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ORIGINAL PAPER

Procedural findings and early healing response after implantation of a self-apposing bioresorbable scaffold in coronary bifurcation lesions

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Abstract

We aimed to evaluate feasibility, early healing and self-correcting properties of the Desolve 150 bioresorbable scaffold (BRS) implanted in bifurcation lesions, using the simple, provisional side branch (SB) stenting technique. BIFSORB pilot was a proof-of-concept study enrolling 10 patients with stable angina pectoris and a bifurcation lesion with SB ≥ 2.5 mm and less than 50% diameter stenosis. Procedure and 1-month outcome was evaluated by optical coherence tomography (OCT) to assess scaffold performance and healing patterns. Nine patients were treated with Desolve 150 BRS and one delivery to the target bifurcation failed. Thrombus formation in the jailed SB ostium was seen in three cases, but was completely resolved at 1-month. OCT confirmed acute self-correcting properties. No clinical events were reported after six months. Scaffold diameter by OCT increased in the proximal main vessel from 3.09 ± 0.16 mm to 3.34 ± 0.18 mm ($p = 0.01$) and in distal main vessel from 2.82 ± 0.26 mm to 3.02 ± 0.29 mm ($p < 0.01$) at one-month follow-up. SB ostial diameter stenosis improved from 42 ± 15% to 34 ± 12% ($p = 0.01$). Malapposition was effectively reduced after 1 month from 4.1 (1.4; 6.1)% to 0.1 (0; 0.6)% ($p = 0.002$). Treatment of bifurcation lesions using Desolve 150 BRS was feasible except for a delivery failure and unsettling thrombus formation behind jailing SB struts, which was completely resolved at 1-month. Self-correcting and even self-expanding properties were confirmed.

Keywords Coronary bifurcations · Bioresorbable stent · Optical coherence tomography · Stent fracture

Introduction

Implantation of bioresorbable scaffolds (BRS) in coronary bifurcations using the provisional side branch treatment technique is appealing as struts jailing the side branch (SB) may disappear over time. This could facilitate positive remodelling of the SB ostium with resulting restoration of flow area. Reports of increased rates of early scaffold thrombosis using Absorb BRS (Abbott, US) [1] and suboptimal outcome in the 321 patient bifurcation subgroup of the real world GHOST registry have raised concerns about use of BRS in bifurcations [2]. Increased early thrombogenicity may be related to under expansion, scaffold malapposition, strut fracture, and increased flow obstruction and flow disturbance around the bulkier struts [3, 4]. Improved implantation strategies have been proposed to accommodate the structural limits of the Absorb BRS [5, 6]. The Desolve 150 (Elixir, US) is a poly-L-lactic acid BRS with 150 µm struts and an absorption time of 12–18 months. Desolve 150 BRS

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has higher expansion capacity compared to the Absorb BRS, allows for inflation of larger balloons at higher pressure in scaffold cells after SB rewiring [7], and possess self-correcting properties [8] of particular importance to bifurcation treatment [9]. We hypothesized that strut malapposition after implantation of the Desolve 150 BRS is corrected spontaneously and aimed to evaluate the feasibility, self-correcting properties, and early healing response when implanting Desolve 150 BRS by the provisional technique in non-true bifurcation lesions leaving the side branch ostium jailed.

Materials and methods

The study was a prospective, single-arm, single centre study assessing the feasibility and 1-month healing result after implanting the Desolve 150 in coronary bifurcation lesions. One-month was chosen in order to characterize self-correcting properties before scaffold dismantling at 3 months. The study was performed at Aarhus University Hospital, Skejby, Denmark. Inclusion criteria were age $\geq$ 18 years old, stable angina pectoris, stabilized non-ST elevation myocardial infarction or silent ischemia with a non-true (SB diameter stenosis $<$ 50%), de novo bifurcation lesion, and SB diameter $\geq$ 2.5 mm. Major exclusion criteria were STEMI within 48 h, expected survival less than 1 year, serum creatinine above 120 µmol/L, severe tortuosity, calcification of the target lesion, or inability to cover the MV lesion with one scaffold. Central Denmark Region Ethics Committee for Biomedical Research and the Danish Data Protection Agency approved the study. All patients provided written informed consent and the study adhered to the Declaration of Helsinki.

Clinical and feasibility endpoints

Six-month clinical safety was determined by the individual endpoints of all-cause mortality, cardiac death, procedural myocardial infarction (MI), non-procedural MI, and target lesion revascularization [10]. Feasibility was the percentage of successful implantations defined as implantation of the Desolve 150 BRS in the target lesion, less than 30% residual diameter stenosis in the MV and TIMI flow III in both the MV and SB. Residual diameter stenosis was assessed using a validated and dedicated bifurcation 3D-QCA software able to construct a tapering reference function.

Study device

The Desolve 150 BRS is a fully bioresorbable coronary scaffold with a backbone of a poly-L-lactic-acid based polymer, 150 µm strut thickness in parallel hoops with three connectors, and a crossing profile of 1.5 mm. The surface is coated by a polymer matrix containing the anti-proliferative drug Novolimus [8]. Within 1 year, 95% of the scaffold material is resorbed to carbon-dioxide and water (vendor information). The device has self-apposing properties until nominal diameter (vendor information) confirmed by in-vitro studies [8]. The mechanism of the self-apposing property is proprietary, protected information.

Implantation sequence

After wiring the MV and the SB, the MV was pre-dilated using a non-compliant balloon or a scoring balloon sized 1:1. Optical coherence tomography (OCT) was acquired after pre-dilatation to exclude severe calcifications, to assess dissections, verify delivery route, and planning scaffold length and diameters. Per protocol strategy was to cover the MV lesion with one scaffold and jailing the SB. The scaffold had to extend at least 8 mm proximal to the carina to ensure that the balloon for proximal optimization technique (POT) did not extend outside the stented segment. The scaffold was sized according to the proximal MV as recommended by the European Bifurcation Club [11]. After scaffold implantation OCT was indicated to evaluate expansion, apposition, lesion coverage, and SB wire position if the SB was rewired. After final POT using a NC balloon sized to the proximal MV and retraction of the jailed guidewire, a final OCT was performed to confirm scaffold expansion, SB result, and to exclude strut fracture. If flow was compromised (less than TIMI III) or diameter stenosis $>$ 75% in the SB, a pre-specified bail-out treatment with the mini-kiss technique was performed (described in supplementary material).

Anti-thrombotic treatment

Treatment with aspirin and ticagrelor or clopidogrel was required during the procedure and dual antiplatelet treatment was indicated for 12 months after the procedure. Heparin was administrated according to local protocol guided by ACT. Bivalirudine was administrated if excess thrombus was identified by angiography or OCT.

Image acquisition technique

OCT was acquired using the Lunawave OCT system (Terumo corp, Jp) at a pullback speed of 15 mm/s during contrast flush. If the SB ostium was covered by a guidewire shadow, the wire was manipulated and the pullback repeated.

Quantitative OCT analysis

Baseline and follow-up recordings were matched on frame-level using stent edges, distinctive plaques and SB which were visible both at baseline and follow-up. Cross sectional analysis sample frequency was 0.5 mm except for the bifurcation core segment where it was 0.1 mm. The OCT-pullback was divided into 6 sub-segments as shown in Fig. 1 and detailed in the supplement. Scaffold area was assessed both by luminal and abluminal scaffold contouring. The abluminal scaffold contour was used for evaluating expansion parameters. Acute scaffold expansion was evaluated by mean and minimal scaffold area and changes in scaffold area were reported as mean and maximum scaffold recoil. Scaffold self-correction was evaluated as an increase in mean scaffold diameter from baseline to follow-up. If the cross sectional mean scaffold diameter increased beyond nominal size at follow-up it was defined as self-expansion. Struts were contoured as (1) the "black box area" excluding the blooming around the struts for detection of changes in black box area, and (2) with full strut tracing including the blooming at a 2nd analysis to assess the footprint of the scaffold. Tissue coverage analysis was performed for jailing and non-jailing struts separately. Struts were indicated as covered if visible tissue was covering all sides of the struts. Struts were classified as apposed if there was no visible separation between the scaffold and the vessel wall on any side of the strut.

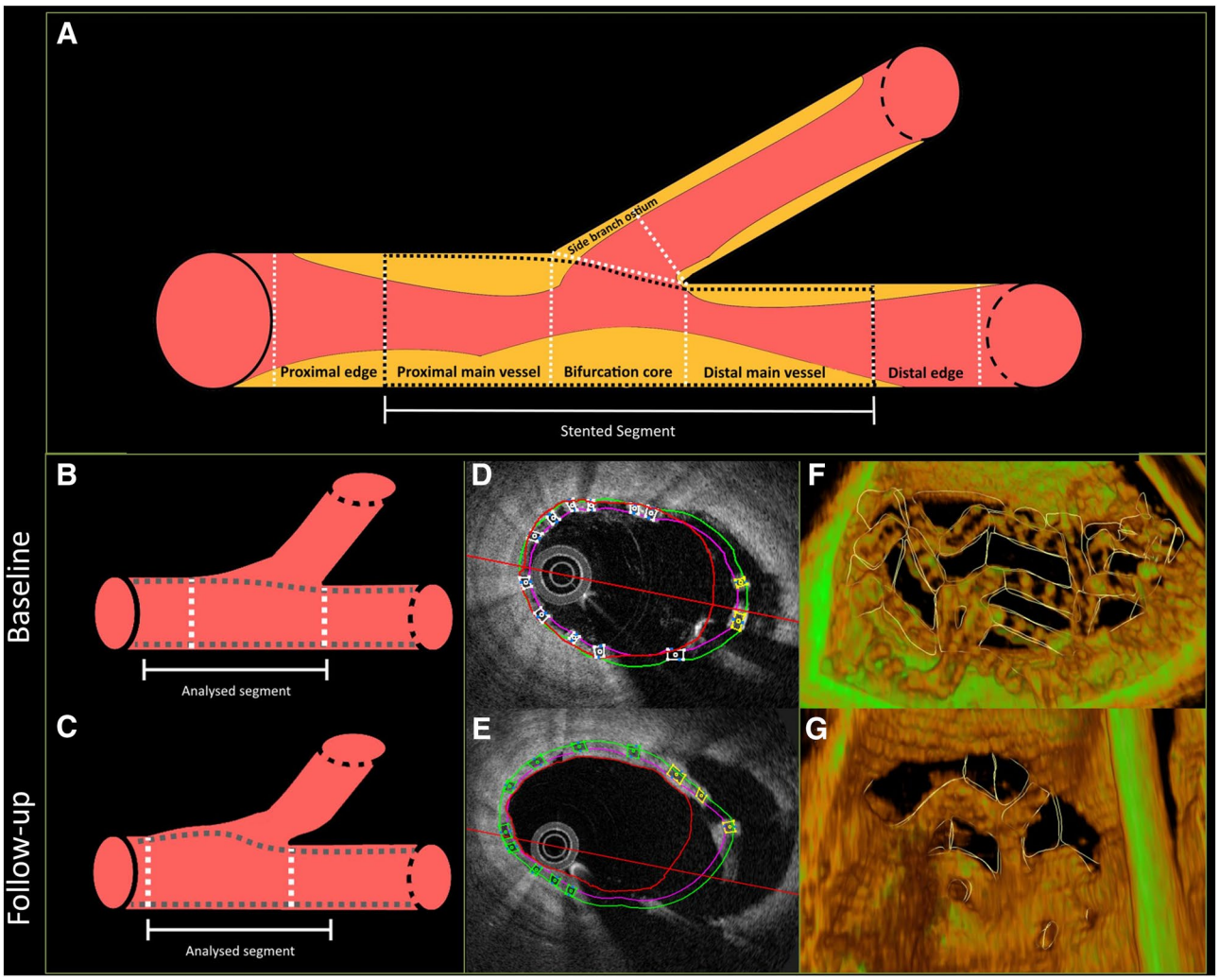

Fig. 1 Segmental OCT analysis. **a** Segments in OCT analysis. **b, c** The bifurcation core segment spans the entire side branch (SB) ostium determined by matched baseline and follow-up OCT. **d, e** Example of matched baseline and follow-up images with marked struts, extrapolated main vessel lumen contour and scaffold contours. **f, g** 3D OCT cutplane analysis of area between struts at baseline and follow-up to assess the ostial SB flow area

Side branch analysis

The SB ostium was analysed using the cut-plane technology [12] by a novel approach where the actual strut obstruction of the SB orificium was quantified by measuring the cumulated strut obstruction area and the area between the struts in front of the SB, the "side branch flow area" (Fig. 1). The cut-plane minimum lumen area of the SB ostium was measured at baseline and follow-up OCT scans to evaluate ostial area late loss (Fig. 2). Analysis was performed at the Interventional Coronary Imaging Core Laboratory at Aarhus University Hospital, Skejby using a customized version of the QCU-CMS semi-automatic analysis software (Leiden University Medical Centre, The Netherlands) except for cut-plane analysis performed using the QAngioOCT RE software (Medis medical imaging, The Netherlands).

Statistics

Clinical baseline data are presented as means ± standard deviation (SD) or as counts and percentages. OCT and 3D-QCA endpoints are presented as means with SD if observations were following a Gaussian distribution if not, they are given as median and interquartile range. Differences were tested using paired t-test if data was Gaussian distributed else a Wilcoxon-signed rank test was performed.

Results

Patient characteristics

Ten patients, 80% male, with a mean age of 64 ± 13 years were included. Patient characteristics are listed in Supplementary Table 1.

Lesion characteristics

Eight study lesions were non-true, and two were true bifurcation-lesions. Mean reference diameter of the proximal MV was 3.3 ± 0.5 mm, the distal MV 2.9 ± 0.3 mm and the SB was 2.4 ± 0.3 mm.

Clinical outcome

No patients had symptomatic procedural myocardial infarction or any major adverse cardiac event within 6 months. All patients returned for invasive follow-up after 1-month. In one patient it was not possible to advance the OCT-catheter through the stented segment despite only having a 30% angiographic stenosis.

Procedural outcome

Nine lesions were treated with 10 Desolve 150 BRS (mean length 22.7 ± 6.2 mm, mean nominal diameter 3.1 ± 0.2 mm). One lesion was treated by regular DES due to delivery failure of the BRS. Lesions were pre-dilated

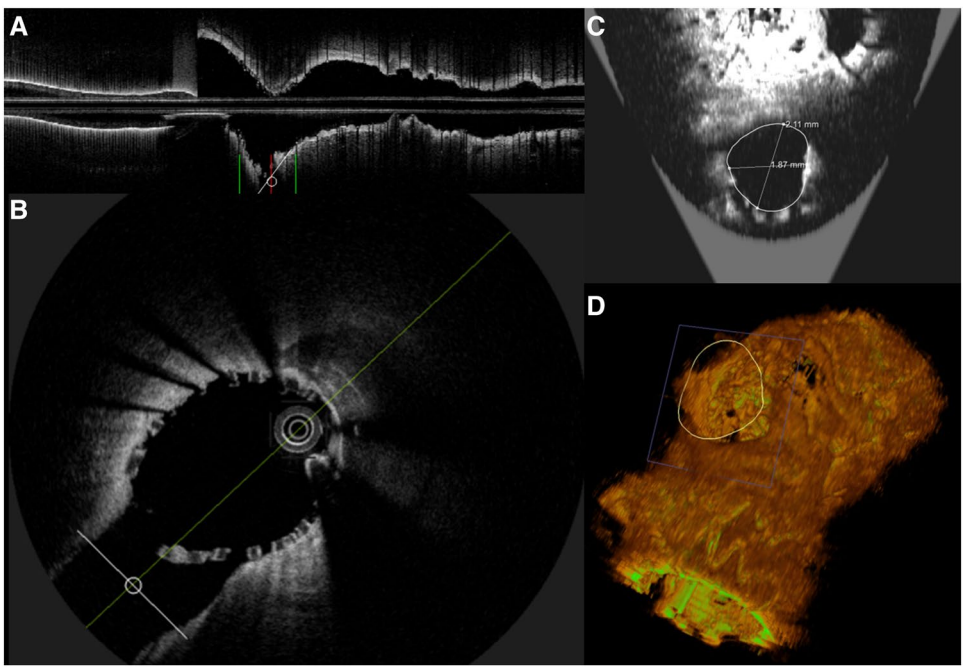

Fig. 2 Side branch ostium reconstruction from main vessel pullback. Longitudinal view (**a**), regular cross-sectional view (**b**), reconstructed 2D view of SB ostium with lumen contour (**c**), cut-plane and ostial side branch lumen contour shown in 3D reconstruction (**d**)

using a non-compliant balloon (n = 5), or a scoring balloon (n = 6). POT was performed in all patients. See Table 1 for lesion characteristics or Supplementary Table 2 for individual cases. Two SBs had mini kissing balloon technique performed due to SB occlusion or thrombus in the side branch ostium (no fracture was observed in the bifurcation segment by 3D OCT). A total of 3 of 10 patients had angiographic visible thrombus in the SB ostium, which was confirmed by OCT. Bivalirudine was administrated in 5 cases—two of them due to excess in-scaffold thrombus (Supplementary Table 2). Three patients were not pre-loaded with ADP receptor antagonist 24 h prior to PCI due to ad hoc PCI. Bolus of 600 mg clopidogrel was administered immediately in these patients.

Procedural OCT findings

The case with failed delivery of a BRS aimed for a Cx/OM bifurcation lesion was stuck in the LCx ostium due to protrusion of a fibro-calcific plaque resulting in a minimal lumen diameter of 1.4 mm hence below the crossing profile. The BRS was deployed across the LAD ostium with subsequent mini-kiss inflation. In-procedure thrombus formation on struts was detected by OCT in nine cases (Fig. 3). Fracture was detected in two BRS during implantation. One due to advancing a child catheter (Guideliner, Vascular Solutions) in the scaffold (Fig. 4a), and the second likely due to POT causing the scaffold to bulge around a jailed wire crossing the ostium of a more proximal side branch (Fig. 4b). The fractures were in both cases not visible by angiography.

Table 1 Procedural characteristic

Procedure time (min)	58 ± 19
Contrast use (mL)	166 ± 33
Fluouro time (min)	14.5 ± 5.3
Medication	
ASA	10 (100%)
ADP inhibitor	9 (90%)
Bivalirudin	5 (50%)
Pre dilation (n = 10)	
Nominal diameter (mm)	2.7 ± 0.5
Maximum diameter (mm)	2.8 ± 0.5
Scaffold length (mm)	22.7 ± 6.2
Scaffold nominal diameter (mm)	3.1 ± 0.21
Maximum deployment pressure (atm)	13.4 ± 4.1
Post dilation (n = 9)	
Balloon length (mm)	11.9 ± 4.3
Nominal diameter (mm)	3.0 ± 0.4
Maximum diameter (mm)	3.2 ± 0.5
POT (n = 10)	
Balloon length (mm)	8.8 ± 2.3
Nominal diameter (mm)	3.4 ± 0.3
Maximum diameter (mm)	3.6 ± 0.4

Numbers are given as mean ± SD or n (%)

ASA acetylsalicylic acid, *ADP* adenosine diphosphate, *POT* proximal optimization technique

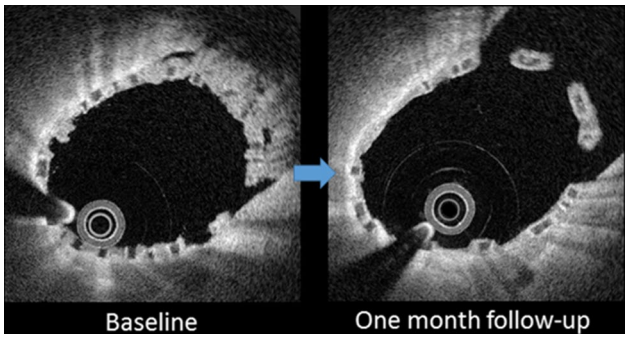

Fig. 3 Thrombus formation in the side branch ostium. The side branch had angiographic signs of thrombus in the ostium after scaffold implantation but maintained TIMI flow III. The patient was treated by bivalirudine. At 1-month follow-up the thrombus had resolved and jailing struts with tissue coverages were visible

Acute scaffold self-correction

In two cases, two repeat OCT-recordings were performed within 4 and 19 min of each other only separated by retraction of the jailed wire (Fig. 5). No dilation of the BRS was performed in between. In both cases severe malapposition of the scaffold was observed after post-dilation due to the jailed wire pushing struts towards the lumen center. After guidewire retraction, self-correction of the scaffolds was seen as spontaneous increase in scaffold area and a reduction in malapposition within minutes.

Quantitative OCT analysis

Two patients were excluded from the OCT-analysis. One due to inability to advance the imaging-catheter to the target lesion at follow-up and the second due to bail-out DES implantation. Quantitative OCT-results are presented in Table 2.

Scaffold self-correction and self-expansion

Changes in mean in- scaffold diameter are plotted in Fig. 6 showing that in-scaffold diameter was smaller than the nominal scaffold diameter at baseline but had become larger than the nominal diameter at 1-month follow-up in four patients. For the proximal MV the difference between actual scaffold diameter and nominal size was − 0.03 ± 0.19 mm at baseline

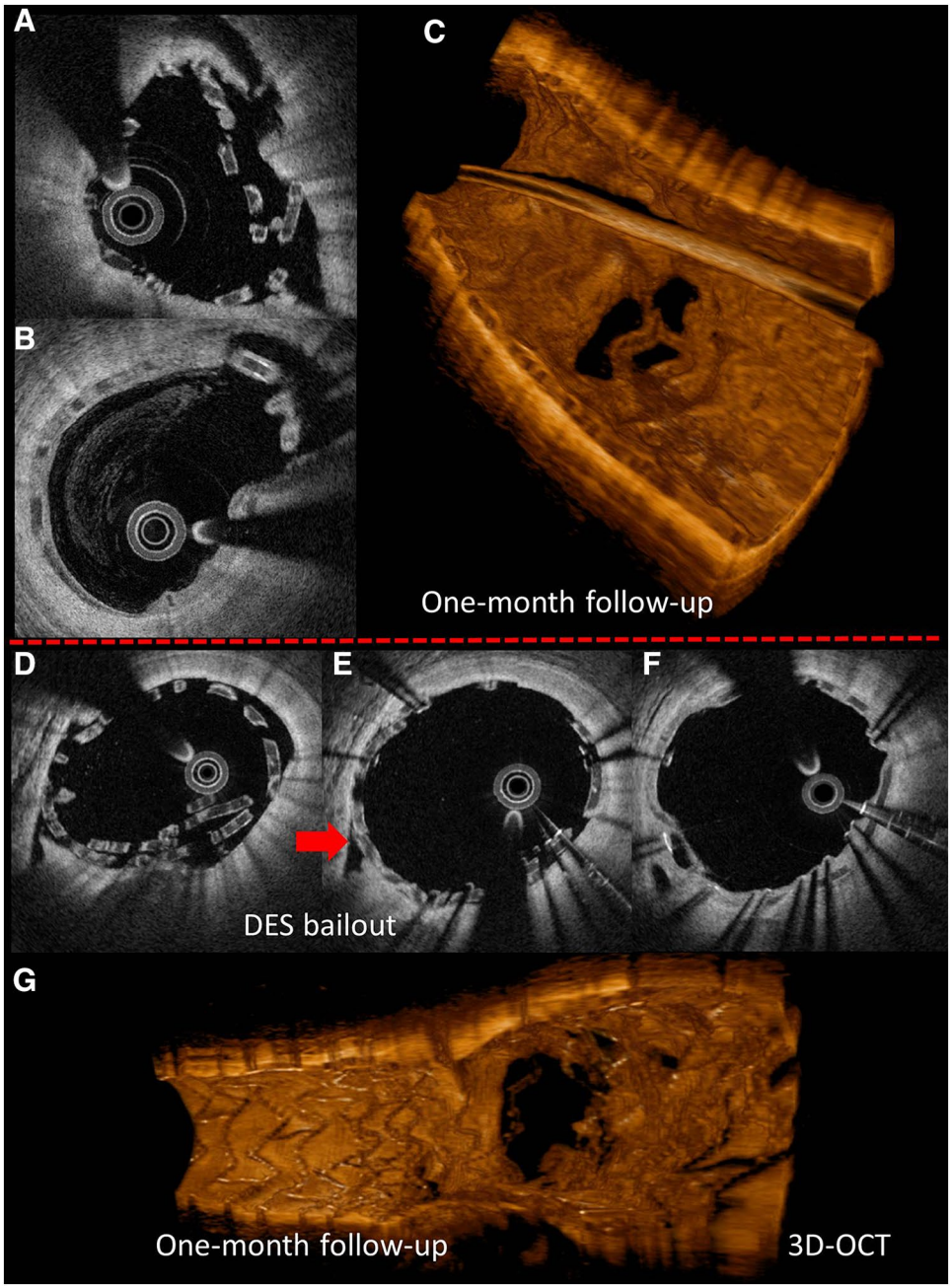

Fig. 4 Scaffold fracture. **a** Cross-sectional OCT after potentially wire induced fracture. Responsible wire has been retracted. **b** One-month follow-up. Note the spontaneously increased scaffold area despite fracture. **c** Partial healing at 1-month follow-up by 3D-OCT. **d** Child catheter induced scaffold fracture. **e** Matched cross-sectional image after bail-out stenting with a permanent stent. Note the reduction from 3 to 4 to 1–2 strut layers. **f** One-month follow-up showing partial strut coverage. **g** 3D-OCT reconstruction of the ostium at follow-up

(p = 0.68) at follow-up the difference was 0.21 ± 0.24 mm (p = 0.05) indicating self-expansion beyond the nominal diameter. In the distal MV, difference between scaffold diameter and nominal was −0.29 ± 0.23 mm (p = 0.02) at baseline compared to -0.11 ± 0.26 mm (p = 0.26) at follow-up.

Scaffold strut malapposition

Percentage malapposed struts at baseline was median 4.1% (1.3; 6.12) and was reduced at 1 month to 0.1% (0; 0.6) (p = 0.002). Segmental results are shown in Table 2.

Healing results

Fraction of non-jailing struts covered at 1 month was 64% (50; 76) and coverage of jailing struts was 66% (48; 100). Mean neointimal thickness was 64 µm (51; 79). The median coronary bifurcation stent healing index score was 17.5 (10.0; 29.5). The scores for the individual components of the healing index are listed in the supplementary material.

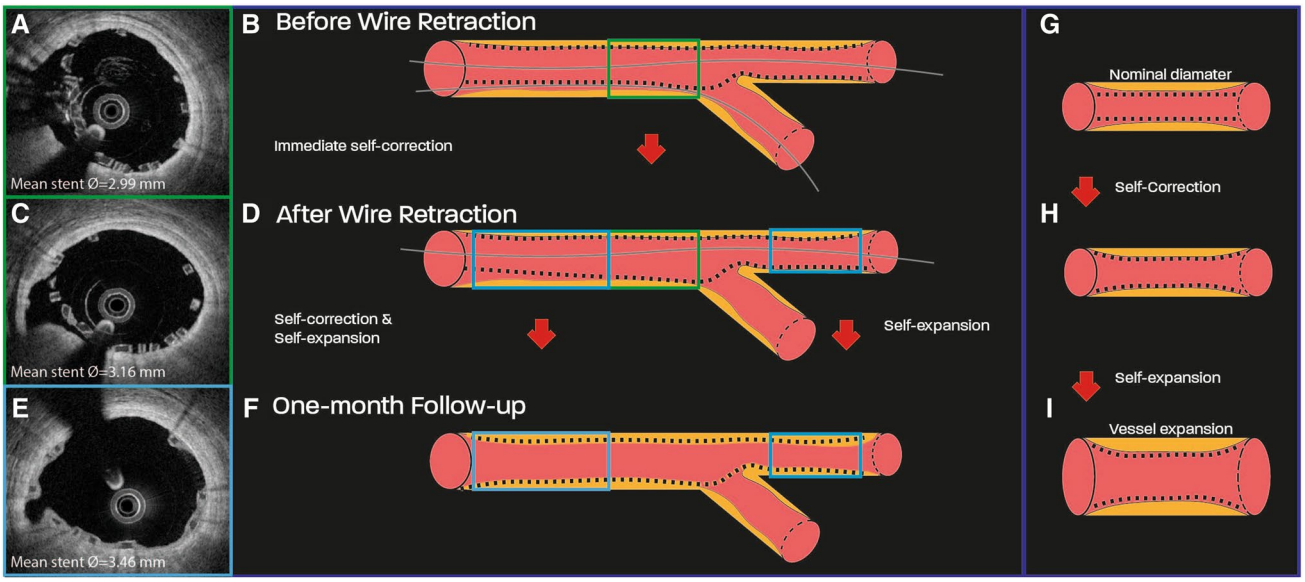

Fig. 5 Self-correction and self-expansion. Mechanisms of self-correction and self-expansion. **a** Malapposition caused by a jailed guidewire, **c** immediate self-correction, and **e** increase in scaffold area from baseline to follow-up. **b, d, f** proposed mechanism of scaffold self-correction and self-expansion. **g–i** Schematic drawing of self-correction from under expansion to nominal and further the self-expansion above nominal diameter

Ostial side branch OCT analysis

The ostial area of the SB was 2.3 ± 0.3 mm^2 at baseline and 3.1 ± 0.5 mm^2 at follow-up ($p = 0.09$) and the SB flow area was 1.4 mm^2 (0.9; 3.6) and 1.9 mm^2 (1.5; 2.3) at follow-up ($p = 0.89$). Area of struts and tissue in front of the SB ostium was 1.0 ± 0.8 mm^2 at baseline and 1.4 ± 1.0 mm^2 ($p = 0.07$) at follow-up (Table 3).

3D QCA results

Reference MV and SB diameters did not change from baseline to 1-month follow-up. In-scaffold diameter stenosis was 39 ± 10% at baseline and 35% (28; 50) at follow-up ($p = 0.58$). Maximum MV diameter stenosis was ≥ 30% in 5 of 9 cases post implantation thus feasibility was 50% (5 of 10 cases) according to the pre specified definition. The mean ostial SB diameter stenosis was reduced from 42 ± 15% to 34 ± 13% ($p = 0.01$) from baseline to follow-up. See Table 3.

Discussion

This is the first clinical study of coronary bifurcation treatment using the Desolve 150 BRS and the first clinical study to demonstrate acute and early self-correcting properties of a BRS. The main findings were as follows: (1) feasibility was acceptable but the large crossing profile caused a failed delivery, (2) some cases had prominent thrombus formation in the jailed SB ostium requiring treatment, (3) SB intervention by the mini-kiss technique was feasible when required, (4) mean scaffold area increased from baseline to 1-month follow-up, and detailed analysis confirmed the self-correcting properties and even self-expansion beyond the nominal scaffold size, (5) 64% of analysed struts were covered with neointima on all sides after 1 month, and (6) ostial SB area stenosis was significantly improved at 1-month follow-up.

Previous clinical trials investigating the Absorb BRS and Desolve 150 BRS excluded bifurcation lesions with SB diameter > 2.0 mm or > 1.5 mm by protocol [8, 13]. Despite theoretically appealing, bifurcation treatment using Absorb BRS has been sparsely characterized. The GHOST registry by Capodanno et al. investigating the Absorb BRS included 333 bifurcation lesions with 80% treated by the provisional strategy [2] and reported alarming 30 days, and 1-year ST rates of 1.4% and 2.5%. A retrospective study by Kawamoto et al. also investigating Absorb BRS found a 1-year TLR of 5.5% and ST rate of 1.5% after provisional stenting and TLR rates of 11.2% and zero ST in patients treated with two-stent techniques [14]. Causes of scaffold failure may be multifactorial but incomplete lesion coverage, device and vessel under expansion, increased surface trombogenecity, and luminal degradation of the scaffold have been identified as primary causes. Careful lesion selection and meticulous implantation techniques respecting the device limits may be of importance. With BRS, complete scaffold apposition may be of particular importance to ensure the scaffold is integrated in the vessel wall before the degradation process

Table 2 Quantitative OCT results

Outcome	Proximal MV segment			Bifurcation core segment			Distal MV segment		
	Baseline	Follow-up	p value	Baseline	Follow-up	p value	Baseline	Follow-up	p value
Mean lumen area (mm^2)	7.62 ± 1.04	7.34 ± 1.15	0.26	6.52 ± 1.26	6.27 ± 0.99	0.4	6.29 ± 1–24	5.66 ± 1.30	0.02
Min. lumen area (mm^2)	6.50 ± 0.91	6.19 ± 0.97	0.12	5.81 ± 1.25	5.40 ± 0.88	0.07	5.42 ± 0.92	4.62 ± 1.14	0.01
Mean lumen diameter (mm)	3.10 ± 0.21	3.05 ± 0.24	0.26	2.87 ± 0.28	2.82 ± 0.22	0.4	2.82 ± 0.28	2.66 ± 0.32	0.02
Mean scaffold area (mm^2)	7.51 ± 0.78	8.80 ± 0.93	0.01	6.80 ± 1.15	8.28 ± 1.17	0.03	6.29 ± 1.15	7.23 ± 1.32	0.01
Min. scaffold area (mm^2)	6.40 ± 0.79	7.26 ± 0.72	0.02	5.87 ± 1.08	6.75 ± 0.76	0.07	5.38 ± 0.91	6.05 ± 1.25	0.07
Mean scaffold diameter (mm)	3.09 ± 0.16	3.34 ± 0.18	0.01	2.93 ± 0.25	3.24 ± 0.23	0.03	2.82 ± 0.26	3.02 ± 0.29	0.01
Footprint (%)	17.1 ± 3.1	–	–	18.9 ± 3.1	–	–	18.5 ± 2.91	–	–
Footprint wide (%)	29.6 ± 3.8	–	–	30.7 ± 5.1	–	–	32.7 ± 4.35	–	–
Strut area (mm^2)	0.24 ± 0.06	0.28 ± 0.17	0.16	0.25 ± 0.05	0.28 ± 0.03	0.12	0.23 ± 0.04	0.26 ± 0.26	0.12
Malapposition (%)	1.1 (0.9; 9.9)	0 (0; 1.0)	0.01	4.6 (3.6; 6.4)	0 (0;0.51)	0.01	2.0 (0; 5.6)	0 (0; 0)	0.02
Malapposed strut counts (n)	3 (2; 19)	0 (0; 1.5)	0.01	16 (12; 20)	0 (0;1)	0.01	5 (0; 12)	0 (0; 0)	0.02
Coverage (%)*	–	62.7 (45.6; 68.5)	–	–	61.0 (43.7; 84.6)	–	–	62.7 (45.6; 68.5)	–
Mean neointimal thickness (µm)	–	54 (46; 67)	–	–	60 (52; 99)	–	–	66 (54; 76)	–
Mean neointimal area (mm^2)**	–	1.28 (1.02; 1.53)	–	–	–	–	–	1.36 (1.16; 1.53)	–
Max neointimal area (mm^2)**	–	1.78 (1.55; 2.29)	–	–	–	–	–	1.78 (1.65; 2.29)	–

Values are given as mean ± SD or median [IQR]

*Struts in front of the SB excluded

**Frames in the bifurcation core segment were excluded

leads to structural scaffold dismantling. We demonstrated that Desolve 150 effectively resolved malapposition by acute correction and early apposing properties. In bifurcations treated with Absorb BRS, one study reported proximal edge malapposition in 40% of cases compared to 23% (p = 0.04) in DES treated lesions [15]. Therefore, the European Bifurcation Club recommended to size Absorb BRS to the proximal MV reference and accept that the distal MV stent was under expanded in relation to the nominal diameter [6]. Still the limited expansion capacity left little room for apposing the scaffold if underestimating the true reference size of the vessel. The Desolve 150 expands to larger diameters before fracture [7], but as the self-correcting properties shown in vitro by Verheye et al., works predominantly up to nominal diameter (vendor information), sizing according to proximal MV reference also seems appropriate for this BRS. A theoretic disadvantage of sizing according to the proximal MV reference size is the deliberate over sizing of the BRS in the distal MV. The oversized scaffold is not fully expanded thereby increasing the scaffold surface to vessel ratio (footprint) which may increase the risk of small SB occlusion. Proximal optimization technique (POT) was mandatory as POT results in less SB obstruction and less malapposition after kissing-balloon using permanent DES [16] but the clinical significance of POT during bifurcation treatment using BRS remains to be investigated. We saw only limited malapposition in the proximal MV after mandatory POT and remaining malappostion was effectively resolved at 1-month follow-up indicating a favourable combined effect of POT and self-correcting properties for the Desolve 150 BRS. In a number of the BIFSORB cases the BRS expanded beyond the nominal size from baseline to 1 month. This surprising finding of self-expansion is in concordance with the increased scaffold area identified after 6-month by Abizaid et al. [17]. As the Desolve 150 BRS has lost about 80% of its molecular weight and most of its radial strength at 6 months it could not be excluded that the observed 6-month increase in- scaffold area was due to the combined effect of strut degradation and remodelling of the vessel. The present study indicates that the scaffold expansion is an early

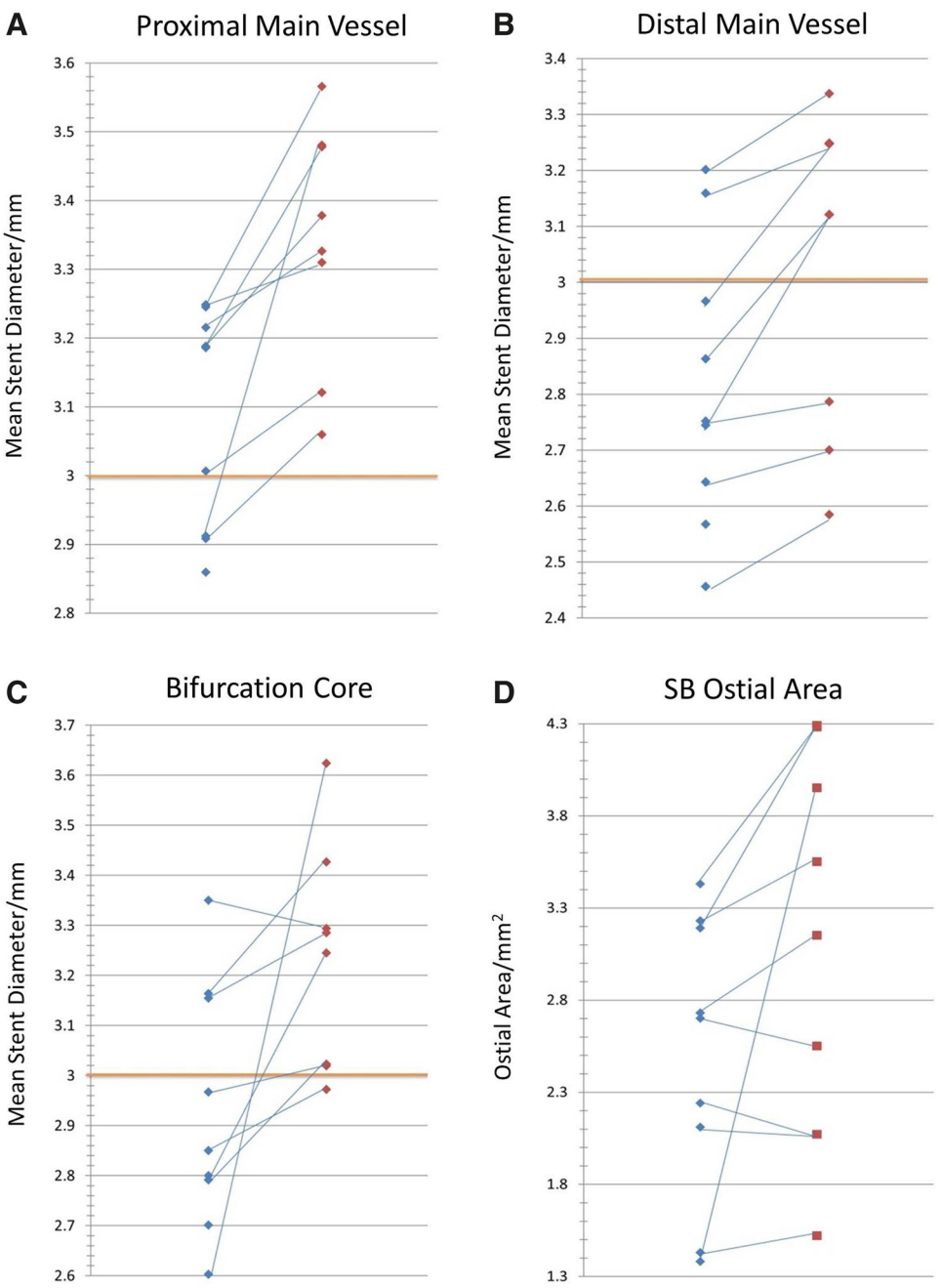

Fig. 6 Segmental mean scaffold diameter (**a**–**d**) shows the increase in ostial side branch area. Blue squares are baseline observations and red squares are the corresponding follow-up observations

phenomenon owing to unique mechanical properties of Desolve 150. This is supported by our finding that severe malapposition induced by the jailed wire was corrected within minutes effectively solving the acute malapposition. It has been proposed to use the "PSP" strategy when implanting the Absorb BRS [18]. The implantation of Desolve 150 scaffolds in BIFSORB pilot followed the same principles except in two cases where the distal MV segment was not post dilated (Supplementary Table 2).

Side branch intervention was performed in two cases due to severe pinching of the ostium after implantation caused by excessive thrombus formation. Other causes of pinching was excluded by OCT and CAG (spasms, plaque- or carina shift).The mechanism may relate to the vastly higher flow disturbance by the bulky BRS struts compared to the thin struts of regular permanent DES [4]. With regular DES, kissing balloon inflation to open a jailed SB should only be performed in case of SB stenosis > 75% or TIMI < 3 [11]. It is possible that the apparent larger risk of thrombus in the SB jailed by bulky BRS struts calls for a lower threshold for dilating the SB ostium. The improvement in our SB results from baseline to follow-up may be explain by; (1) thrombus

Table 3 Side branch ostium results

Outcome	Post implantation	Follow-up	p-value
3D-QCA			
Proximal MV ref. diameter (mm)	3.32 (3.89; 3.64)	3.21 (3.08; 3.21)	0.77
Distal MV ref. diameter (mm)	2.99 (2.81; 3.14)	3.03 (2.84; 3.13)	0.72
Side branch ref. diameter (mm)	2.42 ± 0.34	2.44 ± 0.31	0.85
Maximum in-scaffold area stenosis (%)	38 (31; 46)	35 (28; 50)	0.58
Maximum diameter stenosis (%)	35 (24; 37)	24 (22; 37)	0.33
Ostial area stenosis (%)	50 (42; 46)	44 (33; 49)	0.09
Ostial diameter stenosis (%)	42.3 ± 15.0	34.1 ± 12.7	0.01
3D-OCT measurements			
Ostial area (mm^2)	2.33 ± 0.28	3.06 ± 0.48	0.09
Maximum diameter (mm)	2.16 (1.50; 2.22)	2.13 (1.95; 2.41)	0.64
Minimum diameter (mm)	1.29 (1.17; 1.43)	1.37 (1.26; 1.84)	0.14
Area between struts (mm^2)	1.39 (0.89; 3.64)	1.86 (1.52; 2.34)	0.89
Strut and tissue obstruction area (mm^2)	1.01 ± 0.83	1.44 ± 1.03	0.07
Strut and tissue obstruction (%)	35 (27; 40)	34 (31; 41)	0.26
Flow area (%)	69 ± 6	62 ± 5	0.26

Numbers are given as means ± SD

3D QCA three-dimensional quantitative coronary angiography, *3D-OCT* three-dimensional optical coherence tomography

formation in the ostium at baseline, which has resolved at follow-up, (2) the increased flow after revascularization facilitates positive remodelling of the SB, (3) ostial spasm during implantation was abolished, or (4) the forces by the scaffold self-expansion properties caused favourable remodelling of the SB ostium. Further investigation is needed to characterize these mechanisms.

Ormiston and colleagues showed that with increased balloon pressure the Absorb BRS was more prone to fracture in the hoops than the Desolve 150 [7]. Fractured Absorb struts were found in 6% of bifurcations near the SB ostium after SB dilation using 2.5 mm balloons [19]. In the present study no fractures were apparently caused by overexpansion of the scaffold. One fracture was possibly caused by a jailing wire and another by child catheter collision. Managing the scaffold with extensive fracture by permanent DES implantation effectively reduced the multiple overlapping BRS struts to one or two layers at the facture site. Intravascular imaging has only been mandatory in few BRS studies [20, 21]. The present study showed that OCT findings affected the strategy providing information not detectable by angiography regarding scaffold sizing, the delivery route, thrombus formation, and scaffold fractures. OCT further allowed evaluation of wire positions after SB rewiring and in excluding accidental, abluminal re-wiring of the implanted scaffold [22]. At the present level of experience OCT is highly encouraged for guiding BRS implantation in bifurcations.

The BIFSORB study indicated an increased thrombogenicity during implantation compared to regular DES. The bulkiness of BRS struts and presence of malapposition increases flow disturbance around struts and is believed to increase fibrin deposits [23]. In three patients in BIFSORB pilot, thrombus formation may have been due a lack of ADP-antagonist preloading. None of the patients presented with any in-scaffold thrombus at 1 month. Still, in implanting dense and bulky scaffolds, a strategy of opening the SB ostium on a lower threshold compared to regular DES should be the focus of future research. Our findings suggest that effective ADP-antagonist pre-treatment should be mandatory and ticagrelor might be first choice if the patient tolerates an aggressive DAPT strategy.

Limitations

The present study was a hypothesis generating pilot study and results should be viewed as such. The small sample size precludes evaluation of clinical outcome. Longer term imaging follow-up after the expected BRS absorption time is required to assess the final healing result.

Conclusion

Treatment of coronary bifurcation lesions using Desolve 150 BRS was feasible except for one delivery failure and unsettling cases with thrombus formation in the jailed side branch ostium during implantation. No clinical significance of thrombus formation was found and thrombus was completely resolved at 1-month. Acute self-correcting scaffold properties were confirmed and the Desolve 150 BRS

demonstrated early self-expansion effectively resolving malapposition at 1 month follow-up.

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Compliance with ethical standards

Conflict of interest Emil Nielsen Holck: travel grants from St. Jude Medical, Elixir and Reva Medical; Camilla Fox Maule: travel grants from St. Jude Medical, Boston Scientific; Trine Ørhøj Barkholt travel grants from St. Jude Medical, Terumo; Lars Jakobsen: none; Michael Maeng: none; Jouke Dijkstra: none; Shengxian Tu: research grant from Medis medical imaging; Evald Høj Christiansen: Institutional research grants from Abbott, Elixir, St. Jude Medical and Terumo. Speaker fees from St. Jude Medical, Edwards, Biotronik; Niels Ramsing Holm[1]: institutional research grants from Medis medical imaging, Abbott, Elixir, St. Jude Medical and Terumo. Speaker fees from St. Jude Medical, Terumo, Reva Medical.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all patients included in the study.

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