Everolimus-eluting bioresorbable vascular scaffolds for treatment of complex chronic total occlusions

Jiang Ming Fam[1], MD; Soledad Ojeda[2], MD, PhD; Roberto Garbo[3], MD; Azeem Latib[4], MD; Alessio La Manna[5], MD; Beatriz Vaquerizo[6], MD; Marouane Boukhris[7], MD; Georgios J. Vlachojannis[8], MD, PhD; Robert-Jan van Geuns[1], MD, PhD; Babu Ezhumalai[9], MD; Hiroyoshi Kawamoto[4], MD; Jors van der Sijde[1], MD; Cordula Felix[1], MD; Manuel Pan[2], MD, PhD; Roberta Serdoz[10], MD; Giacomo Giovanni Boccuzzi[3], MD; Marcella De Paolis[1], MD; Gennaro Sardella[11], MD; Massimo Mancone[11], MD, PhD; Corrado Tamburino[5], MD, PhD; Pieter C. Smits[8], MD, PhD; Carlo Di Mario[10], MD, PhD; Ashok Seth[9], MD; Antonio Serra[6], MD; Antonio Colombo[4], MD; Patrick Serruys[1], MD, PhD; Alfredo R. Galassi[7], MD; Felix Zijlstra[1], MD, PhD; Nicolas M. Van Mieghem[1], MD, PhD; Roberto Diletti[1]*, MD, PhD

1. Department of Interventional Cardiology, Thoraxcenter, Erasmus MC, Rotterdam, the Netherlands; 2. Department of Cardiology, Reina Sofia Hospital, University of Córdoba (IMIBIC), Córdoba, Spain; 3. Department of Cardiology, San Giovanni Bosco Hospital, Turin, Italy; 4. San Raffaele Scientific Institute and EMO-GVM Centro Cuore Columbus, Milan, Italy; 5. Ferrarotto Hospital, University of Catania, Catania, Italy; 6. Cardiology Department, Hospital Sant Pau, Barcelona, Spain; 7. Department of Experimental and Clinical Medicine, University of Catania, Catania, Italy; 8. Department of Cardiology, Maasstad Hospital, Rotterdam, the Netherlands; 9. Fortis Escorts Heart Institute, New Delhi, India; 10. National Institute for Health Research, Cardiovascular BRU Royal Brompton & Harefield NHS Foundation Trust, London, United Kingdom; 11. Department of Cardiovascular, Respiratory, Nephrology, Anesthesiologic and Geriatric Sciences, Policlinico Umberto I, "Sapienza" University of Rome, Rome, Italy

J.M. Fam and R. Diletti contributed equally to this study.

GUEST EDITOR: Holger Thiele, MD; *University Heart Center Lübeck, Medical Clinic II, Lübeck, Germany*

KEYWORDS

- bioresorbable scaffolds
- chronic coronary total occlusion
- stable angina

Abstract

Aims: Bioresorbable vascular scaffolds (BVS) represent a novel therapeutic option for the treatment of coronary artery diseases. The objective of this study was to evaluate the feasibility of BVS implantation in complex chronic total occlusions (CTO).

Methods and results: The present report is a multicentre registry evaluating results after BVS deployment in challenging CTO lesions, defined as J-CTO score ≥2 (difficult or very difficult). A total of 105 patients were included in the present analysis. The mean J-CTO score was 2.61 (difficult 52.4%, very difficult 47.6%). Device success and procedural success rates were 98.1% and 97.1%, respectively. The retrograde approach was used in 25.7% of cases. After wire crossing, predilatation was performed in all cases with a mean predilatation balloon diameter of 2.73±0.43 mm. The mean scaffold length was 59.75±25.85 mm, with post-dilatation performed in 89.5% of the cases and a mean post-dilatation balloon diameter of 3.35±0.44 mm. Post-PCI minimal lumen diameter was 2.50±0.51 mm and percentage diameter stenosis 14.53±10.31%. At six-month follow-up, a total of three events were reported: one periprocedural myocardial infarction, one late scaffold thrombosis and one additional target lesion revascularisation.

Conclusions: The present report suggests the feasibility of BVS implantation in complex CTO lesions, given adequate lesion preparation and post-dilatation, with good acute angiographic results and midterm clinical outcomes.

*Corresponding author: Department of Cardiology, Thoraxcenter, Room Ba-581, Erasmus University Medical Center, 's-Gravendijkwal 230, 3015 GE Rotterdam, the Netherlands. E-mail: r.diletti@erasmusmc.nl

Abbreviations

BVS	bioresorbable vascular scaffolds
CTO	chronic total occlusions
ISA	incomplete strut apposition
MACE	major adverse cardiac events
MI	myocardial infarction
MLD	minimal lumen diameter
PCI	percutaneous coronary intervention
QCA	quantitative coronary angiography
RVD	reference vessel diameter
ST	scaffold thrombosis
TLR	target lesion revascularisation
%DS	percentage diameter stenosis

Introduction

Recanalisation of chronic total occlusions (CTO) by percutaneous coronary intervention (PCI) is associated with angina relief, improved left ventricular function[1-3], reduction in the rate of myocardial infarction and coronary artery bypass grafting with possibly improved patient survival[4-9], even in patients with well-developed collateral circulation[9].

However, despite recent advances in techniques and materials, the success rate for PCI in CTO is significantly lower compared to other lesion subsets[10,11]. CTO is present in up to 20% of patients with coronary artery disease undergoing elective angiography[12,13], yet this lesion subset represents only a minority of the target lesions treated with PCI[13,14]. In addition, CTO are often long lesions requiring the implantation of multiple metallic stents resulting in a "full metal jacket" treated artery[15], potentially increasing the risk of thrombosis and restenosis[16].

Furthermore, many patients with CTO have extensive coronary disease, requiring multivessel revascularisation[7,17], potentially benefiting from future bypass graft surgery. Given this background, the introduction of bioresorbable vascular scaffolds (BVS) provides a novel therapeutic option for the treatment of chronic total occlusions, allowing revascularisation without permanent caging of long coronary segments, potentially reducing the long-term limitations related to the presence of metallic stents and maintaining the option for future surgical revascularisations.

Bioresorbable technologies have so far mostly been tested in relatively simple coronary lesions[18,19], but there are very limited data and experience with BVS in complex scenarios, especially in CTO lesions[20-22].

Therefore, the objective of the present study was to evaluate the feasibility and midterm performance of BVS in CTO with challenging characteristics according to the J-CTO score[23].

Methods

This was a multicentre single-arm study conducted in the Netherlands, England, Italy, Spain and India from March 2015 to March 2016, to evaluate the feasibility, procedural results and midterm performance of the Absorb™ BVS (Abbott Vascular, Santa Clara, CA, USA) in patients with complex CTO lesions **(Figure 1)**.

Enrolled patients presented with silent ischaemia, stable angina pectoris or acute coronary syndromes. Lesion difficulty was graded according to the J-CTO score; lesions defined as "easy" (J-CTO score 0) or with intermediate difficulty (J-CTO score 1) were excluded from the analysis and only complex cases, defined as those with J-CTO score ≥2 (difficult or very difficult)[23], were evaluated. Exclusion criteria comprised contraindications to antiplatelet medication, maximal vessel diameter >4 mm, female patients with childbearing potential or currently breastfeeding and acute ST-segment elevation myocardial infarction.

Patients were considered suitable for the assessment of success rates after successful wire crossing of the CTO lesions.

Invasive imaging was per operator discretion. After implantation, optical coherence tomography (OCT) was performed in a patient subgroup of 10 patients to assess scaffold expansion and incomplete strut apposition (ISA).

The post-procedural drug regimen included dual antiplatelet therapy for at least 12 months followed by lifelong aspirin.
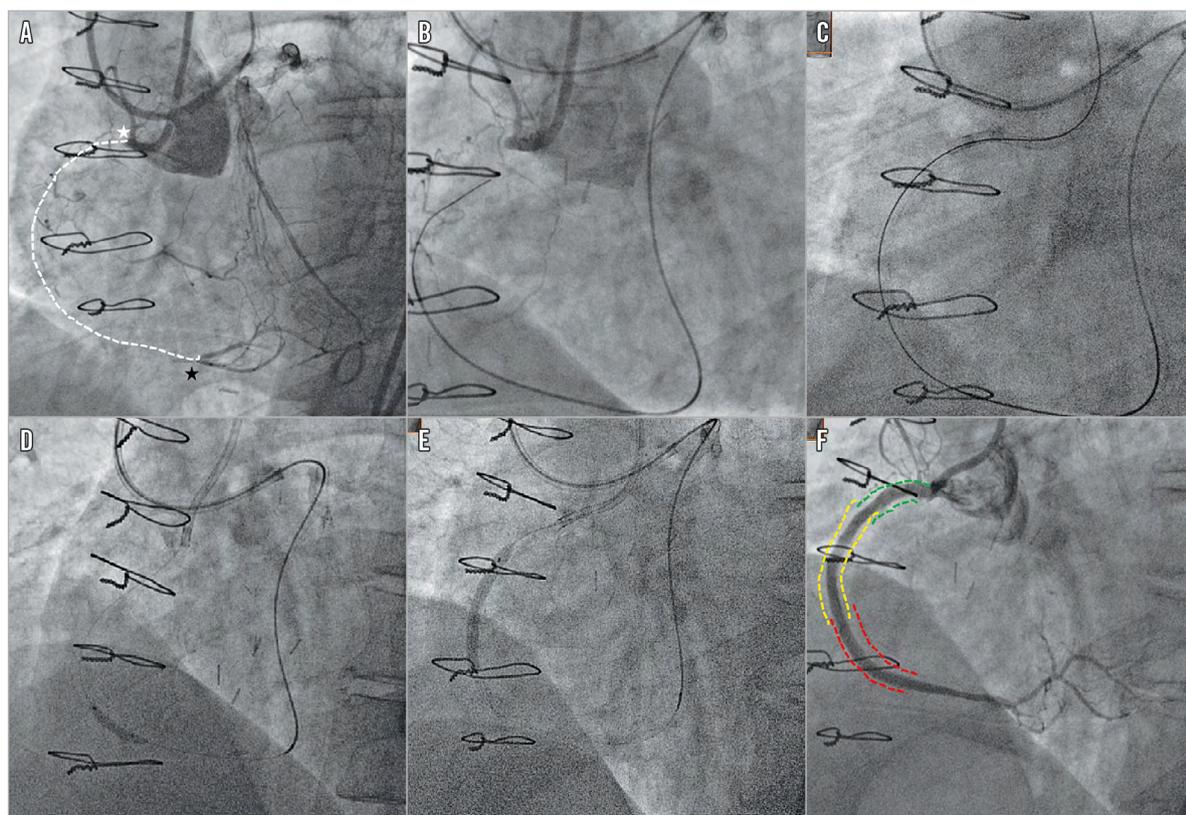
QUANTITATIVE CORONARY ANGIOGRAPHY

Quantitative coronary angiography (QCA) analyses were performed with the Coronary Angiography Analysis System (CAAS; Pie Medical Imaging, Maastricht, the Netherlands). The QCA measurements were performed pre and post BVS implantation. Angiographic views with minimal foreshortening of the lesion and limited overlap with other vessels were used. Pre-procedure QCA analysis was performed as proximally as possible to the occlusion (in case of a side branch, distally to the most proximal take-off of the side branch), as already described[24]. For each lesion, the following QCA parameters were measured in diastole: minimal lumen diameter (MLD), reference vessel diameter (RVD), percent diameter stenosis (%DS), and occlusion length. The J-CTO score was calculated to estimate lesion complexity and probability of successful guidewire crossing within 30 minutes.

OCT IMAGE ACQUISITION AND ANALYSIS

The C7 system or the ILUMIEN™ OPTIS™ system and the corresponding Dragonfly™ or Dragonfly™ Duo imaging catheters (St. Jude Medical, St. Paul, MN, USA) were used for image acquisition. The OCT catheter was advanced distal to the treated segment, and an automated pullback was performed at 20 mm/s with simultaneous contrast injection at a rate of 3 to 4 ml/s using a power injector. Two sequential pullbacks were performed to enable assessment of the entire scaffolded/stented segment when required.

The OCT measurements were performed offline using the QCU-CMS software (Medis medical imaging systems, Leiden, the Netherlands). Analysis was performed at 1 mm intervals within the entire scaffolded segment and 5 mm proximal and distal to the stent edge. Lumen and scaffold area and diameter measurements were performed in the region of interest (ROI), as appropriate, using standard methodology for the analysis of bioresorbable scaffolds[24,25]. Eccentricity index and symmetry index were additionally calculated as previously reported[26,27].

Figure 1. *Successful implantation of bioresorbable vascular scaffolds in a right coronary artery with a chronic total occlusion using a retrograde strategy. The lesion had a blunt stump (white star) with a good distal landing zone (black star) (A). Good septal collaterals were seen from contralateral contrast injection. Successful crossing was achieved with a Conquest Pro wire on a Corsair microcatheter support (Asahi Intecc) (B & C). Predilation (D) was performed before scaffold deployment (two BVS 3.5×28 mm and one 3.0×28 mm in overlap) (E), with a good angiographic result (F).*

STUDY DEFINITIONS

Device success was defined as successful BVS implantation with the attainment of ≤30% final in-segment residual stenosis by angiographic visual estimation after Absorb BVS implantation. Procedure success was defined as device success and no major periprocedural complications (emergent CABG, coronary perforation requiring pericardial drainage, residual dissection impairing vessel flow – TIMI flow 2 or less). Clinical success was defined as procedural success and no in-hospital major adverse cardiac events (MACE). All deaths were considered cardiac unless an undisputed non-cardiac cause was identified. Myocardial infarction (MI) and scaffold thrombosis were defined according to the Academic Research Consortium (ARC) definitions[28]. Any target lesion revascularisation (TLR) was defined as clinically driven if at repeat angiography a diameter stenosis >70% was observed, or if a diameter stenosis >50% was present in association with recurrent angina pectoris, objective signs of ischaemia (ECG changes) at rest or during exercise test likely to be related to the target vessel, or if there were abnormal results of any invasive functional diagnostic test.

MACE was defined as the composite of cardiac death, any reinfarction (Q- or non-Q-wave), emergent bypass surgery (CABG), or clinically driven target lesion revascularisation (TLR).

STATISTICAL ANALYSIS

Categorical variables are reported as counts and percentages and continuous variables as mean±standard deviation. Statistical analyses were performed using SPSS for Windows, Version 20 (IBM Corp., Armonk, NY, USA).

Results

PATIENT DEMOGRAPHICS

Baseline demographics of the patients (N=105) are presented in **Table 1.** Mean age was 59.40±8.96 years, 89.5% of the patients were male, 33.3% had diabetes mellitus, and 68.6% presented with stable angina.

ANGIOGRAPHIC AND LESION CHARACTERISTICS

The most frequently treated vessel was the right coronary artery (44.8%), 35.2% of the CTO were located at the proximal/ostial coronary segment, 28.6% of the cases involved a bifurcation lesion with a side branch ≥2 mm, 56.2% of the cases showed multivessel disease, 74.3% of the lesions had an occlusion length ≥20 mm, and 43.8% had bridging collaterals at the level of the occlusion. Rentrop grade 3 collaterals were present in 29.5% of the lesions.

Table 1. Baseline demographic and clinical characteristics.

Clinical characteristics	N=105
Age, yrs	59.40±8.96
Male gender, %	89.5
History of smoking, %	48.6
Diabetes mellitus, %	33.3
Dyslipidaemia, %	72.4
Hypertension, %	69.5
Family history of CAD, %	21.9
Myocardial infarct, %	29.5
Prior PCI, %	46.7
Prior CABG, %	2.9
Silent ischaemia, %	5.7
Stable angina, %	68.6
Acute coronary syndrome, %	23.8
Congestive cardiac failure, %	1.9
Values specified as percentages or mean with standard deviation. CABG: coronary artery bypass graft; CAD: coronary artery disease; PCI: percutaneous coronary intervention	

Table 2. Baseline lesion and angiographic characteristics.

Lesion characteristics	N=105
Left anterior descending artery, %	41.9
Left circumflex/marginal, %	12.4
Right coronary artery, %	44.8
Ostial-proximal, %	35.2
Mid, %	61.9
Distal, %	2.8
Bifurcation, %	28.6
Single-vessel disease, %	43.8
Two-vessel disease, %	40.0
Three-vessel disease, %	16.2
Severe tortuosity, %	26.7
Blunt stump, %	60.0
Calcification present, %	70.5
Bending >45 degrees, %	49.5
Occlusion ≥20 mm, %	74.3
Retry lesion, %	11.4
(Any) Side branch present, %	65.7
(Any) Bridge collateral present, %	43.8
Rentrop grade 3 collateral, %	29.5
Bad landing zone, %	34.3
Bad distal vessel, %	26.7
Mean J-CTO score	2.61±0.75
Easy (J-CTO score 0), %	0
Intermediate (J-CTO score 1), %	0
Difficult (J-CTO score 2), %	52.4
Very difficult (J-CTO score ≥3), %	47.6
J-CTO score 3	37.1
J-CTO score 4	7.6
J-CTO score 5	2.9
QCA analysis	
Pre-treatment reference vessel diameter, mm	2.71±0.55
Pre-treatment diameter stenosis, %	100.0
Post-treatment minimal lumen diameter, mm	2.50±0.51
Post-treatment reference vessel diameter, mm	2.88±0.51
Post-treatment diameter stenosis, %	14.53±10.31
Values specified as percentages or mean with standard deviation.	

The mean J-CTO score was 2.61, with nearly half of the cases (47.6%) having a score ≥3 **(Table 2)**. QCA showed a pre-treatment reference vessel diameter of 2.71±0.55 mm, a post-PCI mean MLD of 2.50±0.51 mm and a percentage diameter stenosis of 14.53±10.31% **(Table 2)**.

PROCEDURAL CHARACTERISTICS

Procedural characteristics are tabulated in **Table 3.** The majority of the cases (62.9%) were performed with a bifemoral approach and contralateral injections. A retrograde strategy occurred in 25.7% of the procedures **(Figure 1)**. Predilatation was performed in every lesion with a mean predilatation balloon diameter of 2.73±0.43 mm. Guidewires used for successful crossing included the Fielder XT-R/FC (23.8%), Conquest Pro 9/12 (12.4%), Gaia First/Second/Third (11.4%), MIRACLEbros 3/6 (8.6%) (all Asahi Intecc, Aichi, Japan) and Pilot® 150/200 (19.0%) (Abbott Vascular/ Guidant, Santa Clara, CA, USA). A total of 256 BVS were implanted with a mean number of scaffolds implanted per lesion of 2.44±1.12, including 79 overlaps, a total scaffold length per lesion of 59.75±25.85 mm and a mean scaffold diameter per lesion of 3.00±0.31 mm. Post-dilatation was performed in 89.5% of the cases.

OCT MEASUREMENTS POST SCAFFOLD DEPLOYMENT

Post scaffold deployment, imaging of the scaffolds with OCT was performed in 10 cases. Mean lumen area was 7.31±1.28 mm², with a minimum lumen area of 5.35±1.53 mm² and residual area stenosis of 6.83±26.44%. Mean ISA area was 0.03±0.04 mm². Mean eccentricity index was 0.86±0.04 and symmetry index was 0.37±0.10 **(Table 4)**.

CLINICAL OUTCOMES

Device success and procedural success were 98.1% and 97.1%, respectively. No severe in-hospital adverse events were observed.

The six-month follow-up was completed for 96 patients (91.4%). A total of three events were reported, one periprocedural myocardial infarction, one late scaffold thrombosis, and one additional target lesion revascularisation **(Table 5, Figure 2)**.

In particular, the patient who developed late scaffold thrombosis had three Absorb BVS scaffolds (3.0×28 mm; 3.5×18 mm and 3.5×18 mm in an overlapping manner) implanted in the left anterior descending artery (J-CTO score 3). The lesion was predilated with a 3.0 mm balloon and post-dilated with a 3.5 mm non-compliant balloon. On day 47 after the index procedure, the patient was re-admitted with a non-ST-segment elevation myocardial infarction while on DAPT. The coronary angiogram showed

Table 3. Procedural characteristics.

Procedural characteristics	N=105
Single access, femoral	22.8
Single access, radial	9.5
Double access, femoral and radial	4.8
Double access, both femoral	62.9
Contralateral injection	63.8
Intravascular ultrasound	55.2
Optical coherence tomography	9.5
Antegrade strategy	74.3
Retrograde strategy	25.7
Number of guidewires used per lesion	3.27±1.69
Conquest Pro 9/12	12.4
Fielder XT-R/FC	23.8
Gaia First/Second/Third	11.4
MIRACLEbros 3/6	8.6
Pilot 150/200	19.0
Sion/Sion Black/Sion Blue	6.7
Ultimate Bro	5.7
BMW	1.9
Cross-IT 100/200 XT/Progress	8.6
Whisper	1.9
Predilation performed	100
Use of OTW balloon	8.6
Microcatheters used	85.7
Cutting balloon/rotational atherectomy (11/1)	11.4
Maximum predilation balloon diameter, mm	2.73±0.43
Maximum predilation pressure, atm	14.97±2.72
Total number of scaffolds implanted	256
Number of scaffolds per lesion	2.44±1.12
Overlapping scaffolds	79.0
Total scaffold length per lesion, mm	59.75±25.85
Mean scaffold diameter per lesion, mm	3.00±0.31
Maximum scaffold implantation pressure, atm	13.82±2.93
Post-dilation performed	89.5
Maximum post-dilation balloon diameter, mm	3.35±0.44
Procedure time, min	167.06±78.28
Fluoroscopy time, min	60.95±35.16
Contrast volume, ml	334.63±138.01
Antiplatelet therapy	Aspirin	100.0
	Clopidogrel	47.6
	Prasugrel	28.6
	Ticagrelor	23.8
Device success	98.1
Procedural success	97.1

Values specified as percentages or mean with standard deviation. OTW: over the wire.

scaffold thrombosis involving the target vessel which was treated with re-PCI (thrombectomy, implantation of a metal drug-eluting stent and intravenous infusion of eptifibatide).

Table 4. Optical coherence tomography measurements post scaffold deployment.

Number of lesions	N=10
Analysed length, mm	36.64±11.64
Reference lumen area, mm^2	6.00±1.88
Minimum lumen area, mm^2	5.35±1.53
Mean lumen area, mm^2	7.31±1.28
Lumen volume, mm^3	254.02±79.47
Maximum scaffold diameter, mm	3.85±0.45
Minimum scaffold diameter, mm	2.42±0.32
MSA, mm^2	5.84±1.31
Mean scaffold area, mm^2	7.71±1.37
Scaffold volume, mm^3	268.81±93.51
RAS, %	6.83±26.44
EI	0.86±0.04
EI at MSA	0.84±0.06
SI	0.37±0.10
Device with ISA detected	6
Mean ISA area, mm^2	0.03±0.04
Total struts	3,387
Malapposed struts	39
Mean prolapse area, mm^2	0.53±0.42
Edge dissection	8 (80.0)

Values are expressed as mean±standard deviation. EI: eccentricity index; ISA: incomplete strut apposition; MSA: minimum scaffold area; RAS: residual area stenosis; SI: symmetry index
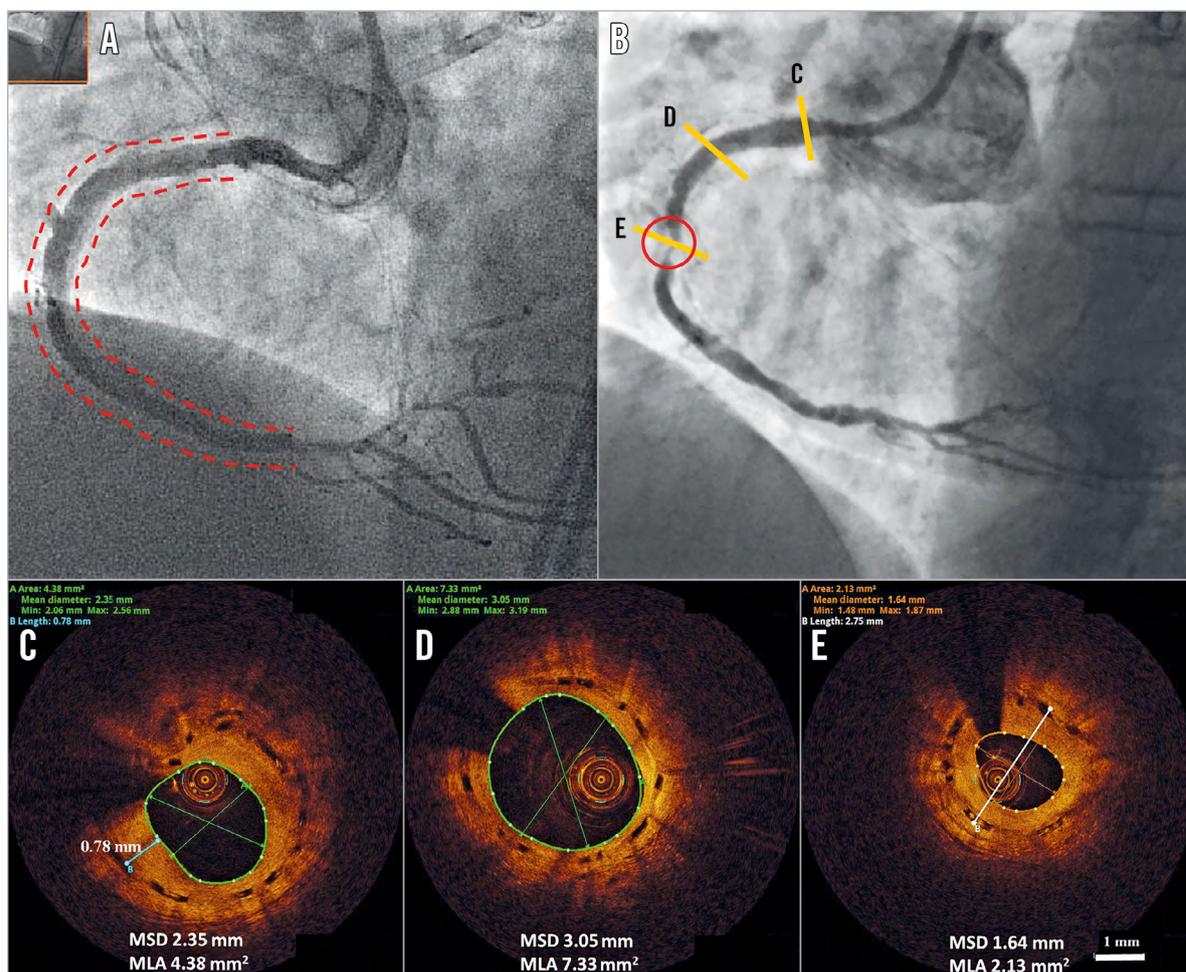
Computed tomography scans were performed at six months in 34 patients **(Figure 3)**, and revealed scaffold restenosis in two patients. One patient was symptomatic and underwent target lesion revascularisation; the other patient was asymptomatic without inducible ischaemia and was managed conservatively. All patients were alive at six-month follow-up.
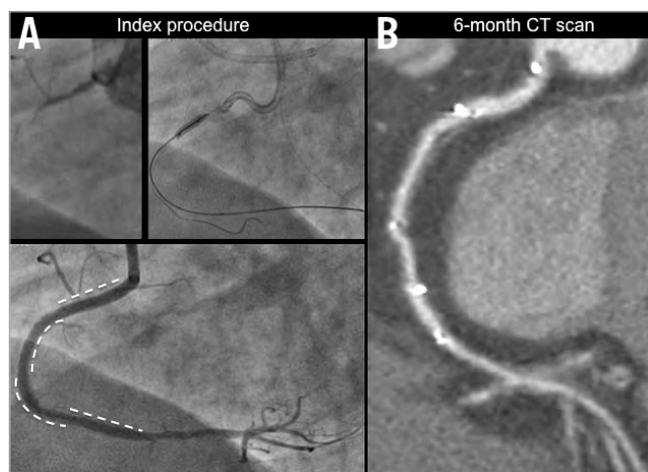
Discussion

Coronary chronic total occlusions are typically regarded as a challenging subset burdened by low procedural success and poorer clinical outcomes when compared to other lesion types. Even

Table 5. Clinical events at 6-month follow-up.

Outcomes		N=96
Cardiac death		(0/96) 0%
All MI		(2/96) 2.08%
Non-Q-wave MI		(2/96) 2.08%
Q-wave MI		(0/96) 0%
Scaffold thrombosis	Early	(0/96) 0%
	Late	(1/96) 1.04%
Clinically driven TLR		(2/96) 2.08%
Non-TLR		(0/96) 0%

A total of three patients had a clinical event: one periprocedural non-Q-wave myocardial infarction, one late scaffold thrombosis (that was reported as ST, MI and TLR), and one additional target lesion revascularisation. MI: myocardial infarction; TLR: target lesion revascularisation

Figure 2. *Subintimal BVS implantation. The final result at the index procedure after subintimal tracking, true lumen re-entry and subintimal BVS implantation (A). Two-year angiographic appearance (B) with an in-scaffold restenosis (circled area). C) In-scaffold restenosis. D) & E) Long-term vascular healing after BVS subintimal implantation. MLA: mean lumen area; MSD: mean scaffold diameter*

Figure 3. *Computed tomography scans at six-month follow-up. An occluded right coronary artery treated with multiple BVS implantation at the index procedure (A). At six-month follow-up the vessel appears patent on CT scan angiography (B). The position of the implanted BVS is described by the presence of the radiopaque markers.*

though the introduction of drug-eluting stents has reduced the rate of in-stent restenosis, the adoption of these devices is not devoid of limitations, especially in chronically occluded vessels.

Treatment of CTO often implies stenting of long coronary segments with permanent vessel caging of a large part of the artery. This is not only associated with a possible increased risk of restenosis and stent thrombosis, but also precludes future surgical revascularisations in patients who often show diffuse and multivessel atherosclerosis, as is confirmed in the present report with 56.2% of the patients having multivessel disease.

Moreover, a flow-dependent positive vascular remodelling process marks a progressive increase in lumen diameter, external elastic membrane (EEM) diameter, lumen area and EEM area[29-31]. Park and colleagues[29] reported that this increase in lumen dimensions results in more incomplete stent apposition at six-month follow-up in patients treated for CTO lesions. Theoretically, the bioresorption process could eliminate this limitation, as the scaffold remnants can already follow the vessel wall motion between six months and one year after implantation[19].

Recently, small series of BVS in CTO reported similar clinical outcomes but they had overall lower lesion complexity[20-22]. The present investigation focused specifically on complex CTO, illustrated by the fact that half of the CTO were very difficult and we excluded all easy or intermediately difficult CTO as per the J-CTO score. The final angiographic results showed a post-PCI minimal lumen diameter of 2.50±0.51 mm with a low percentage diameter stenosis (14.53±10.31%) and good final TIMI flow. Such promising acute results are in line with angiographic data obtained in previous reports evaluating the BVS as well as metallic DES implantation in CTO lesions[20,22,32].

In our series, advanced BVS implantation techniques were applied, including balloon predilatation with a balloon-to-vessel ratio approaching 1:1, scaffold implantation at nominal pressures and post-dilatation with non-compliant balloons up to 5 mm larger than the nominal scaffold diameter. This approach translated into optimal scaffold apposition and expansion with a very low ISA area by OCT. The mean scaffold eccentricity index and symmetry index were similar to those typically reported for BVS and for metal DES in non-chronically occluded vessels[26,27,33].

Clinical follow-up at six months demonstrated survival and target lesion revascularisation rates comparable to metal stents in CTO lesions[34].

A current limitation of bioresorbable technology is the high strut thickness that could be associated with a delayed vascular healing and endothelialisation, especially at the site of the overlap. In addition, the larger profile of this device compared with previous-generation metallic DES could represent an important obstacle when approaching tortuous, calcified vessels. New delivery systems and reduction in strut thickness and crossing profile may further improve device performance in the future.

Our results support the feasibility of BVS implantation in CTO lesions even in complex scenarios, given an appropriate implantation technique, and justify further research including direct comparison with standard metal drug-eluting stents and analysis of angiographic, intravascular imaging and clinical results at long-term follow-up.

Limitations

This was a single-arm retrospective study. As such, procedural and clinical outcomes cannot be directly compared with lesions treated with metallic drug-eluting stents. Given the limited number of patients and the low rate of events, clinical outcome data should be considered as purely descriptive and hypothesis-generating. The BVS was used as per operator discretion; this methodology may be a source of selection bias. Although personnel trained in an independent core lab performed the QCA analysis, a certified core lab analysis was not available. Invasive imaging was also performed per operator discretion and lacked uniformity.

Conclusions

The present report suggests the feasibility of BVS implantation in complex CTO, given adequate lesion preparation and post-dilatation, with good acute angiographic results and midterm clinical outcomes.

Impact on daily practice

Our observations suggest the feasibility of bioresorbable scaffold implantation in patients with chronic total occlusion and complex anatomies. Optimal antiplatelet regimen, accurate comparison with the current-generation metallic DES and long-term performance remain to be evaluated.

Guest Editor

This paper was guest edited by Holger Thiele, MD; University Heart Center Lübeck, Medical Clinic II, Lübeck, Germany.

Conflict of interest statement

The authors have no conflicts of interest to declare. The Guest Editor has no conflicts of interest to declare.

References

1. Sirnes PA, Myreng Y, Mølstad P, Bonarjee V, Golf S. Improvement in left ventricular ejection fraction and wall motion after successful recanalization of chronic coronary occlusions. *Eur Heart J.* 1998;19:273-81.

2. Chung CM, Nakamura S, Tanaka K, Tanigawa J, Kitano K, Akiyama T, Matoba Y, Katoh O. Effect of recanalization of chronic total occlusions on global and regional left ventricular function in patients with or without previous myocardial infarction. *Catheter Cardiovasc Interv.* 2003;60:368-74.

3. Chadid P, Markovic S, Bernhardt P, Hombach V, Rottbauer W, Wohrle J. Improvement of regional and global left ventricular function in magnetic resonance imaging after recanalization of true coronary chronic total occlusions. *Cardiovasc Revasc Med.* 2015;16:228-32.

4. George S, Cockburn J, Clayton TC, Ludman P, Cotton J, Spratt J, Redwood S, de Belder M, de Belder A, Hill J, Hoye A, Palmer N, Rathore S, Gershlick A, Di Mario C, Hildick-Smith D; British Cardiovascular Intervention Society; National Institute for Cardiovascular Outcomes Research. Long-term follow-up of elective chronic total coronary occlusion angioplasty: analysis from the U.K. Central Cardiac Audit Database. *J Am Coll Cardiol.* 2014;64:235-43.

5. Suero JA, Marso SP, Jones PG, Laster SB, Huber KC, Giorgi LV, Johnson WL, Rutherford BD. Procedural outcomes and long-term survival among patients undergoing percutaneous coronary intervention of a chronic total occlusion in native coronary arteries: a 20-year experience. *J Am Coll Cardiol.* 2001;38: 409-14.

6. Aziz S, Stables RH, Grayson AD, Perry RA, Ramsdale DR. Percutaneous coronary intervention for chronic total occlusions: improved survival for patients with successful revascularization compared to a failed procedure. *Catheter Cardiovasc Interv.* 2007; 70:15-20.

7. Valenti R, Migliorini A, Signorini U, Vergara R, Parodi G, Carrabba N, Cerisano G, Antoniucci D. Impact of complete revascularization with percutaneous coronary intervention on survival in patients with at least one chronic total occlusion. *Eur Heart J.* 2008;29:2336-42.

8. Christakopoulos GE, Christopoulos G, Carlino M, Jeroudi OM, Roesle M, Rangan BV, Abdullah S, Grodin J, Kumbhani DJ, Vo M, Luna M, Alaswad K, Karmpaliotis D, Rinfret S, Garcia S, Banerjee S, Brilakis ES. Meta-analysis of clinical outcomes of patients who underwent percutaneous coronary interventions for chronic total occlusions. *Am J Cardiol.* 2015; 115:1367-75.

9. Jang WJ, Yang JH, Choi SH, Song YB, Hahn JY, Choi JH, Kim WS, Lee YT, Gwon HC. Long-term survival benefit of revascularization compared with medical therapy in patients with coronary chronic total occlusion and well-developed collateral circulation. *JACC Cardiovasc Interv.* 2015;8:271-9.

10. Abbott JD, Kip KE, Vlachos HA, Sawhney N, Srinivas VS, Jacobs AK, Holmes DR, Williams DO. Recent trends in the percutaneous treatment of chronic total coronary occlusions. *Am J Cardiol.* 2006;97:1691-6.

11. Prasad A, Rihal CS, Lennon RJ, Wiste HJ, Singh M, Holmes DR Jr. Trends in outcomes after percutaneous coronary intervention for chronic total occlusions: a 25-year experience from the Mayo Clinic. *J Am Coll Cardiol.* 2007;49:1611-8.

12. Fefer P, Knudtson ML, Cheema AN, Galbraith PD, Osherov AB, Yalonetsky S, Gannot S, Samuel M, Weisbrod M, Bierstone D, Sparkes JD, Wright GA, Strauss BH. Current perspectives on coronary chronic total occlusions: the Canadian Multicenter Chronic Total Occlusions Registry. *J Am Coll Cardiol.* 2012;59: 991-7.

13. Christofferson RD, Lehmann KG, Martin GV, Every N, Caldwell JH, Kapadia SR. Effect of chronic total coronary occlusion on treatment strategy. *Am J Cardiol.* 2005;95:1088-91.

14. Kahn JK. Angiographic suitability for catheter revascularization of total coronary occlusions in patients from a community hospital setting. *Am Heart J.* 1993;126:561-4.

15. Sharp AS, Latib A, Ielasi A, Larosa C, Godino C, Saolini M, Magni V, Gerber RT, Montorfano M, Carlino M, Michev I, Chieffo A, Colombo A. Long-term follow-up on a large cohort of "full-metal jacket" percutaneous coronary intervention procedures. *Circ Cardiovasc Interv.* 2009;2:416-22.

16. Moreno R, Fernandez C, Hernandez R, Alfonso F, Angiolillo DJ, Sabate M, Escaned J, Banuelos C, Fernandez-Ortiz A, Macaya C. Drug-eluting stent thrombosis: results from a pooled analysis including 10 randomized studies. *J Am Coll Cardiol.* 2005;45:954-9.

17. Olivari Z, Rubartelli P, Piscione F, Ettori F, Fontanelli A, Salemme L, Giachero C, Di Mario C, Gabrielli G, Spedicato L, Bedogni F; TOAST-GISE Investigators. Immediate results and one-year clinical outcome after percutaneous coronary interventions in chronic total occlusions: data from a multicenter, prospective, observational study (TOAST-GISE). *J Am Coll Cardiol.* 2003;41:1672-8.

18. Serruys PW, Chevalier B, Dudek D, Cequier A, Carrie D, Iniguez A, Dominici M, van der Schaaf RJ, Haude M, Wasungu L, Veldhof S, Peng L, Staehr P, Grundeken MJ, Ishibashi Y, Garcia-Garcia HM, Onuma Y. A bioresorbable everolimus-eluting scaffold versus a metallic everolimus-eluting stent for ischaemic heart disease caused by de-novo native coronary artery lesions (ABSORB II): an interim 1-year analysis of clinical and procedural secondary outcomes from a randomised controlled trial. *Lancet.* 2015;385: 43-54.

19. Serruys PW, Onuma Y, Dudek D, Smits PC, Koolen J, Chevalier B, de Bruyne B, Thuesen L, McClean D, van Geuns RJ, Windecker S, Whitbourn R, Meredith I, Dorange C, Veldhof S, Hebert KM, Sudhir K, Garcia-Garcia HM, Ormiston JA. Evaluation of the second generation of a bioresorbable everolimus-eluting vascular scaffold for the treatment of de novo coronary artery stenosis: 12-month clinical and imaging outcomes. *J Am Coll Cardiol.* 2011;58:1578-88.

20. Vaquerizo B, Barros A, Pujadas S, Bajo E, Estrada D, Miranda-Guardiola F, Rigla J, Jimenez M, Cinca J, Serra A. Bioresorbable everolimus-eluting vascular scaffold for the treatment of chronic total occlusions: CTO-ABSORB pilot study. *EuroIntervention.* 2015;11:555-6.

21. Wiebe J, Liebetrau C, Dorr O, Most A, Weipert K, Rixe J, Bauer T, Mollmann H, Elsasser A, Hamm CW, Nef HM. Feasibility of everolimus-eluting bioresorbable vascular scaffolds in patients with chronic total occlusion. *Int J Cardiol.* 2015;179:90-4.

22. Ojeda S, Pan M, Romero M, Suarez de Lezo J, Mazuelos F, Segura J, Espejo S, Morenate C, Blanco M, Martin P, Medina A, Suarez de Lezo J. Outcomes and computed tomography scan follow-up of bioresorbable vascular scaffold for the percutaneous treatment of chronic total coronary artery occlusion. *Am J Cardiol.* 2015;115:1487-93.

23. Morino Y, Abe M, Morimoto T, Kimura T, Hayashi Y, Muramatsu T, Ochiai M, Noguchi Y, Kato K, Shibata Y, Hiasa Y, Doi O, Yamashita T, Hinohara T, Tanaka H, Mitsudo K; J-CTO Registry Investigators. Predicting successful guidewire crossing through chronic total occlusion of native coronary lesions within 30 minutes: the J-CTO (Multicenter CTO Registry in Japan) score as a difficulty grading and time assessment tool. *JACC Cardiovasc Interv.* 2011;4:213-21.

24. Diletti R, Karanasos A, Muramatsu T, Nakatani S, Van Mieghem NM, Onuma Y, Nauta ST, Ishibashi Y, Lenzen MJ, Ligthart J, Schultz C, Regar E, de Jaegere PP, Serruys PW, Zijlstra F, van Geuns RJ. Everolimus-eluting bioresorbable vascular scaffolds for treatment of patients presenting with ST-segment elevation myocardial infarction: BVS STEMI first study. *Eur Heart J.* 2014;35:777-86.

25. Serruys PW, Onuma Y, Ormiston JA, de Bruyne B, Regar E, Dudek D, Thuesen L, Smits PC, Chevalier B, McClean D, Koolen J, Windecker S, Whitbourn R, Meredith I, Dorange C, Veldhof S, Miquel-Hebert K, Rapoza R, Garcia-Garcia HM. Evaluation of the second generation of a bioresorbable everolimus drug-eluting vascular scaffold for treatment of de novo coronary artery stenosis:

six-month clinical and imaging outcomes. *Circulation.* 2010; 122:2301-12.

26. Brugaletta S, Gomez-Lara J, Diletti R, Farooq V, van Geuns RJ, de Bruyne B, Dudek D, Garcia-Garcia HM, Ormiston JA, Serruys PW. Comparison of in vivo eccentricity and symmetry indices between metallic stents and bioresorbable vascular scaffolds: insights from the ABSORB and SPIRIT trials. *Catheter Cardiovasc Interv.* 2012;79:219-28.

27. Shaw E, Allahwala UK, Cockburn JA, Hansen TC, Mazhar J, Figtree GA, Hansen PS, Bhindi R. The effect of coronary artery plaque composition, morphology and burden on Absorb bioresorbable vascular scaffold expansion and eccentricity - A detailed analysis with optical coherence tomography. *Int J Cardiol.* 2015;184:230-6.

28. Cutlip DE, Windecker S, Mehran R, Boam A, Cohen DJ, van Es GA, Steg PG, Morel MA, Mauri L, Vranckx P, McFadden E, Lansky A, Hamon M, Krucoff MW, Serruys PW; Academic Research Consortium. Clinical end points in coronary stent trials: a case for standardized definitions. *Circulation.* 2007;115:2344-51.

29. Park JJ, Chae IH, Cho YS, Kim SW, Yang HM, Seo JB, Kim SY, Oh IY, Yoon CH, Suh JW, Park KW, Chung WY, Youn TJ, Choi DJ, Kim HS. The recanalization of chronic total occlusion leads to lumen area increase in distal reference segments in selected patients: an intravascular ultrasound study. *JACC Cardiovasc Interv.* 2012;5:827-36.

30. Gomez-Lara J, Teruel L, Homs S, Ferreiro JL, Romaguera R, Roura G, Sanchez-Elvira G, Jara F, Brugaletta S, Gomez-Hospital JA, Cequier A. Lumen enlargement of the coronary segments located distal to chronic total occlusions successfully treated with drug-eluting stents at follow-up. *EuroIntervention.* 2014;9:1181-8.

31. Galassi AR, Tomasello SD, Crea F, Costanzo L, Campisano MB, Marza F, Tamburino C. Transient impairment of vasomotion function after successful chronic total occlusion recanalization. *J Am Coll Cardiol.* 2012;59:711-8.

32. Colmenarez HJ, Escaned J, Fernandez C, Lobo L, Cano S, del Angel JG, Alfonso F, Jimenez P, Banuelos C, Gonzalo N, Garcia E, Hernandez R, Macaya C. Efficacy and safety of drug-eluting stents in chronic total coronary occlusion recanalization: a systematic review and meta-analysis. *J Am Coll Cardiol.* 2010;55:1854-66.

33. Mattesini A, Secco GG, Dall'Ara G, Ghione M, Rama-Merchan JC, Lupi A, Viceconte N, Lindsay AC, De Silva R, Foin N, Naganuma T, Valente S, Colombo A, Di Mario C. ABSORB biodegradable stents versus second-generation metal stents: a comparison study of 100 complex lesions treated under OCT guidance. *JACC Cardiovasc Interv.* 2014;7:741-50.

34. Kandzari DE, Kini AS, Karmpaliotis D, Moses JW, Tummala PE, Grantham JA, Orr C, Lombardi W, Nicholson WJ, Lembo NJ, Popma JJ, Wang J, Larracas C, Rutledge DR. Safety and Effectiveness of Everolimus-Eluting Stents in Chronic Total Coronary Occlusion Revascularization: Results From the EXPERT CTO (Evaluation of the XIENCE Coronary Stent, Performance, and Technique in Chronic Total Occlusions) Multicenter Trial. *JACC Cardiovasc Interv.* 2015;8:761-9.