Transcatheter Laceration of Aortic Leaflets to Prevent Coronary Obstruction During Transcatheter Aortic Valve Replacement Concept to First-in-Human

Jaffar Khan, Emory University
Danny Dvir, University of Washington
Adam Greenbaum, Emory University
Vasilis Babaliaros, Emory University
Toby Rogers, National Institutes of Health
Gabriel Aldea, University of Washington
Mark Reisman, University of Washington
G. Burkhard Mackensen, University of Washington
Marvin H.K. Eng, Henry Ford Health System
Gaetano Paone, Henry Ford Health System

Only first 10 authors above; see publication for full author list.

Journal Title: JACC: Cardiovascular Interventions
Volume: Volume 11, Number 7
Publisher: Elsevier: 12 months | 2018-04-09, Pages 677-689
Type of Work: Article | Post-print: After Peer Review
Publisher DOI: 10.1016/j.jcin.2018.01.247
Permanent URL: https://pid.emory.edu/ark:/25593/tpn9d

Final published version: http://dx.doi.org/10.1016/j.jcin.2018.01.247

Copyright information:
Copyright © 2019 Elsevier B.V. or its licensors or contributors. This is an Open Access work distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Accessed January 21, 2020 4:43 PM EST
Transcatheter Laceration of Aortic Leaflets to Prevent Coronary Obstruction During Transcatheter Aortic Valve Replacement: Concept to First-in-Human.”

Jaffar M. Khan, BM, BCh#*, Danny Dvir, MD#†, Adam B. Greenbaum, MD‡, Vasilis C. Babaliaros, MD§, Toby Rogers, BM, BCh‡, Gabriel Aldea, MD†, Mark Reisman, MD†, G. Burkhard Mackensen, MD†, Marvin H.K. Eng, MD‡, Gaetano Paone, MD‡, Dee Dee Wang, MD‡, Robert A. Guyton, MD§, Chandan M. Devireddy, MD§, William H. Schenke, BS‡, and Robert J. Lederman, MD†

# These authors contributed equally to this work.

Abstract

Background: Coronary artery obstruction is a rare but fatal complication of transcatheter aortic valve replacement (TAVR).
**Objectives:** We developed a novel technique called BASILICA (Bioprosthetic or native Aortic Scallop Intentional Laceration to prevent Coronary Artery obstruction).

**Methods:** We lacerated pericardial leaflets *in vitro* using catheter electrosurgery, and tested leaflet splaying after benchtop TAVR. The procedure was tested in swine. BASILICA was then offered to patients at high risk of coronary obstruction from TAVR and ineligible for surgical aortic valve replacement. BASILICA used marketed devices. Catheters directed an electrified guidewire to traverse and lacerate the aortic leaflet down the centreline. TAVR was performed as usual.

**Results:** TAVR splayed lacerated bovine pericardial leaflets.

BASILICA was successful in pigs, both to left and right cusps. Necropsy revealed full length lacerations with no collateral thermal injury. Seven patients underwent BASILICA on a compassionate basis. Six had failed bioprosthetic valves, both stented and stent-less. Two had severe aortic stenosis, including one patient with native disease, three had severe aortic regurgitation, and two had mixed aortic valve disease. One patient required laceration of both left and right coronary cusps. There was no hemodynamic compromise in any patient following BASILICA. All patients had successful TAVR, with no coronary obstruction, stroke, or any major complications. All patients survived to 30 days.

**Conclusions:** BASILICA may durably prevent coronary obstruction from TAVR. The procedure was successful across a range of presentations, and requires further evaluation in a prospective trial. Its role in treatment of degenerated TAVR devices remains untested.

**Graphical Abstract**

![Graphical Abstract Image]

**CONDENSED ABSTRACT**

Bioprosthetic or native Aortic Scallop Intentional Laceration to prevent Iatrogenic Coronary Artery obstruction (BASILICA) is a technique to prevent coronary artery obstruction complicating transcatheter aortic valve replacement (TAVR). BASILICA uses catheter electrosurgery to split aortic valve leaflets lengthwise immediately prior to TAVR. We describe the technique on the benchtop and in animals. We also report the first-in-human application in seven patients, including both aortic stenosis and regurgitation, in both bioprosthetic and native aortic valves. All patients had high predicted risk of coronary artery obstruction. All patients had successful BASILICA and TAVR, with no coronary obstruction, stroke or 30-day mortality.
INTRODUCTION

Transcatheter aortic valve replacement (TAVR) is an effective alternative to surgical aortic valve replacement in intermediate- and high-risk patients with native aortic stenosis(1,2). TAVR is also an effective treatment for failure of bioprosthetic surgical aortic valves, a treatment known as valve-in-valve TAVR(3,4). Coronary artery obstruction is a devastating complication of TAVR, with a greater than 50% mortality (5). Coronary artery obstruction occurs when the transcatheter heart valve displaces the underlying surgical or native aortic valve leaflets outwards and obstructs the coronary artery ostia, either by sealing the sinus of Valsalva at the sinotubular junction or by the leaflet itself covering the coronary ostia due to low lying coronary ostia and inadequate sinus width [FIGURE 1]. Coronary artery obstruction is four times as common during valve-in-valve TAVR as during TAVR for native aortic stenosis (6), likely because most surgical prostheses are supra-annular in design, lowering coronary heights relative to the valve leaflets, and because valve suturing draws the coronaries closer, decreasing sinus width. The risk of coronary obstruction is highest during TAVR for surgical bioprosthesis designs intended to maximize effective aortic orifice area (both “stent ed” bioprostheses that have externally mounted leaflets, and “stent-less” surgical bioprostheses) (5). Treatment requires bail-out percutaneous coronary intervention, which may not be possible with a valve leaflet obstructing the coronary artery, or emergency bypass surgery. Pre-emptive coronary protection with a guidewire, with or without a coronary balloon or stent prepositioned down the coronary artery, is variably successful(7,8) in the short and intermediate term. One third of coronary obstruction events may manifest after the TAVR is concluded(9).

We propose a solution based on the LAMPOON procedure(10,11), which uses catheters to split the mitral valve leaflet and prevent obstruction of the left ventricular outflow tract during transcatheter mitral valve replacement. Here we report a technique to split aortic valve leaflets, whether bioprosthetic or native, to prevent coronary artery obstruction after TAVR. The new technique is called BASILICA (Bioprosthetic or native Aortic Scallop Intentional Laceration to prevent Coronary Artery obstruction).

We developed the technique in vitro and in animals, and then offered the procedure to patients suffering aortic valve failure who were ineligible for conventional surgical aortic valve replacement, and high or prohibitive risk of coronary artery obstruction from TAVR.

METHODS

We set out to demonstrate several key technical principles. First, that an aortic leaflet scallop can be traversed in situ by an electrified guidewire between the sinus of Valsalva and the left ventricular outflow tract. Second, that the traversed leaflet, whether native or bioprosthetic, can be lacerated in situ by the mid-shaft of an electrified guidewire. Third, that the lacerated
leaflets splay after TAVR to allow blood flow across them towards otherwise obstructed coronary ostia. Fourth, whether partial (mid-scallop versus basal leaflet) lacerations extend lengthwise when stretched by an implanted valve, which may influence the required spatial precision of the procedure. Fifth, that both left and right coronary cusps can be lacerated simultaneously in vivo.

**In vitro**

We tested radiofrequency-assisted transcatheter perforation and laceration of exterior-mounted bovine pericardial leaflets on a representative bioprosthetic heart valve (19mm Trifecta valve, Abbott St Jude Medical) submerged in a 0.9% saline bath with a remote dispersive electrode [Supplement Figure 1]. Two lacerations were attempted on the bioprosthetic heart valve. One leaflet was lacerated from base to tip and the second from mid-point to tip. A third scallop was left intact and served as a control.

Balloon expandable (20mm Sapien 3, Edwards Lifesciences) and self-expanding (23mm Evolut Pro, Medtronic) were deployed in the bioprosthetic valve to test splaying of split leaflet around the open cells of the transcatheter heart valve and propagation of the split in the leaflet. A second valve (25mm Mitroflow, Sorin Livanova) was cut with a scalpel and leaflet splaying was also tested with appropriately sized balloon expanding and self-expanding valves.

**Animals**

Animal experiments on naïve Yorkshire and Yucatan pigs were approved by the institutional animal care and use committee and conducted per contemporary NIH guidelines. Anaesthesia was induced and maintained with mechanical ventilation and inhaled isoflurane, two 6Fr femoral arterial sheaths and a 9Fr femoral venous sheath were placed percutaneously, and heparin and amiodarone were administered. The BASILICA procedure without TAVR was performed using catheters directed under biplane X-ray fluoroscopy and intracardiac echocardiography guidance. Pre-procedural cardiac MRI was performed at 1.5T (Aera, Siemens, Erlangen, Germany) to plan fluoroscopy projection angles. Hemodynamics were recorded for one hour after laceration till euthanasia. The length of scallop laceration relative to the overall length of the scallop was measured using calipers at necropsy. The heart was carefully inspected for evidence of bystander electrical or mechanical injury.

**Clinical**

**Patients**—Patients with high or prohibitive risk for surgical aortic valve replacement and high risk of coronary artery obstruction with TAVR, underwent TAVR with BASILICA at three medical centres (University of Washington, Henry Ford, and Emory University Hospitals). All consented to clinical treatment on a compassionate basis, despite explicitly high risk, after consensus from the local multidisciplinary heart teams. The institutional ethics review boards of all participating institutions approved this retrospective report.

The local heart teams determined coronary obstruction risk based on manufacturer-described geometry of the specific implanted bioprosthetic valve; and CT and angiographic measurements of the coronary ostia heights, sinus of Valsalva width, presence and type of...
bioprosthetic valve, and virtual transcatheter heart valve to coronary (VTC) distance (5) [FIGURE 1].

**BASILICA procedure**—The procedure was planned using ECG-gated contrast-enhanced CT, performed under general anaesthesia, and guided by fluoroscopy and transoesophageal echocardiography. Catheter access was obtained typically via three femoral arterial (two typically ipsilateral for BASILICA, and one for TAVR) and at least one venous (for temporary transvenous pacing) introducer sheaths. Heparin anticoagulation achieved an activated clotting time >300s.

A pair of coaxial catheters (typically a 5Fr mammary diagnostic catheter inside a 6Fr extra backup shape guiding catheter) was positioned in the targeted aortic leaflet scallop to direct a guidewire across it, near the scallop hinge point, by echocardiographic and angiographic guidance. These aimed at a snare positioned immediately below the leaflet using a separate retrograde catheter [FIGURE 2].

To traverse the aortic leaflet scallop, an 0.014” guidewire (Astato XS 20, Asahi-Intecc) sheathed in an insulated polymer jacket (Piggyback Wire Convertor, Vascular Solutions Teleflex) was electrified, advanced, and snare-retrieved. The wire was electrified using a short burst of “cutting” radiofrequency energy (~30W) by clamping to an electrosurgery pencil (Valleylab FX, Covidien Medtronic).

After externalization of the free guidewire end, the guidewire straddles across the leaflet scallop between two catheters. The scallop was lacerated by applying radiofrequency energy at approximately 70W while tensioning both free ends of the guidewire. A pigtail catheter was pre-positioned in the left ventricle to allow TAVR to be performed immediately afterwards.

TAVR was performed using established techniques. Coronary artery stent systems were positioned prophylactically at the discretion of the operator. Cracking of a failed bioprosthetic heart valve frame, using a high-pressure balloon (12), was performed at operator discretion to achieve an optimum hemodynamic result. Coronary artery patency was assessed using angiography and post-TAVR CT. Antiplatelet and anticoagulation therapy were prescribed at operator discretion. Complications were assessed according to the Valve Academic Research Consortium-2 Consensus Document (13).

**Statistical analysis**

In this small clinical series, we express continuous variables as median and interquartile range. We express categorical variables as counts and percentages. We made no statistical comparisons because of the small sample size.

**Role of the funding source**

All investigators were supported by their respective intramural academic programs. All authors had full access to all data. JMK and RJL had final responsibility for the decision to submit for publication.
RESULTS

In vitro

A guidewire (Astato XS 20, Asahi) perforated a bioprosthetic bovine pericardial valve leaflet (Trifecta, Abbott St Jude) using a <1s burst of radiofrequency energy at 20W in a saline bath. Laceration with a continuous non-ionic (5% dextrose) flush through two guiding catheters required 5s (half leaflet) and 18s (full leaflet) of radiofrequency energy at 20W. Laceration using mechanical force without electrification was not possible in this valve.

A 20mm Sapien 3 valve (Edwards Lifesciences) was deployed on the benchtop inside the lacerated Trifecta valve. The laceration mid-way down the bioprosthetic scallop did not propagate, nor did it result in satisfactory parting of the leaflet. The full-length laceration did not propagate further and resulted in satisfactory parting of the leaflet. The intact leaflet completely draped the Sapien 3 stent cells. The results with the cut Mitroflow valve were similar [FIGURE 3]. Flaring of the bioprosthetic stent posts increased splaying of the split leaflet.

Animals

Five consecutive pigs (38–47kg) underwent attempted BASILICA, three on the left coronary cusp and two on both left and right coronary cusps [Supplement TABLE S1]. The procedure time reduced with further experience, despite the increased complexity of double BASILICA. BASILICA resulted in severe aortic regurgitation with a reduction in diastolic blood pressure in all pigs. Two pigs required euthanasia before one hour was complete due to poor hemodynamics – the first after inadvertent mitral chordal laceration, and the other following double BASILICA.

Guidewire traversal required <1s of radiofrequency energy at 20–30W for all five animals. Guidewire laceration required 2–3s of radiofrequency energy at 30W and <1s at 70W. Minimal subjective mechanical force was required for both traversal and laceration. Laceration was central and extended from base to tip in all animals (mean laceration length was 12mm and mean cusp length 14mm for the left, and 12mm and 12.5mm respectively for the right) [FIGURE 4].

Major complications occurred in the first attempted animal BASILICA for left and right coronary cusps respectively. These included mitral chord entrapment and laceration resulting in severe mitral regurgitation, misdirected wire traversal into the left atrium or interventricular septum, the latter causing ventricular fibrillation requiring defibrillation, and partial annular laceration without pericardial effusion from annulus rather than leaflet traversal. Thereafter we refined the BASILICA technique (assiduous positioning of the traversal wire and of the snare catheter in the distal left ventricular outflow tract) and observed no important complications. There was no macroscopic evidence of collateral thermal damage in benchtop or in vivo necropsy specimens.
Clinical

Seven patients underwent TAVR with BASILICA [FIGURES 5–9]. There were a range of diseased aortic valve substrates: one had a porcine aortic stent-less bioprosthetic valve, one had a stent-less bovine pericardial valve, four had stented bovine pericardial valves, and one had native aortic valve stenosis. One of the seven required laceration of two aortic leaflet scallops and the rest of only the left.

TABLE 1 shows their clinical characteristics. All were felt unsuitable for surgery by the multidisciplinary heart teams. Five had prior coronary artery bypass grafts that were felt not to protect threatened vessels. Six had failed bioprosthetic aortic valves and one had native aortic stenosis. All were felt to be at high risk of left coronary obstruction with median coronary height of 6.8mm, left sinus of Valsalva width of 24.3mm, and VTC of 2.8mm [Supplement Figure 2]. One patient also had a threatened right coronary artery [Supplement TABLE S2].

TABLE 2 details the procedure. All attempted leaflets were successfully traversed and lacerated. The laceration was central and along most of the leaflet length as depicted on transoesophageal echocardiography [FIGURE 8B]. All patients had severe aortic regurgitation after laceration. Heart rate and systolic blood pressures were unchanged in all cases, and no patient required pharmacologic or mechanical hemodynamic support in the 8–30 minutes between laceration and valve deployment, nor afterwards.

No patient had coronary obstruction evident on coronary and aortic root angiography, nor echocardiographic regional wall motion assessment. One of the pre-positioned stents was entrapped by the transcatheter heart valve and so was deployed in the left main coronary artery in the absence of coronary obstruction, otherwise all others were removed from the body undeployed. Procedural hemodynamics confirmed satisfactory valve gradients and no patient with more than mild paravalvular leak. Three patients had follow-up CT scans confirming good flow in the coronary arteries.

Clinical outcomes and standardized TAVR endpoints are shown in TABLE 3 and Supplement TABLE 3 (13). One patient had transient sinus bradycardia requiring temporary transvenous pacing. There were no other complications. Four patients underwent precautionary intensive care unit observation overnight; the remainder were transferred directly to ward beds. The median length of stay was 4 days. All patients survived beyond 30 days.

DISCUSSION

We describe a new technique that allows transcatheter heart valve treatment in patients otherwise ineligible for any therapy because of a high risk of valve leaflet-induced coronary artery obstruction. We have demonstrated through benchtop testing, animal experiments, and experience from seven patients that (1) BASILICA appears technically feasible in all valve types and valve conditions, including single and double leaflet laceration, porcine and bovine pericardial bioprostheses, stented and stent-less bioprostheses, and in one case of native aortic leaflet disease, (2) there was no hemodynamic collapse after laceration.
regardless of baseline aortic regurgitation (n=5) or aortic stenosis (n=2), and (3) there was uniform success in preserving coronary blood flow.

The current strategy of ad-hoc percutaneous intervention or up-front coronary protection using a pre-positioned wire, with or without balloon or stent, is problematic. Coronary obstruction may be delayed despite normal flow at the end of the TAVR procedure. There are few data to support the longevity of a “chimney” coronary stent extending beyond the coronary ostium with a valve leaflet draped across it. The ostial left main stent is at risk of fatal restenosis and thrombosis. Re-engaging a coronary artery is challenging after TAVR, and becomes almost impossible with an ostial “chimney” stent (15, 16). As seen in one patient #7, the stent can be entrapped and then requires unnecessary deployment. Applying caution in this initial human experience, the threatened coronaries were still protected by wiring and placing a stent mid-vessel after BASILICA. While the one entrapped stent confirmed the preprocedural concern for coronary obstruction and need for intervention to allow safe TAVR, the inability to remove the stent necessitated deployment despite otherwise successful BASILICA. It is difficult to know at this early stage whether pre-positioning a stent after successful BASILICA is mandated or whether the harm outweighs the benefits. As experience with BASILICA and its success increases, we would predict a transition to no prophylactic coronary stent protection.

One application of BASILICA not yet performed but worth considering is to treat failed TAVR devices, which are likely to become more common as TAVR is applied to lower risk patients who are expected to live longer. The risk of coronary obstruction in patients with previous TAVR may be elevated in patients with high implantation and supra-annular TAVR devices engineered to have longer leaflets (such as Medtronic CoreValve). Several transcatheter heart valves are implanted with the top of the valve at the sinotubular junction where coronary filling is dependent on diastolic valve-leaflet closure. We speculate that BASILICA may be helpful in this setting.

In this small series, we observed that split leaflets continued to appose during diastole, and caused incremental but not catastrophic aortic regurgitation. Patients did not require pharmacologic or mechanical support during the short period before TAVR.

**Limitations**

Our experience remains limited, and confined to the specific bioprosthetic devices and single native valve described. The leaflets may splay variably depending on the type of bioprosthetic and transcatheter heart valve combination used, as may flow through the open cells of the transcatheter heart valve. Despite successful BASILICA, TAVR device commissures may limit flow to the coronary arteries by accidentally unfavorable rotational orientation.

We observed no hemodynamic deterioration between BASILICA laceration and TAVR in this small series. Our patients had relatively preserved left ventricular systolic function (Table 1). Although 2/7 had primarily stenotic lesions and 3/7 primarily mixed stenotic and regurgitant, the applicability to patients with more profound ventricular dysfunction requires
further investigation. Likewise, despite operator precautions, BASILICA may injure mitral valvular structures.

The role of BASILICA combined with intentional balloon fracture to expand the valve frame (12), remains uncertain. Double leaflet BASILICA poses extra challenges particularly with vascular access. Heavily calcified leaflets are probably unsuited to BASILICA, as evidenced by the prolonged procedure time due to difficulty traversing in patient 4.

While there were no evident strokes in this initial series, lacerating a heavily calcified leaflet may generate embolic debris that cause stroke and in this setting, judicious use of cerebral embolic protection strategies, and brain MRI, may be appropriate. Protracted radiofrequency ablation is widely employed in the left atrium and left ventricle with a low risk of coronary and cerebral thromboembolism. By comparison we use shorter bursts of vaporizing high duty-cycle “cutting mode” electrosurgery, also with full antic oagulation. Human cadaver experiments may shed light on the potential for embolization during bioprosthetic and native aortic valve manipulation.

Coronary flow was assessed angiographically by assessing echocardiographic left ventricular wall motion but a pressure wire or other intracoronary imaging was not used.

Finally, there was no comparator and so coronary artery obstruction was not certain but predicted using prevailing standards, which have their limitations. The potential risk and benefit of BASILICA should be weighed before applying it to any patient, including the risk of embolization and, in patients with severe ventricular dysfunction, the risk of acute severe aortic regurgitation.

We believe technical descriptions are no substitute for live observation, and we recommend BASILICA only be undertaken with appropriate training.

CONCLUSION

Bioprosthetic and native aortic leaflet laceration appears feasible and may reduce the risk of coronary artery obstruction following TAVR in patients at high risk. No patient had a drop in blood pressure following BASILICA. The technique offers a promising alternative to “chimney” stenting to provide durable prevention against coronary obstruction from TAVR. BASILICA needs careful prospective investigation, which begins with an FDA-approved trial in early 2018.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGEMENTS

Supported by the National Heart Lung and Blood Institute, National Institutes of Health, USA (Z01-HL006040-7), and by the intramural programs of the participating centres.

We thank Alan Hoofring for medical illustrations; Katherine Lucas for animal care; Daniel Herzka, Merdim Sonmez, and Dmitri Levin for technical assistance; Norihiko Kamioka, Lauren Wheeler, and Patricia Keegan for
data assistance; and Elena Grant and James McCabe for thoughtful advice. We thank Richard Olson of Abbott for supplying a sample Trifecta valve in anticipation of helping the first patient.

ABBREVIATIONS

**BASILICA**
Bioprosthetic or native Aortic Scallop Intentional Laceration to prevent Iatrogenic Coronary Artery obstruction

**LAMPOON**
Intentional Laceration of the Anterior Mitral leaflet to Prevent left ventricular Outflow Obstruction

**TAVR**
Transcatheter aortic valve replacement

**VTC**
Virtual Transcatheter valve to Coronary distance

REFERENCES


PERSPECTIVES

WHAT IS KNOWN?
Coronary obstruction following transcatheter aortic valve replacement (TAVR) carries up to 50% mortality, and CT-predicted coronary obstruction may deprive patients of TAVR as a therapeutic option. Current methods of pre-emptive or bail-out coronary stenting are suboptimal.

WHAT IS NEW?
We describe a catheter technique (BASILICA) to lacerate aortic leaflets that otherwise threaten to obstruct a coronary artery during TAVR. After TAVR, which is performed immediately after BASILICA, blood is able to flow across the lacerated aortic leaflets into the coronary arteries.

WHAT IS NEXT?
BASILICA may have value in the future as more patients have bioprosthetic surgical and even transcatheter aortic valves likely to degenerate. BASILICA warrants further prospective evaluation in a larger number of patients.
Figure 1. Illustrations of coronary obstruction and prevention by BASILICA.

In normal TAVR performed in a capacious aortic root, blood flows unrestricted around valve leaflets into coronary arteries. In patients with a crowded sinus and low lying coronary arteries, coronary blood flow is obstructed by the bioprosthetic valve leaflets after TAVR. After BASILICA, blood flows through the open cells of the transcatheter heart valve unimpeded into the coronary artery.
Figure 2. Illustration of the BASILICA procedure.
(A) a catheter directs an electrified guidewire through the base of the left aortic cusp into a snare in the left ventricular outflow tract; (B) after snare retrieval, the mid-shaft of the guidewire is electrified to lacerate the leaflet (C); (D) the leaflet splays after TAVR permitting coronary flow.
Figure 3. Benchtop simulation of BASILICA
Two different transcatheter heart valves (23mm Sapien 3, top, and 26mm Evolut Pro, bottom) implanted in 25mm Mitroflow before (left) and after (right) the leaflet is cut with a scalpel.
Figure 4. Necropsy after BASILICA in an animal
Animal necropsy viewed from the aorta showing a split left coronary cusp in line with the left coronary artery ostium.
NCC = non-coronary cusp; LCC = left coronary cusp; RCC = right coronary cusp.
Figure 5. BASILICA for TAVR with Sapien 3 in failed Mitroflow valve.

A) left coronary injection demonstrates a high risk of left coronary obstruction from the Mitroflow leaflet (double headed arrow); B) Co-axial catheters direct an electrified guidewire through the left coronary leaflet of the Mitroflow valve into the left ventricular outflow tract snare; C) laceration with radiofrequency concentrated at the kinked mid-shaft of the Astato guidewire (arrow); D) left cusp injection with flow through split leaflet and patent left coronary artery that would otherwise have been obstructed.

LCA = left coronary artery; LCC = left coronary cusp.
Figure 6. BASILICA and TAVR with Sapien 3 for native aortic stenosis
A) An electrified guidewire traverses native left coronary cusp leaflet into the LVOT snare; B) leaflet laceration through exposed kinked guidewire shaft (arrow); C) aortic root angiography showing coronary flow in a low lying coronary artery that may have been obstructed without BASILICA.
Figure 7. Double BASILICA and TAVR with Sapien 3 for failed Magna valve
A) Heavily calcified leaflets, especially the left coronary cusp. B) Left coronary height is low at 3.4mm. C) Both left and right VTC are low at 3.3mm. D) An electrified guidewire traverses the left coronary leaflet of a Magna valve; E) The left coronary leaflet guidewire has been externalized to form a loop and a second electrified guidewire traverses the right coronary leaflet; F) Loops formed around both left (white arrow) and right (black arrow) coronary cusps, ready for sequential laceration; G) After TAVR a high pressure balloon is inflated to crack the bioprosthetic valve to improve hemodynamics; H) The bioprosthetic
valve has been fractured at the site of the black arrow; I) Angiography demonstrates good flow to both coronary arteries that may otherwise have been completely obstructed.

LCC = left coronary cusp; RCC = right coronary cusp; NCC = non-coronary cusp; RCA = right coronary artery; LCA = left coronary artery; VTC = virtual transcatheter valve to coronary distance.
Figure 8. Transoesophageal echocardiography during BASILICA and TAVR with Sapien 3 for failed Sorin Solo Freedom valve

A) Echocardiography view showing the traversal catheter is aligned at the base of the left coronary cusp (upward arrow). A snare catheter is positioned across the valve (downward arrow); C) The laceration in the left coronary cusp is seen (arrow), adjacent to the left coronary artery ostium.

LCA = left coronary artery
Figure 9. CT images following BASILICA and TAVR with SAPIEN 3 (A-C) and Evolut Pro (D-E).

A-B) A narrow neo-sinus (double-headed arrow) maintains flow to the right coronary artery but the left sinus (B-C) is completely effaced. D-E) The left coronary artery was at risk of occlusion but there is adequate filling following BASILICA.
<table>
<thead>
<tr>
<th>Patient number</th>
<th>ALL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>74 (70–76)</td>
<td>87</td>
<td>74</td>
<td>74</td>
<td>67</td>
<td>78</td>
<td>68</td>
<td>71</td>
</tr>
<tr>
<td>Female sex</td>
<td>86%</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>STS PROM aortic replacement %</td>
<td>12.7% (6.3–14.1)</td>
<td>13.40%</td>
<td>4.6%</td>
<td>19.5%</td>
<td>2.0%</td>
<td>12.7%</td>
<td>8.0%</td>
<td>14.7%</td>
</tr>
<tr>
<td>Frailty</td>
<td>67%</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>Coronary artery disease, binary</td>
<td>71%</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Prior CAGB, %</td>
<td>71%</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Prior stroke, %</td>
<td>14%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Atrial fibrillation, %</td>
<td>57%</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>eGFR mL/min/1.73 m²</td>
<td>53 (41–61)</td>
<td>60</td>
<td>31</td>
<td>12</td>
<td>62</td>
<td>51</td>
<td>65</td>
<td>53</td>
</tr>
<tr>
<td>NT pro BNP baseline (pg/mL)</td>
<td>517 (289–709)</td>
<td>701</td>
<td>332</td>
<td>712</td>
<td>2145</td>
<td>262</td>
<td>275</td>
<td>N.A.</td>
</tr>
<tr>
<td>NYHA CHF Class</td>
<td>3 (3–4)</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Severe pulmonary disease</td>
<td>29%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>LV ejection fraction</td>
<td>0.58 (0.45–0.60)</td>
<td>65%</td>
<td>58%</td>
<td>45%</td>
<td>45%</td>
<td>60%</td>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>RV dysfunction</td>
<td>14%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Porcelain aorta</td>
<td>14%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Bioprosthetic valve nominal diameter, mm</td>
<td>21 (21–23)</td>
<td>19</td>
<td>21</td>
<td>21</td>
<td>23</td>
<td>NA</td>
<td>21</td>
<td>23</td>
</tr>
<tr>
<td>Bioprosthetic valve type</td>
<td>Trifecta</td>
<td>Toronto SPV</td>
<td>Mitroflow</td>
<td>Mitroflow</td>
<td>NA</td>
<td>Magna</td>
<td>Sorin Solo Freedom SMT</td>
<td></td>
</tr>
<tr>
<td>Bioprosthetic implant age, years</td>
<td>5 (3–11)</td>
<td>6</td>
<td>14</td>
<td>4</td>
<td>3</td>
<td>NA</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Primary lesion</td>
<td>Regurgitation, 3; Stenosis, 2; Mixed, 2</td>
<td>Regurgitation</td>
<td>Regurgitation</td>
<td>Mixed</td>
<td>Mixed</td>
<td>Stenosis</td>
<td>Stenosis</td>
<td>Regurgitation</td>
</tr>
<tr>
<td>Suitability for cardiac surgery</td>
<td>Inoperable because of advanced age, marked frailty, and prospect of repeat</td>
<td>Inoperable because of grafts threatened by repeat surgery, marked frailty, prospect of combined</td>
<td>Inoperable because of class IV symptoms, prospect of combined</td>
<td>Prolonged recovery after prior MVR/AVR/CABG felt by surgical team better treated by catheter; Patient</td>
<td>Inoperable because of very poor functional status and ongoing radiation</td>
<td>Prohibitively high operative risk with porcelain aorta, mitral annular</td>
<td>Inoperable because of NYHA Class IV symptoms, radiotherapy for malignancy, moderate left ventricular</td>
<td></td>
</tr>
<tr>
<td>Patient number</td>
<td>ALL</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>----------------</td>
<td>-----</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>cardiac surgery. and renal dysfunction</td>
<td>mitral and aortic surgery after prior AVR, worsening kidney disease with creatinine &gt; 300umol/L, recent cardiopulmonary arrest</td>
<td>declined repeat surgery</td>
<td>therapy for thoracic malignancy. Long aortic leaflets obstruct coronaries during test balloon inflation and aortography</td>
<td>calcification, prospect of ascending and root aorta repair long with AVR and MVR</td>
<td>dysfunction, prior stroke, prior AVR + MVR + atrial ablation + LAA ligation.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STS PROM = Society of thoracic surgery predicted risk of mortality; CABG = coronary artery bypass grafting; NT pro BNP = N-terminal pro brain natriuretic peptide; LV = left ventricle; RV = right ventricle; NA = Not applicable
### Table 2: Procedure characteristics and Hemodynamics

<table>
<thead>
<tr>
<th>Patient number</th>
<th>ALL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transcatheter heart valve</td>
<td>Sapien 3, 6; Evolut Pro, 1</td>
<td>Sapien 3</td>
<td>Evolut Pro</td>
<td>Sapien 3</td>
<td>Sapien 3</td>
<td>Sapien 3</td>
<td>Sapien 3</td>
<td></td>
</tr>
<tr>
<td>Transcatheter heart valve size, mm</td>
<td>23 (22–23)</td>
<td>20</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>26</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>Transcatheter heart valve post-dilatation</td>
<td>14%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Invasive Hemodynamics BASELINE

<table>
<thead>
<tr>
<th></th>
<th>ALL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic regurgitation severity (0=None, 1=Trace, 2=Mild, 3=Moderate, 4=Severe)</td>
<td>4 (3–4)</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Aortic valve peak-to-peak gradient (mmHg)</td>
<td>43 (14–64)</td>
<td>12</td>
<td>8</td>
<td>43</td>
<td>72</td>
<td>56</td>
<td>135</td>
<td>15</td>
</tr>
<tr>
<td>HR</td>
<td>75 (71–80)</td>
<td>84</td>
<td>72</td>
<td>67</td>
<td>77</td>
<td>69</td>
<td>83</td>
<td>75</td>
</tr>
<tr>
<td>SBP</td>
<td>126 (96–148)</td>
<td>151</td>
<td>126</td>
<td>93</td>
<td>95</td>
<td>166</td>
<td>145</td>
<td>97</td>
</tr>
<tr>
<td>DBP</td>
<td>44 (39–50)</td>
<td>32</td>
<td>47</td>
<td>35</td>
<td>53</td>
<td>73</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>LVEDP</td>
<td>31 (22–34)</td>
<td>23</td>
<td>21</td>
<td>35</td>
<td>36</td>
<td>31</td>
<td>32</td>
<td>16</td>
</tr>
</tbody>
</table>

#### Invasive Hemodynamics COMPLETION

<table>
<thead>
<tr>
<th></th>
<th>ALL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic regurgitation severity (0=None, 1=Trace, 2=Mild, 3=Moderate, 4=Severe)</td>
<td>0 (0–1)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Aortic valve peak-to-peak gradient (mmHg)</td>
<td>1 (1–7)</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>HR</td>
<td>81 (79–84)</td>
<td>80</td>
<td>82</td>
<td>85</td>
<td>79</td>
<td>62</td>
<td>87</td>
<td>40 (sinus brady - paced at 80)</td>
</tr>
<tr>
<td>SBP</td>
<td>175 (151–179)</td>
<td>177</td>
<td>151</td>
<td>175</td>
<td>120</td>
<td>181</td>
<td>197</td>
<td>150</td>
</tr>
<tr>
<td>DBP</td>
<td>68 (64–72)</td>
<td>64</td>
<td>63</td>
<td>79</td>
<td>68</td>
<td>72</td>
<td>57</td>
<td>71</td>
</tr>
<tr>
<td>LVEDP</td>
<td>27 (26–30)</td>
<td>34</td>
<td>28</td>
<td>26</td>
<td>26</td>
<td>27</td>
<td>18</td>
<td>31</td>
</tr>
</tbody>
</table>

#### Echocardiography, Baseline

<table>
<thead>
<tr>
<th>Aortic regurgitation</th>
<th>ALL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient number</td>
<td>ALL</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>----------------</td>
<td>-----</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>severity (0=None, 1=Trace, 2=Mild, 3=Moderate, 4=Severe)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aortic valve peak velocity (m/s)</td>
<td>3.4 (3.2–4.6)</td>
<td>3.3</td>
<td>3.1</td>
<td>5.6</td>
<td>4.1</td>
<td>3.4</td>
<td>5</td>
<td>1.6</td>
</tr>
<tr>
<td>Aortic valve mean gradient (mmHg)</td>
<td>24 (22–48)</td>
<td>24</td>
<td>22</td>
<td>67</td>
<td>22.6</td>
<td>45.4</td>
<td>51</td>
<td>4.8</td>
</tr>
<tr>
<td>Indexed effective orifice area (cm²/m²)</td>
<td>0.62 (0.49–1.00)</td>
<td>1</td>
<td>1.6</td>
<td>0.48</td>
<td>0.31</td>
<td>0.49</td>
<td>0.62</td>
<td>1.0</td>
</tr>
<tr>
<td>LVEF</td>
<td>58% (45–60)</td>
<td>65%</td>
<td>58%</td>
<td>45%</td>
<td>45%</td>
<td>60%</td>
<td>60%</td>
<td>35%</td>
</tr>
</tbody>
</table>

Echocardiography, pre-discharge

| Aortic regurgitation severity (0=None, 1=Trace, 2=Mild, 3=Moderate, 4=Severe) | 0 (0–0) | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Aortic valve peak velocity (m/s) | 2.9 (2.7–3.2) | 3.3 | 2.7 | 3.6 | 2.6 | 3.1 | 2.9 | 1.6 |
| Aortic valve mean gradient (mmHg) | 18 (17–21) | 17 | 16 | 28.2 | 17.6 | 21 | 20 | 4.8 |
| LVEF | 61% (56–65) | 71% | 64% | 61% | 51% | 60% | 65% | 35% |

HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; LVEDP = left ventricular end diastolic pressure; LVEF = left ventricular ejection fraction
### Table 3:

**Clinical outcomes**

<table>
<thead>
<tr>
<th>Patient number</th>
<th>ALL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length of stay after TAVR (days)</strong></td>
<td>4 (4–5)</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td><strong>ICU stay (days)</strong></td>
<td>1 (0–2)</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Survival to hospital discharge</strong></td>
<td>100%</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Survival 30d</strong></td>
<td>100%</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Survival ascertainment days</strong></td>
<td>116 (109–153)</td>
<td>154</td>
<td>154</td>
<td>151</td>
<td>116</td>
<td>109</td>
<td>109</td>
<td>95</td>
</tr>
<tr>
<td><strong>NYHA Class at latest follow-up</strong></td>
<td>2.0 (1.5–2.0)</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

ICU = intensive care unit; NYHA = New York heart association functional classification