Percutaneous transluminal angioplasty is a minimally invasive therapy for the treatment of patients with peripheral artery disease who suffer from intermittent claudication or critical limb ischemia. The main advantages of the endovascular approach are a low complication rate ranging between 0.5% and 4%, a high technical success rate approaching 90% even in long occlusions, and an acceptable clinical outcome. Traditionally, percutaneous transluminal angioplasty (PTA) has been the standard for revascularization in aortoiliac, femoropopliteal, and below-the-knee arteries, and in many interventional centers, PTA still is the first and most frequently used methodology. However, high rates of failure resulting from an unacceptable incidence of restenosis, particularly in long and complex disease, are the main limitations of PTA.

Modern bare metal stents (BMS), nitinol self-expanding stents, and cobalt-chromium balloon-expanding stents improved the durability of endovascular interventions, particularly in certain lower-limb indications. Advantages of self-expanding nitinol stents include acceptable radial strength combined with shape-memory characteristics, crush recoverability, and reduced foreshortening, which allows precise placement. Self-expanding nitinol stents are used mainly for external iliac and femoropopliteal indications but have its limitation in ostial common iliac artery lesions. Advantages of cobalt-chromium balloon-expanding stents are high radial strength, specifically for ostial iliac lesions with reduced strut thickness, allowing smaller introducer sizes. These properties of both stents types were expected to improve patency rates compared with PTA and earlier types of stents. However, the main obstacle of these BMS remains exaggerated neointimal hyperplasia, leading to in-stent restenosis in 25% to 50% within 12 to 24 months, depending on the location of implantation.

New developments over the last several years include drug-eluting balloons (DEBs), new types of stents such as drug-eluting stents (DES) and covered stent grafts, and novel atherectomy systems. These are designed to reduce restenosis and to improve long-term outcomes. However, large comparative trials evaluating these novel tools are still rare, and current guidelines do not always consider these technologies.

This article reviews the current evidence on novel technologies for endovascular treatment of lower-limb arteries, focusing on devices for revascularization of chronic obstructive arterial disease of the aortoiliac, femoropopliteal, and below-the-knee segments. Issues of acute or subacute thrombotic disease, thrombolysis, and thrombus aspiration technologies are not covered in this review.

Evaluating and Passing the Lesion and Assessing a Gradient

From a purely technical perspective, 3 major parameters determine the success of any endovascular procedure: passage of the recanalization wire through the obstruction, removal of the obstruction by an endovascular tool, and keeping the artery open in the short and long term.

Recent advances in improving lesion crossing include novel recanalization wire technology and the development of dedicated chronic-total-occlusion–crossing catheters. Furthermore, a variety of recanalization wires, including 0.035-, 0.018-, and 0.014-in platforms, have been introduced, although interestingly, there are no systematic comparative data on the impact of novel recanalization wires. Today, parameters like tip load, wire coating, and shaft stiffness provide different options when choosing a recanalization wire. In general, more proximal lesions require thicker and stiffer wires, and more distal lesions are treated with thinner wires to avoid the risk of perforation.

A further development in treating peripheral chronic total occlusions was the introduction of reentry catheters. These catheters assist recanalization of extremely long lesions (≥20 cm) by redirecting a wire into the distal true lumen of an occlusion. In some series, reentry catheters have been associated with >90% success rates for treating chronic total occlusions. Reentry systems were initially developed for femoropopliteal applications but are used successfully in the aortoiliac segment and in below-the-knee arteries.

After lesion crossing, the significance of the stenosis can be evaluated by the pressure gradient across the stenosis; a mean pressure gradient of 10 mm Hg at rest or 15 mm Hg after vasodilators is considered significant. A pressure wire system is likely to give more accurate measurements of the pressure gradient because a catheter placed through the
stenosis might overestimate the gradient by partial obstruction of the residual lumen. In clinical practice, financial limitations will be the main driver for catheter-based pressure gradients, and in most peripheral interventions, vessel diameters, particularly in the aorta-iliac segment, will allow adequate estimations of the hemodynamic impact of a stenosis with a small catheter (eg, 4F or smaller). Pressure gradients are also useful when assessing balloon angioplasty results and deciding whether further steps like stent implantation are necessary. For example, in the Dutch Iliac Stent Trial, optimal angioplasty without a residual pressure gradient had long-term results comparable to primary stenting in short iliac lesions. For femoropopliteal and below-the-knee interventions, the importance of pressure gradient measurement is completely unclear. Because these arteries are smaller, catheter-induced gradients are more likely and pressure wires are probably preferable for assessing the hemodynamic significance of a stenosis in these small arteries.

Balloon Versus Stent: When Do We Need to Stent?

In general, stenting offers superior results to PTA in longer lesions (≥6 cm), in chronic total occlusions, and in heavily calcified arteries. Stenting is also indicated if there is a suboptimal result after PTA. PTA alone often requires longer balloon inflations compared with predilation before primary stenting. For example, in several clinical trials, at least 2 inflations of at least 1 minute each were used as minimal inflation times for PTA, whereas some authors have used much longer inflations (eg, 25 minutes) to obtain an acceptable PTA result. Nevertheless, generally accepted indications for stenting are conditions in which PTA does not improve flow to the ischemic area such as a flow-limiting dissection after (long-term inflation) PTA, a residual stenosis <50% leading to flow limitation, acute or subacute recoil >50% leading to flow limitation, and acute or subacute reocclusion after (long-term inflation) PTA.

Stents Versus PTA in Specific Locations

Aortoiliac Arteries

Long-term outcomes after iliac artery endovascular interventions are similar to outcomes after open surgical revascularization with less morbidity. As a result, most guidelines recommended endovascular treatment as the treatment of first choice for almost all patients with iliac artery obstructions, including complex and long lesions. Rates of restenosis at 1 year range from 5% to 25%, depending on the length and location of the target lesion. In the Dutch Iliac Stent Trial, 279 patients were treated either with primary stenting (n=143) or with plain balloon angioplasty (n=136) and selective stenting. Patency at 2 years was similar between primary stenting and balloon angioplasty with selective stenting (71% versus 70%, respectively). In addition, long-term data from this trial on ankle-brachial index, iliac patency, and quality of life did not support a difference between the 2 groups.

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distance after 1 and 2 years was also improved by the use of stents. Limb salvage rates in patients with critical limb ischemia have not yet been shown to be reduced by the use of stents in the femoropopliteal area.

**Below-the-Knee Arteries**

Endovascular treatment for below-the-knee arteries is traditionally reserved for patients with critical limb ischemia. This condition is typically characterized by diffuse and long segmental disease of all 3 tibioperoneal arteries rather than by short focal obstructions. Conventional balloon angioplasty with long balloons and long inflation times frequently yields astonishingly good immediate results with the use of modern, low-profile, long-segment angioplasty balloons, which are available in up to 200-mm lengths (Figure 2). The restenosis rate with these long balloons is still considered extremely high, ranging between 60% and 80% at 6 months, although limb salvage rates are in the range of 90% according to the Bypass Versus Angioplasty in Severe Ischemia of the Leg (BASIL) trial and cohort studies. Stenting with BMS, both self-expanding nitinol stents and modern balloon-expanding products, did not improve restenosis rates. Therefore, the use of BMS in below-the-knee arteries was restricted to spot stenting in bailout situations when balloon angioplasty failed. In terms of clinical outcomes like walking distance and limb salvage, data are still lacking.

**New Stent Types: Evidence for Durability, Stent Fracture, and Restenosis**

**New BMS**

Many of the initial bare nitinol stents have clinically relevant rates of in-stent restenosis and therefore suboptimal patency rates. Stent fractures, which may increase restenosis, are less frequent with the newer generation of nitinol self-expanding stents. Recent stent improvements designed to decrease stent fracture include rearranging strut alignment toward helical connecting bridges or a full helical stent designs. The second generation of nitinol stents have enhanced flexibility, particularly in the axial direction, owing to fewer cell interconnections and a more spiral orientation of the interconnections. Despite these improvements, there is no definite proof of any impact of stent design on the restenosis rate.

The enhanced flexibility and superior fracture resistance of the latest stent generation, in combination with the production of long nitinol stents of up to 20 cm in length, enable the endovascular treatment of more difficult and complex lesions. Recent registry studies suggest that the newer stent designs may have more acceptable long-term results in the femoral artery. The Leipzig SUPERA (supera stent) registry with 107 SFA lesions demonstrated a 24-month patency rate of 76%, and no stent fractures were observed. In the Durability-200 Study, the Protege EverFlex 200-mm-long self-expanding nitinol stent (ev3 Endovascular Inc, Plymouth, MN) was assessed in 100 patients with femoropopliteal TransAtlantic Inter-Society Consensus C and D lesions at least 150 mm in length (average lesion length, 24 mm). The primary patency at 12 months was 64.8% (judged by duplex ultrasound imaging).

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**Figure 1.** Restenosis rates at 12 months after balloon angioplasty vs primary stent implantation in the superficial femoral artery in 4 randomized, controlled trials using nitinol self-expanding stents. PTA indicates percutaneous transluminal angioplasty; FAST, Femoral Artery Stenting Trial.

**Figure 2.** Long segment occlusion of all 3 tibioperoneal arteries with excellent immediate response to balloon angioplasty with a 2.5×200-mm angioplasty balloon. A, Preprocedural images. B, Final angiograms after balloon angioplasty.
Another new development is the availability of low-profile self-expanding nitinol stents, which can be deployed via a 4F sheath. Low-profile delivery systems with long shafts also increase the feasibility of treating selected SFA lesions by the transbrachial or transradial approach.

Drug-Eluting Stents
The concept of combining the advantages of the mechanical scaffolding properties of nitinol stents with the antiproliferative action of drugs is based on the proven effectiveness of this concept in decreasing restenosis and reintervention in interventional cardiology. Because restenosis is particularly high with femoral-popliteal interventions, DES studies in the peripheral circulation have focused on this territory.

DES in the Femoropopliteal Arteries
Only a few trials have been conducted on the use of DES in the femoropopliteal arteries, and the positive results seen in coronary studies could not be reproduced until recently. Two trials using DES releasing limus derivatives failed to demonstrate any advantage in patency compared with BMS. Sirolimus Coated Cordis Self-Expandable Stent (SIROCCO) was the first randomized trial with a DES in the infrapopliteal arteries. It was a multicenter, double-blind study of a sirolimus-eluting self-expanding nitinol stent compared with the same BMS in the SFA. The study was performed in 2 phases because, after an interim analysis demonstrating a rather high stent fracture rate, the maximally allowed lesion length was reduced to 14.5 cm with a maximum of 2 implanted stents. The mean lesion length in the 93 patients included in SIROCCO II was 8.3 cm. At 24 months, the in-stent restenosis rate, measured by duplex ultrasound, in the sirolimus group was 22.9% versus 21.1% in the BMS group (P>0.05). The lack of a significant difference between the sirolimus-eluting stent and the BMS may be related to the unexpectedly low restenosis rate in the BMS group. The efficacy of DES may also be limited by incomplete suppression of neointimal hyperplasia between the stent struts, especially with larger stent strut distances.

The Safety and Efficacy Study of the Dynalink-E Everolimus Eluting Peripheral Stent System (STRIDES) was a prospective, nonrandomized, single-arm trial using an everolimus-eluting self-expanding nitinol stent in 104 patients with femoropopliteal disease and a mean lesion length of 9.0 cm. Primary patency defined as freedom from in-stent restenosis was 94% and 68% at 6 and 12 months, respectively, and plain radiographic examination of 122 stents revealed no evidence for stent fracture after 12 months. However, a retrospective comparison with the Vienna Absolute trial demonstrated nearly identical restenosis rates with the corresponding BMS; unfortunately, no formal study has compared these results yet.

The Zilver PTX stent with a polymer-free paclitaxel coating (dose, 3 µg/mm²) on the abluminal side of the stent struts uses a nonlimus drug delivery system. The Zilver PTX Single-Arm Study included 787 patients with implantation of 2.2 stents per patient for a mean lesion length of 100±82 mm, and 22% of the lesions were >15 cm. After 12 months, the fracture rate was 1.5%. The 12-month primary patency rate, evaluated by duplex sonography with a peak systolic velocity ratio of <2.5, was 86.2%. Especially interesting were the data of a subgroup analysis of patients with femoropopliteal in-stent restenosis demonstrating a 1-year primary patency of 80%, which was much higher than in historical controls using other treatment modalities. After 2 years, there was also a sustained clinical benefit concerning improved Rutherford class and improved ankle-brachial index and patient-reported walking distance. The authors concluded that there was an ~50% reduction in restenosis compared with published BMS results.

Recently, the 12-month results of the Zilver PTX Randomized Study were reported. This prospective, randomized, multicenter trial with 479 patients (Zilver PTX, n=241; angioplasty, n=238) had 2 randomization protocols. First, the patients were randomized to treatment with either traditional PTA or the Zilver PTX. In the angioplasty group, about half of the patients had suboptimal angioplasty and underwent secondary randomization to provisional stenting with a Zilver PTX (n=61) or bare metal Zilver (n=59). Inclusion criteria included a maximum lesion length of 14 cm, and the mean lesion length was 63 and 66 mm, respectively. The primary patency rate (with duplex sonography and patency defined by peak systolic velocity ratio <2.0 or angiography if available and patency defined by diameter stenosis <50%) was 83.1% in the Zilver PTX group and 65.3% in the optimal PTA group. To examine the drug effect, the investigators conducted a head-to-head comparison of secondary randomization to provisional stenting with Zilver PTX or BMS and found 12-month patency rates of 89.9% and 73%, respectively (P=0.01; Figure 3). Stent fractures were rare in both Zilver PTX and BMS patients, with an overall rate of 0.9% through 12 months, and no fractures resulted in clinical sequelae. Very recently, the 24-month update of this randomized trial was reported. The primary patency remained significantly improved in the Zilver PTX arm compared with patients with successful PTA (74.8% versus 57.8%; P=0.029).

In terms of clinical end points like walking distance or limb salvage, no data are available yet from randomized, controlled trials.
The data were recently presented, and there was a significant improvement in the sirolimus-eluting stent group compared with a BMS; unfortunately, clinical outcome data like walking distance for claudicants and limb salvage rates for critical limb ischemia patients are still missing.

The preliminary 12-month results from the Cordis-sponsored Comparing Angioplasty and DES in the Treatment of Subjects With Ischemic Infrapopliteal Arterial Disease Study (ACHILLES), a prospective, randomized, multicenter trial in 200 patients comparing balloon angioplasty and the Cypher Select Plus stent, were recently reported. The mean lesion length was 27 mm. After 12 months, the in-segment binary restenosis rate, as measured by quantitative angiography on an intention-to-treat basis, was 19% for the DES arm and 42% for the PTA arm. The authors concluded that midterm patency rates of focal infrapopliteal lesions are substantially improved with a sirolimus-eluting stent compared with a BMS; unfortunately, the failure to provide a mechanical scaffold for the prevention of acute recoil and the inability to treat dissection flaps. Moreover, the issue of stent crushing should be considered because DES are balloon-expandable stents. Currently, they are available only in short lengths, whereas patients with critical limb ischemia, especially diabetics mellitus, mostly have long-distance lesions of the lower-leg arteries.

Future Development of DES

A potential future improvement in local drug application for the necessary time span without the disadvantages of permanent stent implantation can be expected by the development of completely bioabsorbable DES. Two main types of bioabsorbable stents currently exist: polymer stents and metallic stents. Polymer stents seem not to be good candidates for endovascular use because of their strut thickness and lack of radial force. Absorbable metal stents have the potential to perform well, although current infrapopliteal studies have yielded unsatisfactory results. To date, no studies with bioabsorbable stents have been conducted in the SFA.

Drug-Eluting Balloons

The concept of using a balloon catheter to deliver an antiproliferative drug directly at the site of injury has gained interest during the last years. The use of DEBs may be an effective alternative to the use of DES because any stentless technology for the improvement of long-term patency is preferable to overcome the drawbacks of stenting. DEBs have a number of advantages over standard angioplasty and stent technologies: homogeneous drug delivery to the vessel wall; drug release without the need to use a polymer, which may induce chronic inflammation; application in locations where stent implantation is not desirable like motion segments in the common femoral or popliteal arteries; and the potential to reduce antiplatelet therapy.

Otherwise, there are potential problems with use of DEBs without further stents, especially in complex lesions, such as the failure to provide a mechanical scaffold for the prevention of acute recoil and the inability to treat dissection flaps. Furthermore, in severely calcified arteries, DEBs might be less effective because lower drug concentrations reach the vessel wall. Another problem could be inhomogeneous drug distribution in eccentric lesions. This limitation may be overcome by combining the use of DEBs with initial atherectomy. Possible drug loss on the way to the target lesion, another potential problem, can probably be prevented with the use of long guiding catheters or sheaths.
Economic aspects also have to be considered. Because DEBs are designed for single inflation only and the treatment of long lesions might necessitate the use of multiple balloons, DEB technology may not be cost-effective in such patients.

In the meantime, different methods have been developed by different companies to coat the balloon with an antiproliferative agent. This is important for biological efficacy; therefore, it will be necessary to evaluate the safety and efficacy of each method separately without generalizing study data to the whole group of DEBs. Currently, there is a rapidly increasing clinical study program using DEBs in different locations and indications. Because the available data are very promising, one can expect an increased use of DEB technology over the next years, at least in the treatment of in-stent restenosis.

**DEB in Aortoiliac Arteries**

This new technology has been used only anecdotally in this segment, so systematic data are missing.

**DEB in the Femoropopliteal Arteries**

Three randomized trials have demonstrated a significant improvement in midterm patency with drug-coated balloons compared with plain balloon angioplasty. In the multicenter Local Taxan With Short Time Contact for Reduction of Restenosis in Distal Arteries (THUNDER) trial, 154 patients with femoropopliteal disease were randomized to treatment with standard balloon catheters coated with paclitaxel (3 \(\mu\)g/mm\(^2\)), uncoated balloons with paclitaxel dissolved in the contrast medium, or uncoated balloons without paclitaxel.\(^36\) At 6 months, the mean angiographic late lumen loss qjwas 1.7\(\pm\)1.8 mm in the control group compared with 0.4\(\pm\)1.2 mm (\(P<0.001\)) in the group treated with paclitaxel-coated balloons. The rate of revascularization of target lesions at 6 months was 37% in the control group, 4% in the group treated with paclitaxel-coated balloons (\(P<0.001\) versus control), and 29% in the group treated with paclitaxel in the contrast medium, or uncoated balloons without paclitaxel.\(^36\)

In a recent small, randomized, controlled trial\(^40\) comparing 29 patients treated by filter-protected atherectomy and 29 patients treated with balloon angioplasty, target lesion revascularization at 12 months was 16.7% versus 11.1%, respectively (\(P=0.017\)). Thus, atherectomy offered no improvement in clinical results compared with balloon angioplasty other than the reduced need for stents. Although the SilverHawk device is approved for femoropopliteal use in the United States, no larger studies have compared this device with balloon angioplasty or stents. In ongoing studies, atherectomy in conjunction with DEB is under investigation as a potentially promising concept for avoiding stents in difficult locations such as lesions across joints that experience repeated flexion and other forces.

**SilverHawk Atherectomy**

In a small, randomized, controlled trial\(^40\) comparing 29 patients treated by filter-protected atherectomy and 29 patients treated with balloon angioplasty, target lesion revascularization at 12 months was 16.7% versus 11.1%, respectively (\(P=0.017\)). Secondary stenting was performed in 62% of the patients in the balloon angioplasty group versus 28% in the atherectomy group (\(P=0.017\)). Thus, atherectomy offered no improvement in clinical results compared with balloon angioplasty other than the reduced need for stents. Although the SilverHawk device is approved for femoropopliteal use in the United States, no larger studies have compared this device with balloon angioplasty or stents. In ongoing studies, atherectomy in conjunction with DEB is under investigation as a potentially promising concept for avoiding stents in difficult locations such as lesions across joints that experience repeated flexion and other forces.

**Rotational Atherectomy**

Several rotational atherectomy systems have been used in femoropopliteal arteries in retrospective patient series.\(^41\) These series suggest a reduced need for stents, but no studies have assessed the efficacy of rotational atherectomy compared with PTA.

**Excimer Laser Atherectomy**

Laser atherectomy was introduced >2 decades ago for peripheral interventions but has not been tested in a published randomized trials. Current data do not allow the recommendation of laser for endovascular peripheral artery disease treatment, and further studies are necessary.\(^42\)

**Covered Versus Noncovered Stents**

The concept of covered stent graft implantation within the native artery to exclude the disease seems appealing, and stent grafts have been evaluated for several years in iliac and femoropopliteal locations. In patients with acute vascular interventions has still to be demonstrated by randomized trials. Initial registry data from Leipzig in 107 patients with long lesions (mean lesion length, 17 cm) demonstrated an impressive reduction of restenosis after 3 months from 69% with a standard PTA balloon to 31% with the IN.PACT Amphirion paclitaxel-coated balloon.\(^39\)

Several other studies using different devices are currently ongoing or planned.
rupture and bleeding, covered stents are live-saving tools and are considered mandatory equipment for all catheterization laboratories (Figure 5). However, it is uncertain whether covered stent grafts are superior to PTA or conventional stenting in de novo or restenotic lesions.

Two recently published studies favor the use of Viabahn stent grafts for femoral applications. In extremely long lesions (>20 cm), these devices were equivalent to prosthetic bypass surgery, and complication rates seemed to have dramatically decreased as a result of lower profile introducer sizes. Similarly, the devices showed superior results compared with balloon angioplasty in another randomized trial.

Nevertheless, it remains to be determined whether the mechanical properties of these devices can withstand the forces exerted in the femoropopliteal segment and whether acute and subacute stent graft thrombosis can be reduced by an active (heparin) coating of the devices.

In our practice, stent grafts are used exclusively for bailout bleeding situations.

Conclusions
Several novel technologies have become available recently for peripheral artery interventions. Unfortunately, comparative prospective data are still lacking for many devices. From the current perspective, the concepts for restenosis prevention by DES and DEBs are under systematic investigation, and preliminary data from randomized trials show promising short-term outcomes in certain indications. Nevertheless, PTA and BMS remain standard treatments for aortoiliac, femoropopliteal, and below-the-knee interventions with acceptable results in many situations.

Disclosures
None.

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