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CASE SERIES
Other

Transcatheter treatment of severe aortic stenosis in patients with complex coronary artery disease: case series and proposed therapeutic algorithm

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Background Patients with severe aortic stenosis (AS) and complex coronary artery disease with a clinical indication to both transcatheter aortic valve implantation (TAVI) and percutaneous coronary intervention (PCI) pose a clinical dilemma since it is unclear which lesion should be treated first and careful planning is required.

Case summary We report two cases of AS with complex PCI (ASCoP) features. In the first one, easy coronary cannulation with an Acurate Neo2 valve and commissural alignment was predicted; therefore, TAVI was performed first, and subsequently complex high-risk PCI of the left main was performed in the same procedure but without the burden of ongoing severe AS. In the second case, complex coronary cannulation after TAVI with an Evolut PRO valve was predicted; therefore, balloon aortic valvuloplasty and Impella placement were performed first to allow for complex, high-risk multivessel PCI and subsequent TAVI. In both cases, a single-stage approach was preferred to reduce the use of large-bore arterial access with possible consequent adverse events.

Discussion In this case series, we illustrate a possible approach to the treatment of ASCoP patients. In such complex cases, a thorough preprocedural planning is mandatory, and clinical decision-making should be centred upon the predicted chance of cannulation of coronary arteries after TAVI.

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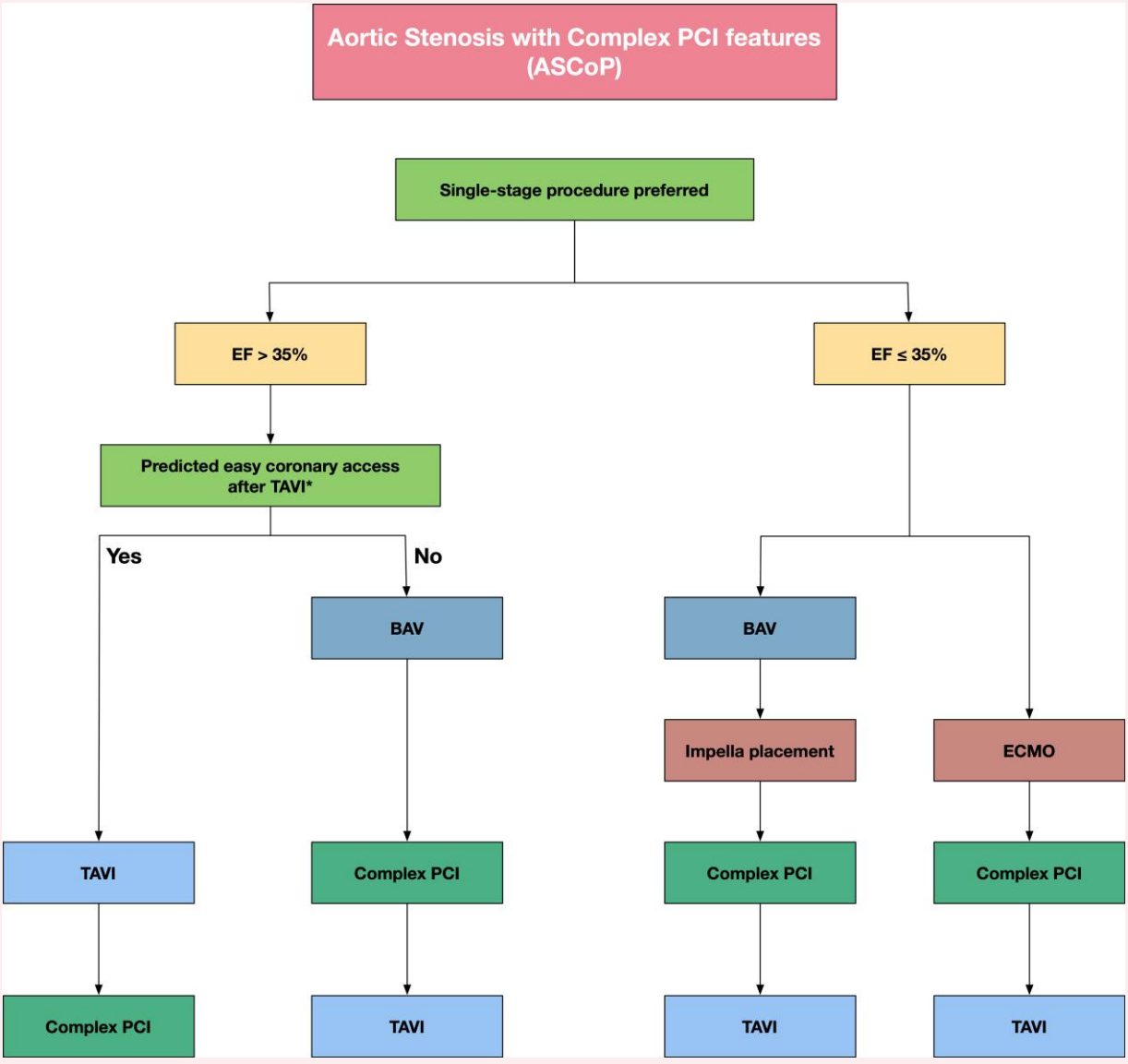
Graphical Abstract



A possible flowchart to treat patients with ASCoP patients. *Predicted easy coronary access based on the combination between aortic root anatomy and the selected transcatheter heart valve. BAV, balloon aortic valvuloplasty; ECMO, extracorporeal membrane oxygenation; EF, ejection fraction; PCI, percutaneous coronary intervention.

Keywords TAVI • CHIP • Commissural alignment • Complex PCI • Case reports

ESC Curriculum 3.1 Coronary artery disease • 3.3 Chronic coronary syndrome • 4.2 Aortic stenosis

Learning points

- Aortic stenosis with complex PCI (ASCoP) patients requires thorough pre-procedural planning.
- Clinical decision-making should be centred upon the anticipated chance of coronary cannulation after TAVI and a single-staged approach is possible to reduce the use of large-bore accesses
- If easy coronary cannulation after TAVI with commissural alignment is predicted, it is possible to perform TAVI first and subsequently to perform the high-risk PCI without the burden of severe AS.
- If complex coronary cannulation after TAVI is predicted, it is possible to perform the high-risk PCI with ongoing mechanical circulatory support followed by subsequent TAVI.

Introduction

Transcatheter aortic valve implantation (TAVI) is recommended in recent European and American guidelines to treat patients with severe, symptomatic aortic stenosis (AS) who are elderly or at increased surgical risk.[1,2] Despite TAVI being considered as a relatively low-risk procedure, these patients often feature co-existing coronary artery disease (CAD)[3,4] complicating both TAVI and subsequently revascularization. In particular, coronary lesions requiring complex percutaneous coronary intervention (PCI) require a careful and dedicated planning (*Figure 1*). In patients with combined severe AS and high-risk CAD with clinical indication to PCI (AS with complex PCI, ASCoP), it is unclear which lesion should be treated first, and nowadays CAD is often treated initially due to concerns for difficult coronary access after TAVI.[5] However, the use of more recent transcatheter heart valves (THVs) in combination with commissural alignment allow for an individually tailored strategy.[6,7] We present two ASCoP cases with different features and propose a possible therapeutic algorithm.

Timeline

Day	Case 1 Event	Case 2 Event
0	ER: presenting with unstable angina	ER: presenting with unstable angina
	Echo: severe AS	Echo: severe AS
		CT angio
1	Angiogram: critical calcific stenosis involving distal LM and the ostium of a dominant LCx	Angiogram: multivessel coronary artery disease with calcific LAD lesion
2	Heart team discussion: indication to TAVI plus complex percutaneous coronary intervention	Heart team discussion: indication to TAVI plus complex PCI
3	CT-angio	
	Pre-procedural planning: easy coronary access with Acurate Neo2 + commissural alignment is predicted	Pre-procedural planning: difficult coronary access with Evolut PRO is predicted
4	1. TAVI procedure	1. Balloon aortic valvuloplasty
	2. Complex high-risk PCI (Only 1 large-bore access used)	2. Impella placement
		3. Complex high-risk PCI
		4. TAVI (only 1 large-bore access used)
	Overnight stay in ICCU	Overnight stay in ICCU
5	Transferred to cardio ward	ICCU
8	Discharged home	Transferred to cardio ward
9		Discharged home

AS, aortic stenosis; CT, computed tomography; CT-angio, computed tomography angiography; ER, emergency room; ICCU, intensive care cardiac unit; LAD, left anterior descending artery; LM, left main; LCx, left circumflex artery; PCI, percutaneous coronary intervention; TAVI, transcatheter aortic valve intervention.

Case presentation

Case 1: predicted post-TAVI easy coronary access

A 78-year-old man with multiple risk factors, including hypertension, type 2 diabetes mellitus, dyslipidaemia, chronic obstructive pulmonary disease and prior PCI on left anterior descending (LAD) artery was admitted for unstable angina and dyspnoea at minimal efforts [New York Heart Association (NYHA) III]. His blood tests revealed normal renal function. A harsh aortic systolic murmur was present, and echocardiogram showed severe AS [mean gradient 42 mmHg, aortic valve area (AVA) 0.9 cm^2] with preserved left ventricular ejection fraction (LVEF). Coronary angiography revealed a critical calcific stenosis involving distal left main (LM) and the ostium of a dominant left circumflex (LCx) artery requiring complex PCI of the LM bifurcation with the use of rotational atherectomy. (*Figure 2A and B*; Supplementary material online, *Video S1*) The local Heart Team deemed the patient at high risk for surgery (EuroScore II 4.4%, STS 4.0%), and TAVI in combination with PCI was recommended. Computed tomography angiography (CT-angio) revealed low calcium burden both at aortic annulus and in left ventricular outflow tract, as well as relative low take-off of the coronary arteries. Pre-procedural measurements and additional images from CT-angio are in Supplementary material online, *Figure S1*.

We opted for concomitant procedures performing TAVI with ACURATE neo2 THV (Boston Scientific, Marlborough, MA) as first step to reduce the risk of haemodynamic instability during complex PCI on the LM bifurcation. This strategy was chosen because of the open-cell frame design of the Acurate neo2 THV that ensures easy access to the coronary ostia after valve deployment, as well as possibility for patient-specific easy commissural alignment (*Figure 2C*). Moreover, a self-expandable THV minimize the need of rapid pacing during the procedure, which in turn reduces the overall risk of such a complex severe LM stenosis.

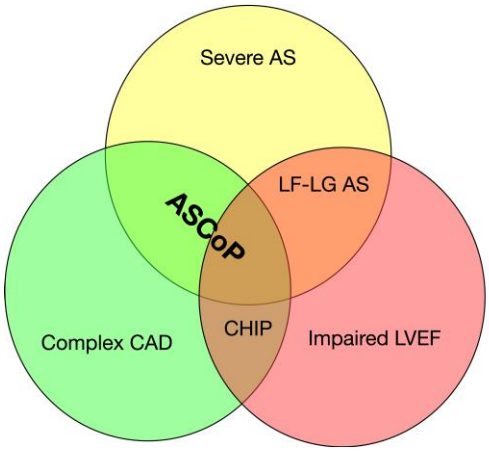
After TAVI, coaxial access to LM ostium between the open-cell frame of the arches was uncomplicated with a 7Fr XB3.5 catheter through the femoral large-bore access already in place. Rotational atherectomy with RotaPRO (Boston Scientific) 1.75 mm burr was successfully performed on the LM-LCx axis (*Figure 2D*), and the LM bifurcation was treated provisionally with two drug eluting stents (DES) post-dilated with a 5.5 × 8 mm (LM) and 4.0 × 15 mm (LCx) non-compliant balloons. Final intravascular ultrasound (IVUS) confirmed the optimal apposition and expansion of the implanted DES (*Figure 2E and F*).

The patient was discharged 4 days after the procedure with no symptoms and well-functioning THV at echocardiogram both at discharge and 1-month follow-up, as well as no conduction abnormalities. At 6 months, the patient was well and without residual symptoms and dual antiplatelet therapy with clopidogrel was stopped.

Case 2: Concomitant severely depressed LV function

An 83-year-old man with hypertension, type 2 diabetes mellitus and a previous PCI of the LCx for a non-ST elevation myocardial infarction was admitted for unstable angina and dyspnea at rest (NYHA III-IV). At physical examination, a harsh holosystolic murmur and mild pulmonary congestion with bilateral basal crackles were observed. Echocardiogram showed a severely reduced LVEF (28%) accompanied by severe AS (mean gradient 45 mmHg, AVA 0.8 cm^2). CT-angio revealed moderate LVOT calcifications (see Supplementary material online, *Figure S2*).

Coronary angiogram demonstrated critical, calcific, stenoses of LAD and ostial right coronary artery (RCA) (*Figure 3A and B*; Supplementary material online, *Video S2*). The patient had a prohibitive surgical risk (EuroScore II: 8.72%; STS-PROM 4.2%) and was referred for TAVI with multivessel PCI. An Evolut PRO 34 mm (Medtronic, Dublin,



Aortic Stenosis with Complex PCI (ASCoP)

Severe Aortic stenosis
+ one or more of the following:

- Left main stenosis / proximal lesion
- Last remaining vessel
- Multivessel CAD
- Calcific lesion requiring debulking
- Bifurcation (clinically significant)
- Long (> 30 mm) lesion

+/- severely impaired LVEF / severe MR

Figure 1 Summary of aortic stenosis with complex percutaneous coronary intervention features. CAD, coronary artery disease; LVEF, left ventricular ejection fraction; MR, mitral regurgitation.

Ireland) was considered the most appropriate THV due to the calcified LVOT with risk of annulus rupture. However, access to the coronary ostia through the Evolut stent frames may be challenging.[8] Therefore, we opted to proceed with a single-stage strategy of PCI followed by TAVI. Considering the complexity of this multivessel CAD and the severity of the LV dysfunction, a mechanical support with Impella CP (Abiomed, Danvers, MA) was deemed necessary. Since it is potentially challenging to cross the stenotic aortic valve with the Impella system, balloon aortic valvuloplasty (BAV) was performed first (*Figure 3C*). After placement of the Impella CP (*Figure 3D*), we performed multivessel PCI with implantation of 1 DES at the ostium of RCA and rotational atherectomy with RotaPRO 1.5 mm burr on distal left main and proximal LAD followed by provisional stenting of the LM-LAD with 3 DES. Optimal PCI result was confirmed by IVUS and the Impella CP was retrieved (*Figure 3E* and *F*).

After achieving complete coronary revascularization, an Evolut PRO THV was successfully implanted during the same procedure through the same large-bore arterial access used for Impella placement. In this case, a single-stage strategy allowed for minimal contrast use and the need of only one large-bore arterial access.

The patient was discharged 5 days later with no residual symptoms, good function of the bioprosthesis (mean gradient 6 mmHg) and a minimal paravalvular leak. At discharge, mild improvement of LVEF (28 to 32%) was observed. After 6 months, the patient was still asymptomatic and did not experience any events; also in this case dual antiplatelet therapy with clopidogrel was stopped.

Discussion

Scarce evidence is available to guide the management of ASCoP patients. The two presented cases were treated with complex, high risk, clinically indicated PCI (CHIP) and TAVI in a single-stage procedure. This strategy is of clinical importance as CAD and severe AS share several risk factors and often coexist in the same patients. Although the recent ACTIVATION trial (NCT04310046) showed similar rates of death and re-hospitalization at 1-year in TAVI patients treated with PCI or managed conservatively, LM stenosis were excluded from this trial that prevalently enrolled short, single-vessel and not sub-occlusive stenosis.[9] Important messages can be drawn from these data but they appear to be poorly applicable to the context of CHIP that mandates a dedicated tailored management.

Considering that access to coronary arteries may be difficult or even impossible after TAVI, nowadays CAD is often treated beforehand. Although most PCIs might be performed safely despite the ongoing severe AS, anatomic complexity and/or high-risk clinical features might require advanced circulatory support with extracorporeal membrane oxygenation (ECMO)[5,10,11] and the need for a staged procedure for TAVI. On the other hand, THV with intra-annular leaflet position or large stent cells in combination with commissural alignment has led to easier selective coronary cannulation after TAVI.[7]

In general, coronary cannulation after TAVI with balloon-expandable valve is easier,[6] whereas it is often more challenging with the Evolut THV due to the supra-annular valve design, the tall skirt that extends over the coronary ostia especially at the level of the commissures, and the relatively narrow stent frame cells. Coronary access might be further impaired by higher THV implantation to mitigate the need of pacemaker implantation. The ACURATE neo2 THV features tall but wide stabilizing arches and supra-annular stent-free leaflets that optimize future coronary access.[12] In both cases, commissural alignment, which consists in device- and patient-specific orientation at deployment to optimize the relationship between the neo-commissures and the coronary artery ostia, is associated with increased rates of selective coronary cannulation after TAVI.[7]

With self-expanding prostheses, commissural alignment is considered a technique to preserve coronary access for future events in the ever-younger TAVI population. However, this technique also facilitates coronary access early after TAVI and allows a strategy of anticipated TAVI (*Graphical abstract*) to unload the left ventricle and to reduce the risk of haemodynamic compromise during CHIP, including unprotected left main stenosis or heavily calcified lesions requiring debulking with calcium-modification techniques and prolonged, multiple balloon inflations. A single-stage strategy has several potential advantages, including shorter hospital stay and less risk of access-related bleedings (since the same femoral access is used for both CHIP and TAVI), both factors that are associated with worst outcomes after TAVR.[13,14] On the other hand, some cases might benefit from a two-staged strategy and are presented in *Table 1*.

Our cases also highlights that the valve anatomy and the predicted difficulty to access coronary arteries after TAVI should guide the

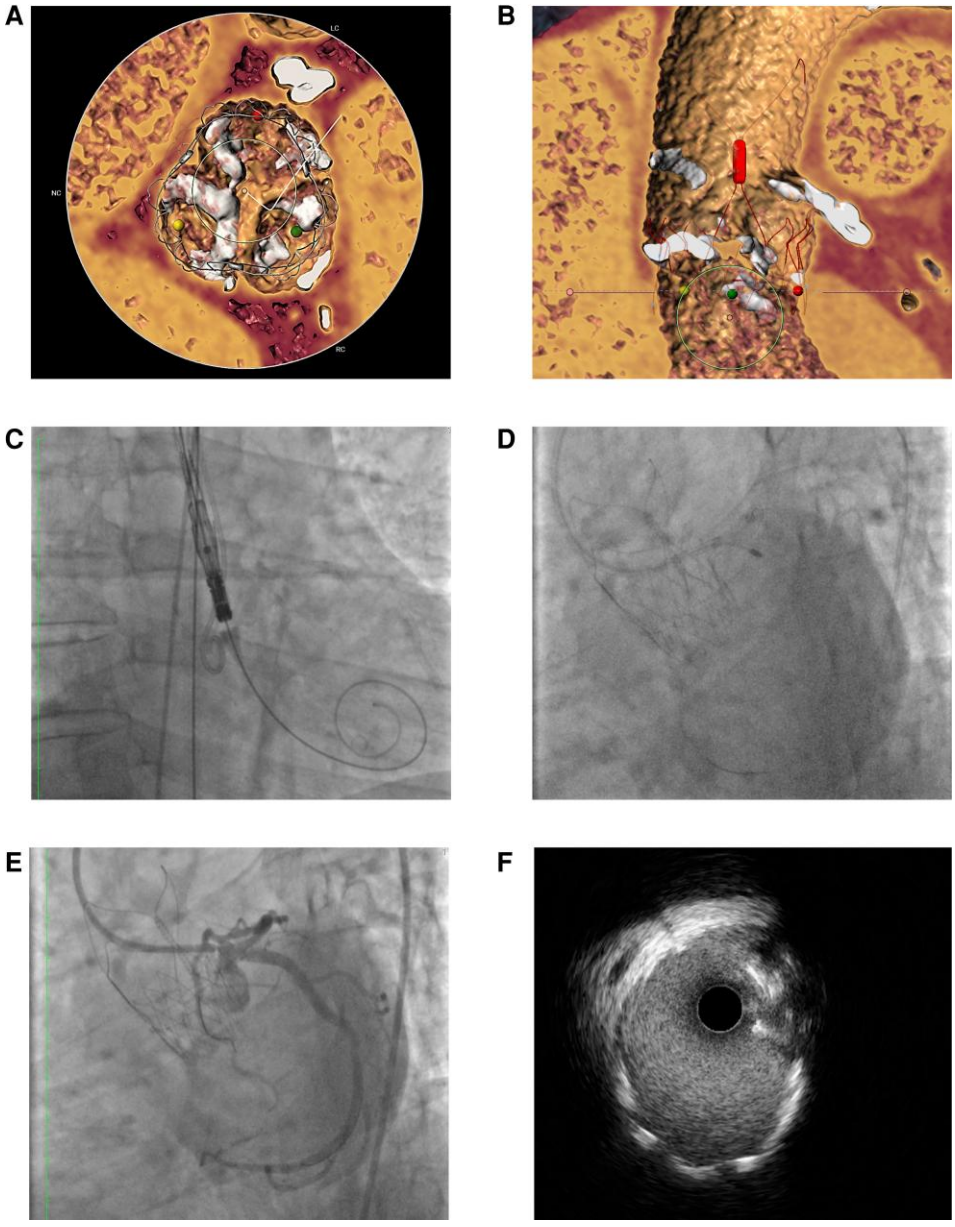


Figure 2 Summary of case 1. (*A* and *B*) Pre-procedural computed tomography scan showing severe aortic valve calcification involving the left main and left circumflex artery; an Acurate Neo2 M model is superimposed on the computed tomography scan suggesting that coronary take-off free from the stent frame and high likelihood of easy coronary access after transcatheter aortic valve implantation. (*C*) Cusp overlap view showing the free-stent struts for commissural alignment; (*D*) RotaPRO 1.75 burr crossing through the large stabilizing arches of the Acurate Neo2; (*E* and *F*) final angiographic and intravascular ultrasound result showing optimal stent expansion and apposition and adequate minimal stent area on the left main-left circumflex artery axis.

decision of performing TAVI or CHIP first, whenever both are needed. For THVs where access to coronary artery is feasible, TAVI can be performed first to unload the left ventricle and minimize the risk associated with CHIP. On the contrary, when CT-angio reveals an unfavourable anatomy with possible difficult access to coronary arteries after TAVI, CHIP should be performed first—and possibly preceded by BAV which might reduce the risk of haemodynamic compromise and allow the use of Impella CP device in cases of severely depressed LV function. It is worthwhile to mention that, although affordable and easy to use, intra-aortic balloon pumping offer only a slight improvement in cardiac output and might be contraindicated in certain phases of the TAVI procedure, such as when rapid pacing is used and if transitory aortic regurgitation occurs. On the contrary, ECMO offers full cardiocirculatory support but might not be available in many centres and it requires large-bore accesses that increase the overall risk of the procedure. Moreover, increased afterload with ECMO might augment oxygen demand and worsen ischaemia in the area at risk, especially during a complex PCI. For these reasons we believe that ECMO might not be

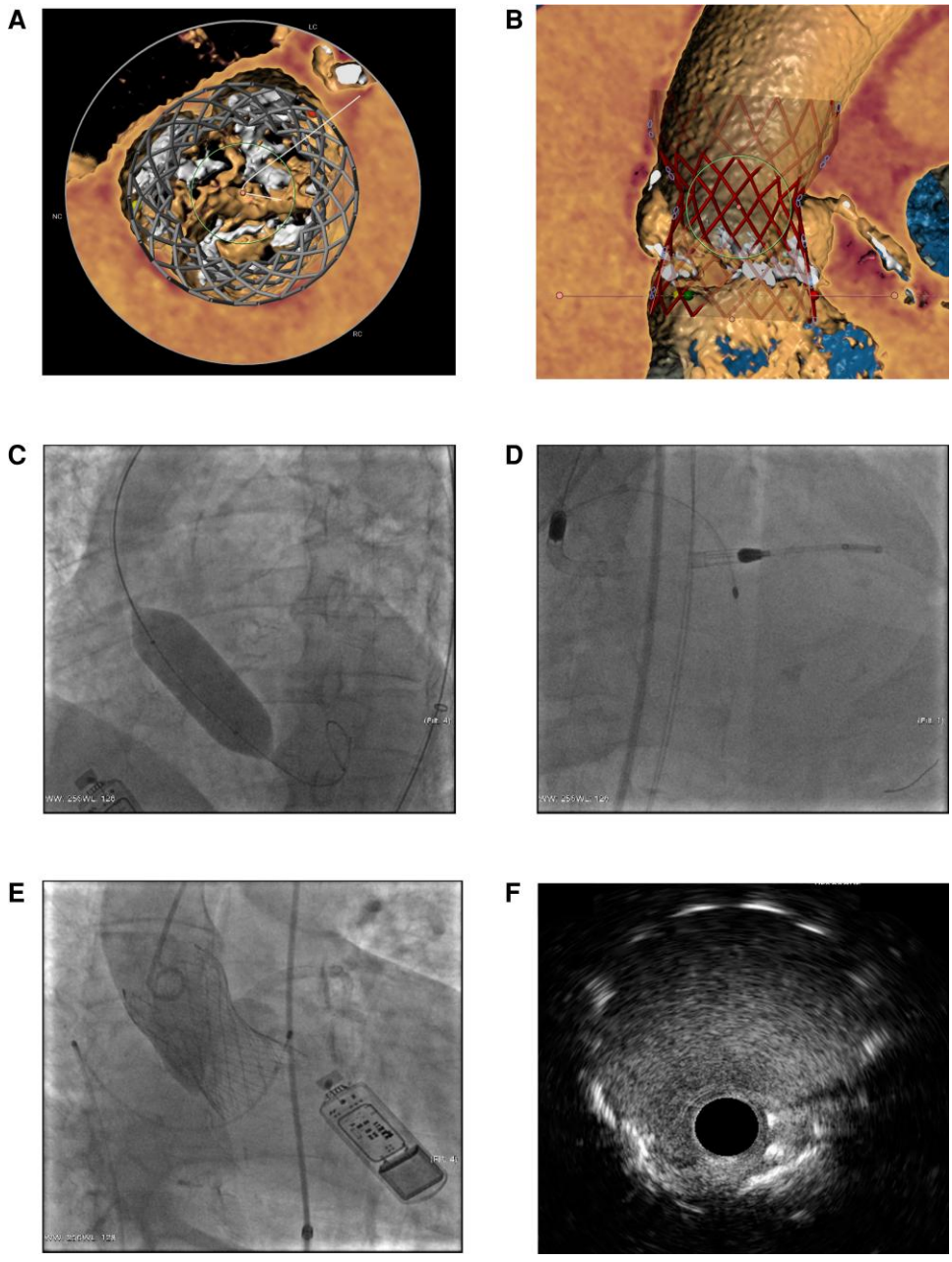


Figure 3 Summary of case 2. (*A* and *B*) Pre-procedural computed tomography scan showing severe aortic valve calcification; a Evolut PRO model is superimposed on the computed tomography scan suggesting coronary ostia covered by stent frames and possible difficult coronary access after transcatheter aortic valve implantation. (*C*) Upfront balloon aortic valvuloplasty to allow circulatory support with Impella; (*D*) Impella support is in place and complex percutaneous coronary intervention with rotational atherectomy of left main-left anterior descending artery axis is commenced; (*E*) Evolut PRO is placed after percutaneous coronary intervention; (*F*) final intravascular ultrasound result showing optimal stent expansion and apposition and adequate minimal stent area on the left main-left anterior descending artery axis.

the preferred choice in several ASCoP cases, because both of availability issues and for the addition of possible ECMO-related adverse events, including major or life-threatening vascular complications and bleedings, increased risk of renal and liver failure, septicaemia and sepsis, vascular thrombosis, haemolysis, etc.[15] For these reasons, a thorough Heart Team evaluation of the risk-benefit ratio of a fully-percutaneous strategy, altogether with in-depth discussion with patient and care holders, appears mandatory when an ECMO-supported strategy is favoured.

In conclusion, ASCoP patients represent a high-risk population whose treatment strategy should be carefully planned. A tailored, single-stage strategy could be adopted in selected cases. The predicted difficulty to cannulate coronary artery post-TAVI should guide whether TAVI or CHIP should be performed first. In cases of severely depressed

Table 1 Characteristics that might favour a single- vs. two-step procedure to treat ASCoP patients

Single-stage preferred	Two-stage preferred
High bleeding risk	Chronic kidney disease
Unfavorable femoral access	Coronary lesion(s) of uncertain clinical significance
	Complications during TAVI procedure

TAVI, transcatheter aortic valve implantation.

LV function, the adjunctive use BAV and Impella might reduce the need of ECMO.

Lead author biography

Dr Soriano earned his medical degree and cardiovascular specialization in Milan Bicocca University (Italy). He is an expert TAVI and CHIP operator at De Gasperis Cardio Center, Niguarda Hospital (Milan, Italy), and has been co-investigator in multiple clinical trials in this area.

Supplementary material

Supplementary material is available at *European Heart Journal – Case Reports* online.

Slide sets: A fully edited slide set detailing this case and suitable for local presentation is available online as Supplementary data.

Consent: written consent for submission and publication of this case report including images and associated text has been obtained from the patient in line with COPE guidance.

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References

1. Vahanian A, Beyersdorf F, Praz F, Milojevic M, Baldus S, Bauersachs J, Capodanno D, Conradi L, De Bonis M, De Paulis R, Delgado V, Freemantle N, Gilard M, Haugaa KH, Jeppsson A, Jüni P, Pierard L, Prendergast BD, Sádaba JR, Tribouilloy C, Wojakowski W. 2021 ESC/EACTS guidelines for the management of valvular heart disease. *Eur Heart J* 2021;**00**:1–72.
2. Otto CM, Nishimura RA, Bonow RO, Carabello BA, Erwin JP, Gentile F, Jneid H, Krieger EV, Mack M, McLeod C, O'Gara PT, Rigolin VH, Sundt TM 3rd, Thompson A, Toly C. 2020 ACC/AHA guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association joint committee on clinical practice guidelines. *Circulation* 2021;**143**:e72–227.
3. Leon MB, Smith CR, Mack MJ, Makkar RR, Svensson LG, Kodali SK, Thourani VH, Tuzcu EM, Miller DC, Herrmann HC, Doshi D, Cohen DJ, Pichard AD, Kapadia S, Dewey T, Babaliaros V, Szeto WY, Williams MR, Kereiakes D, Zajarias A, Greason KL, Whisenant BK, Hodson RW, Moses JW, Trento A, Brown DL, Fearon WF, Pibarot P, Hahn RT, Jaber WA, Anderson WN, Alu MC, Webb JG; PARTNER 2 Investigators. Transcatheter or surgical aortic-valve replacement in intermediate-risk patients. *N Engl J Med* 2016;**374**:1609–1620.
4. Smith CR, Leon MB, Mack MJ, Miller DC, Moses JW, Svensson LG, Tuzcu EM, Webb JG, Fontana GP, Makkar RR, Williams M, Dewey T, Kapadia S, Babaliaros V, Thourani VH, Corso P, Pichard AD, Bavaria JE, Herrmann HC, Akin JJ, Anderson WN, Wang D, Pocock SJ; PARTNER Trial Investigators. Transcatheter versus surgical aortic-valve replacement in high-risk patients. *N Engl J Med* 2011;**364**:2187–2198.
5. Marchese A, Tarantini G, Tito A, Margari V, Resta F, Dhojniku I, Paparella D, Speziale G. Mechanical circulatory support and intravascular lithotripsy in high-risk patients undergoing percutaneous coronary intervention and transcatheter aortic valve replacement: a case series. *Eur Hear J Case Rep* 2021;**5**:ytab498.
6. Tarantini G, Nai Fovino L, Le Prince P, Darremont O, Urena M, Bartorelli AL, Vincent F, Hovorka T, Alcalá Navarro Y, Dumonteil N, Ohlmann P, Wendler O. Coronary access and percutaneous coronary intervention up to 3 years after transcatheter aortic valve implantation with a balloon-expandable valve. *Circ Cardiovasc Interv* 2020;**13**:e008972.
7. Tarantini G, Nai Fovino L, Scotti A, Massussi M, Cardaioli F, Rodinò G, Benedetti A, Boiago M, Matsuda Y, Continisio S, Montonati C, Cacciavillani L, Pavei A, Masiero G, Napodano M, Fraccaro C, Fabris T, Iliceto S. Coronary access after transcatheter aortic valve replacement with commissural alignment: the ALIGN-ACCESS study. *Circ Cardiovasc Interv* 2022;**15**:e011045.
8. Barbanti M, Costa G, Picci A, Criscione E, Reddavid C, Valvo R, Todaro D, Deste W, Condorelli A, Scalia M, Licciardello A, Politi G, De Luca G, Strazzieri O, Motta S, Garretto V, Veroux P, Giaquinta A, Giuffrida A, Sgroi C, Leon MB, Webb JG, Tamburino C. Coronary cannulation after transcatheter aortic valve replacement: the RE-ACCESS study. *JACC Cardiovasc Interv* 2020;**13**:2542–2555.
9. Patterson T, Clayton T, Dodd M, Khawaja Z, Morice MC, Wilson K, Kim WK, Meneveau N, Hambrecht R, Byrne J, Carrié D, Fraser D, Roberts DH, Doshi SN, Zaman A, Banning AP, Eltchaninoff H, Le Breton H, Smith D, Cox I, Frank D, Gershlick A, de Belder M, Thomas M, Hildick-Smith D, Prendergast B, Redwood S, ACTIVATION Trial Investigators. ACTIVATION (Percutaneous coronary inTervention prIor to transcatheter aortic VAlve implantaTION). *JACC Cardiovasc Interv* 2021;**14**:1965–1974.
10. Ajmi I, Mahnkopf C, Brachmann J, Sinani M, Oudeh M, Schnupp S. Rotablation of heavily calcified left main stenosis and aortic valve valvuloplasty under ECMO cardiopulmonary support. *JACC Case Rep* 2020;**2**:2448–2454.
11. Ahsan M, Jánosi RA, Rassaf T, Lind A. Use of extracorporeal membrane oxygenation as a bridge to transcatheter aortic valve replacement in a patient with aortic stenosis and severe coronary artery disease: a case report. *Eur Hear J Case Rep* 2021;**5**:1–5.
12. Bieliauskas G, Wong I, Bajoras V, Wang X, Kofoed KF, De Backer O, Søndergaard L. Patient-Specific implantation technique to obtain neo-commissural alignment with self-expanding transcatheter aortic valves. *JACC Cardiovasc Interv* 2021;**14**:2097–2108.
13. Wayangankar SA, Elgendy IY, Xiang q, Jneid h, Vemulapalli S, Khachatryan T, Pham D, Hilliard AA, Kapadia SR. Length of stay after transfemoral transcatheter aortic valve replacement: an analysis of the Society of Thoracic Surgeons/American College of Cardiology transcatheter valve therapy registry. *JACC Cardiovasc Interv* 2019;**12**:422–430.
14. Mangieri A, Montalto C, Poletti E, Sticchi A, Crimi G, Giannini F, Latib A, Capodanno D, Colombo A. Thrombotic versus bleeding risk after transcatheter aortic valve replacement: JACC review topic of the week. *J Am Coll Cardiol* 2019;**74**:2088–2101.
15. Zangrillo A, Landoni G, Biondi-Zoccai G, Greco M, Greco T, Frati G, Patroniti N, Antonelli M, Pesenti A, Pappalardo F. A meta-analysis of complications and mortality of extracorporeal membrane oxygenation. *Crit care Resusc* 2013;**15**:172–178.