Cor et Vasa

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/crvasa

Kasuistika | Case report

High shear stress on the background of clinical restenosis at the site of step-down phenomenon after drug eluting stent implantation

Csaba Jenei[a], Gábor Závodszky[b], György Paál[b], Balázs Tar[c], Zsolt Kőszegi[a,c]

[a] *Szabolcs – Szatmár – Bereg County Hospitals and University Teaching Hospital, Nyíregyháza, Hungary*
[b] *Department of Hydrodynamic Systems, Budapest University of Technology and Economics, Budapest, Hungary*
[c] *Institute of Cardiology, University of Debrecen, Debrecen, Hungary*

ARTICLE INFO

Article history:
Received: 3. 8. 2015
Received in revised form: 17. 8. 2015
Accepted: 18. 8. 2015
Available online: 11. 9. 2015

Klíčová slova:
DES
Restenóza
Smykové napětí

SOUHRN

U nemocného s restenózou zjištěnou šest měsíců po implantaci lékového stentu (drug-eluting stent, DES) byla ve snaze zhodnotit vliv zmenšování průměru stentu směrem k jeho distálnímu konci (step-down) na smykové napětí ve stěně tepny (wall shear stress, WSS) provedena retrospektivní remodelace 3D koronarografickou rekonstrukcí a průběhu intrakoronárního tlaku během srdečního cyklu. Kinetika WSS se vypočítávala v průběhu celého cyklu podél rekonstruované tepny metodou analýzy dynamiky tekutin. Na rozdíl od starších zpráv byla největší amplituda a průměrná hodnota WSS tepny zjištěna v místě zmenšení průměru (step-down), kde později došlo ke vzniku restenózy.

Keywords:
DES
Restenosis
Shear stress

ABSTRACT

A retrospective modeling was performed in a case with restenosis after 6 months of a DES implantation to investigate the effect of the step-down at the distal edge of the stent on the wall shear stress (WSS) using 3D coronary angiography reconstruction and the intracoronary pressure traces during a cardiac cycle. The kinetics of the WSS was calculated through the cardiac cycle along the reconstructed vessel by fluid dynamic analysis. Contrary to the previous reports the greatest amplitude and average of the arterial WSS was detected where the restenosis developed later at the site of the step-down.

Address: Zsolt Kőszegi, MD, PhD, FESC, Institute of Cardiology, University of Debrecen, Móricz Zs. Krt. 22, 4004 Debrecen, Hungary,
e-mail: koszegi@med.unideb.hu
DOI: 10.1016/j.crvasa.2015.08.005

Please cite this article as: C. Jenei, et al., High shear stress on the background of clinical restenosis at the site of step-down phenomenon after drug eluting stent implantation, Cor et Vasa 58 (2016) e518–e521 as published in the online version of *Cor et Vasa* available at http://www.sciencedirect.com/science/article/pii/S0010865015000843

Introduction

It is generally accepted that low or/and oscillating wall shear stress (WSS) has a role in the development of restenosis after coronary stent implantation but there is only a limited amount of data about systematic follow-up investigation of clinical endpoints and WSS calculation in clinical population after stent implantation.

Description of the case

A 49-year-old female diabetic patient who had stent implantation in the left circumflex coronary (LCx) artery was admitted because of recurrent anginal symptoms. Coronary angiography revealed a patent LCx stent while a long 50–60% stenosis was detected in the medial segment of the left anterior descending artery (LAD). Fractional flow reserve (FFR) measurement during maximum vasodilatation proved the hemodynamic significance of the lesion (FFR: 0.77). Therefore, a drug-eluting stent (DES) was implanted (3.5/28 mm Promus Element) which improved the FFR to 0.86. The resting pressure ratio was detected to be 0.92 (Fig. 1).

After 6 months repeated coronary angiography was performed because of reoccurrence of the symptoms of effort angina pectoris showing severe restenosis at the distal edge of the DES (Fig. 2A and 2B). This lesion was successfully treated by another DES implantation. A retrospective modeling was performed to investigate the possible effect of the step-down at the distal edge of the previous DES on the wall shear stress (WSS) conditions (Fig. 2A and 2C) using fluid dynamic analysis by the ANSYS CFX 15.0 software. The investigated vessel geometry was generated on the basis of the 3D anatomical reconstruction of the target vessel segment by a dedicated 3D QCA software package (QAngio XA 3D Research Edition 1.0, Medis Specials bv, Leiden, the Netherlands) software and the pressure traces during a cardiac cycle after the previous DES implantation at resting condition.

Blood was considered as a homogeneous, non-Newtonian fluid modeled by the Carreau-Yasuda shear dependent viscosity equation with the same parameters as in Boyd et al. [1,2], and a density of 1050 kg/m^3. Blood flow was assumed to be laminar and incompressible. The arterial wall was considered to be rigid and no-slip conditions were applied at the baseline luminal surface. Shear stress at the reconstructed poststent luminal surface was calculated as the product of blood viscosity and the gradient of blood velocity at the wall during the cardiac cycle (Fig. 3).

The kinetics of the WSS was calculated along the cardiac cycle (Video 1). The changes in direction and magnitude of WSS could be approximated by the oscillatory shear index OSI (its values may range from 0 to 0.5 – 0 being a total unidirectional WSS, and 0.5 being a total bidirectional shear flow) [2]. The OSI and the average WSS were calculated at 5 points of the reconstructed vessel (1–3: within the stent, 4–5 distal to the stent) (Fig. 2C and Table 1).

Supplementary Video 1 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.crvasa.2015.08.005.

Contrary to the previous reports the greatest amplitude and the greatest average WSS of the arterial WSS had been detected where the restenosis developed later at the site of the step-down. It is also in contradiction to the previous calculations that the oscillation of the WSS was the lowest at the site of restenosis compared to the other points (Fig. 2C and Table 1).

Discussion

According to published data the normal average WSS in coronary arteries during resting condition ranges from 0.5 to

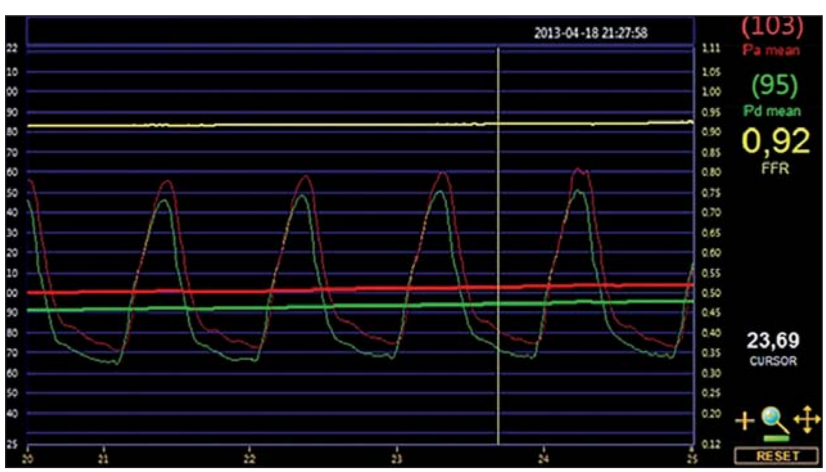

Fig. 1 – Resting intracoronary pressure trace (green line) after the DES implantation in the LAD. The ratio of the distal pressure and the proximal one (in the aorta: red line) was 0.92.

Table 1 – The average wall shear stress (WSS) and the oscillatory shear index (OSI) values at points 1–5 (according to Fig. 2C). At the site of the restenosis (point 4) there is extremely high WSS with low OSI.

Points	1	2	3	4	5
Average WSS (Pa)	5.26	3.89	3.91	18.54	9.98
OSI	0.03	0.03	0.04	0.02	0.21

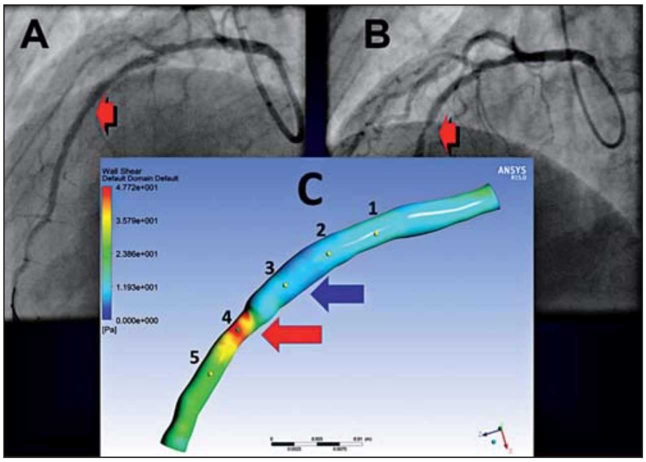

Fig. 2 – Coronary angiography from lateral view of the LAD after the DES implantation (A), and 6 months later (B). The computation by the ANSYS CFX software shows the greatest the arterial wall shear stress at the site of the step-down (C) where the restenosis has developed (B). The 3D reconstruction of the wall shear stress is shown at the early diastole (C). The 5 points indicate the sites of the kinetic analysis of the shear patter during the cardiac cycle. The results at the points 3 and 4 (blue and red arrow) shown in Fig. 3, while the average WSS and the OSI are summarized in Table 1.

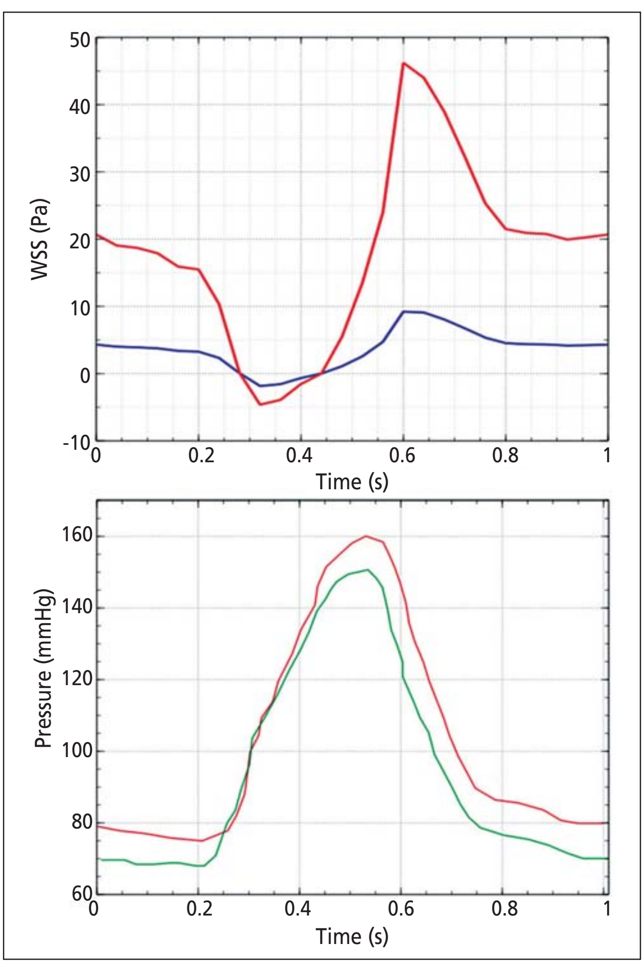

Fig. 3 – The synchronized time histories of the WSS at points 3 and 4 (above) and the pressure traces (below) during the cardiac cycle. (In part of the systolic phase the shear stress is negative, indicating a local change of flow direction due to the backflow.)

7 Pa and depends on the applied calculation method [3]. The pathological low WSS (inducing intimal hyperplasia or plaque formation) was reported to be with values below 0.5–1 Pa [4]. However, the pathologically high WSS is less defined. Fan et al. reported that plaque wall thickness correlated positively with flow shear stress, but there are no available data about the potential role of high WSS in restenosis, despite the fact that higher sheer stress values can be seen frequently in areas of turbulent flow considered also deteriorating for normal intimal function/formation [5].

After stent implantation, adequately functionally neointimal formation is the prerequisite of the normal healing process. Previous studies stated that low WSS was associated with increased neointimal hyperplasia (NIH), but in the present state of the research it is not clarified that when the compensatory NIH re-establishes the WSS to physiological level and when it overshoots into the clinical restenosis. The NIH was used as a surrogate end point and not a clinical one [6–11] in most of the publications raising the question whether the detected NIH is a part of the healing process after stent implantation or a predictor of a later restenosis.

To the best of our knowledge only Thury et al. had reported one case showing clinical restenosis requiring repeat revascularization as a consequence of the intimal thickening at the site of step-up phenomenon with low and oscillating WSS [12]. In contrast to that observation, we found very high resting average WSS (18.54 Pa) with low oscillation in our case at the site of the later restenosis. The different results may be explained by the different shear patters at the site of the step-up and step-down formations, and highlights the possibility that the extremely high WSS can also associate to restenosis at the distal edge of the stent.

Conflict of interest

No conflict of interest.

Funding body

None.

Ethical statement

I declare, on behalf of all authors, that the research was conducted according to Declaration of Helsinki.

Informed consent

I declare, on behalf of all authors that informed consent was obtained from the patient participating in this study.

References

[1] A.K. Politis, G.P. Stavropoulos, M.N. Christolis, et al., Numerical modelling of simulated blood flow in idealized composite arterial coronary grafts: transient flow, Journal of Biomechanics 41 (2008) 25–39.
[2] J. Boyd, J.M. Buick, S. Green, Analysis of the Casson and Carreau-Yasuda non-Newtonian blood models in steady and oscillatory flows using the lattice Boltzmann method, Physics of Fluids (2007) 093103.
[3] D.S. Molony, L.H. Timmins, O.Y. Hung, et al., An assessment of intra-patient variability on observed relationships between wall shear stress and plaque progression in coronary arteries, Biomedical Engineering Online 14 (Suppl. 1) (2015) S2.
[4] P.H. Stone, S. Saito, S. Takahashi, et al., Prediction of progression of coronary artery disease and clinical outcomes

using vascular profiling of endothelial shear stress and arterial plaque characteristics: the PREDICTION Study, Circulation 126 (2012) 172–181.
[5] R. Fan, D. Tang, C. Yang, et al., Human coronary plaque wall thickness correlated positively with flow shear stress and negatively with plaque wall stress: an IVUS-based fluid-structure interaction multi-patient study, Biomedical Engineering Online 13 (2014) 32.
[6] J.J. Wentzel, R. Krams, J.C. Schuurbiers, et al., Relationship between neointimal thickness and shear stress after Wallstent implantation in human coronary arteries, Circulation 103 (2001) 1740–1745.
[7] J. García, A. Crespo, J. Goicolea, et al., Study of the evolution of the shear stress on the restenosis after coronary angioplasty, Journal of Biomechanics 39 (2006) 799–805.
[8] N. Suzuki, H. Nanda, D.J. Angiolillo, et al., Assessment of potential relationship between wall shear stress and arterial wall response after bare metal stent and sirolimus-eluting stent implantation in patients with diabetes mellitus, International Journal of Cardiovascular Imaging 24 (2008) 357–364.
[9] M.I. Papafaklis, C.V. Bourantas, P.E. Theodorakis, et al., The effect of shear stress on neointimal response following sirolimus- and paclitaxel-eluting stent implantation compared with bare-metal stents in humans, JACC Cardiovascular Interventions 3 (2010) 1181–1189.
[10] C.V. Bourantas, L. Räber, S. Zaugg, et al., Impact of local endothelial shear stress on neointima and plaque following stent implantation in patients with ST-elevation myocardial infarction: a subgroup-analysis of the COMFORTABLE AMI-IBIS 4 trial, International Journal of Cardiology 186 (2015) 178–185.
[11] S. Pant, N.W. Bressloff, A.I. Forrester, N. Curzen, The influence of strut-connectors in stented vessels: a comparison of pulsatile flow through five coronary stents, Annals of Biomedical Engineering 38 (2010) 1893–1907.
[12] A. Thury, J.J. Wentzel, R.V. Vinke, et al., Images in cardiovascular medicine. Focal in-stent restenosis near step-up: roles of low and oscillating shear stress?, Circulation 105 (2002) e185–e187.