No	
18	61	0.7	Left	7.7	No	N/A	26	Stent	No	No	N/A	N/A	23.9	No	
19	83	19.5	Right	6.6	Trifecta	5	N/A	Stent	No	No	N/A	N/A	13.7	No	Successful BASILICA to left
20	79	3.4	Left	10.1	No	N/A	21.9	Stent	No	No	N/A	N/A	17.5	No	
21	80	8.8	Left	8.9	No	N/A	27	Stent	No	No No	N/A	N/A	13.1	No	
22	71	3.0	Right	9.8	No	N/A	21.5	Stent	No	No	N/A	N/A	12.7	Non-CV death	
23	62	2.5	Right	9.9	No	N/A	26	Balloon	No	No	N/A	N/A	13.7	No	Bicuspid
24	82	5.3	Left	9.5	No	N/A	26.8	Stent	No	No	N/A	N/A	13.4	No	Bicuspid; failed BASILICA to left, successful BASILICA to right
25	86	12.0	Right	11	No	N/A	N/A	Stent	Yes	No	N/A	N/A	5.1	No	

STS = The Society of Thoracic Surgeons; SAVR = surgical aortic valve replacement; VTC = virtual transcatheter valve to coronary distance; BASILICA = bioprosthetic or native aortic scallop intentional laceration to prevent iatrogenic coronary artery obstruction during TAVI; N/A = not applicable or not available; EKG = electrocardiogram; CV = cardiovascular; DES = drug eluting stent; BMS = bare metal stent.

[a] As a rescue stenting after pre-emptively placed wire pulled out, using an off-labelled biliary stent (Herculink 7.0 × 15 mm) due to very big left main artery.

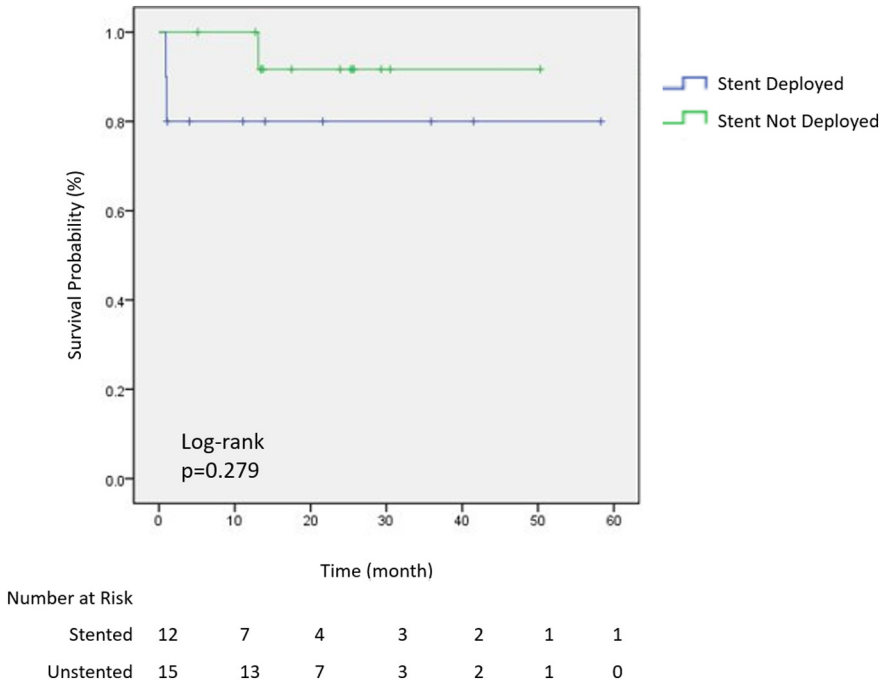

Fig. 2. Kaplan-Meier curve for transcatheter aortic valve replacement with coronary protection stratified by "chimney" stent deployment or not.

thoroughly considered especially in younger TAVR patients. Intravascular ultrasound was used more often during CP in more recent patients. It not only could aid stent sizing but could also help the diagnosis of coronary impingement (Fig. 1) especially in the absence of electrocardiographic and hemodynamic changes. Finally, drug-eluting stents was used more frequently than bare-metal stents despite the absence of pre-existing lesion in stented target, primarily due to operators' preference. However, it is uncertain which stent is superior especially with the theoretical need of radial strength to prevent stent distortion by surrounding calcified leaflets and the need to maintain patency.

4.2. Coronary patency and coronary re-access

The recently published multicenter chimney registry [10] included 60 patients with chimney stenting for established or impending CO, with and without upfront CP. Although self-expanding valve was more commonly used (>70%) and more drug-eluting stents were used (>90%) in the Chimney registry than in our study, a similar mid-term coronary patency was observed. This relieved our previous concern on the risk of stent related complications in "chimney" stenting (e.g. stent thrombosis or fracture) and risk of delayed CO [9]. However, coronary re-access issue would still limit the usage of this technique in younger TAVR patients [10,11]. Aortic scallop laceration (the BASILICA technique) [7] could potentially alleviate the challenge in coronary re-access if re-intervention is needed. However, this approach was not widely used due to its technical difficulty, especially compared to CP which was technically more friendly to interventional cardiologists. Direct comparison of the acute and long-term outcomes of these two techniques would be very helpful to guide decision. Above all, the role of open-heart surgery that allows excision of the native leaflets or even re-implantation of coronaries in patients with CO risk should not be overlooked.

4.3. Importance of prediction of coronary occlusion

The Chimney registry [10] identified that the absence of upfront coronary protection was the sole independent risk factor for the combined endpoint of death, cardiogenic shock, or myocardial infarction, which highlighted the importance of CO prediction and pre-emptive measures. Despite the advancement in pre-procedural CT which identify various anatomical risk factors for CO, the complex interactions between the transcatheter heart valve and unique aortic anatomy of individual patient made accurate prediction of CO challenging [12]. This was further complicated with balloon valve fracture technique in VIV procedures and balloon post-dilatation (performed 50% and 46.7% in our study). CP was a pre-emptive procedure to aid management of CO if it happened. However, the additional steps performed on top of TAVR was not without risk (e.g. additional vascular complication, stent or stent-balloon entrapment, etc.) and the pre-emptively placed stent could potentially be unnecessarily deployed due to technical complications or ambiguous diagnosis of CO after TAVR. Moreover, it is important to understand the mechanism of CO and distinguish ostial CO from sinus sequestration in the case of a low sinotubular junction height or excessively long leaflet. Chimney stenting could only prevent CO in case of direct coronary impingement, alternative technique like BASILICA or surgery might be needed if sinus sequestration was the predicted mechanism of CO. Above all, there exists a need for better prediction modality/algorithm for CO to guide the optimal approach, avoid unnecessary complex procedural steps and at the same time to prevent this deadly complication.

4.4. Limitations

First, the study was a single centre study with small sample size. Second, there was no imaging or physiological testing to verify the presence target vessel ischemia. Third, majority of TAVR was performed using balloon-expandable valve, it was uncertain whether the use of self-expanding or mechanical expandable valves would carry a different long-term outcome.

5. Conclusion

Our study found that pure angiographic evidence of coronary impingement (63.6%) was the most common reason for final stent

deployment during TAVR with CP. The mid-term clinical outcome of CP with TAVR was favorable. It also highlighted the current knowledge gap in the prediction and diagnosis of CO.

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CRediT authorship contribution statement

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Declaration of competing interest

Dr Frisoli is a clinical proctor for Edwards Lifesciences, Abbott, Boston Scientific, and Medtronic. Dr. Wang has served as a consultant to Edwards Lifesciences, Boston Scientific, and Materialise; and received research grant support from Boston Scientific. Dr. O'Neill is a consultant to Abiomed, Medtronic, and Boston Scientific. Dr. Eng is a clinical proctor for Edwards Lifesciences, Medtronic and Boston Scientific. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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