Mid-term results and predictors of restenosis in patients undergoing endovascular therapy for isolated popliteal artery steno-occlusive disease

Short title: Results of isolated popliteal artery interventions

Dat Tin Nguyen M.D.¹, Patrik Bayerle M.D.¹, Miklós Vértes M.D.¹, Ákos Bérczi M.D.¹, Edit Dósa M.D., Ph.D.¹

¹Heart and Vascular Center, Semmelweis University, Budapest, Hungary

Corresponding author: Edit Dósa M.D., Ph.D., Heart and Vascular Center, Semmelweis University, Városmajor Street 68, Budapest 1122, Hungary, Phone: +36-20-825-8108, Fax: +36-1-458-6746, E-mail: dosa.edit@med.semmelweis-univ.hu

(Received: 2020.07.23.; Revised: 2020.09.20. Accepted: 2020.11.24)

Copyright: The Author(s)

Open Access statement. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited, a link to the CC License is provided, and changes – if any – are indicated. (SID_1)
Abstract

Background and Aim: There is only a limited number of major publications on the outcome of interventions for isolated popliteal artery stenosis. The purpose of this study was to report our results on mid-term patency and predictors of restenosis.

Patients and Methods: This single-center retrospective study included 61 symptomatic patients (males, N=33; median age, 65.1 years [IQR, 60.7–71.9 years]; Rutherford grade 4–6, N=14) with at least two patent crural arteries, whose atherosclerotic stenoses/occlusions were treated with percutaneous transluminal angioplasty (PTA) or stenting (using self-expanding bare-metal Astron Pulsar stents) between 2011 and 2018.

Results: Twenty-six patients had PTA, while 35 underwent stenting. The median follow-up was 29 months (IQR, 10–47 months). The primary patency rates were not significantly different (P = 0.629) between PTA and stenting groups. Restenosis developed in nine patients (34.6%) in the PTA group, and in 12 (34.3%) in the stenting group. Restenotic lesions required re-intervention in nine cases (100%) in the PTA group, and in eight (66.7%) in the stenting group. Restenosis developed significantly less frequently (P = 0.010) in patients with a popliteal/P1 stent; the primary patency rates were also significantly better (P = 0.018) in patients with a popliteal/P1 stent when compared to popliteal/P2 plus multi-segment stents. Cox regression analysis identified lesion location as a predictor of in-stent restenosis (HR, 2.5; 95% CI, 1.2–5.5; P = 0.019).

Conclusion: Stenting was not superior when compared to PTA (if selective stenting was not considered as loss of patency). Follow-up should be more thorough in patients undergoing popliteal/P2 or multi-segment stenting.

Keywords: popliteal artery, endovascular therapy, PTA, stenting, restenosis, patency
Introduction

Popliteal artery steno-occlusive disease could be truly isolated if no stenosis or occlusion were present elsewhere in the ipsilateral lower extremity. Atherosclerosis is usually a multilevel pathological process, therefore the probability of an isolated popliteal manifestation is minimal. In many cases, the cause of a truly isolated popliteal artery luminal narrowing is from external compression due to e.g. entrapment syndrome or cystic adventitial disease.

In the majority of studies, a presumed atherosclerotic popliteal artery stenosis is considered isolated if the patient has no ipsilateral femoral artery stenosis, requiring invasive therapy. However, publications are heterogeneous in terms of arterial runoff and the type of radiological intervention used. [1–7] Although percutaneous transluminal angioplasty (PTA) with a plain or drug-coated balloon plus or minus bare-metal stenting is the most commonly applied treatment method, [1, 2, 4, 7–11] reports have outlined stentgraft implantation [12] and atherectomy [3, 4, 13]. However, studies also appear to be inconsistent in terms of the composition of deployed (mainly self-expanding) stents. [1, 2, 5, 7–9, 11]

The mid- and long-term efficacy of endovascular procedures can be characterized by the restenosis rate. Depending on radiological intervention types, the restenosis rate of popliteal endovascular therapy is approximately 5–70%, [1–6] which is slightly better than the restenosis rate of femoropopliteal interventions (40–70%; most likely because femoral lesions are almost always longer than popliteal lesions, and the longer the treated lesion, the greater the probability of restenosis) [14, 15].

Therefore, the goal of this study was to examine mid-term results of endovascular methods and identify predictors of restenosis in a single-center, homogeneous population in terms of crural runoff arteries and implanted stent type.
Patients and methods

Patient selection

Sixty-one patients from a single institution, who underwent an intervention for symptomatic isolated popliteal artery de novo steno-occlusive disease (no ipsilateral iliofemoral stenosis, two patent crural run-off arteries) between June 2011 and June 2018, were retrospectively analyzed. The study procedures were carried out in accordance with the Declaration of Helsinki. Institutional review board approval was granted (Approval No: 138/2013). Due to the retrospective nature of the study, no informed consent for analysis of data was obtained from patients.

Pre-procedural data

The following clinical data were collected from our medical record archiving system (MedSol; T-Systems Hungary Ltd., Budapest, Hungary): age; gender; anthropometric parameters (e.g. weight, height); atherosclerotic risk factors and comorbidities (smoking, hypertension, hyperlipidemia, diabetes mellitus, chronic kidney disease); past medical history (coronary, supra-aortic, and/or lower extremity radiological interventions or surgical reconstructions); Rutherford grade; [16] ankle-brachial index (ABI); and medication regimen.

Procedural information

Radiological interventions were executed through the common femoral artery. The choice of approach (antegrade versus retrograde) was left to the discretion of the interventional radiologist performing the procedure. Patients underwent either PTA or stenting (selective or primary). Selective stenting was defined as stent placement after PTA with suboptimal results (residual stenosis of \(\geq 30\%\), flow-limiting dissection). Primary stenting was defined as stent placement after predilation of the lesion, regardless of the PTA outcome. [17] Generally, in patients with non-occlusive, short lesions, PTA was favored, while in the presence of heavily calcified, long lesions or total occlusions, primary stenting was chosen. All procedures were
performed by three experienced interventional radiologists with more than 10 years of experience in the treatment of peripheral arterial occlusive disease.

Technical success was defined as <30% residual stenosis without dissection or extravasation. [16] Punctured arteries were manually compressed. In uncomplicated cases, patients were discharged 1–2 days after the procedure. Patients were on dual antiplatelet therapy for 1 month, followed by a lifelong acetylsalicylic acid or clopidogrel monotherapy.

Post-procedural data
According to international and in-house guidelines, patients were scheduled for a follow-up visit at 6 weeks, 6 months, and 12 months after the intervention, and yearly thereafter, or sooner if symptoms arose. The following follow-up data were collected: Rutherford grade, [16] ABI, and duplex ultrasound (DUS) results. Significant restenosis was defined as peak systolic velocity of ≥250 cm/s as measured by DUS in the treated popliteal segment. Primary patency was defined as a patent popliteal artery, without further intervention. Secondary patency was defined as an open popliteal artery after endovascular re-intervention or surgical reconstruction due to restenosis. Clinical success was defined as subjective improvements as reported by the patient, and/or at least one stage improvement in Rutherford grade.

Imaging data
Digital subtraction angiography data were extracted from picture archiving and communication systems (PACS; GE Healthcare Inc., Chicago, IL, USA). Lesion parameters consisted of localization (P1: from the intercondylar fossa to the proximal edge of the patella; P2: from the proximal edge of the patella to the center point of the knee joint; P3: from the center of the knee joint to the origin of the anterior tibial artery, and multi-segment disease: combinations of the above), [18] stenosis grade and length, calcification presence and grade, and residual stenosis grade.
Calcification was evaluated on the baseline fluoroscopic images. Lesions were mildly calcified if single or multiple punctate calcifications were present, moderately calcified if single or multiple linear areas of calcification were seen, and heavily calcified if continuous calcification with no visible breaks was observed. [19]

**Analyzed parameters**

Both PTA and stenting groups were divided into restenotic and non-restenotic subgroups, and were compared for pre-procedural, imaging, procedural, and post-procedural data.

**Statistical analysis**

Statistical analyses were performed using StatSoft Statistica 13.4 (Moonsoft Oy, Espoo, Finland) and GraphPad Prism 7.01 (GraphPad Software Inc., La Jolla, CA, USA) software. Continuous data were expressed as medians and interquartile ranges (IQR, Q1–Q3); categorical data were represented as counts (percentages). Significant differences in groups/subgroups for continuous and categorical data were evaluated using Mann-Whitney \( U \) and Fisher’s exact tests, respectively. Patency was calculated using Kaplan-Meier analysis. Kaplan-Meier curves were compared using a log-rank test. Cox regression analysis was used to determine significant predictors of restenosis; the hazard ratio (HR) was presented together with its 95% confidence interval (CI). The threshold for statistical significance was \( P < 0.05 \).

**Results**

**Patient data**

Twenty-six patients (42.6%) were in the PTA group, while 35 patients (57.4%) were in the stenting group. The median age was 65.1 years (IQR, 60.7–71.9 years) in the PTA group. Indications for radiological intervention were severe claudication (Rutherford grade 3) in 12 cases (46.2%), and critical limb ischemia (CLI; Rutherford grade 4–6) in 14 cases (53.8%). Twenty-two patients (84.6%) smoked, 22 (84.6%) had hypertension, 10 (38.5%) had hyperlipidemia,
13 (50%) had diabetes mellitus, six (23.1%) were obese, and three (11.5%) had chronic kidney disease. (Table 1) Six patients (23.1%) had coronary artery bypass grafting and/or percutaneous coronary intervention, one patient (3.8%) had supra-aortic surgical and/or endovascular reconstruction, and three patients (11.5%) had contralateral lower extremity open and/or percutaneous revascularization.

In the stenting group, the median age was 63.5 years (IQR, 56.9–71 years). Indications for radiological intervention were severe claudication in 21 cases (60%), and CLI in 14 cases (40%). Thirty patients (85.7%) smoked, 30 (85.7%) had hypertension, 20 (57.1%) had hyperlipidemia, 15 (42.9%) had diabetes mellitus, 11 (31.4%) were obese, and one (2.9%) had chronic kidney disease. (Table 2) Six patients (17.1%) had coronary artery bypass grafting and/or percutaneous coronary intervention, three patients (8.6%) had supra-aortic surgical and/or endovascular reconstruction, and 14 patients (40%) had contralateral lower extremity open and/or percutaneous revascularization.

**Lesion, balloon, and stent characteristics**

For all cases, the pathological background was atherosclerosis. The ipsilateral antegrade approach was chosen in 42 patients (68.9%), while the contralateral approach was used in 19 cases (31.1%).

In the PTA group, lesions were left-sided in 12 patients (46.2%). Steno-occlusive disease affected the P1 segment in 13 cases (50%), and the P2 in eight cases (30.8%). Multi-segment disease within the popliteal artery was observed in five cases (19.2%). The median degree of stenosis was 95% (IQR, 90–100%), the median lesion length was 26.7 mm (IQR, 11.6–72.9 mm), and calcification was observed in 13 patients (50%). The median balloon diameter and the median balloon length were 5 mm (IQR, 5–5 mm) and 40 mm (IQR, 40–80 mm), respectively. (Table 3)
In the stenting group, lesions were left-sided in 15 patients (42.9%). Steno-occlusive
disease affected the P1 segment in 14 cases (40%), and the P2 in 12 cases (34.3%). Multi-
segment disease within the popliteal artery was present in nine cases (25.7%). The median
degree of stenosis was 100% (IQR, 90–100%), the median lesion length was 52.8 mm (IQR, 
23.4–80.6 mm), and calcification was observed in 22 patients (62.9%). (Table 4) In all cases, 
a self-expanding Astron Pulsar stent (Biotronik AG, Büach, Switzerland) was deployed. The 
median stent diameter was 6 mm (IQR, 6–7 mm), while the median stent length was 60 mm 
(IQR, 40–120 mm). Primary stenting was performed in 15 patients (42.9%), while selective 
stenting was chosen for 20 cases (57.1%).

Early post-procedural period (within 30 days)

Technical success was achieved in 100% of patients. In one of the stented patients, a 
retroperitoneal hematoma was observed, but did not require evacuation. After observation for 
2 days, the patient was discharged. None of the patients had distal embolization. The 30-day 
all-cause mortality rate was zero.

Follow-up period

At 6 weeks, the clinical success rate was 92% in the PTA group, while it was 89% in the 
stenting group. In the PTA group, the median resting ABI was significantly improved ($P < 
0.001$) from 0.40 (IQR, 0.28–0.52) before the procedure to 0.90 (IQR, 0.84–1.02) at the 6-
week follow-up. For the stenting group, it significantly improved ($P < 0.001$) from 0.37 (IQR, 
0.24–0.51) to 0.89 (IQR, 0.80–1.0).

The median follow-up time was 29 months (IQR, 16–47 months) for the PTA group, 
and 26.5 months (IQR, 6–47 months) for the stenting group. Follow-up times did not 
significantly differ ($P = 0.435$) between groups. Restenosis developed in nine patients 
(34.6%) in the PTA group (stenosis, N=7; occlusion, N=2), and in 12 patients (34.3%) in the 
stenting group (stenosis, N=5; occlusion, N=7). Restenotic lesions required re-intervention in
nine cases (100%) in the PTA group (PTA with a plain balloon, N=5; stenting with an Astron
Pulsar stent, N=4), and in eight cases (66.7%) in the stenting group (PTA with a plain balloon,
N=6; stenting with an Astron Pulsar stent, N=1; femoropopliteal bypass grafting, N=1).

The primary patency rate was 86% at 6 months, and 71% at 12 and 24 months in the
PTA group, while the rate was 91% at 6 months, 88% at 12 months, and 69% at 24 months in
the stenting group. There were no significant differences ($P = 0.629$) in the primary patency
rates between groups. (Figure 1A) The primary patency rate in the pooled patient group was
89% at 6 months, 82% at 12 months, and 70% at 24 months.

Recurrent restenosis was observed in three patients (3/9; 33.3%) in the PTA group,
and in six patients (6/8; 75%) in the stenting group. Two of three patients received invasive
therapy in the PTA group (PTA with a plain balloon, N=1; femoropopliteal bypass grafting,
N=1), while four of six patients underwent repeat revascularization in the stenting group
(PTA with a plain balloon, N=2; stenting with an Astron Pulsar stent, N=1; femorocrural
bypass grafting, N=1).

The secondary patency rate was 100% at 6 months, and 90% at 12 and 24 months in
the PTA group, while the rate was 100% at 6 months, 94% at 12 months, and 90% at 24
months in the stenting group. There were no significant differences ($P = 0.603$) in the
secondary patency rates between groups. The secondary patency rate in the pooled patient
group was 100% at 6 months, 93% at 12 months, and 90% at 24 months.

Restenoses and recurrent restenoses were treated invasively only in patients with
Rutherford stage 3–6.

Predictors of restenosis

In the PTA group, neither atherosclerotic risk factors nor lesion and balloon parameters
significantly differed between restenotic and non-restenotic subgroups. (Tables 1 and 3)
In the stenting group, restenosis developed significantly less frequently ($P = 0.010$) in stents implanted into the P1 segment when compared to P2 plus multi-segment stents. The primary patency rate was 100% at 6 and 12 months, and 91% at 24 months in patients with a P1 segment lesion location, while it was 86% at 6 months, 81% at 12 months, and 56% at 24 months in patients with P2 plus multi-segment lesion locations. The primary patency rates were significantly improved ($P = 0.018$) in patients with a P1 stent when compared to P2 and multi-segment stents. (Figure 1B) The secondary patency rate was 100% at 6, 12, and 24 months in patients with a P1 segment lesion location, while it was 100% at 6 months, 91% at 12 months, and 65% at 24 months in patients with P2 plus multi-segment lesion locations. The secondary patency rates were significantly improved ($P = 0.025$) in patients with a P1 stent when compared to P2 and multi-segment stents. Cox regression analysis identified lesion location as a predictor of in-stent restenosis (HR, 2.5; 95% CI, 1.2–5.5; $P = 0.019$).

**Discussion**

Among single-center studies, ours has the largest number of patients. The other studies included 18 to 46 patients. [1, 3, 5, 6, 10, 11] We have shown that the mid-term (24-month) primary patency of endovascular procedures performed on isolated popliteal artery stenosis was good (71% in the PTA group, 69% in the stenting group, 70% in the pooled group), and did not significantly differ between PTA and stenting groups (when selective stenting was not considered as loss of patency). In the stenting group, lesion location was identified as a predictor of restenosis.

As previously outlined, studies investigating patients with isolated popliteal artery steno-occlusive disease were heterogeneous in terms of patent crural runoff arteries. No studies were found where all crural arteries were patent. Our literature review revealed two studies where patients with no patent crural arteries were included. [2, 10] Other studies
consisted of patients with at least one patent crural artery. [1, 3–7, 13, 20] To our knowledge, our study was the only investigation based on patients with at least two patent crural arteries.

The following treatment methods were used in these studies: (1) angioplasty with plain balloons, (2) PTA with drug-coated balloons, (3) stenting with bare-metal stents, (4) stentgraft implantation, (5) directional atherectomy, and (6) combinations of the above. [1–7, 13] For the majority of studies (similar to this study), PTA with plain balloons and stenting (either primary or selective) with bare-metal stents was the technique of choice. [1, 2, 5–7, 10] The type of stents implanted varies from study to study. [1, 2, 5–11] In the present patient population, only Astron Pulsar stents have been deployed, which has the advantage over other stents that in most cases the intervention can be executed through a 4F sheath.

In our study, the primary patency rate was 82% at 12 months, and 70% at 24 months in the pooled patient group. Other research studies have observed similar or worse patency rates. [1, 2, 5, 7] For example, in an article, published in 2020, similar rates (72%), [20] while in another article, published in 2018, worse 24-month primary patency rates (59%) [6] can be found when compared to our data. It should be noted that procedures performed with novel endovascular methods (atherectomy alone or combined with PTA with a drug-coated balloon) resulted in improved 12-month primary patency rates (atherectomy alone: 85%, atherectomy combined with PTA with a drug-coated balloon: 95%) [3, 4] when compared to plain balloon angioplasty with or without bare-metal stenting (PTA with bare-metal stenting: 68%, PTA without bare-metal stenting: 59%) [1]. In accordance with our findings, no studies evaluating the patency of PTA and stenting in patients with isolated popliteal artery stenosis showed any significant difference between the two radiological intervention types (when selective stenting was not considered as loss of patency). [1, 2, 5, 7]

Known predictors of restenosis in patients treated endo-surgically for isolated popliteal artery stenosis include the following: body mass index (BMI), anemia, reference
vessel diameter, long lesion (>60 mm), baseline occlusion, stent placement into the P3
segment, and high-grade residual stenosis. [2, 5, 6] In our study, restenosis occurred less
frequently in patients with P1 segment stenting when compared to those with P2 segment and
multi-segment stenting. The popliteal region is critical in that vessels must adapt to
movement-induced mechanical forces (e.g. axial compression and bending). [21–23] Stent
deployment disrupts artery elastic capabilities and results in reduced axial compressibility,
which may cause extreme kinking at the marginal sections of the popliteal stents, leading to
chronic vessel micro-trauma, intimal injuries, hyperplasia, and loss of patency. [11, 21, 24]
Furthermore, stented popliteal arteries exhibit additional bending when compared to bare
arteries. During knee flexion, bare popliteal arteries have a smooth C shape, while stented
popliteal arteries adopt a ‘three-shape’ configuration, generating increased stress both inside
and at marginal sections of the stents. [23] Movement-induced mechanical forces also affect
each popliteal segment differently. Axial compression and bending are most pronounced
behind the knee, suggesting that stents implanted into the P2 segment are exposed to greater
mechanical forces than those placed into the P1 segment. [21–23, 25] Thus, patients with P1
segment stenting have reduced chances of restenosis when compared to those with P2
segment or multi-segment stenting.

The main limitation of the study was its retrospective nature. Additionally, stent
fracture (an important cause of restenosis) was not examined.

In conclusion, mid-term patency of the popliteal artery interventions was good.
Stenting exhibited no superiority when compared to PTA (if selective stenting was not
considered as loss of patency). Lesions located in the P2 segment or at multi-segments were
more prone to restenosis, therefore follow-up should be more thorough in patients undergoing
stenting in these segments.
Authors’ contribution

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by P.B., Á.B., M.V., and D.T.N. The first draft of the manuscript was written by D.T.N. and E.D., and all authors commented on previous versions of the manuscript. All authors read and approved the final version of the manuscript, and agreed to submit it to IMAGING for publication.

Funding sources

No financial support was received for this study.

Conflicts of interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

Acknowledgement

None.
References

1. Elens M, Verhelst R, Mastrobuoni S, Bosiers MJ, Possoz J, Lacroix V, et al: Balloon Angioplasty Versus Bailout Stenting for Isolated Chronic Total Occlusions in the Popliteal Artery. Vasc Endovascular Surg 2019; 53: 126–131.

2. Soga Y, Tomoi Y, Sato K, Iida O, Yokoi H: Clinical outcome after endovascular treatment for isolated common femoral and popliteal artery disease. Cardiovasc Interv Ther 2013; 28: 250–257.

3. Stavroulakis K, Bisdas T, Torsello G, Stachmann A, Schwindt A: Combined Directional Atherectomy and Drug-Eluting Balloon Angioplasty for Isolated Popliteal Artery Lesions in Patients With Peripheral Artery Disease. J Endovasc Ther 2015; 22: 847–852.

4. Stavroulakis K, Schwindt A, Torsello G, Stachmann A, Hericks C, Bosiers MJ, et al: Directional Atherectomy With Antirestenotic Therapy vs Drug-Coated Balloon Angioplasty Alone for Isolated Popliteal Artery Lesions. J Endovasc Ther 2017; 24: 181–188.

5. Cui C, Huang X, Liu X, Li W, Lu X, Lu M, et al: Endovascular treatment of atherosclerotic popliteal artery disease based on dynamic angiography findings. J Vasc Surg 2017; 65: 82–90.

6. Spiliopoulos S, Kitrou P, Galanakis N, Papadimatos P, Katsanos K, Konstantos C, et al: Incidence and Endovascular Treatment of Isolated Atherosclerotic Popliteal Artery Disease: Outcomes from the IPAD Multicenter Study. Cardiovasc Intervent Radiol 2018; 41: 1481–1487.

7. Rastan A, Krankenberg H, Baumgartner I, Blessing E, Müller-Hülsbeck S, Pilger E, et al: Stent placement vs. balloon angioplasty for popliteal artery treatment: two-year
results of a prospective, multicenter, randomized trial. J Endovasc Ther 2015; 22: 22–27.

8. Siracuse JJ, Gill HL, Cassidy SP, Messina MD, Catz D, Egorova N, et al: Endovascular treatment of lesions in the below-knee popliteal artery. J Vasc Surg 2014; 60: 356–361.

9. Goltz JP, Ritter CO, Kellersmann R, Klein D, Hahn D, Kickuth R: Endovascular treatment of popliteal artery segments P1 and P2 in patients with critical limb ischemia: initial experience using a helical nitinol stent with increased radial force. J Endovasc Ther 2012; 19: 450–456.

10. León LR Jr, Dieter RS, Gadd CL, Ranellone E, Sr Mills JL, Montero-Baker MF, et al: Preliminary results of the initial United States experience with the Supera woven nitinol stent in the popliteal artery. J Vasc Surg 2013; 57: 1014–1022.

11. Chang IS, Chee HK, Park SW, Yun IJ, Hwang JJ, Lee SA, et al: The primary patency and fracture rates of self-expandable nitinol stents placed in the popliteal arteries, especially in the P2 and P3 segments, in Korean patients. Korean J Radiol 2011; 12: 203–209.

12. Peidro J, Boufi M, Loundou Dieudonné A, Hartung O, Dona B, Vernet F, et al: Atheromatous occlusive lesions of the popliteal artery treated with stent grafts: predictive factors of midterm patency. Ann Vasc Surg 2015; 29: 708–715.

13. Rastan A, McKinsey JF, Garcia LA, Rocha-Singh KJ, Jaff MR, Harlin S, et al: One-Year Outcomes Following Directional Atherectomy of Popliteal Artery Lesions: Subgroup Analysis of the Prospective, Multicenter DEFINITIVE LE Trial. J Endovasc Ther 2018; 25: 100–108.
14. 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.

15. Dick P, Wallner H, Sabeti S, Loewe C, Mlekusch W, Lammer J, et al: Balloon angioplasty versus stenting with nitinol stents in intermediate length superficial femoral artery lesions. Catheter Cardiovasc Interv 2009; 74: 1090–1095.

16. Stoner MC, Calligaro KD, Chaer RA, Dietzek AM, Farber A, Guzman RJ, et al: Reporting standards of the Society for Vascular Surgery for endovascular treatment of chronic lower extremity peripheral artery disease. J Vasc Surg 2016; 64: e1–e21.

17. Hüttl AB, Hüttl A, Vértes M, Nguyen DT, Bérczi Á, HüttlK, et al: The presence of long and heavily calcified lesions predisposes for fracture in patients undergoing stenting of the first part of the subclavian artery. J Vasc Surg 2019; 70: 1146–1154.e1.

18. Kruse RR, Doomernik DE, Maltha KV, Kooloos JGM, Kozicz TL, Reijnen MMPJ: Collateral artery pathways of the femoral and popliteal artery. J Surg Res 2017; 211: 45–52.

19. Doris I, Dobranowski J, Franchetto AA, Jaeschke R: The relevance of detecting carotid artery calcification on plain radiograph. Stroke 1993; 24: 1330–1334.

20. San Norberto EM, Flota CM, Fidalgo-Domingos L, Taylor JH, Vaquero C: Real-World Results of Supera Stent Implantation for Popliteal Artery Atherosclerotic Lesions: 3-Year Outcome. Ann Vasc Surg 2020; 62: 397–405.

21. Smouse BH, Nikanorov A, LaFlash D: Biomechanical Forces in the Femoropopliteal Arterial Segment. Endovascular Today 2005; 60–66.
22. Poulson W, Kamenskiy A, Seas A, Deegan P, Lomneth C, MacTaggart J: Limb flexion-induced axial compression and bending in human femoropopliteal artery segments. J Vasc Surg 2018; 67: 607–613.

23. MacTaggart JN, Phillips NY, Lomneth CS, Pipinos II, Bowen R, Baxter BT, et al: Three-dimensional bending, torsion and axial compression of the femoropopliteal artery during limb flexion. J Biomech 2014; 47: 2249–2256.

24. Fortier A, Gullapallia V, Mirshams RA: Review of biomechanical studies of arteries and their effect on stent performance. IJC Heart & Vessels 2014; 4: 12–18.

25. Klein AJ, Chen SJ, Messenger JC, Hansgen AR, Plomondon ME, Carroll JD, et al: Quantitative assessment of the conformational change in the femoropopliteal artery with leg movement. Catheter Cardiovasc Interv 2009; 74: 787–798.
Table 1. Indication for treatment, atherosclerotic risk factors, and comorbidities in the PTA group

| Indication, atherosclerotic risk factors, comorbidities | PTA group (N=26) |  |  |
|--------------------------------------------------------|------------------|---|---|
|                                                        | RR subgroup      | Non-RR subgroup | P value |
|                                                        | (N=9)            | (N=17)           |         |
| CLI, N (%)                                              | 4 (44.4)         | 10 (58.8)        | > 0.999 |
| Age (year), median (IQR)                                | 70.3 (63–75.5)   | 63.5 (56.2–69.9) | 0.124   |
| Female gender, N (%)                                    | 5 (55.6)         | 11 (64.7)        | 0.692   |
| Smoking, N (%)                                          | 9 (100)          | 13 (76.5)        | 0.263   |
| Hypertension, N (%)                                     | 9 (100)          | 13 (76.5)        | 0.263   |
| Hyperlipidemia, N (%)                                   | 3 (33.3)         | 7 (41.2)         | 0.206   |
| Diabetes mellitus, N (%)                                | 4 (44.4)         | 9 (52.9)         | > 0.999 |
| Obesity (BMI≥30 kg/m²), N (%)                           | 2 (22.2)         | 4 (23.5)         | > 0.999 |
| Chronic kidney disease, N (%)                           | 1 (11.1)         | 2 (11.8)         | > 0.999 |

1 BMI, Body mass index; CLI, critical limb ischemia; IQR, interquartile range; PTA, percutaneous transluminal angioplasty; RR, restenotic.
Table 2. Indication for treatment, atherosclerotic risk factors, and comorbidities in the stenting group

| Indication, atherosclerotic risk factors, comorbidities | Stenting group (N=35) |  |
|--------------------------------------------------------|-----------------------|---|
|                                                        | RR subgroup (N=12)    | Non-RR subgroup (N=23) | P value |
| CLI, N (%)                                             | 6 (50)                | 8 (34.8)               | 0.477   |
| Age (year), median (IQR)                               | 63.3 (57.9–70.2)      | 63.5 (56.9–71.5)       | 0.794   |
| Female gender, N (%)                                   | 3 (25)                | 9 (39.1)               | 0.477   |
| Smoking, N (%)                                          | 11 (91.7)             | 19 (82.6)              | 0.640   |
| Hypertension, N (%)                                     | 10 (83.3)             | 20 (87)                | > 0.999 |
| Hyperlipidemia, N (%)                                   | 6 (50)                | 14 (60.9)              | 0.721   |
| Diabetes mellitus, N (%)                                | 5 (41.7)              | 10 (43.5)              | > 0.999 |
| Obesity (BMI≥30 kg/m²), N (%)                           | 2 (16.7)              | 9 (39.1)               | > 0.999 |
| Chronic kidney disease, N (%)                           | 0 (0)                 | 1 (4.3)                | > 0.999 |

1 BMI, Body mass index; CLI, critical limb ischemia; IQR, interquartile range; RR, restenotic.
Table 3. Lesion and balloon parameters in the PTA group

| Parameters                        | PTA group (N=26) |       |       |       |
|----------------------------------|------------------|-------|-------|-------|
|                                  | RR subgroup (N=9) | Non-RR subgroup (N=17) |       |       |
| Lesion                           |                  |       |       |       |
| Left-sided, N (%)                | 5 (55.6)         | 7 (41.2) | 0.683 |       |
| P1 segment, N (%)                | 6 (66.7)         | 7 (41.2) | 0.411 |       |
| P2 segment, N (%)                | 2 (22.2)         | 6 (35.3) | 0.667 |       |
| P3 segment, N (%)                | 0 (0)            | 0 (0)   | NA    |       |
| Multi-segment disease, N (%)     | 1 (11.1)         | 4 (23.5) | 0.628 |       |
| Stenosis grade (%), median (IQR) | 100 (90–100)     | 90 (90–100) | 0.293 |       |
| Occlusion, N (%)                 | 6 (66.7)         | 7 (41.2) | 0.411 |       |
| Length (mm), median (IQR)        | 49.6 (17.3–72.6) | 24.9 (11.6–60.9) | 0.666 |       |
| Calcification, N (%)             | 4 (44.4)         | 9 (52.9) | > 0.999 |       |
| Heavy calcification, N (%)       | 1 (11.1)         | 1 (5.9)  | > 0.999 |       |
| Balloon                          |                  |       |       |       |
| Diameter (mm), median (IQR)      | 5 (5–5)          | 5 (4–5)  | 0.686 |       |
| Length (mm), median (IQR)        | 40 (40–80)       | 40 (40–80) | 0.225 |       |

IQR, Interquartile range; NA, not applicable; P1–3, popliteal; PTA, percutaneous transluminal angioplasty; RR, restenotic.
Table 4. Lesion and stent parameters in the stenting group

| Parameters                          | Stenting group (N=35)                                      |
|------------------------------------|-----------------------------------------------------------|
|                                    | RR subgroup (N=12) | Non-RR subgroup (N=23) | P value |
| Lesion                             |                |                          |         |
| Left-sided, N (%)                  | 5 (41.7)        | 10 (43.5)                | > 0.999 |
| P1 segment, N (%)                  | 1 (8.3)         | 13 (56.5)                | 0.010   |
| P2 segment, N (%)                  | 6 (50)          | 6 (26.1)                 | 0.261   |
| P3 segment, N (%)                  | 0 (0)           | 0 (0)                    | NA      |
| Multi-segment disease, N (%)       | 5 (41.7)        | 4 (17.4)                 | 0.220   |
| Stenosis grade (%), median (IQR)   | 100 (100–100)   | 100 (90–100)             | 0.357   |
| Occlusion, N (%)                   | 10 (83.3)       | 15 (65.2)                | 0.434   |
| Length (mm), median (IQR)          | 58.3 (30.6–82.7)| 49.6 (17.3–72.6)         | 0.289   |
| Calcification, N (%)               | 9 (75)          | 13 (56.5)                | 0.463   |
| Heavy calcification, N (%)         | 2 (16.7)        | 4 (17.4)                 | > 0.999 |
| Stent                              |                |                          |         |
| Diameter (mm), median (IQR)        | 6 (6–7)         | 6 (6–7)                  | 0.972   |
| Length (mm), median (IQR)          | 60 (60–120)     | 60 (40–80)               | 0.476   |

IQR, Interquartile range; NA, not applicable; P1–3, popliteal; RR, restenotic.
Figure 1A. Primary patency rates of PTA and stenting groups

No., Number; PTA, percutaneous transluminal angioplasty; SE, standard error.

Figure 1B. Primary patency rates of different popliteal artery segments

No., Number; P1–2, popliteal; SE, standard error.
Central illustration

Primary patency rates of different popliteal artery segments

No., Number; P1–2, popliteal; SE, standard error.