Bioresorbable scaffold technology: The yet unfulfilled promise of becoming the workhorse stent in the cardiac catheterization laboratory

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1. Introduction

In 1977, Andreas Gruntzig performed the first human balloon angioplasty and ushered in the era of percutaneous treatment for coronary artery disease. Initial enthusiasm was tempered down by reports of acute vessel occlusion due to dissections and late constrictive remodeling. Next large leap was the introduction of bare metal stents. The BENESTENT trial reported reduced vessel restenosis (22% vs. 32%, P = 0.02) and the need for repeat coronary angioplasty (RR, 0.58; P = 0.005) in BMS treated patients. The rate of sub-acute vessel occlusion decreased to 1.5%; reducing the need for emergency bypass surgery.

In 1996 Schömig et al. introduced dual anti-platelet instead of anticoagulant therapy, resulting in 82% lower risk of MI and 78% reduction in need for repeat interventions (RR 0.25(0.06–0.77).

In 2001 Surreys et al. reported the first use of Drug Eluting Stents in 45 patients, who were treated with Sirolimus eluting Bx VELOCITY stents with negligible neo-intimal hyperplasia at one-year follow-up. The RAVEL trial reported lower mean late luminal loss (−0.01 mm vs. 0.80 mm, P < 0.001) and no recurrent revascularization attempts (vs. 26% in control). However, reports on late stent thrombosis surfaced, which increased to 3.5% at 4 years.

2. The promise of bioresorbable scaffolds

Initially, Tamai et al. examined the feasibility of a bio-absorbable poly-lactic acid (PLLA) Igaki-Tamai stents (Igaki Medical, Kyoto, Japan) with a thickness of 0.17 mm and a zigzag helical coil pattern (not drug eluted). They reported 18% repeat revascularization at 4 years and 28% target vessel revascularization at 10 years. One case of definite stent thrombosis was reported.

Di Mario et al. used magnesium stents in de-novo coronary lesions, with modest results (1-year Target Lesion Revascularization (TLR) rate 45%).

The Biodegradable Vascular Scaffold (BVS) (Abbott Vascular, California) consists of processed Poly-L-Lactic acid (PLLA) backbone covered with amorphous Everolimus/PLLA matrix coating for controlled drug release. The use of polyactic acid is widespread in clinical practice, ranging from absorbable sutures to orthopedic screws and dermology fillers. Safety of PLLA is supported by the benign vascular response to its use in Angioseal closure devices. PDLLA (poly(D,L-lactide), the polymer used for controlled release of Everolimus, has also been used previously.
(Novartis, Switzerland) is a semi-synthetic macrolide immunosuppressant which blocks cell proliferation by arresting cell division in G1-S phase. BVS contains 8.2 mcg/mm of Everolimus, 80% of which is released within 30 days; similar to Xience V stent. Safety and efficacy of Everolimus eluting stents were attested in SPIRIT and FUTURE trials.14–16

The BVS stent strives to perform comparably to others: its crossing profile is comparable to that of BX Velocity stent (1.4 mm). At room temperature, its radial strength is similar to MULTILINK stent.12 Its balloon delivery system is the same as for MULTI LINK, VISION and XIENCE V stents. BVS also shows higher conformability to vessel structure.21

Its initial version (Revision 1.0) had to be stored at low temperatures in order to avoid device instability and cracks upon deployment. The second generation (Revision 1.1) can be stored at room temperature.24 Its previous polymer treatment and scaffold design were replaced with in-phase zigzag hoops linked by bridges, allowing for more uniform strut distribution, higher radial support, less vessel recoil and uniform drug distribution.30

The BVS is composed of repeating units of PLLA/PDLLA. After implantation, bonds between repeating units get hydrolyzed producing lactic acid, which is metabolized via Krebs cycle and residual small particles (<2 μm) are phagocytosed by macrophages.

Chemically, scaffold resorption takes place in three phases; initially water starts hydrolysis of ester bonds, resulting in decline of stent’s molecular weight. In the second stage there is scission of chains linking regions, causing decline in the radial strength. At third stage, remaining short polymer chains diffuse out of the device to get reabsorbed into blood.

Degradation of scaffold governs mechanical performance, which divides into three phases: during initial “revascularization phase” it acts like mainstream drug eluting stents (comparable deliverability, minimal acute recoil and high radial strength). At the restoration phase there is hydrolysis of amorphous regions and connecting points, causing a decline in radial strength. In studied cases it took three months after implantation for the process to start. During the last “resorption phase” the BVS becomes discontinuous and ceases to act as a scaffold while hydrolysis continues and generates L- and D-lactate into the body,22 meanwhile the stent start. During the last “resorption phase” the BVS becomes discon-

In 2006, Ormiston et al. reported the first BVS in man implanta-
tion.17 In 2008 the ABBSORB FIRST17 reported 94% device success rate in 30 patients with single de-novo coronary lesions who underwent BVS implantation (Table 1). At one year, only one patient needed target vessel revascularization. IVUS showed post-procedural incomplete strut apposition in 6 patients and no late stent thrombosis was reported. At 6 months, the OCT sub-study showed 99% of struts where covered with tissue. At 2 years there was 34.5% decrease in strut thickness.24 These patients showed higher acute stent recoil than EES stents (percent recoil 6.9% ± 4.3% historical data from SPIRIT FIRST and SPIRIT II; p = 0.25).18 IVUS data also noted significant late stent recoil (7.6% vs. 0.03% Xience V).15,17 This translated into 0.44 mm late lumen loss at six months. Partly, this is due to neointimal hyperplasia and the rest is due to reduction inside stent area. Hyperplasia was comparable to that observed in SPIRIT FIRST with Xience and was better than BMS.12 Reduction in inside stent area was due to acute stent recoil, non-uniform vessel wall support and loss of radial strength through scaffold resorption. In-stent restenosis rate was 11.5%, which did not necessitate re-intervention.

From 6 months to 2 years there was a reduction in plaque area,24 while the vessel size remained same, leading to gain in lumen area, with no scaffold mal-apposition noted.25 At 3 and 5 years,26,27 the ischemia-driven major adverse cardiac event rate was 3.4%. Scaffold thrombosis was not observed.

The ABBSORB II trial enrolled 501 patients with one or two de-novo native vessel disease to receive BRS or Xience (Abbott Vascular, Santa Clara, CA, USA). Although acute recoil was similar, acute lumen gain was less for BVS (IVUS: 2.85 mm2 vs. 3.60 mm2, p < 0.0001). Composite device oriented endpoint at 1-year was similar (5% vs.3%, p = 0.35), myocardial infarction (MI) (4% vs. 1%) and TLR (1% vs. 2%).46 Three BVS patients had definite or probable scaffold thrombosis. At three years27 BVS showed no difference in vasomotor reactivity (BVS 0.047 mm vs. Xience 0.056 mm; psuperiority 0.49). Late luminal loss was larger for BVS (0.37 mm vs. 0.25 mm; pnon-inferiority 0.78). This was confirmed by IVUS (BVS MLA 4.32 mm2 vs. 5.38 mm2 Xience; p < 0.0001). There was a higher rate of device-oriented composite endpoint in the BVS group (10% vs 5%, hazard ratio 2.17 [95% CI 1.01–4.70]; log-rank test p = 0.0425), mainly due to target vessel MI (6% vs 1%; p = 0.0198).

The ABBSORB III is a multicenter trial where 2008 patients undergoing PCI for one or two new native coronary lesions were randomly assigned to BRS or Xience. High-pressure post-dilatation was enforced to achieve <10% residual stenosis. Acute segmental gain was less for BVS. At 1 year, target-lesion failure occurred in 7.8% of BVS and 6.1% in Xience (pon-inferiority = 0.007, psuperiority = 0.15). Sub-acute thrombosis up to 30 days was more common with BVS, similar to findings noted from GHOST EU (1.4% 30 days, 1.9% 180 days; 2.0% 360 days). The primary end point remained similar between years 1 and 2.58 At the end of year 2, BVS arm had a higher risk of target lesion failure (10.9% vs. 7.8% for DES; p < 0.05). This was driven by target vessel MI (7.3% vs. 4.9% for DES; p < 0.05).

The ABBSORB IV trial avoided small vessels, while aggressive pre-dilatation and routine high-pressure post-dilatation were encouraged. 3000 patients were randomized 1:1 to Absorb BVS or XIENCE. Post-dilatation was at pressures 16–18 atmospheres, and with a balloon-to-scaffold ratio of 1.1–1. At 30 days, target lesion failure occurred in 5.1% of BVS patients and 3.7% of XIENCE patients (p = 0.07). The composite of death, MI, and revascularization occurred in 5.2% of BVS and 4.1% of XIENCE patients (p = 0.17). Device thrombosis occurred in 0.6% of BVS vs. 0.2% of XIENCE patients (p = 0.06).

The EVERBIO II randomly assigned 240 patients to EES, Biolimus Eluting Stents (BES), or BVS. Nine months in-stent lumen loss was similar (BVS: 0.28 mm vs. EES/BES: 0.25 mm; p = 0.30). Patient-oriented MACE was similar (27% in BVS; 26% in EES/BES group; p = 0.83) as was device-oriented MACE rate (12% in BVS; 9% in the EES/BES group; p = 0.6).

In the largest metaanalysis of BVS trials, a total of 3389 patients with stable CAD or stabilized ACS assigned to BVS: n = 2164) or Xience (n = 1225). BVS implantation took longer (43.7 vs. 39.7, p < 0.05), attained a smaller reference vessel diameter (2.37 vs. 2.58; p < 0.05) despite a higher post-dilatation rate (66% vs. 55%; p < 0.05) and required a higher IVUS/OCT use (23.9 vs. 20; p = 0.02). At 1 year, rates of patient-oriented and device-oriented composite endpoints were similar (RR 1.09 [0.89–1.34]; p = 0.38 for earlier and 1.22,0.91–1.64, p = 0.17 for later), the rate of Target vessel MI was increased with BVS due to increased peri-procedural myocardial infarction and device thrombosis with BVS (TVMI RR 1.45; 1.02–2.07, p = 0.04; BVS thrombosis 1.3% vs. 0.6%; RR
2.09:0.92–4.75, p = 0.08), highlighting the issue of BVS thrombosis and shedding light on the need for attention to details required when implanting BVS.

3. Evidence from real life registries

The large GHOST-EU registry\(^\text{34}\) in 11 European centers looked at target lesion failure among 1549 lesion in 1304 real life patients. It was an “all-comer” registry, including patients with ostial lesions, in-stent restenosis (ISR), bifurcations, chronic total occlusions and left main disease. 53% of patients were treated for stable angina, while rest presented with an acute coronary syndrome. Acute technical success was 99.7%. Target Lesion Failure was 2.2% at 30 days; 4.4% at six months. At six months cardiac death was 1.0%, target vessel infarction was 2.0%, and Target Lesion Revascularization was 2.5%. Procedural-related myocardial injury was higher in the BVS group (25% vs. 12%, p = 0.001). Diabetes mellitus was an independent predictor of TLF (HR 2.41, 95% confidence interval: 1.28–4.53; p < 0.05). The incidence of definite/probable scaffold thrombosis was 1.5% at 30 days and 2.1% at six months. Diabetes mellitus was the only independent predictor of TLF (hazard ratio 2.41, 95% confidence interval: 1.28–4.53; p = 0.006) and cardiac mortality did not differ between BVS and EES.

Increased target vessel-related myocardial infarction observed in BVS group (RR 1.45 [95% CI 1.02–2.07], p = 0.04) and cardiac death, target-vessel MI, ischemia-driven target-lesion revascularization or device thrombosis at 1 yr.

Late luminal loss and clinical outcomes were similar among groups. The large GHOST-EU registry\(^\text{34}\) in 11 European centers looked at target lesion failure among 1549 lesion in 1304 real life patients. It was an “all-comer” registry, including patients with ostial lesions, in-stent restenosis (ISR), bifurcations, chronic total occlusions and left main disease. 53% of patients were treated for stable angina, while rest presented with an acute coronary syndrome. Acute technical success was 99.7%. Target Lesion Failure was 2.2% at 30 days; 4.4% at six months. At six months cardiac death was 1.0%, target vessel infarction was 2.0%, and Target Lesion Revascularization was 2.5%. Procedural-related myocardial injury was higher in the BVS group (25% vs. 12%, p = 0.001). Diabetes mellitus was an independent predictor of TLF (HR 2.41, 1.28–4.53; p < 0.05). The incidence of definite/probable scaffold thrombosis was 1.5% at 30 days and 2.1% at six months. Diabetes mellitus was the only independent predictor of TLF (hazard ratio 2.41, 95% confidence interval: 1.28–4.53; p = 0.006) and cardiac mortality did not differ between BVS and EES.
Another analysis of the GHOST-EU registry looked at BVS use in diffusely diseased vessels. Patients were divided into 3 groups (short: <30 mm, intermediate: 30–60 mm, and long scaffold length: >60 mm). Patients with longer BRS were mostly diabetic (24% vs. 30.8% vs. 34.6%, p = 0.01) with higher SYNTAX scores (10.4 ± 7.2 vs. 14.6 ± 8.6 vs. 16.4 ± 7.8, p < 0.001). Despite higher use of Intravascular ultrasound and post-dilatation, there was higher incidence of peri-procedural myocardial infarction (MI) in longer BVS group (6.5% vs. 7.5% vs. 11.3%, p = 0.45). Target lesion failure was higher at 1-year (14.3% long vs. 4.8% in short and 4.5% in intermediate group; p = 0.001). This lead to a higher rate of repeat revascularization (HR = 1.962; 95% CI: 1.25–3.08; p = 0.0034). Incidence of scaffold thrombosis was higher in the long stent group (3.8% vs. 2.1% in short, 1.1% in intermediate group; p = 0.29). Mode of presentation was a significant determinant too (one-year MACE 3.7% in stable vs. 6.9% in ACS patients; p < 0.05). BVS restenosis was observed in 15.6% among diffusely diseased lesions (median follow-up 192 days), compared to 3.4% ISR in the whole GHOST EU registry. Overall, restenosis patients had a higher prevalence of diabetes (20% vs. 7%, p = 0.03), longer implanted BVS (33.4 ± 26 mm vs. 28.0 ± 18 mm, p = 0.33), more residual stenosis >20% (56% vs. 9%, p < 0.001) despite higher post-dilation rate (55% vs. 30%, p = 0.02). BVS restenosis was mostly focal (body in 47%, margin in 35%) and rarely diffuse (3% of lesions). Total occlusion was observed in 6% of lesions and aneurysm formation was seen in 6% of lesions. Percent residual stenosis post implantation was the only independent predictor for restenosis.39,41

In another registry, 302 bifurcation lesions were treated using BVS (provisional single-stenting 86%; elective double-stenting 14%). True bifurcation (Medina 1.1.1/1.0.1/0.1.1) were observed in 45%. Pre-dilation and post-dilation of the main branch were performed in 96% and 61%. Final kissing inflation with small protrusion of a side branch balloon into main branch was performed in 19%. At 356 days follow up rates of target lesion failure and scaffold thrombosis were high at 6.4% and 2.5%. Independent predictors for TLF were age 75+ (HR 1.91; 95% CI: 1.29–2.86; p = 0.001), diabetes (HR 1.48; 95% CI: 1.11–1.98; p = 0.009) and post-stent thrombosis (HR 2.51; 95% CI: 1.54–4.04; p < 0.001). Majority of patients with scaffold thrombosis occurred within 35 days from index PCI (75%) and lacked use of intravascular imaging.40,43

Acute coronary syndrome presentation once again showed poorer outcomes (MACE 9.3% vs. 4.7%, p < 0.001; TLR 6.1% vs. 1.9%, p < 0.001) with increased stent thrombosis (BVS 2.8% vs. 0.9% EES group, p = 0.01). Here post-dilatation resulted in lower MACE (BVS with post-dilatation 6.0% vs. 12.6%, BVS without post-dilatation vs. 4.7% EES group, p < 0.001). Post dilatation did not alter the rate of stent thrombosis (post-dilatation: 2.6% vs. no post-dilatation: 3.2% vs. 0.9%; EES patients, p = 0.045).45

Review of real world registries shows an increasing trend for post-dilatation. We note a change from 52.3% rate in GHOST EU,41 to 68% in GABI-R,54 72% in FRANCE ABSORB,55 to 96.8% in IT-DISAPPEAR.54,55 Which also enrolled the most complicated patients (59%; diabetics 23.7%, bifurcation lesions 22.3%). This is accompanied by a concomitant decline in BVS thrombosis, initially observed at 3.4% in GHOST EU (least post-dilatation rate) to 0.6% in IT-DISAPPEAR.

Recent emphasis on implantation technique formulated the nomenclature of four Ps: Prepare the lesion with non-compliant balloon, Proper sizing with use of intracoronary nitroglycerin and imaging as necessary; Pay attention to expansion limits; staying within nominal limits of 0.5 mm and expanding the scaffold at 2 mm every five seconds while implanting, then staying 30 s when fully expanded before deflating. Finally Post-dilating with a non-compliant balloon at high pressure aiming at <10% residual stenosis after implantation. By using this protocol and avoiding small vessels with lumen diameters <2.5; BVS thrombosis rates can be reduced by 70%.46

In order to clarify the issues concerning BVS use for clinicians, the FDA issued a “Dear Doctor” letter noting it that the higher risk of stent-related thrombosis and other major cardiac events among patients who got Absorb GT1 BVS is under investigation. It reminds operators using BVS to follow instructions in FDA labeling, avoiding its use in small vessels and to adhere to the label’s recommended implantation technique.

In 14th September 2017, Abbott decided to voluntarily withdraw its product from market except for patients in the setting of a registry or study, citing low market penetration. Abbott promised to come back with a new improved scaffold of 92 µm thickness.

To summarize, despite having only a fraction of the tensile strength of metallic stents (30–45 compared to 820–1200 MPa); the BVS showed favorable 1 year results in large studies despite a possible small but statistically significant increased risk of peri-procedural MI. Longer term follow up showed higher BVS late thrombosis rates and higher target lesion failure. This may be due to numerous factors. For example, 19% of patients in ABSORB III60 were treated for vessels which were smaller than the size advised by the FDA. Clinicians tend to use visual assessment to estimating vessel size rather than quantitative analysis. This may result in underestimating vessel size. Moreover, techniques of implantation have been largely suboptimal (only 63% of BVS recipients had post-dilatation in ABSORB III60). Diligent attention to choosing vessels of appropriate diameter and paying attention to technique of implantation, more frequent use of imaging for vessel sizing should result in improved outcomes. This needs to be shown in long-term follow up of Absorb III and IV studies which could then open the door for introduction of newer generation of scaffolds. Other scaffolds are also already in clinical use, though to a lesser extent and their long term clinical efficacy remains to be shown too.

Conflict of interest
None.

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