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ORIGINAL ARTICLE

A serial three- and nine-year optical coherence tomography evaluation of neoatherosclerosis progression after sirolimus- and paclitaxel--eluting stent implantation

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Abstract

Background: Early-generation drug-eluting stents (DESs) have been shown to accelerate neoatherogenesis. Limited optical coherence tomography (OCT) data on the very long-term neoatherosclerotic progression after DES implantation are available.

Aim: The aim of this study was a serial OCT evaluation of neoatherosclerosis at three and nine years after implantation of sirolimus-eluting stents (SESs) and paclitaxel-eluting stents (PESs).

Methods: Consecutive patients undergoing elective percutaneous coronary intervention with SES (Cypher, Cordis) or PES (Taxus, Boston Scientific) were included in this single-centre, longitudinal study. OCT analysis was performed after three and nine years by an independent core laboratory.

Results: A total of 39 OCT recordings were assessed at three years after the index procedure; of them, 22 (eight SES and 14 PES) OCT pullbacks were evaluated in a paired analysis at three and nine years post implantation. Overall, neoatherosclerosis was identified in 23.1% of stents at three years and in 30.8% at nine years after the index procedure ($p = 0.289$). No features of significant neoatherosclerotic progression were found in either group between three- and nine-year assessment.

Conclusions: At nine years after implantation of early-generation DES no significant neoatherosclerotic progression was observed among patients with uneventful follow-up at three years after PCI, as assessed by OCT. These observations need to be confirmed in larger studies including the current generation of DESs.

Key words: optical coherence tomography, early-generation drug-eluting stent, neoatherosclerosis

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INTRODUCTION

Atherosclerotic plaque formation within neointimal tissue covering the stent struts, referred to as neoatherosclerosis, may contribute to late adverse events, such as stent thrombosis (ST) [1–3] and in-stent restenosis, and has been recognised as a major concern after early-generation drug-eluting stent (DES) implantation [1, 4, 5].

Some histologic studies revealed an earlier onset and more pronounced course of neoatherogenesis within first-generation DES, as compared to bare-metal stents (BMSs) [6], indicating the need for long-term evaluation of vessel healing response after coronary angioplasty. The longest systematic follow-up periods in autopsy studies evaluating neointimal growth following DES implantation reached six years maximally after percutaneous coronary intervention (PCI) [1, 6].

Optical coherence tomography (OCT) constitutes a precise intravascular diagnostic method recently suggested to

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enable an in vivo identification of some neoatherosclerotic features [7, 8]. Nevertheless, scarce OCT data are available on the very long-term dynamics of neoatherogenesis after DES implantation, with the longest follow-ups of up to five years [9–12].

Optical coherence tomography evaluation of neointimal response and neoatherosclerotic progression in longer follow-up might provide a valuable insight into the response of coronary arteries after metallic stent implantation and allow for identification of patients at risk for future ischaemic events.

Given this background, we performed a serial, very long-term, three- and nine-year OCT evaluation of neoatherosclerotic progression after sirolimus-eluting stent (SES) and paclitaxel-eluting stent (PES) implantations in patients with stable coronary artery disease (CAD).

METHODS

Study population

Consecutive patients presenting with stable CAD, who underwent elective PCI with implantation of either SES (Cypher, Cordis, Johnson & Johnson, Milpitas, CA, USA) or PES (Taxus, Boston Scientific, Boston, MA, USA) between January 2003 and December 2004, were included in this single-centre, non-randomised, longitudinal study with the aim of a long-term OCT evaluation.

The inclusion criteria involved: (1) a single DES implantation in clinically and angiographically relevant stenosis of a native vessel; (2) implantation of a stent with a diameter of 2.5 to 3.5 mm; (3) at least 36 months of uneventful follow-up after the index PCI; (4) providing an informed consent to participate in the intravascular imaging follow-up; (5) continuation of adherent dual antiplatelet therapy for 12 months following the index procedure, according to the recommendations applicable at the time when the study was conducted.

Exclusion criteria comprised a history of target vessel revascularisation, myocardial infarction, and stroke in the period between the index PCI and planned OCT examination; left main as a culprit vessel, lesions located < 10 mm from the native vessel ostium preventing from performing OCT measurement with proximal balloon occlusion, PCI of a chronic total occlusion of a native artery, and chronic kidney disease with baseline estimated glomerular filtration rate < 30 mL/min/1.73 m^2. All index procedures were performed using routine interventional cardiology techniques, with performance of predilatation and postdilatation left to the operator's discretion.

In all included patients, OCT examination was performed at three years or more following the initial procedure. Thereafter, patients were clinically followed-up for up to nine years and underwent a second OCT evaluation at the end of the follow-up.

OCT imaging

At three-year follow-up, a time-domain OCT imaging system (M2 system, LightLab Imagining Inc., Westford, MA, USA) was used according to the manufacturer's recommendations. Briefly, the occlusive over-the-wire balloon (Helios) was advanced into the target vessel proximally to the lesion. An optic fibre probe (ImageWire, LightLab Imaging Inc.) was inserted through the balloon to the distal part of the vessel. After proximal balloon occlusion an automatic OCT pullback was performed with a continuous infusion of Ringer's lactate solution.

Optical coherence tomography images at nine-year follow-up were obtained with a commercially available frequency domain OCT imaging system (C7-XR system) with Dragonfly® image catheters, (LightLab Imaging Inc.) using the nonocclusive flushing technique. Following the diagnostic coronary angiography, the ImageWire (Lightlab Imaging Inc.) was carefully placed distally to the stenosis. After administration of 200 mg of intracoronary nitroglycerine, the target vessel was flushed via the guiding catheter with isomolar, nonionic contrast liquid.

All OCT imaging analyses were performed in the same independent core laboratory (Krakow Cardiovascular Research Institute, Krakow, Poland), using the proprietary LightLab offline analytical software, by two analysts blinded to the angiographic data and patients' clinical characteristics. Stent analyses for qualitative evaluation frames of neoatherosclerosis were performed at 0.2-mm intervals.

OCT definitions

The OCT analyses applied previously reported definitions [7, 13].

Neoatherosclerosis (neoatherosclerotic lesion) was defined as the presence of fibroatheroma or fibrocalcific plaque within the neointima of a stented segment with a longitudinal extension of ≥ 1 mm, following the recently suggested definition [11, 14]. In addition, the presence of neoatherosclerosis was disregarded whenever the calcific pool was located both inside and behind the stent.

Thin-cap fibroatheroma (TCFA) was defined as fibroatheroma with a fibrous cap ≤ 65 mm (a mean value of two adjacent measurements), whereas calcified plaques were described as signal-poor region with low attenuation and clear borderlines extending over one quadrant.

Plaque erosion was recognised in the case of the presence of attached thrombus overlying an intact fibrous cap in the neoatherosclerotic lesion and visualised on multiple adjacent OCT frames.

The neointima structure was evaluated and incidences of heterogenous neointima (tissue with focally altered optical properties demonstrating various backscattering patterns), homogeneous neointima (tissue with uniform optical properties without focal variation in the backscattering pattern), as well

as layered neointima (concentric layers with different optical properties), were reported.

The study was approved by the Local Research Ethics Committee and was conducted in accordance with the Declaration of Helsinki. All patients provided written informed consent upon inclusion and at nine-year follow up.

Statistical analysis

Categorical variables are presented as numbers and percentages, and continuous variables as mean ± standard deviation. Student t test, χ^2 test (or Fisher exact test), and the Wilcoxon test were used for comparison of means and percentages. All statistical tests were two-sided and p-values of 0.05 were considered statistically significant. All reported parameters required the agreement of two independent observers who were blinded to the clinical and procedural characteristics. In addition, one of the observers repeated the analysis after two weeks to assess the intraobserver variability. Interobserver and intraobserver variability is expressed as the kappa (κ) coefficient of agreement. Statistical analyses were performed using SPSS, version 21 (Chicago, IL, USA).

RESULTS

A total of 156 consecutive stable CAD patients who underwent PCI with implantation of the first-generation DES were screened for eligibility; 47 patients (22 SES and 25 PES) met the inclusion criteria. Of these, 39 patients underwent a successful OCT evaluation at three years post the index procedure and 22 patients were assessed at nine years post implantation (eight SES and 14 PES). Baseline clinical and angiographic characteristics were well-balanced between the SES and PES groups (Table 1).

Table 1. Baseline clinical and angiographic characteristics

	SES (n = 15)	PES (n = 24)	p
Age [years]	60.5 ± 10.1	61.3 ± 9.6	0.792
Sex (male)	8 (53.33)	20 (83.33)	0.766
Previous MI	6 (40.0)	7 (29.17)	0.778
Hypertension	12 (80.0)	14 (58.33)	0.568
Hyperlipidaemia	13 (86.67)	21 (87.5)	0.385
Diabetes mellitus	6 (40.0)	8 (33.33)	0.458
Smoking	3 (20.0)	3 (12.5)	0.464
Kidney disease	3 (20.0)	3 (12.5)	0.654
Statin therapy	12 (80.0)	21 (87.5)	0.873
Culprit vessel:			
Left anterior descending artery	8 (53.33)	13 (54.17)	0.861
Left circumflex artery	4 (26.67)	5 (20.83)	0.542
Right coronary artery	3 (20.0)	7 (29.17)	0.653
Lesion type (AHA/ACC):			
A			0.532
B1			0.761
B2			0.871
C			0.322

Data are presented as mean ± standard deviation or number (percentage). AHA/ACC — American Heart Association/American College of Cardiology; MI — myocardial infarction; PES — paclitaxel-eluting stent; SES — sirolimus-eluting stent

Neoatherosclerotic progression analysis

In this event-free population, the OCT qualitative analysis identified any features of neoatherosclerosis in 23.1% of stents at three years and in 30.8% at nine years after the index procedure (p = 0.289). The cumulative incidence of lipid plaque, calcification, and TCFA reached 23.1%, 0.0%, and 7.7% at three years and 25.6% (p = 0.456), 2.6% (p = 0.321), and 10.3% (p = 0.345) at nine years after PCI, respectively (Fig. 1A). No significant differences were found in the incidence of OCT-detected features of neoatherosclerosis between the SES and PES groups at three and nine years post implantation (Table 2).

In the PES group, there were some incidental observations of plaque erosion with intraluminal thrombus (one patient at three years, who presented with a profuse lipid plaque within the stent but with no clearly visible uncovered or malapposed struts on OCT) (Fig. 1B).

The analysis stratified according to the stent type revealed comparable rates of OCT-detected neoatherosclerotic features, including the presence of lipid plaque, calcifications, and TCFA in both stent types (Tables 2 and 3).

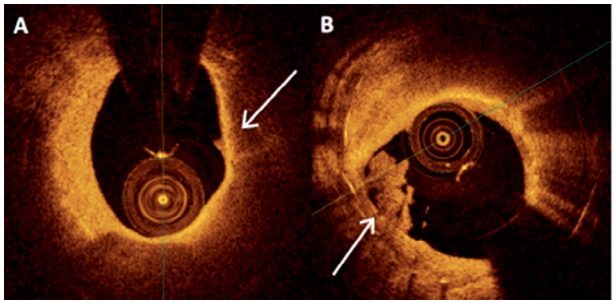

Figure 1. **A.** A thin-cap fibroatheroma in paclitaxel-eluting stent demonstrated on optical coherence tomography (OCT) at nine-year follow-up (arrow); **B.** Intraluminal thrombus revealed on OCT at the nine-year follow-up (arrow). The patient presented with a lipid neoplaque observed within 18 mm of total stent length. No clearly visible uncovered or malapposed struts could be identified by OCT

Overall, at nine years, in-stent heterogenous neointimal structure was observed in six (27.3%) patients, homogenous neointimal structure in 15 (68.2%) patients, and layered neointima was shown in one (4.5%) patient.

Inter- and intraobserver variability

The quality of the measurements was confirmed by a low inter- and intraobserver variability, calculated for lipid

Table 2. Comparison of neoatherosclerotic features in SES versus PES at three and nine years post implantation assessed by optical coherence tomography (OCT)

Parameter	Three years		p	Nine years		p
	SES (n = 15)	PES (n = 24)		SES (n = 8)	PES (n = 14)	
OCT-detected neoatherosclerotic plaque	3 (20.0)	6 (25.0)	1.000	2 (25.0)	6 (42.9)	0.657
Any neoatherosclerotic features	3 (20.0)	6 (25.0)	1.000	2 (25.0)	7 (50.0)	0.399
Lipid plaque	3 (20.0)	6 (25.0)	1.000	1 (12.5)	6 (42.9)	0.345
Lipid arc [degrees]	258.8 ± 87.8	279.5 ± 59.8	0.517	237.2 ± 0.0	226.3 ± 88.5	0.617
Lipid length [degrees]	5.8 ± 3.2	6.1 ± 3.8	0.796	3.4 ± 0.0	8.0 ± 6.6	0.617
Calcification	0 (0.0)	0 (0.0)	1.000	1 (12.5)	0 (0.0)	0.348
Minimal fibrous cap thickness [μm]	133 ± 87	121 ± 64	0.696	60 ± 0	107 ± 52	0.449
TCFA	1 (6.7)	2 (8.3)	1.000	1 (12.5)	2 (14.3)	1.000
Plaque rupture	0 (0.0)	1 (4.2)	1.000	0 (0.0)	0 (0.0)	1.000
Microvessels	0 (0.0)	0 (0.0)	1.000	0 (0.0)	1 (7.1)	1.000

Data are presented as mean ± standard deviation or number (percentage). SES — sirolimus eluting stent; PES — paclitaxel-eluting stent; TCFA — thin-cap fibroatheroma

Table 3. Comparison of neoatherosclerotic features assessed by optical coherence tomography (OCT) at three and nine years in a paired (stent-to-stent) analysis

Parameter	SES (n = 8)			PES (n = 14)		
	Three years	Nine years	p	Three years	Nine years	p
OCT-detected neoatherosclerotic plaque	1 (12.5)	2 (25.0)	0.317	5 (35.7)	6 (42.9)	0.317
Any OCT-detected neoatherosclerosis*	1 (12.5)	2 (25.0)	0.317	5 (35.7)	7 (50.0)	0.157
Lipid plaque	1 (12.5)	1 (12.5)	1.000	5 (35.7)	6 (42.9)	0.314
Calcification	0 (0.0)	1 (12.5)	0.314	0 (0.0)	0 (0.0)	1.000
TCFA	0 (0.0)	1 (12.5)	0.314	2 (14.3)	2 (14.3)	1.000
Plaque erosion	0 (0.0)	0 (0.0)	1.000	1 (7.1)	0 (0.0)	0.375
Thrombus	0 (0.0)	0 (0.0)	1.000	0 (0.0)	1 (7.1)	0.375
Microvessels	0 (0.0)	0 (0.0)	1.000	0 (0.0)	1 (7.1)	0.375
Neointima thickness [mm]	0.10 ± 0.08	0.15 ± 0.17	0.195	0.13 ± 0.10	0.14 ± 0.12	0.952

Data are presented as mean ± standard deviation or number (percentage). Abbreviations — see Table 2.
*Including at least one of the following: lipid plaque, calcification within the neointima, TCFA, plaque rupture, thrombus.

plaque and TCFA. Interobserver or intraobserver variability for the qualitative OCT assessment was as follows: 1 (1.00–1.00)/1 (1.00–1.00) for the presence of lipid plaque and 0.77 (0.47–1.00)/0.88 (0.65–1.00) for TCFA, respectively.

DISCUSSION

To the best of our knowledge, this is the longest OCT evaluation of neoatherosclerotic progression among patients treated with DES published to date. The main finding of this study is that neoatherosclerosis was a relatively prevalent finding at three years; however, no further progression was observed over the next six years in either group.

The longest OCT assessments of DES implantation to date reached five years, while the studies with serial OCT imaging reported data up to four years post procedure [8, 9, 15, 16].

The late neointimal response has been related to the continuous inflammatory stimuli from the non-degradable polymer, in the absence of antiproliferative drug elution [17].

At present, such histopathological features of neoatherosclerosis as peristrut lipid-laden foamy macrophage clusters within neointima with or without calcification, necrotic core, fibroatheromas, with emphasis on TCFA, and neointimal ruptures with thrombi formation may be visualised on the OCT [7, 11, 13, 14, 18].

Nevertheless, OCT studies evaluating neoatherogenesis within metallic stents have yielded some controversial observations [3, 8, 11, 12, 14, 18–20]. In a recent OCT study, neoatherosclerosis and lipid neointima were more often found and more extended in BMSs compared with DESs among patients suffering from very late ST [12], whereas another study showed that very late ST occurring as a consequence of the in-stent neoatherosclerotic plaque rupture was very rare (1.6% of lesions) and was encountered with comparable frequency in both BMSs (1.8%) and first-generation DESs (1.9%) [19].

Interestingly, the OCT parameters suggestive of neoatherosclerosis, although relatively prevalent in the overall study population at three years, did not aggravate over the next six years, with a numerically higher incidence of neoatherosclerotic features found in the PES group at nine years.

These findings are consistent with the recent study on neoatherosclerosis that applied a similar methodology of neoatherosclerosis assessment [14] as well as with the previous studies demonstrating a higher incidence of neoatherosclerosis in the PES-treated patients, particularly within the peristrut region [21].

On the other hand, our rates are lower as compared with those observed in the first OCT study with a long-term follow-up by Yonetsu et al. [22], who reported the neoatherosclerosis incidence of 75% at four years. Such differences may appear unsurprising, taking into account the heterogeneity of neoatherosclerosis definitions applied in clinical trials to date [3, 8, 11, 12, 14, 22]. In addition, some patient populations comprised symptomatic patients, making these rates not liable for direct comparisons [12, 22]. Notably, only incidental presence of microvessels at three and nine years was detected in this analysis. One should bear in mind that possibly they could not be detected by the first generation of OCT technology used for the three-year follow-up. In addition, as all patients experiencing major adverse cardiovascular events up to three years (before inclusion into the study) have been excluded from our study, the analysed population was highly preselected. Consequently, these relatively favourable results should be interpreted with caution, especially in light of some reports on serious adverse events, including ST resulting from severe late neoatherogenesis [23].

The results of the presented study should be interpreted in light of several limitations. Firstly, it was conducted in a selected and non-randomised population. Given the limited sample size, we cannot draw firm conclusions on the patterns of neoatherosclerosis in the investigated population. Secondly, there were two different types of OCT technologies used at three- and nine-year follow-ups, which could affect the evaluation of the corresponding frames, given the lower resolution of the first-generation time-domain OCT. Finally, the "two time-point" assessment does not allow firm conclusions to be drawn regarding the dynamics of neoatherosclerosis. Notwithstanding, our data on the six-year observation between the two OCT recordings give valuable insight into the incidence of neoatherosclerosis after early-generation DES implantation.

In conclusion, at nine years after implantation of early-generation DESs no significant neoatherosclerotic progression was observed among patients with uneventful follow-up at three years after PCI, as assessed by OCT. These observations need further confirmation in larger studies including the current generation of DES.

Conflict of interest: *none declared*

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WHAT IS NEW?

Neoatherosclerosis is recognised as a one of the mechanisms underlying late adverse events occurring after percutaneous coronary interventions, such as stent thrombosis and in-stent restenosis. Limited optical coherence tomography data are available on the very long-term neoatherosclerotic progression after drug-eluting stents implantation, with the longest follow-ups reaching up to five years. We performed a serial, very long-term three- and nine-year optical coherence tomography evaluation of neoatherosclerotic progression after sirolimus- and paclitaxel-eluting stents implanted in patients with stable coronary artery disease.