ESC European Society of Cardiology

European Heart Journal - Case Reports (2021) **5**(7), 1–6
doi:10.1093/ehjcr/ytab246

CASE REPORT
Other

A case report of successful stent implantation through a fractured stent-strut in a superficial femoral artery based on bench testing simulation

Haruya Yamane, Shumpei Kosugi , Motoo Date, and Yasunori Ueda *

Cardiovascular Division, NHO Osaka National Hospital, 2-1-14 Hoenzaka, Chuo-ku, Osaka, 540-0006, Japan

Received 11 January 2021; first decision 3 February 2021; accepted 25 May 2021

Background Stent implantation through the stent-strut of a previously implanted self-expandable stent in the superficial femoral artery (SFA) is not usually performed because the additional stent cannot dilate sufficiently. The key point to achieve sufficient expansion of an additional stent is to break the stent-strut of the previously implanted stent. However, there is no report of how to break the stent-strut.

Case summary A 72-year-old man was admitted to our hospital with acute rest pain and coldness of his left leg; he was diagnosed with acute limb ischaemia. The angiogram demonstrated a fractured stent as well as stent occlusion in the left distal SFA. The guidewire could pass only through the stent-strut because of stent fracture. Fortunately, balloon angioplasty through the stent-strut and thrombolysis achieved successful revascularization. Thereafter, an additional stent was implanted in an attempt to manage the fractured and deformed stent. To obtain sufficient expansion of the additional stent, an experimental study to examine the balloon diameter and pressure to break the stent-strut was performed. Based on the results of the experiment, the stent-strut was successfully broken, and the additional stent was expanded through the stent-strut on the second intervention.

Discussion If an additional self-expandable stent is deployed through the stent-strut directly, it would not be sufficiently dilated. The key point in such a case is to break the stent-strut of the previously implanted stent by balloon inflation before deployment of the additional stent. The experimental study examined the balloon diameter and pressure that can break the stent-strut. This information would be useful when we implant an additional stent through a stent-strut.

Keywords Stent fracture • Self-expandable stent • Stent-strut • Peripheral artery disease • Endovascular treatment • Case report

* Corresponding author. Tel: +81-6-6942-1331, Fax: +81-6-6943-6467, Email: yellowplaque@gmail.com
Handling Editor: Panagiotis Xaplanteris
Peer-reviewers: Roman Komorovsky; Roberto Lorusso; Giampiero Vizzari
Compliance Editor: Debbie Falconer
Supplementary Material Editor: Elhosseyn Guella

Learning points

- Stent implantation through a stent-strut in the superficial femoral artery is not usually performed because the stent would not be sufficiently expanded.
- Bench testing simulation demonstrated that stent expansion can be obtained by breaking the stent-strut.
- The implantation of a stent through the stent-strut after breaking the stent-strut resulted in acceptable expansion of the additional stent.

Introduction

Stenting in the superficial femoral artery (SFA) is a well-established strategy of endovascular treatment (EVT), especially in cases of flow-limiting dissection; however, stent fracture is an important complication.[1] Although drug-coated balloon (DCB) treatment has become an important treatment option to prevent restenosis, stent implantation is still often required. The incidence of stent fracture ranges between 3% and 28%.[2–5] In the present case, stent fracture caused acute limb ischaemia (ALI), and additional stent implantation through a stent-strut was required due to stent deformation. Since SFA self-expandable stents are made of nickel-titanium, i.e., nitinol, it is difficult to expand the additional stent through the stent-strut due to the strut's shape-memory function. A successful case of stent implantation through a stent-strut using a bench testing simulation is presented.

Timeline

10 years ago	A self-expandable stent was implanted in the left distal superficial femoral artery (SFA).
Initial presentation	The patient was admitted with acute limb ischaemia.
	Angiography showed in-stent occlusion of the fractured left SFA stent. Endovascular treatment (EVT) was successfully performed through the stent-strut with balloon and thrombolysis.
Day 5	A bench testing simulation was performed to determine the detailed strategy for the second EVT.
Day 8	The second EVT was performed. The fractured and deformed stent was successfully fixed by implanting an additional stent through the stent-strut.
Day 10	The patient was discharged.
Year 1	Computed tomography showed that the additionally implanted stent was patent.

Case presentation

A 72-year-old man was admitted to our hospital with acute rest pain and coldness in his left lower leg lasting for 2 h. He had diabetes mellitus and dyslipidaemia that had been treated for about 20 years. Although he was taking alogliptin (25 mg/day) and rosuvastatin (5 mg/day), his HbA_{1c} was 7.0%, and his low-density lipoprotein cholesterol level was 110 mg/dL. His triglyceride level was 110 mg/dL, and his high-density lipoprotein cholesterol level was 39 mg/dL. He had chronic kidney disease, and his estimated glomerular filtration rate was 36.3 mL/min/1.73 m^2. He had a history of smoking. He was not obese (body mass index 24 kg/m^2) and had no history of hypertension, coronary artery disease, or cerebrovascular disease. He had a history of peripheral arterial disease in his left leg treated with a LUMINEXX stent (BARD, Inc., Murray Hill, NJ, USA) more than 10 years earlier and was taking aspirin (100 mg/day) since the treatment.

On physical examination, his left leg showed ischaemic changes, i.e., pain, paleness, and pulselessness. His left popliteal pulse was not detected. Ultrasonography demonstrated in-stent occlusion in the left SFA. Serum creatine phosphokinase (423 IU/L) and D-dimer (10.8 mg/mL) levels were elevated. Excluding aortic dissection and popliteal artery entrapment syndrome by computed tomography (CT) angiography, the diagnosis of ALI was made. Since his leg motor and sensory nerve functions remained normal, and the classification of ALI was grade IIb, his leg was judged salvageable by urgent revascularization.

The angiogram demonstrated that the left SFA was occluded in the proximal part of the previously implanted stent (*Figure 1A*). The stent was deformed and appeared protruded from the vessel (*Figure 1A*), suggesting that the stent was fractured. A guidewire (Jupiter FC; Boston Scientific, Tokyo, Japan) was inserted through the occluded lesion; however, the angiogram showed that the guidewire passed through the stent-strut (*Figure 1B*). An attempt was made to insert the guidewire throughout the stent without crossing the stent-strut by antegrade and retrograde approaches but failed. Therefore, aspiration thrombectomy and balloon angioplasty with a 4.0-mm balloon (ULTRAVERSE RX; Medicon, Osaka, Japan) were performed through the stent-strut. Recanalization was successful, although a massive thrombus was still seen in the lumen (*Figure 1C*).

In addition, selective thrombolysis was performed for 24 h by infusing urokinase (10 000 U/h) through the sheath. The angiogram after thrombolysis demonstrated a definite reduction of thrombus without flow delay (*Figure 1D*). Although limb salvage was successful, the SFA was jailed by the fractured stent.

Therefore, additional stent implantation through the stent-strut to remove the stent-strut from the vessel lumen was planned, and a bench testing simulation was performed to determine the procedures required to achieve successful results. The balloon (ULTRAVERSE RX) was gradually inflated through the stent-strut of the LUMINEXX stent, and the pressure at which the stent-strut was broken was determined (*Figure 2A*). The LUMINEXX stent has two types of open-cell and closed-cell stent-struts. When the open-cell of the 6.0-mm LUMINEXX stent was dilated by 7.0-mm and 8.0-mm balloons, the stent-strut was broken at 10 atm and 4 atm, respectively. On the other hand, the closed-cell of the 6.0-mm LUMINEXX

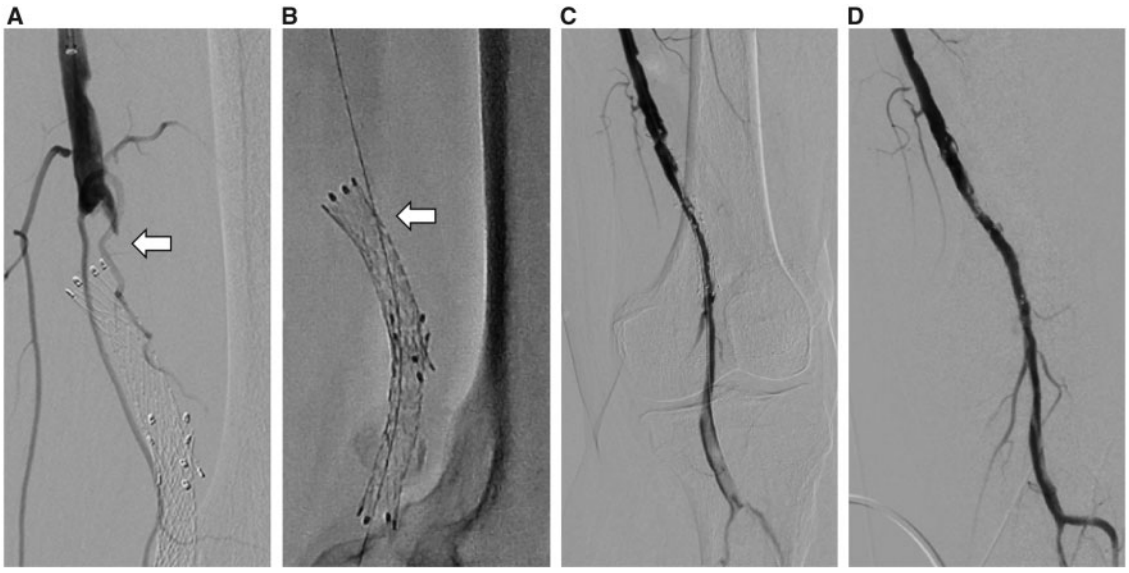

Figure 1 Angiogram of the first procedure and after thrombolysis. (*A*) The angiogram demonstrates that the left superficial femoral artery is occluded in the proximal part of the previously implanted stent (white arrow). (*B*) The guidewire passes through the stent-strut (white arrow). (*C*) Aspiration thrombectomy and balloon angioplasty with a 4.0-mm balloon are performed through the stent-strut. Recanalization is successful, although massive thrombus is still seen in the lumen. (*D*) Angiogram after thrombolysis demonstrates definite reduction of thrombus without flow delay.

stent was broken at 4 atm by the 7.0-mm balloon. Then, it was possible to adequately expand a drug-eluting stent (ELUVIA, Boston Scientific, Marlborough, MA, USA) through the broken stent-strut (*Figure 2B*).

A second EVT was performed to implant an additional stent through the stent-strut. A guidewire was inserted through the lesion, which was seen to cross the open-cell of the fractured stent. It was dilated by a 7.0-mm balloon at 10 atm according to the results of the bench testing simulation (*Figure 3A*), and a 6.0-mm ELUVIA stent was deployed and expanded adequately by the 6.0-mm balloon at 14 atm (*Figure 3B*). Intravascular ultrasound imaging confirmed the expansion of the additional stent up to 5.5 mm in diameter (*Figure 3C*). The final angiogram showed a good result (*Figure 4A*). The patient was discharged without any complications 10 days after EVT with double anti-platelet therapy. At the 12-month follow-up, the patient had no leg pain or intermittent claudication. CT angiography at 12 months demonstrated stent patency (*Figure 4B*). The 3D reconstruction image of the CT angiogram clearly showed that the proximal part of the fractured stent was located outside the vessel wall (*Figure 4C*).

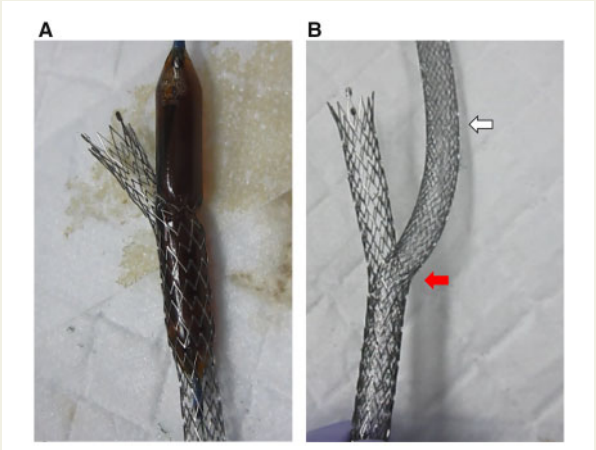

Figure 2 Bench testing simulation. (*A*) The balloon diameter and pressure that can break the stent-strut are examined. Inflation pressure is gradually increased by 1 atm until the stent-strut is broken. (*B*) An ELUVIA stent (white arrow) is implanted through the broken open-cell (red arrow) of the LUMINEXX stent.

Discussion

According to current guidelines for peripheral artery disease, EVT is recognized as the preferred revascularization strategy for symptomatic patients with an SFA lesion.[6,7] However, stent fracture is one of the important complications. Multiple stent deployment and long lesions are known risk factors for stent fracture.[5] A higher incidence of fracture has been reported for the LUMINEXX stent than for other self-expanding nitinol stents.[8] Although stent fractures do not always lead to stent occlusion, they occasionally cause symptomatic complications.[9] In the present case, stent fracture caused ALI, and the fractured stent was successfully managed by implanting an additional stent. This is the first case report in which additional stent implantation through a stent-strut was required to treat an SFA occluded by a fractured and deformed stent.

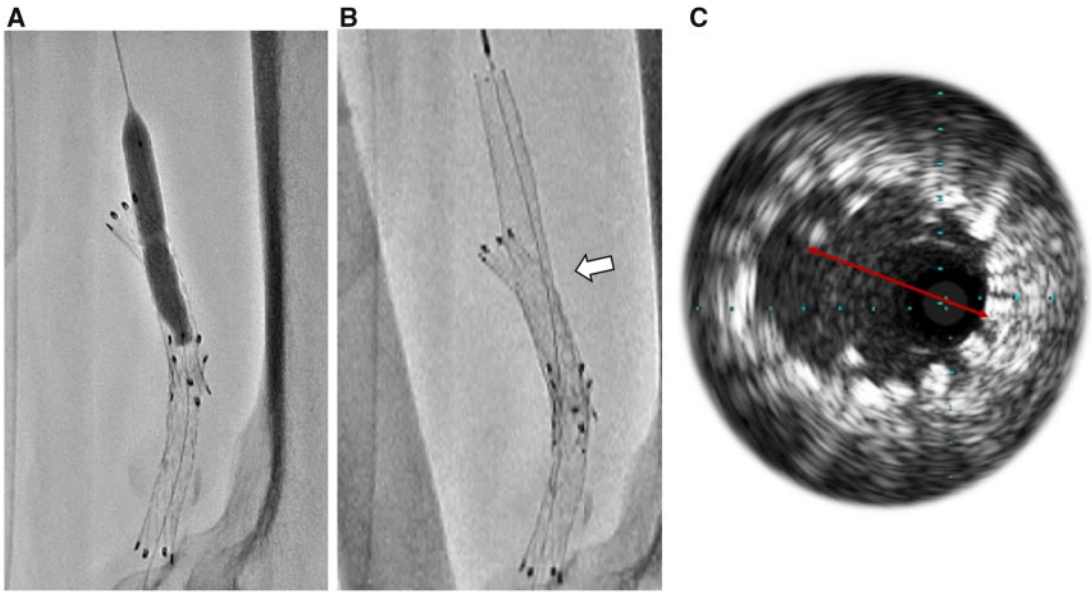

Figure 3 Angiogram of the second procedure. (*A*) The guidewire passes through the open-cell, which is dilated by a 7.0-mm balloon at 10 atm according to the results of the bench testing simulation. (*B*) A stent is deployed through the stent-strut (white arrow) and expanded adequately. (*C*) Intravascular ultrasound image demonstrates that the stent has been expanded up to 5.5 mm in diameter (red line).

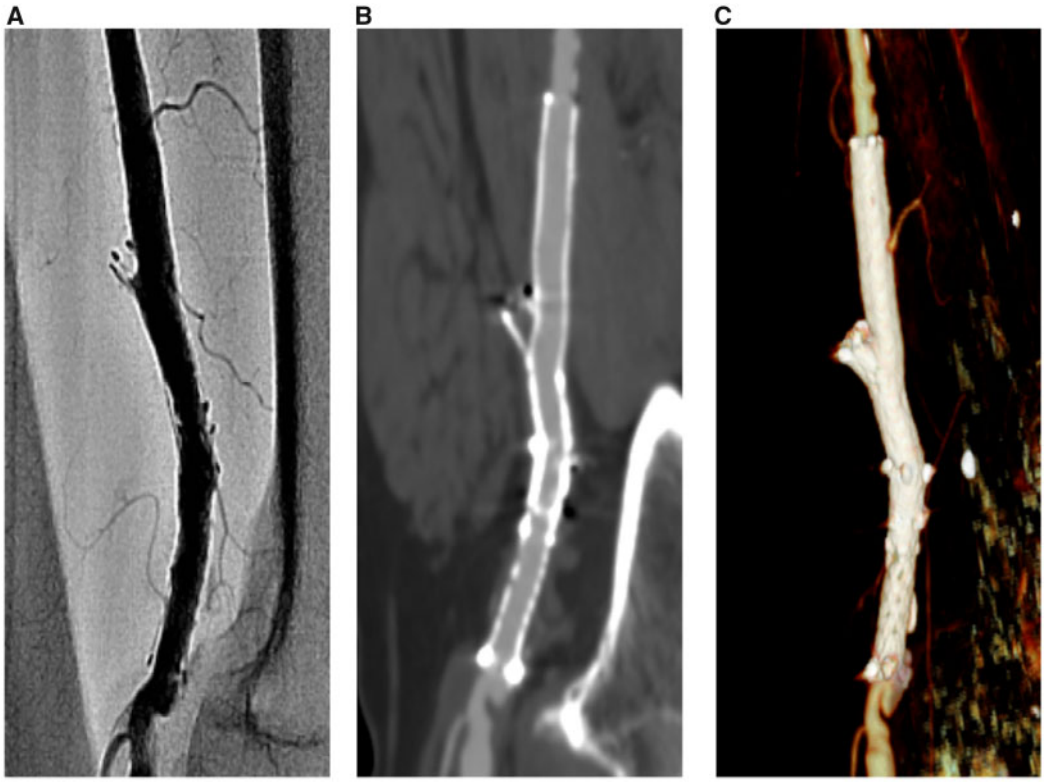

Figure 4 Final angiogram after procedures and follow-up computed tomography angiogram. (*A*) The final angiogram after procedures shows adequate stent expansion. (*B*) Follow-up computed tomography angiogram demonstrates stent patency. (*C*) The 3D reconstruction image of the computed tomography angiogram clearly shows that the proximal part of the fractured stent is located outside the vessel wall.

Table 1 **Inflation pressure for breaking the stent-strut**

Open-cell	SMART		ELUVIA	LIFE STENT		
	6.0 mm	7.0 mm	6.0 mm	7.0 mm	6.0 mm	7.0 mm
Balloon diameter						
6.0 mm	×14	×14	×14	×14	×14	×14
7.0 mm	8.2 ± 0.4	9.6 ± 0.5	×14	×14	×14	×14
8.0 mm	4.0 ± 0.7	4.2 ± 0.8	×14	×14	×14	×14
9.0 mm	-	-	×14	×14	10.4 ± 1.5	14.0 ± 0.0
10.0 mm	-	-	7.0 ± 0.7	7.0 ± 0.0	-	-

Closed-cell	ELUVIA	
	6.0 mm	7.0 mm
Balloon diameter		
6.0 mm	8.4 ± 1.1	11.6 ± 2.4
7.0 mm	8.7 ± 1.5	10.3 ± 0.6
8.0 mm	-	-

Inflation pressure is presented as mean ± SD by atm.
×, stent-strut was not broken. -, not performed.
The number after '×' indicates the maximum pressure (atm) tried.
The balloon used in this experiment was Stering (Boston Scientific, Marlborough, MA, USA).
The stent-strut of a 6.0-mm SMART stent (Cordis Corp., Miami Lakes, FL, USA) can be broken by a 7.0-mm balloon at an average pressure of 8.2 atm, whereas that of a 6.0-mm ELUVIA stent cannot be broken even by a 9.0-mm balloon. Among the SFA stents, stent-strut of a SMART stent can be easily broken.

If the stent occlusion was caused by in-stent restenosis, conventional balloon angioplasty and DCB treatment might be a treatment option to prevent ALI recurrence due to restenosis. However, in the present case, removal of the jailed stent-strut from the vessel lumen was thought to be required to prevent a recurrence. Therefore, additional stent implantation through the stent-strut to remove the stent-strut from the vessel lumen was planned.

If an additional self-expandable-stent is deployed directly through the stent-strut of a previously implanted stent, it would not be dilated sufficiently. Thus, breaking the stent-strut was considered necessary to achieve sufficient expansion of the additional stent. The key point in the present case was that the stent-strut was broken by balloon inflation before the deployment of an additional stent. However, the balloon diameter and pressure that could break the stent-strut were unknown. Therefore, the bench testing simulation was important for this successful bailout procedure.

The reason why it was thought that the guidewire crossed the open-cell in the second EVT was that the route of the guidewire passage was too distant from the proximal edge of the fractured stent. The closed cell is located only at the proximal edge of the stent.

Since Iida *et al.*[10] reported that a smaller minimum stent area is one of the important risk factors for restenosis, we can expect a better outcome with our procedures. However, since a >6-mm-diameter balloon is required to break the stent-strut, it is impossible in smaller vessels. There would be a potential risk of vessel rupture by breaking the stent-strut with an oversized balloon; therefore, the precise evaluation of vessel size by imaging modalities is important. Another possible complication would be that intravascular imaging catheters or balloon catheters may be stuck at the stent-strut and become unremovable. If breaking the stent-strut is impossible, full expansion of the additional stent cannot be expected; therefore, an alternative treatment such as bypass surgery should be considered. The results of bench testing simulations with other SFA stents are presented in *Table 1*.

Conclusions

A case of ALI caused by stent fracture was presented. The fractured stent was successfully managed by implanting an additional stent. When a guidewire can pass only through the stent-strut, breaking the stent-strut would be a necessary procedure before implanting an additional stent to obtain sufficient expans ion. Information from bench testing simulation would be useful.

Lead author biography

Dr Haruya Yamane, MD, graduated from Kagoshima university, Japan. He began clinical training in Cardiology at Otemae Hospi tal, Osaka, Japan, which was conducted from 2015 to 2020. He currently works as a Cardiologist in NHO Osaka National Hospital, Osaka, Japan.

Supplementary material

Supplementary material is available at *European Heart Journal - Case Reports* online.

Slide sets: A fully edited slide set detailing these cases and suitable for local presentation is available online as Supplementary data.

Consent: The authors confirm that written consent for submission and publication of this case report including images and associated text has been obtained from the patient in line with COPE guidance.

Conflict of interest: Y.U.: Research grants from Abbott Vascular, Pfizer, Bayer, Daiichi-Sankyo, Astellas, Shionogi, Sanofi, Ono, Nihon Kohden, Amgen Astellas, Actelion, Bristol-Myers Squibb, Medtronic, AstraZeneca, Otsuka, and Novartis. Lecture fees from Daiichi-Sankyo, MSD, Goodman, Sanofi, Mochida, Takeda, Kowa, Teijin, Astellas, Actelion, Bristol-Myers Squibb, AstraZeneca, Boston Scientific, Sumitomo Dainippon Pharma, Eisai, and Amgen Astellas. Others declared no conflicts of in terest.

Funding: None declared.

References

1. Schillinger M, Sabeti S, Loewe C, Dick P, Amighi J, Mlekusch W et al. Balloon angioplasty versus implantation of nitinol stents in the superficial femoral artery. *N Engl J Med* 2006;**354**:1879–1888.
2. Davaine JM, Quérat J, Guyomarch B, Brennan MÁ, Costargent A, Chaillou P et al. Incidence and the clinical impact of stent fractures after primary stenting for TASC C and D femoropopliteal lesions at 1 year. *Eur J Vasc Endovasc Surg* 2013; **46**:201–212.
3. Iida O, Nanto S, Uematsu M, Morozumi T, Kotani J, Awata M et al. Effect of exercise on frequency of stent fracture in the superficial femoral artery. *Am J Cardiol* 2006;**98**:272–275.
4. Laird JR, Katzen BT, Scheinert D, Lammer J, Carpenter J, Buchbinder M, et al.; for the RESILIENT Investigators. Nitinol stent implantation versus balloon angioplasty for lesions in the superficial femoral artery and proximal popliteal artery: twelve-month results from the RESILIENT randomized trial. *Circ Cardiovasc Interv* 2010;**3**:267–276.
5. Iida O, Nanto S, Uematsu M, Ikeoka K, Okamoto S, Nagata S. Influence of stent fracture on the long-term patency in the femoro-popliteal artery. *JACC Cardiovasc Interv* 2009;**2**:665–671.
6. Gerhard-Herman MD, Gornik HL, Barrett C, Barshes NR, Corriere MA, Drachman DE et al. 2016 AHA/ACC guideline on the management of patients with lower extremity peripheral artery disease: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Circulation* 2017;**135**:e686–e725.
7. Aboyans V, Ricco JB, Bartelink MEL, Björck M, Brodmann M, Cohnert T, et al.; ESC Scientific Document Group. 2017 ESC guidelines on the diagnosis and treatment of peripheral arterial diseases, in collaboration with the European Society for Vascular Surgery (ESVS). *Eur Heart J* 2018;**39**:763–816.
8. Iida O, Soga Y, Hirano K, Okamoto S, Dohi T, Uematsu M et al. Retrospective multicentre analysis of S.M.A.R.T. vs. Luminexx nitinol stent implantation for superficial femoral artery lesions (REAL SL) Registry. 5 years' experience. *Circ J* 2011;**75**:421–427.
9. Rahimi M, Robertson B, Doctor LM, Bath J. Successful management of arterial pseudoaneurysm caused by stent fracture. *Ann Vasc Surg* 2017;**41**: 281.e11-281.e14–281.e14.
10. Iida O, Takahara M, Soga Y, Nakano M, Yamauchi Y, Zen K, et al.; ZEPHYR Investigators. 1-Year results of the ZEPHYR registry (Zilver PTX for the Femoral Artery and Proximal Popliteal Artery): predictors of restenosis. *JACC Cardiovasc Interv* 2015;**8**:1105–1112.