Endovascular treatment of peripheral artery disease has recently become more important due to its minimally invasive nature. Elderly patients as well as fragile patients, like diabetics and those with end-stage renal disease, can benefit from this low-morbidity/-mortality treatment. Very successful results have been achieved with percutaneous balloon angioplasty and stenting in the superficial femoral and iliac arteries. In some areas, however, such as the common femoral artery and the popliteal artery, vascular physicians remain somewhat reluctant to use endovascular strategies. Common femoral endarterectomy, the most often used technique for treatment of common femoral artery lesions, has shown very good long-term results, but is associated with relatively high complication rates, such as superficial and deep wound problems and lymph leakage. This article describes less-invasive endovascular alternatives, such as atherectomy, drug-coated balloons and stenting, and their results. The popliteal artery is also difficult to treat in an endovascular manner due to biomechanical forces during bending and stretching of the knee or leg. Thus, we also describe currently available minimally invasive treatment options for the popliteal artery.
The prevalence of peripheral artery disease (PAD) is more than 4% in persons aged 40 years and older. This prevalence increases dramatically with age and exceeds 14% in patients aged 70 years or over. Ever since the introduction of percutaneous balloon angioplasty by Dotter in 1964 and the development of the balloon-expandable stent by Palmaz in 1985, endovascular treatment of PAD has become more important.1

The introduction of self-expandable nitinol stents, covered stents, drug-eluting stents and different kinds of debulking and thrombectomy systems has made all vascular areas ripe for endovascular treatment. The femoropopliteal segment remains one of the most challenging areas in endovascular treatment. An extensive plaque burden, often “bone-like” calcification and exposure to numerous internal and external mechanical stressors like flexion, extension, elongation, compression and external compression make these particular arteries difficult to deal with.3

Stenting interferes with the long femoropopliteal geometry and imposes a mechanical burden that leads to chronic mechanical stress. Once the stent is implanted, the re-stenotic cascade starts, and inflammation and smooth muscle cell proliferation develop a new tissue mass. The common femoral artery, where the calcium burden is huge and the femoral bifurcation is very often involved, and the popliteal artery, where external forces are even greater than in the superficial femoral artery, are still considered “no-stent zones”.4

**COMMON FEMORAL ARTERY**

Although endovascular treatment of lower-extremity atherosclerotic disease is becoming increasingly common and even preferred in certain vascular territories to achieve revascularization,4,5 most operators still prefer a surgical rather than an endovascular approach for common femoral artery (CFA) disease. Surgical endarterectomy is still considered the gold standard treatment. The bulky, eccentric, heavily calcified character of CFA plaques, frequent involvement of the femoral bifurcation, easy surgical accessibility and favorable long-term outcomes all mean that surgery still plays an important role in the treatment of CFA disease (Figs. 1, 2). Several studies have reported very high technical success and patency rates following endarterectomy in the CFA.4-10 In 2010, Ballotta et al.6 published the results of an 8-year single-center prospective study of 117 patients who underwent common femoral endarterectomy (CFE), with primary patency rates of 100% at 1 year, 9% at 3 years and 96% at both 5 and 7 years of follow-up. In 2008, Kang et al.8 published the results of a prospective study of 58 patients who underwent the standard treatment for steno-occlusive common femoral disease; primary patency rates were 93% and 91% after 1 and 5 years, respectively. Kechagias et al.11 performed a prospective study over 15 years that included 111 patients; primary patency rates were 93.7% at both 5 and 10 years and 85.2% after 15 years of follow-up.

However, the open approach has some disadvantages. For example, the peri-operative morbidity rate is remarkable. Derksen et al.12 retrospectively reviewed 140 patients following endarterectomy; in-hospital complications occurred in 17% of the patients, with a wound infection rate of 14%. In a study by Ploeg et al.,13 65% of patients who were approached with a medial incision in the groin had some grade of surgical site infection during follow-up.

Ballotta et al.6 reported a minor complication rate, mainly lymph leaks, of 6.6%. Kang et al.8 mentioned a complication rate of 13.8%, and 5% required reintervention. Kechagias et al.11 showed 17.1% wound infections and 9% postoperative hematomas. Thus, CFE is not as benign a procedure as previously believed and careful selection of patients and close postoperative follow-up are mandatory.

Over the past 10 years, improvements in both endovascular equipment and the technical skill of operators have led to an increase in percutaneous CFA procedures. The current literature presents excellent results in terms of the medium-term outcome of endovascular treatment of the CFA. Stricker and Jacomella14 reported primary patency rates of 87% at 12 months and 83% at 24 months in 27 patients who underwent stent angioplasty. Another retrospective review of patients undergoing stent implantation in the CFA alone or in combination with endovascular treatment of other vessels showed a primary patency rate of 94.7% at 12 months and 81.7% at 24 months.15

In a report on the early results of a randomized trial16 comparing bioabsorbable stent implantation to CFE, primary patency rates at 30 days follow-up were 92.5% versus 100% (p=0.038), respectively. At one year, primary patency rates were 80% in the stent...
group versus 100% in the endarterectomy group. Surgical site infection was reported in none of the patients in the endovascular group versus 18% in the CFE group.

One of the largest studies to date concerning endovascular treatment in the CFA reported an impressive low complication rate of 6.4% at 1 year follow-up in 360 procedures. Balloon angioplasty was performed in all patients and bailout stenting was applied following flow-limiting dissection or a poor result. The 1-year restenosis rate was 27.6% and the 1-year target lesion revascularization (TLR) rate was 19.9%. This study also found that stenting was a favorable independent predictor of lower rates of restenosis and TLR at 1 year compared to angioplasty alone.

Stavroulakis et al. performed a retrospective review of the treatment of CFA lesions in 47 patients using either drug-coated balloon (DCB) angioplasty alone or directional atherectomy with antirestenotic therapy (DAART). They noted that both modalities had promising outcomes in terms of both technical success rates (89% following DCB angioplasty and 95% for DAART) and primary patency after 12 months (68% after DCB angioplasty alone and 88% after DAART).

Cioppa et al. evaluated the safety, feasibility, and 1-year efficacy of the endovascular treatment of CFA obstructions with DAART. They treated 30 patients and achieved procedural success in all cases. At one year, the primary patency rate was 93.4% and freedom from TLR was 96.7%.

While these endovascular treatment results seem very promising, longer-term results with each endovascular treatment method as well as randomization to open surgery are still needed.

The TECCO trial (Endovascular Versus Open Repair of the Common Femoral Artery) by Gouëffic et al. investigated the differences in outcome when CFA lesions were treated with open surgery or stenting. They treated 117 patients: 61 were randomly assigned to undergo surgery and 56 underwent endovascular treatment by stenting. The morbidity and mortality rate within 30 days (which was the primary outcome of the study) in the open surgery group (26%) was significantly higher than that in the stenting group (12.5%). In addition, the mean hospital stay in the open surgery group was almost double that in the endovascular treatment group (6.3 ± 3 days vs. 3.2 ± 2.9 days). After two years of follow-up, however, the sustained clinical improvement, primary patency rate, and target lesion and extremity revascularization rates were comparable in the two groups. The authors concluded that endovascular treatment of CFA disease could be both safer and as efficient as open surgery.

In these previous studies, various types of stents were used in the stent arm. However, a new generation of stent devices has been developed and may perform even better in this challenging area. Especially, the interwoven design of the Supera® vascular mimetic implant (Abbott Vascular Inc., Santa Clara, CA, USA) seems to be ideal for dealing with challenging CFA disease. Its extreme crush resistance (if correctly implanted) seems to be ideal for dealing with eccentric calcified plaques and maintaining a potential for access in this area (Fig. 3).
Several studies have demonstrated that the Supera® Peripheral Stent System can improve patency and reduce stent fractures.21-30 Twelve-month primary patency rates of 79% and 86% were reported in femoropopliteal lesions. While copious data are available for popliteal disease, heavily calcified lesions and long-segment femoropopliteal disease, there is still inadequate data on its use in CFA disease.


One-hundred subjects were enrolled at 7 centers: 11% were total occlusions and the mean degree of stenosis was 82.6%. Most (81%) of the patients had heavily calcified lesions. The primary endpoint of the trial was core lab-adjudicated duplex ultrasound primary patency at 12 months and the safety endpoint was the absence of periprocedural adverse events up to 30 days post-procedure. The procedural success rate, defined as <30% residual stenosis, was 100%. A 12-month cumulative primary patency rate of 95.2% was observed. The cumulative freedom from TLR rate was 97.8% and the freedom from TVR rate was 92.6%. From a clinical point of view, there was a tremendous switch from Rutherford 2-4 to Rutherford 0-1. No procedure- or device-related adverse events were observed, except for 2 clinically driven TLRs. Interestingly, there were no differences between the groups with and without femoral bifurcation involvement (97.7% versus 97.9% freedom from TLR respectively; p=0.94). A longer follow-up will be needed to study the durability of this promising therapy. A logical next step would be a head-to-head randomized controlled trial of Supera® versus endarterectomy.

Figure 4. (a) Segments P1, P2 and P3 of the popliteal artery. (b) Demonstration of the straight-leg (SL) and crossed-leg (CL) positions in which angiography was performed to observe changes in length, curvature and twist of the popliteal artery.21 (c) Absolute changes in the lengths of the SFA, popliteal artery and the full Fem-Pop segment between the SL and CL positions for each patient.

Figure 5. (a) Fluoroscopic image of severe calcification in the popliteal artery. (b) Angiographical image of a severely calcified popliteal artery during flexion of the knee. (c) Complete absence of kinking during knee flexion after implantation of a Supera® vascular mimetic implant peripheral stent system (Abbott Vascular).
The popliteal artery is also considered to be a “no-stent zone”. The popliteal artery is situated at the height of the knee joint and is not contained in a muscular compartment. This makes the artery susceptible to multiple biomechanical forces during bending and stretching of the knee or leg. Klein et al. investigated these forces during movement and sought to identify the conformational changes in the artery between the straight-leg (SL) and crossed-leg (CL) positions.11

Angiography of 10 femoropopliteal arteries in the straight-leg and crossed-leg positions (Fig 4) showed significant differences in length, curvature, and twist in the popliteal artery. These conformational changes were also seen in the superficial femoral artery, but were less pronounced. These findings have important implications for endovascular treatment of isolated popliteal artery disease.

There is a considerable amount of clinical evidence regarding endovascular treatment and stenting of the superficial femoral artery, but not for the popliteal artery. While many studies have evaluated the treatment of femoropopliteal lesions in general, isolated popliteal lesions are underrepresented in the literature.

Because of the aforementioned anatomical difficulties of the popliteal artery, interventionists now prefer to avoid permanent metallic implants in this area. The introduction of drug-coated balloons and the strategy of “leaving nothing behind” seems to be a very attractive approach in this challenging anatomy.

In large clinical trials with drug-coated balloons (DCB) like the Lutonix® Global trial (Becton Dickinson Inc., Franklin Lakes, NJ, USA) and the ILLUMENATE Global trial (Philips Inc., Amsterdam, The Netherlands), unfortunately, only 29.7% and 13.9%, respectively, of the femoropopliteal lesions were popliteal lesions. These trials have shown very good results with the use of DCBs, with a freedom from TLR rate of 94.3% in the Lutonix® Global trial and 94.8% in the ILLUMENATE Global trial.3,13

The IN.PACT Flexion study investigated the performance of the drug-coated balloon IN.PACT Admiral (Medtronic Inc., Santa Rosa, CA, USA) in isolated popliteal lesions of 100 patients (38% diabetics, 35% critical limb ischemia (CLI) patients). The primary endpoint was defined as primary patency at 12 months. Mean lesion length was 55.20 mm ± 26.80. Thirty-three percent of the lesions were occlusions. A primary patency rate of 85.6% was reached at 1 year and the freedom from TLR rate was 87.5% (Boisiers M. Endovascular treatment of atherosclerotic popliteal artery lesions – the IN.PACT Admiral: 12 year results of IN.PACT Flexion. Presented at the Charing Cross International Symposium (CX), London, UK, April 16, 2019). The bailout stent rate was 12%.

Although evidence supports the idea that the performance of DCBs is independent of lesion complexity, it is quite clear that in patients with longer lesions (P1 up to and including P3), severely calcified lesions, and a high number of chronic total occlusions, the bailout stent rate is more than 40%. In arteries that are obstructed by an overwhelming atherosclerotic plaque deposition, balloon angioplasty increases the vessel lumen by uncontrolled dissection, resulting in longitudinal tears which create tissue flaps of varying degrees of severity. Additional data also suggest that untreated post-plain old balloon angioplasty (POBA) dissections, and not just those that are flow-limiting, are associated with reduced patency.3,15 In this context, the “leave nothing behind” strategy sounds promising, but may be realistic only in easier, more straightforward, “pivotal trial” popliteal conditions. Leaving something behind, while respecting the As Less As Reasonable Achievable Stent (ALaras) principle, seems to be a more appropriate strategy for popliteal endovascular interventions.16 On one hand, the re-stenotic cascade is blocked by paclitaxel transferred by the balloon. On the other hand, some scaffolding is foreseen where necessary to secure the dissection flaps, ensure the integrity of the lumen and finally to avoid early thrombosis and residual stenosis. Hong et al.17 reported that patency rates were significantly higher with “spot” stenting (which is a very subjective and consequently inappropriate term) than with long stenting following an intentional subintimal approach for long femoropopliteal chronic total occlusions. Another way to limit the amount of metallic implants in the popliteal artery is a debulking strategy with an endovascular atherectomy device: this simultaneously increases lumen gain and decreases the need for stenting.

Stavroulakis et al.18 performed a prospective analysis in 72 patients treated with either DCB angioplasty alone (n=31) or Directional Atherectomy and Anti Restenotic Treatment (DAART) (n=41) for isolated popliteal artery stenotic disease. Different DCBs and atherectomy devices were randomly used. An embolic protection device was placed when using DAART. The technical success rate following DCB was 84% versus 93% (p=0.24) after DAART. The primary outcome measure was primary patency after 12 months. While the primary patency rate in the DAART group was significantly higher than that in the DCB group (65% vs 82%; hazard ratio 2.64, 95% confidence interval 1.09 to 6.37, p=0.021), there was no significant difference in freedom from TLR (82% vs 94%, p=0.072). Bailout stenting was seen more often in the DCB-alone group (16% vs 5% for DAART, p=0.13), but this difference was not statistically significant.

A remarkable complication in this series was the 7% incidence of (false) aneurysm formation post-DAART. These findings may be due to trauma of the vessel wall, created by (the too extensive?) atherectomy, combined with high-dose microcrystalline paclitaxel. More studies will be needed to define the safety of this approach.

A few clinical trials have investigated the results of stent placement in the popliteal artery. For example, the ETAP and MELOPEE trials (Zeller T. Endovascular treatment of atherosclerotic popliteal artery lesions – ETAP, Presented at the Transcatheter Cardiovascular Therapeutics Meeting (TCT 2012), Miami, FL, October 24, 2012; Bosiers M. MELOPEE study 12 months results. Presented at the International Symposium on Endovascular Therapy (ISET) Conference, Hollywood, FL, January 22, 2008), which both examined placement of a Lifestent® (Becton Dickinson), showed primary patency rates of 67.4% and 70.2%, respectively. Stent occlusions were encountered in 33% and 48% of patients, respectively, with stent fractures in 4% and 10%.14,15 While these trials show that stents offer advantages compared to POBA, the overall results are rather disappointing.
regarding primary patency and the rate of stent fractures. The Durability-POP study (which investigated the safety and efficacy of the EverFlex® stent; Medtronic) showed that, in 60 patients with a mean popliteal lesion length of 71 mm, a primary patency rate of 70.3% and a stent fracture rate of 0% at 1 year.

The previously mentioned Supera® vascular mimetic implant (Abbott Vascular) is a new-generation stent that could play an important role in treating lesions in the popliteal artery because of its crush resistance and extremely high flexibility (Fig 5).

The Leipzig Supera® popliteal registry²¹ investigated 101 patients with popliteal artery disease treated with the Supera® stent. Procedural success, i.e., residual arterial stenosis < 30%, was achieved in 99 patients (98.0%). More than half of the included lesions were moderately to severely calcified. The primary patency rates of the stents after 6 and 12 months were 94.6% and 87.7%, respectively. In-stent occlusions and in-stent stenosis were seen in 4 and 6 cases, respectively, and were all recanalized successfully. Radiographs of the stents were obtained in 51 patients after a mean follow-up of 15.2 months, and no stent fractures were seen.

**Discussion**

Atherosclerotic lesions of the common femoral artery (CFA) are characterized by bulky, eccentric calcium and frequent femoral bifurcation involvement with the disease extending to the proximal deep femoral and superficial femoral arteries. These characteristics (residual stenosis due to calcium, caging of the deep femoral artery) make this area not very popular among endovascular specialists. The fact that the CFA is seen quite often, albeit incorrectly, as being very flexible and is frequently used as an access site increases the resistance to endovascular treatment. The ease of surgical accessibility and apparently favorable long-term outcomes⁶ still make surgery a suitable option for the treatment of CFA disease. Importantly, all of the reported surgical results are based on patency definitions according to the Rutherford-Ahn criteria,¹⁸ and not on objective duplex ultrasound peak systolic velocity measurements. A substantial morbidity-mortality rate with open surgery, especially in obese patients with other cardiopulmonary comorbidities, is a dark drawback of this treatment method.

Over the past 5 years, improvements in both endovascular equipment and the technical skill of operators have led to an increase in percutaneous CFA procedures. Previous experiences with angioplasty were quite disappointing because of the characteristics of early CFA plaques. We are convinced that plaque needs to be either removed or scaffolded. Removal of plaque means debulking using an atherectomy device. Since stand-alone treatment with these devices has not been shown to be sufficiently durable, it has to be combined with drug-eluting technology. Especially, the DÅART (directional atherectomy and anti-restenotic treatment) approach seems to be attractive in this area.¹⁸,¹⁹

Scaffolding the plaque has to be done by correct stent implantation, with efficient clinical outcomes and an important increase in safety. The two-year data from the randomized TECCO trial⁴⁰ (a French multicenter randomized trial comparing surgery to stenting for the treatment of CFA atherosclerotic lesion) showed significantly lower periprocedural morbidity and mortality compared to endarterectomy (26% versus 6.4%), but comparable mid-term clinical, hemodynamic and morphological outcomes. Different kinds of scaffolds/stents were used in that study.

The vascular mimetic implant Supera® Peripheral Stent system (Abbott Vascular), with its extreme crush resistance (if correctly implanted), seems to be an ideal tool for use in patients with eccentric calcified plaques or a crush risk, and for maintaining access possibilities. This stent has been shown to give excellent results in the femoropopliteal region.¹⁸,⁴⁰ Especially long lesions, heavily calcified segments and chronic total occlusions are efficiently and durably treated when the Supera stent is deployed correctly. This 6 French-compatible, 0.018” OTW stent, composed of 6 pairs of closed-ended interwoven nitinol wires arranged in a helicoidal pattern, is very flexible and resistant to fracture, and offers a 4-fold greater crush resistance than other nitinol stents, which is ideal for the treatment of CFA disease. Due to its structure, puncturing/re-puncturing, inserting a sheath, performing procedures and closing with different types of closure devices present no difficulties.

The multicentric, prospective, single-arm VMI-CFA trial is evaluating the short- and mid-term outcomes of treatment of symptomatic (Rutherford 2-4) CFA stenotic or occlusive lesions with the Supera® Peripheral Stent System (Deloose K, Maene L, Verbist J et al. One year results VMI-CFA trial. Presentation VIVA Las Vegas 8-11-2018. J Vasc Surg 2019, submitted). A preliminary data analysis showed a cumulative primary patency rate of 100% at up to 210 days. The cumulative freedom from TLR rate was 100%. While four patients died, these deaths were not procedure- or device-related. From a clinical point of view, there was a tremendous transition from Rutherford 2-4 towards Rutherford 0-1. No procedure- or device-related adverse events were observed.

These short-term data confirm the safety and feasibility of an endovascular approach with the Supera® stent in the "no-stent zone" CFA. Patency, freedom from TLR and clinical improvement at 6 months are outstanding. The 12-month results were presented by Deloose at VIVA 2018 (Las Vegas, NV): an independent core lab-controlled primary patency of 95.2%, a freedom-from-TLR rate of 97.8% and a sustained clinical benefit up to 12 months were achieved. The patients in the VMI-CFA trial will be followed with duplex ultrasound peak systolic velocity ratio (PSVR) measurements at 24 and 36 months to obtain longer-term data.

The popliteal artery remains one of the most challenging arteries of the human body. The popliteal artery possesses distinct anatomic and embryologic characteristics that influence endovascular treatment. Compared to the femoral region, the popliteal artery is not housed within a muscular compartment and is subject to torsional forces related to knee flexion. While a “leave nothing behind” strategy seems to be the most attractive solution for a difficult artery like the popliteal artery, the results of angioplasty alone are very disappointing, especially in the mid- and long-term. The introduction of drug-coated balloons definitely added durability to this procedure, although isolated popliteal data are sparse. It also seems unrealistic to adhere to a “leave...
nothing behind” strategy. In many cases, there is a need for scaffold implantation due to recoil or flow-limiting dissections. Initial debulking with an atherectomy system followed by the addition of paclitaxel with a drug-coated balloon seems to be an attractive strategy that combines durability, lumen gain and a reduced need for stenting. Unfortunately, a risk of creating false aneurysms, as well as the extreme high cost of these procedures, are serious disadvantages. Respecting the ALARAS strategy, where the amount of scaffold needed is really limited to the absolute minimum, where the amount of scaffold needed is limited to the absolute minimum, the development of endovascular systems such as with the Tack Endovascular System® (Intact Vascular Inc., Wayne, PA, USA) or VasculFlex® Multi LOC system (B Braun Inc., Melsungen, Germany), seems an attractive bailout after DCR treatment in isolated popliteal lesions. The addition of more metal with a full metal jacket stent is not the solution for a durable result. Only the interwoven design of the Supera® seems to adapt very well to the difficult behavior of this specific artery.

### Conclusion

Although endovascular treatment of peripheral artery disease has become very popular due to its minimally invasive nature, in some areas, such as the common femoral artery and the popliteal artery, vascular specialists still remain somewhat reluctant to use an endovascular approach. Common femoral endarterectomy, the most frequently used technique for the treatment of common femoral artery lesions, has shown very good long-term results, but is associated with relatively high complication rates. The popliteal artery, due to its very specific and challenging anatomy and embryology, does not respond easily to different endovascular approaches. Nevertheless, with the advancement of endovascular technology as well as the greater experience of interventionists, several endo-solutions are now available for these so-called “no endo zones”. Less invasive endovascular alternatives, such as atherectomy, drug-coated balloons and modern stenting, not only show lower morbidity rates than open surgical approaches, but also offer highly successful and durable results. Further studies with head-to-head randomization between devices and between techniques (surgery versus endo) with the same assessment methods will be key for gaining insights into future directions.

### Authors’ Disclosures

The authors have no conflicts of interest to declare.

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