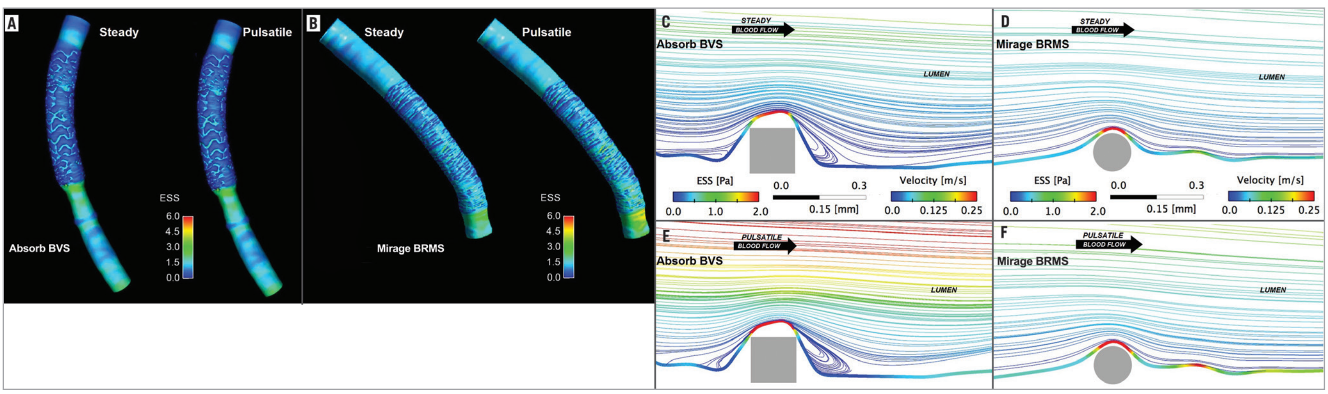
EuroIntervention 2016;12:1296 published online ahead of print May 2016

Preclinical assessment of the endothelial shear stress in porcine-based models following implantation of two different bioresorbable scaffolds: effect of scaffold design on the local haemodynamic micro-environment

Erhan Tenekecioglu[1], MD; Ryo Torii[2], PhD; Christos Bourantas[3,4], MD, PhD; Tom Crake[3], MD; Yaping Zeng[1], MD, PhD; Yohei Sotomi[5], MD; Yoshinobu Onuma[1], MD, PhD; Mustafa Yılmaz[6], MD; Teguh Santoso[7], MD, PhD; Patrick W. Serruys[1,8]*, MD, PhD

The authors' affiliations together with the complete references and the supplementary data are published online at: http://www.pcronline.com/eurointervention/107th_issue/211

GUEST EDITOR: Peter Barlis, MBBS, MPH, PhD, FCSANZ, FACC, FRSA, FRACP, FESC; *Faculty of Medicine, Dentistry & Health Sciences, The University of Melbourne, Melbourne, Victoria, Australia*



In vitro studies have demonstrated that stent implantation changes local haemodynamics as the protruding struts disturb the flow resulting in recirculation zones and low endothelial shear stress (ESS)[1-3]. Angiographic and OCT data were used to reconstruct 3D geometry of the right coronary artery of two healthy mini-swine implanted with 3.0×18 mm Absorb BVS (Abbott Vascular, Santa Clara, CA, USA) and 3.0×15 mm Mirage BRMS (Manli Cardiology Ltd., Singapore) **(Online Figure 1)**. The angiographic data were used to estimate flow velocity[4].

During the computational flow dynamic study, ESS was measured in the scaffolded segment around the circumference of the lumen per 5° interval and along the axial direction per 0.2 mm interval (cross-section). Mean ESS was lower in Absorb BVS compared to Mirage BRMS in steady flow simulation (0.60±0.51 Pa [n=5,256] vs. 1.09±0.76 Pa [n=6,336], respectively; $p<0.001$); 70% of the scaffolded surface in Absorb BVS and 53% in Mirage BRMS was exposed to a low (<1 Pa) athero-promoting ESS **(Online Figure 1)**. The presented p-value is for hypothesis generation based on 5° subunit analysis (n=11,592) and needs cautious interpretation.

The difference in ESS may have arisen from strut geometry, strut thickness **(Online Figure 2)**, alignment of the strut connectors, luminal diameter, vessel curvature and boundary conditions. In our case, after excluding other factors, lower ESS in Absorb BVS is potentially attributed to the flow disturbances caused by thicker rectangular struts **(Panel A, Panel B, Panel C, Panel D, Online Figure 2)**. Longitudinal images **(Panel A, Panel B)** portray the flow patterns and ESS distribution during steady **(Panel C, Panel D)** and pulsatile **(Panel E, Panel F)** models; flow streamlines were taken at the highest velocity point in diastole. While recirculation zones were noted in proximal/distal regions of Absorb BVS **(Panel C, Panel E)**, there was no recirculation in Mirage BRMS **(Panel D, Panel F, Moving image 1, Moving image 2)**.

OCT-based reconstruction provides *in vivo* assessment of the effect of different scaffold designs on local haemodynamics and can be useful in optimising scaffold design.

Funding

E. Tenekecioglu has received a research grant from TUBITAK (The Scientific and Technological Research Council of Turkey).

Conflict of interest statement

P.W. Serruys and Y. Onuma are members of the International Advisory Board of Abbott Vascular. The other authors have no conflicts of interest to declare. The Guest Editor has no conflicts of interest to declare.

**Corresponding author: Cardiovascular Science Division of the NHLI within Imperial College of Science, Technology and Medicine, South Kensington Campus, London, SW7 2AZ, United Kingdom. E-mail: patrick.w.j.c.serruys@gmail.com*

SUBMITTED ON 23/11/2015 - REVISION RECEIVED ON 07/02/2016 - ACCEPTED ON 24/02/2016

DOI: 10.4244/EIJY16M05_01

Supplementary data

Authors' affiliations

1. Department of Interventional Cardiology, Erasmus University Medical Center, Thoraxcenter, Rotterdam, The Netherlands; 2. Department of Mechanical Engineering, University College London, London, United Kingdom; 3. Department of Cardiovascular Sciences, University College London, London, United Kingdom; 4. Department of Cardiology, Barts Heart Centre, London, United Kingdom; 5. Academic Medical Center-University of Amsterdam, Amsterdam, The Netherlands; 6. Department of Cardiology, Bursa Postgraduate Education and Research Hospital, Bursa, Turkey; 7. Department of Internal Medicine, Faculty of Medicine, Cipto Mangunkusumo Hospital, University of Indonesia, Jakarta, Indonesia; 8. International Centre for Circulatory Health, Imperial College London, London, United Kingdom

E. Tenekecioglu and R. Torii contributed equally as first author.

Guest Editor

This paper was guest edited by Peter Barlis, MBBS, MPH, PhD, FCSANZ, FACC, FRSA, FRACP, FESC, Faculty of Medicine, Dentistry & Health Sciences, The University of Melbourne, Melbourne, Victoria, Australia.

References

1. Jiménez JM, Davies PF. Hemodynamically driven stent strut design. *Ann Biomed Eng.* 2009;37:1483-94.

2. Kolandaivelu K, Swaminathan R, Gibson WJ, Kolachalama VB, Nguyen-Ehrenreich KL, Giddings VL, Coleman L, Wong GK, Edelman ER. Stent thrombogenicity early in high-risk interventional settings is driven by stent design and deployment and protected by polymer-drug coatings. *Circulation.* 2011;123:1400-9.

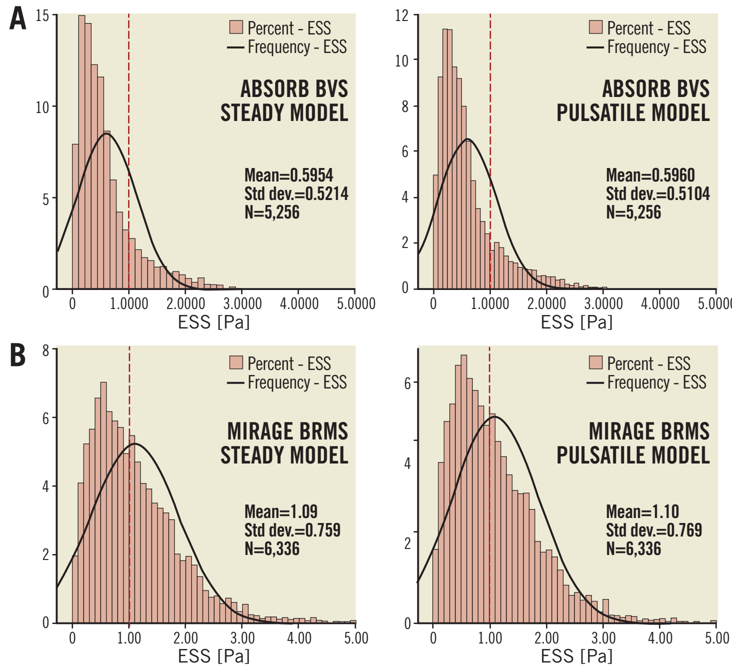
3. LaDisa JF Jr, Olson LE, Douglas HA, Warltier DC, Kersten JR, Pagel PS. Alterations in regional vascular geometry produced by theoretical stent implantation influence distributions of wall shear stress: analysis of a curved coronary artery using 3D computational fluid dynamics modeling. *Biomed Eng Online.* 2006;5:40.

4. Bourantas CV, Papafaklis MI, Lakkas L, Sakellarios A, Onuma Y, Zhang YJ, Muramatsu T, Diletti R, Bizopoulos P, Kalatzis F, Naka KK, Fotiadis DI, Wang J, Garcia Garcia HM, Kimura T, Michalis LK, Serruys PW. Fusion of optical coherence tomographic and angiographic data for more accurate evaluation of the endothelial shear stress patterns and neointimal distribution after bioresorbable scaffold implantation: comparison with intravascular ultrasound-derived reconstructions. *Int J Cardiovasc Imaging.* 2014;30:485-94.

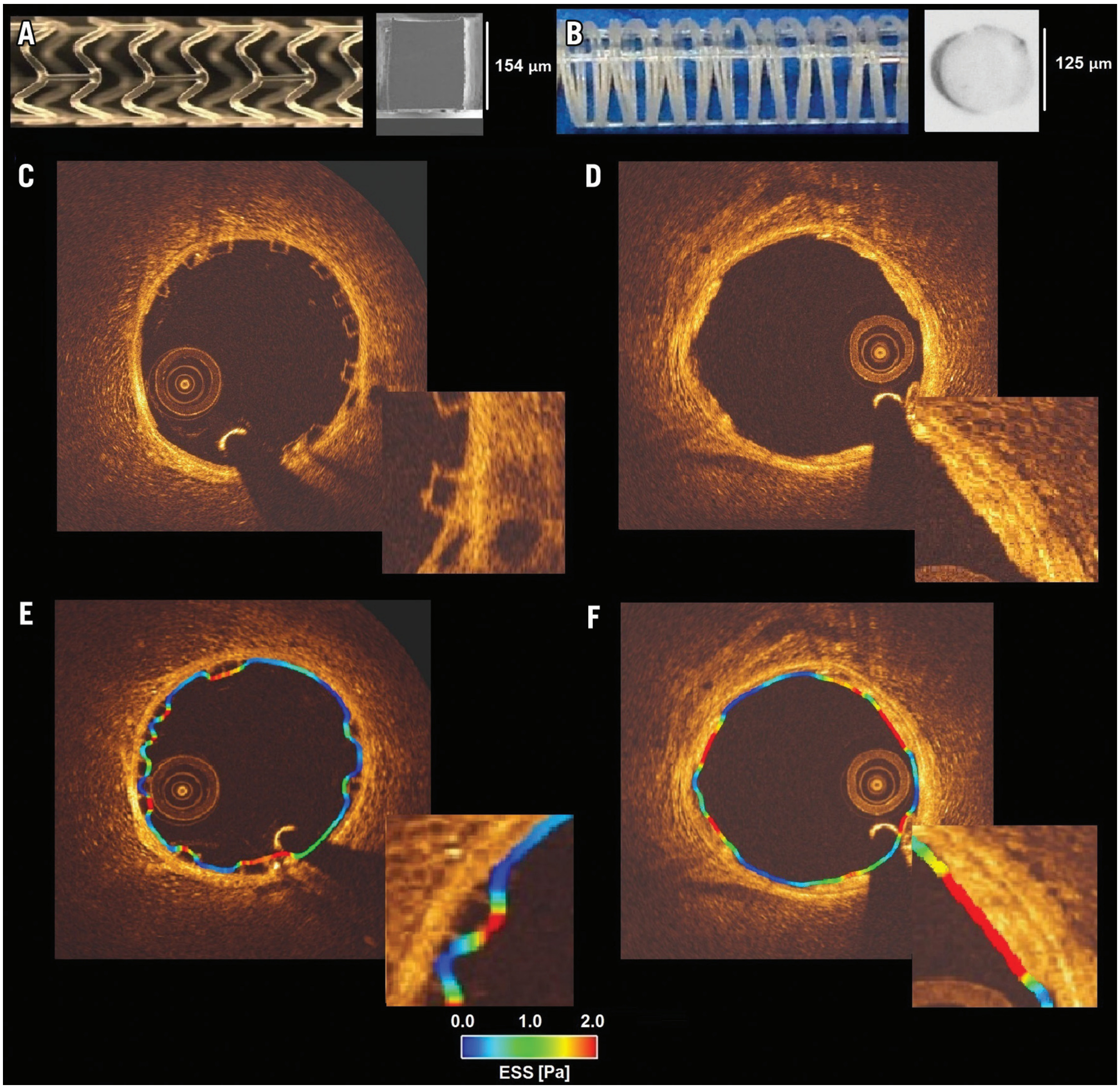
Moving image legends

Moving image 1. Pulsatile flow simulation in Absorb BVS.

Moving image 2. Mirage BRMS. It is obvious that the different strut design has an impact on the flow velocity which is reduced in the surface of the Absorb BVS.



Online Figure 1. *ESS distribution in Absorb BVS and Mirage BRMS in steady and pulsatile flow models. ESS distribution in Absorb BVS (A) and Mirage BRMS (B) in steady (left) and pulsatile (right) flow models. There was no significant difference in ESS distribution between steady and pulsatile flow simulation in both devices (0.60±0.51 Pa vs. 0.60±0.52 Pa; p=0.95 in Absorb BVS and 1.09±0.76 Pa vs. 1.10±0.76 Pa; p=0.89 in Mirage BRMS). The observed differences in ESS between Absorb BVS and Mirage BRMS were maintained even if the pulsatile conditions were applied for the flow simulation. ESS results were skewed towards lower ESS in Absorb BVS compared to Mirage BRMS as shown in the histograms of ESS distributions.*



Online Figure 2. *Differences in scaffold design, strut geometry and related ESS distribution at both scaffolds. Absorb BVS 1.1 and cross-section of Absorb BVS strut (A). Mirage BRMS and cross-section of Mirage BRMS strut (B). OCT cross-sectional image of Absorb BVS 1.1 with magnified view of a rectangular strut (C). OCT cross-sectional image of Mirage BRMS with magnified view of an ovoid strut (D). ESS distribution in the cross-sections (C & D). Low ESS noted in the areas between the struts and high ESS on the top of the struts in Absorb BVS (E) and Mirage BRMS (F).*