Optical coherence tomography assessment of efficacy of thrombus aspiration in patients undergoing a primary percutaneous coronary intervention for acute ST-elevation myocardial infarction

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Objective We used optical coherence tomography (OCT) to assess the impact of thrombus aspiration before angioplasty on poststenting tissue protrusions in patients undergoing a primary percutaneous coronary intervention (PCI) for ST-segment elevation myocardial infarction (STEMI).

Methods and results A total of 188 patients with STEMI who underwent thrombus-aspiration PCI (n = 113) or standard PCI (n = 75) were examined in this study. OCT was performed immediately after primary PCI to assess lesion morphology in the stented segment. The minimum stent area was similar between the thrombus-aspiration PCI group and the standard PCI group (7.4 interquartile range (IQR): 5.8–8.9 mm², P = 0.788). The maximum tissue protrusion area [0.6 (IQR: 0.3–1.1) vs. 1.2 (IQR: 0.8–1.9) mm², P < 0.001], the mean tissue protrusion area [0.1 (IQR: 0.1–0.2) vs. 0.5 (IQR: 0.3–0.8) mm², P < 0.001], and tissue protrusion volume [2.3 (IQR: 1.3–4.3) vs. 8.3 (IQR: 5.4–14.6) mm³, P < 0.001] were significantly smaller in the thrombus-aspiration PCI group compared with the standard PCI group. Minimum lumen area was significantly greater in the thrombus-aspiration PCI group compared with the standard PCI group [6.9 (IQR: 5.4–8.8) vs. 6.3 (IQR: 4.6–7.8) mm², P = 0.033].

Conclusion Thrombus aspiration before angioplasty in patients with STEMI was associated with significantly smaller tissue protrusion and larger lumen poststenting compared with standard PCI. Thrombus aspiration in primary PCI favorably influenced lesion morphologies in the stented segment. Coron Artery Dis 26:567–572 Copyright © 2015 Wolters Kluwer Health, Inc. All rights reserved.

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Keywords: acute myocardial infarction, optical coherence tomography, percutaneous coronary intervention, stents, thrombus

Introduction Acute myocardial infarction with ST-segment elevation myocardial infarction (STEMI) is caused by intraluminal thrombosis resulting in coronary artery occlusion. Primary percutaneous coronary intervention (PCI) is the standard of care for patients with STEMI and is effective for restoration of coronary blood flow [1,2]. Major complications of primary PCI are related to coronary thrombus. Distal embolization of thrombus leads to coronary no-reflow and increases infarct size [3,4]. In-stent protrusion of residual thrombus has been associated with future adverse events such as stent thrombosis [5]. Thrombus aspiration is a useful adjunctive therapy of primary PCI. Previous studies have shown that thrombus aspiration before angioplasty prevents thrombus embolization, reduces infarct size, and improves clinical outcome in comparison with standard primary PCI [3,4]. However, the efficacy of thrombus aspiration before angioplasty for preventing poststenting tissue protrusion has not been fully elucidated. Optical coherence tomography (OCT) is an optical analogue of intravascular ultrasound (IVUS) that provides high-resolution (10–20 μm) cross-sectional images of coronary arteries. Recent studies have shown that OCT can identify intracoronary thrombus more accurately than conventional imaging methods [6]. Therefore, we used OCT to assess the impact of thrombus aspiration before angioplasty on poststenting tissue protrusions in patients undergoing primary PCI for STEMI.

Methods

Study population From our OCT registry between April 2011 and March 2013, we retrospectively identified 188 STEMI patients...
who underwent OCT immediately after primary PCI. The enrollment criteria of STEMI in the present study were based on the concurrence of all the following: (a) continuous chest pain for at least 30 min; (b) arrival at our hospital within 6 h from the onset of symptoms; (c) ST-segment elevation at least 0.1 mV in two or more contiguous leads on 12-lead ECG; and (d) elevated myocardial enzyme [plasma creatine-kinase myocardial band (CK-MB) fraction level more than two times higher than normal]. All patients had a de-novo infarct-related lesion in the native coronary artery, which was treated with drug-eluting or bare-metal stents (40 Xience everolimus-eluting stents; Abbott Vascular, Santa Clara, California, USA; 18 Promus everolimus-eluting stents; Boston Scientific, Natrick, Massachusetts, USA; 65 Multi-link Vision bare-metal stents; Abbott Vascular; 33 Driver bare-metal stents; Medtronic, Santa Rosa, California, USA; 18 Duraflex bare-metal stents; Goodman, Nagoya, Japan; and 14 Liberté bare-metal stents; Boston Scientific). The general exclusion criteria for OCT imaging were cardiogenic shock, chronic renal failure, or extremely tortuous vessels. The present study was approved by the institutional review board, and written informed consent was obtained from all patients.

**Thrombus aspiration and PCI**

All patients were pretreated with aspirin 200 mg, intravenous heparin 100 U/kg, and clopidogrel 300 mg before PCI. No patients received thrombolytic therapy. The decision to perform thrombus aspiration was left to the clinician’s discretion. Manual thrombus aspiration was performed before any angioplasty using the Thrombuster III GR catheter (Kaneka Corp., Osaka, Japan). This device is a dual-lumen, monorail design, 6 Fr compatible catheter. The smaller lumen accommodates a 0.014 inch coronary guidewire. The larger extraction lumen allows the removal of thrombus, which is aspirated with a 30 ml locking vacuum syringe. After placement of the guidewire, the aspiration catheter was carefully advanced into the infarct-related coronary artery. Aspiration was started proximal to the infarct-related lesion, gently pushing the catheter through the lesion and then pulling it in a proximal direction, maintaining negative pressure even when the lesion was crossed. Multiple passages of the catheter across the lesion were enforced for aspiration. Withdrawal of the catheter from the coronary artery was performed with permanent negative pressure. Irrespective of the thrombus aspiration, balloon angioplasty and stent implantation were performed in a standard manner. Thrombus aspiration was not performed after stent implantation.

**OCT imaging and analysis**

Immediately after primary PCI, OCT was performed using C7-XR/ILUMIEN (St. Jude Medical, St Paul, Minnesota, USA). Following automatic calibration, an OCT catheter was advanced distally to the stented segment over a 0.014 inch conventional angioplasty guidewire. After the catheter placement, preheated contrast media at 37°C were flushed through the guiding catheter at a rate of 3–4 ml/s for ~3–4 s through an injector pump. When a blood-free image was observed, the OCT imaging core was pulled back over a longitudinal distance up to 50 mm at a rate of 20 mm/s using standalone electronic control of the pullback motor. OCT images (100 frames/s) were stored digitally for analysis.

All OCT images were analyzed by an experienced investigator (I.Y.) who was blinded to the clinical information and angiographic findings. The OCT analysis was carried out using a dedicated off-line review system with a semiautomated contour-detection software (St. Jude Medical). Image calibration was adjusted again before the OCT analysis. Tissue protrusion was defined as a tissue prolapse between stent struts extending inside a circular arc [6] (Fig. 1). A malapposed strut was defined as a strut with a distance of greater than 200 μm between the center of the strut blooming and the adjacent lumen border [7]. Cross-sectional areas of the stent, lumen (intrastent lumen + extrastent lumen), and tissue protrusion were measured at longitudinal intervals of 1 mm in the stented segment [8]. Volume measurements were determined using Simpson’s rule and also reported as mean areas.

**Angiographic analysis**

Quantitative coronary angiographic analysis was carried out using a validated automated edge detection algorithm (CAAS-5; Pie Medical, Maastricht, the Netherlands) by

![Image](image_url)

**Fig. 1**

OCT assessment of stent, lumen, and tissue protrusion area. OCT shows tissue protrusions within the stent (arrows). The tissue protrusion area is calculated as the stent area minus the intrastent lumen area. Outer circle with dots (area B) = stent; inner circle with dots (area A) = intrastent lumen; asterisk = guidewire shadow. OCT, optical coherence tomography.
Laboratory analysis
Blood samples were obtained on admission, at 3 h intervals during the first 24 h, and at 6 h intervals for the next 2 days after PCI. These samples were analyzed to derive peak CK-MB levels by a fluorometric enzyme immunoassay.

Statistical analysis
Statistical analysis was carried out using Statview 5.0.1 (SAS Institute, Cary, North Carolina, USA). Categorical variables were presented as incidences, with comparison using $\chi^2$ statistics or the Fisher exact test if there was an expected cell value less than 5. Continuous variables were presented as medians and interquartile ranges (IQRs), and were compared using the Mann–Whitney $U$-test. All analyses required a $P$ value less than 0.05 for statistical significance.

Results

Patient characteristics
During the study period, 202 STEMI patients underwent primary PCI (thrombus aspiration: $n = 116$; and nonthrombus aspiration: $n = 86$). OCT was not performed in 11 patients according to the exclusion criteria of the OCT imaging. In addition, we excluded three patients from the analysis because of inadequate OCT images. Thus, the final study population included 188 patients. Of 188 patients, 113 patients underwent successful thrombus aspiration before any angioplasty (thrombus-aspiration PCI group) and 75 patients underwent PCI without thrombus aspiration (standard PCI group). Four patients had unsuccessful thrombus aspiration because of a failure to advance the catheter across the lesion in the standard PCI group. The patients’ clinical characteristics are summarized in Table 1. There were no significant differences in terms of age, sex, and cardiovascular risk factors between the thrombus-aspiration PCI group and the standard PCI group.

Angiography and PCI
Angiographic findings and PCI procedural characteristics are summarized in Table 2. The time interval from the onset of symptoms to angiography was comparable between the thrombus-aspiration PCI group and the standard PCI group [5 (IQR: 4–6) vs. 5 (IQR: 4–6) h].

| Table 1 | Patients' clinical characteristics |
|---------|-----------------------------------|
|         | Thrombus aspiration PCI ($n = 113$) | Standard PCI ($n = 75$) | $P$-value |
| Age (years) | 68 (59–76) | 68 (64–77) | 0.196 |
| Male | 92 (77) | 54 (72) | 0.439 |
| Hypertension | 86 (76) | 52 (69) | 0.303 |
| Diabetes mellitus | 41 (36) | 22 (29) | 0.323 |
| Dyslipidemia | 58 (51) | 39 (52) | 0.928 |
| Current smoking | 46 (41) | 32 (43) | 0.790 |
| Obesity | 21 (19) | 14 (19) | 0.989 |
| Family history of IHD | 13 (12) | 9 (12) | 0.918 |
| Previous MI | 9 (8) | 7 (9) | 0.742 |
| Previous PCI | 10 (9) | 10 (13) | 0.443 |

Values are $n$ (%) or median (interquartile range). IHD, ischemic heart disease; MI, myocardial infarction; PCI, percutaneous coronary intervention.

| Table 2 | Angiographic findings and PCI procedural characteristics |
|---------|----------------------------------------------------------|
|         | Thrombus aspiration PCI ($n = 113$) | Standard PCI ($n = 75$) | $P$-value |
| Pre-PCI angiography | | | 0.969 |
| Infarct-related vessel | | | |
| LAD | 48 (42) | 33 (44) | 0.492 |
| LCX | 21 (19) | 13 (17) | 0.482 |
| RCA | 44 (39) | 29 (39) | 0.303 |
| TIMI flow grade | | | 0.320 |
| Grade 0 | 72 (64) | 42 (56) | 0.989 |
| Grade 1 | 7 (6) | 9 (12) | 0.211 |
| Grade 2 | 20 (18) | 13 (17) | 0.149 |
| Grade 3 | 14 (12) | 11 (15) | 0.149 |
| PCI procedure | | | |
| Stent diameter (mm) | 3.5 (3.0–3.5) | 3.5 (3.0–3.5) | 0.265 |
| Stent length (mm) | 18 (15–20) | 18 (15–23) | 0.554 |
| Multiple stents | 2 (2) | 3 (4) | 0.821 |
| Prestent ballooning | 97 (86) | 67 (89) | 0.320 |
| Poststent ballooning | 57 (50) | 41 (53) | 0.570 |
| Maximum balloon size (mm) | 3.5 (3.0–3.5) | 3.5 (3.0–3.5) | 0.265 |
| Maximum inflation pressure (atm) | 14 (11–16) | 14 (10–16) | 0.781 |
| Stent-to-artery ratio | 1.00 (0.97–1.03) | 1.00 (0.95–1.01) | 0.211 |
| Drug-eluting stents | 30 (27) | 28 (37) | 0.149 |
| Bare-metal stents | 83 (73) | 47 (63) | 0.149 |
| Post-PCI angiography | | | 0.821 |
| Reference vessel diameter (mm) | 3.3 (2.9–3.6) | 3.3 (3.1–3.6) | 0.821 |
| Minimum lumen diameter (mm) | 3.2 (2.8–3.4) | 3.1 (2.9–3.5) | 0.989 |
| Diameter stenosis (%) | 3 (2–4) | 4 (2–7) | 0.155 |
| Distal embolization | 4 (4) | 7 (9) | 0.119 |
| No-reflow | 8 (7) | 13 (17) | 0.029 |

Values are $n$ (%) or median (interquartile range). LAD, left anterior descending coronary artery; LCX, left circumflex coronary artery; PCI, percutaneous coronary intervention; RCA, right coronary artery; TIMI, thrombolysis in myocardial infarction.
Table 3  OCT findings immediately after PCI

| Stent area (mm²) | Thrombus aspiration PCI (n=111) | Standard PCI (n=75) | P-value |
|-----------------|---------------------------------|---------------------|---------|
| Mean stent area  | 8.1 (6.5–10.2)                  | 8.7 (6.6–9.9)       | 0.840   |
| Mean intrastent lumen area (mm²) | 8.0 (6.5–10.0) | 7.8 (5.9–9.3) | 0.293   |
| Mean extrastent lumen area (mm²) | 0 (0–0) | 0 (0–0) | 0.767   |
| Mean tissue protrusion area (mm²) | 0.1 (0.1–0.2) | 0.5 (0.3–0.8) | <0.001 |
| Stent volume (mm³) | 146.6 (111.4–199.9) | 150.8 (110.1–189.7) | 0.737   |
| Intrastent lumen volume (mm³) | 144.7 (109.4–194.3) | 141.7 (100.6–173.2) | 0.719   |
| Extrastent lumen volume (mm³) | 0 (0–0.4) | 0 (0–0) | <0.001 |
| Tissue protrusion volume (mm³) | 2.3 (1.3–4.3) | 8.3 (5.4–14.6) | <0.001 |

Values are represented as median (interquartile range).
OCT, optical coherence tomography; PCI, percutaneous coronary intervention.

Preprocedural angiographic findings were not different between the two groups. In the thrombus-aspiration PCI group, multiple passages [3 (IQR: 3–3) per patient] of the aspiration catheter across the lesion were performed in all patients. Stent profiles, PCI procedural characteristics, and post-PCI quantitative angiographic measurements were similar in the two groups. Although the frequency of distal embolization was not different between the two groups, the frequency of no-reflow was significantly lower in the thrombus-aspiration PCI group than the standard PCI group (7 vs. 17%, P = 0.029).

**OCT analysis**

The OCT findings immediately after PCI are summarized in Table 3. Minimum stent area was similar between the thrombus-aspiration PCI group and the standard PCI group [7.4 (IQR: 5.8–9.4) vs. 7.4 (IQR: 5.8–8.9) mm², P = 0.788]. Maximum tissue protrusion area [0.6 (IQR: 0.3–1.1) vs. 1.2 (IQR: 0.8–1.9) mm², P < 0.001], the mean tissue protrusion area [0.1 (IQR: 0.1–0.2) vs. 0.5 (IQR: 0.3–0.8) mm², P < 0.001], and tissue protrusion volume [2.3 (IQR: 1.3–4.3) vs. 8.3 (IQR: 5.4–14.6) mm³, P < 0.001] were significantly smaller in the thrombus-aspiration PCI group compared with the standard PCI group. Minimum lumen area was significantly greater in the thrombus-aspiration PCI group compared with the standard PCI group [6.9 (IQR: 5.4–8.8) vs. 6.3 (IQR: 4.6–7.8) mm², P = 0.033]. The percentage of malapposed struts per stented segment [0 (IQR: 0–0) vs. 0 (IQR: 0–0%), P = 0.939] and the frequency of stented segment with any malapposed struts [27 (24%) vs. 18 (24%), P = 0.987] were not different between the two groups.

**Early outcome**

There was no difference in the peak CK-MB level between the two groups [138 (IQR: 65–330) vs. 250 (IQR: 82–360) IU/l, P = 0.361]. Early stent thrombosis occurred in one (0.9%) patient with thrombus-aspiration PCI and in one (1.3%) patient with standard PCI (P > 0.001).

**Discussion**

The main finding of the present OCT study is that thrombus aspiration before angioplasty in patients with STEMI was associated with significantly smaller poststenting tissue protrusion and larger lumen compared with those achieved by standard PCI. Thrombus aspiration in primary PCI favorably influenced lesion morphologies in the stented segment.

**Clinical impact of thrombus aspiration**

There is still a certain amount of controversy as to the clinical effect of thrombus aspiration in primary PCI for STEMI. The VAMPIRE (Vacuum Aspiration Thrombus Removal) trial showed a trend toward lower incidence of no-reflow and a significantly higher rate of myocardial blush grade 3 in patients treated with thrombus aspiration compared with standard primary PCI [11]. The EXPIRA (Thrombectomy with Export Catheter in Infarct-Related Artery during Primary Percutaneous Coronary Intervention) trial showed a decrease in MRI-determined infarct size by thrombus aspiration [12]. The TAPAS (Thrombus Aspiration during Percutaneous Coronary Intervention in Acute Myocardial Infarction Study) showed an almost 50% reduction in 1-year mortality by thrombus aspiration [3,4]. On the basis of these results, the most recent guidelines suggest the routine use of manual
thrombus aspiration in primary PCI (class IIa) [1,2]. However, the TASTE (Thrombus Aspiration in ST-Elevation Myocardial Infarction in Scandinavia) trial recently showed no significant benefit of thrombus aspiration with respect to mortality, reinfarction, stent thrombosis, target-lesion revascularization, and target-vessel revascularization at 30 days [13]. Currently, a large-scale (n=10,700) trial called TOTAL (A Randomized Trial of Routine Aspiration Thrombectomy with PCI versus PCI alone in patients with SATEMI undergoing primary PCI) is in progress [14]. This trial would determine the effect of thrombus aspiration in primary PCI on clinically important outcomes.

**Thrombectomy with PCI versus PCI alone in patients with STEMI**

Thrombectomy with PCI versus PCI alone in patients with STEMI undergoing primary PCI is in progress [14]. Thrombectomy with PCI versus PCI alone in patients with STEMI undergoing primary PCI is in progress [14].

**Clinical implication of tissue protrusion**

There is an IVUS study reporting the clinical outcome of tissue protrusion after stenting in patients with STEMI. The HORIZONS-AMI (Harmonizing Outcomes With Revascularization and Stents in Acute Myocardial Infarction) trial showed that IVUS-documented tissue protrusion was associated with early stent thrombosis, but not with late stent restenosis [5,16]. Unfortunately, the present OCT study was not powered to show a correlation between tissue protrusion after stenting and clinical events. Therefore, a further study with a larger population is needed to assess whether the reduction of tissue protrusion volume by thrombus aspiration is associated directly with improvement in clinical outcome in patients undergoing primary PCI for STEMI.

**Limitations**

The present study has several limitations. First, this was a single-center, nonrandomized, retrospective study with a small sample size. Hence, caution must be exercised when interpreting the results. Second, the study lacks OCT data before thrombus aspiration or stent implantation. OCT cannot provide clear images in the thrombus-occluded coronary artery because of signal attenuation caused by red blood cells. Third, OCT cannot discriminate mural thrombus from plaque tissue; therefore, OCT-documented tissue protrusion might include thrombus protrusion and plaque protrusion. Finally, various types of stents were used in the present study. Tissue protrusion could be influenced by stent designs.

**Conclusion**

Thrombus aspiration before angioplasty in patients with STEMI prevents poststenting tissue protrusion and preserves luminal area in the treated segment, and it therefore represents a useful adjunctive therapy in primary PCI.

**Acknowledgements**

**Conflicts of interest**

Dr Kubo and Dr Akasaka have received lecture fees from St. Jude Medical. For the remaining authors there are no conflicts of interest.

**References**

1. O’Gara PT, Kushner FG, Ascheim DD, Casey DE Jr, Chung MK, de Lemos JA, et al. CF/AHA Task Force. 2013 ACCF/AHA guideline for the management of ST-elevation myocardial infarction: executive summary: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. Circulation 2013; 127:529–555.

2. Steg PG, James SK, Atar D, Badano LP, Böhm M, Cibis G, et al. ESC Guidelines for the management of acute coronary syndromes in patients presenting with ST-segment elevation. Eur Heart J 2012; 33:2569–2619.

3. Svilaaas T, Vllaar PJ, van der Horst IC, Diercks GF, de Smet BJ, van den Heuvel AF, et al. Thrombus aspiration during primary percutaneous coronary intervention. N Engl J Med 2008; 358:567–567.

4. Vllaar PJ, Svilaaas T, van der Horst IC, Diercks GF, Fokkema ML, de Smet BJ, et al. Cardiac death and reinfarction after 1 year in the Thrombus Aspiration during Percutaneous coronary intervention study in Acute Myocardial Infarction Study (TAPAS): a 1-year follow-up study. Lancet 2008; 371:1915–1920.

5. Choi SY, Wilzenbichler B, Maehara A, Lansky AJ, Guagliumi G, Brodie B, et al. Intravascular ultrasound findings of early stent thrombosis after primary percutaneous intervention in acute myocardial infarction: a Harmonizing Outcomes with Revascularization and Stents in Acute Myocardial Infarction (HORIZONS-AMI) substudy. Circ Cardiovasc Interv 2011; 4:239–247.

6. Kubo T, Akasaka T, Shite J, Suzuki T, Uemura S, Yu B, et al. OCT compared with IVUS in a coronary lesion assessment: the OPUS-CLASS study. JACC Cardiovasc Imaging 2013; 6:1095–1104.

7. Chen BX, Ma FY, Luo W, Ruan JH, Xie WL, Zhao XZ, et al. Neointimal coverage of bare-metal and sirolimus-eluting stents evaluated with optical coherence tomography. Heart 2008; 94:566–570.

8. Kubo T, Akasaka T, Kozuma K, Kimura K, Fusazaki T, Okura H, et al. Vascular response to drug-eluting stent with biodegradable vs. durable polymer. Optical coherence tomography study of the NEXT. Circ J 2014; 78:2408–2414.

9. Chesero JH, Knatterud G, Roberts R, Borer J, Cohen LS, Dalen J, et al. Thrombolysis in Myocardial Infarction (TIMI) Trial, Phase I: a comparison between intravenous tissue plasminogen activator and intravenous...
streptokinase. Clinical findings through hospital discharge. *Circulation* 1987; 76:142–154.

10 Cutlip DE, Windecker S, Mehran R, Boam A, Cohen DJ, van Es GA, et al. Clinical end points in coronary stent trials: a case for standardized definitions. *Circulation* 2007; 115:2344–2351.

11 Ikari Y, Sakurada M, Kozuma K, Kawano S, Katsuki T, Kimura K, et al. Upfront thrombus aspiration in primary coronary intervention for patients with ST-segment elevation acute myocardial infarction: report of the VAMPIRE (VAcuum asPIration thrombus REmoval) trial. *JACC Cardiovasc Interv* 2008; 1:424–431.

12 Sardella G, Mancone M, Bucciarelli-Ducci C, Agati L, Scardala R, Carbone I, et al. Thrombus aspiration during primary percutaneous coronary intervention improves myocardial reperfusion and reduces infarct size: the EXPIRA (thrombectomy with export catheter in infarct-related artery during primary percutaneous coronary intervention) prospective, randomized trial. *J Am Coll Cardiol* 2009; 53:309–315.

13 Fröbert O, Lagerqvist B, Olivecrona GK, Omerovic E, Gudnason T, Maeng M, et al. Thrombus aspiration during ST-segment elevation myocardial infarction. *N Engl J Med* 2013; 369:1587–1597.

14 Jolly SS, Cairns J, Yusuf S, Meeks B, Shestakovska O, Thabane L, et al. Design and rationale of the TOTAL trial: a randomized trial of routine aspiration Thrombectomy with percutaneous coronary intervention (PCI) versus PCI ALone in patients with ST-elevation myocardial infarction undergoing primary PCI. *Am Heart J* 2014; 167:315.e1–321.e1.

15 Onuma Y, Thuesen L, van Geuns RJ, van der Ent M, Desch S, Fajadet J, et al. Randomized study to assess the effect of thrombus aspiration on flow area in patients with ST-elevation myocardial infarction: an optical frequency domain imaging study – TROFI trial. *Eur Heart J* 2013; 34:1050–1060.

16 Maehara A, Mintz GS, Lansky AJ, Witzenbichler B, Guagliumi G, Brodie B, et al. Volumetric intravascular ultrasound analysis of paclitaxel-eluting and bare metal stents in acute myocardial infarction: the harmonizing outcomes with revascularization and stents in acute myocardial infarction intravascular ultrasound substudy. *Circulation* 2009; 120:1875–1882.