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Crossing techniques and devices in femoropopliteal chronic total occlusion intervention☆

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ABSTRACT

Chronic total occlusions (CTO) are common in patients with symptomatic peripheral arterial disease. Endovascular CTO intervention remains a challenging endeavor for interventionalists, but is being increasingly considered as a plausible alternative to surgical revascularization, even for complex CTO lesions. We review common endovascular techniques using antegrade, retrograde and transcollateral approaches in femoropopliteal CTO intervention. In addition, we review the current literature on the utility, efficacy, and safety of novel crossing and re-entry devices in femoropopliteal CTO interventions.

Contents

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1. Introduction

Peripheral arterial disease (PAD) affects approximately 8.5 million people over 40 years old in the United States, and is associated with significant morbidity and mortality [1]. Up to 40% of patients with symptomatic PAD have chronic total occlusions (CTO), characterized by the presence of atherosclerotic plaque resulting in complete occlusion of an artery for >3 months [2–6]. Crossing femoropopliteal CTOs remains a challenging endeavor for endovascular interventionalists. A typical CTO plaque consists of intracellular and extracellular lipids, smooth muscle cells, extracellular matrix and calcium. A rigid fibrous cap is typically present at both ends of CTO with soft or loose tissue segments of lipids, thrombus and extracellular matrix in the core. CTOs often have endothelialized microchannels (160–230 μm), generated via neovascularization, that span the occluded segment from proximal to distal cap [7,8]. The presence of microchannels within CTOs facilitates guidewire passage across occlusion. However, more commonly, a dense homogenous fibrous core is present, which renders guidewire crossing and subsequent balloon inflation very difficult. Endovascular CTO interventions compared with less complex interventions result in greater procedural equipment use, increased fluoroscopic and procedural times, and increased utilization of interventional lab staff. For patients, undergoing complex CTO intervention increases the risk of vessel perforation, dissection, collateral vessel loss, arteriovenous fistula, radiation exposure and contrast load [4].

Endovascular intervention is being increasingly used as the initial strategy in the treatment of complex peripheral CTO lesions. A recent supplement to the Inter-Society Consensus for the Management of Peripheral Arterial Disease (TASC II) highlights the shift towards using endovascular approach in treating complex femoropopliteal lesions, including TASC D lesions [9]. A more recent meta-analysis of published data comparing endovascular with surgical revascularization reported early postprocedural outcome benefits in favor of endovascular treatment, but the short and medium-term results were similar with respect to target vessel patency, amputation-free survival, and overall survival rates [10]. The investigators concluded that there was insufficient evidence to demonstrate the superiority of one approach over the other. The choice between surgical versus endovascular approach in femoropopliteal CTO intervention should be based on individual risk factors, comorbidities, and operator experience with complex endovascular interventions. With advances in guidewire crossing techniques and novel crossing and re-entry devices, the success rates for femoropopliteal CTO interventions have improved. The scope of this manuscript is to illustrate current revascularization techniques and to review current literature on crossing and re-entry devices in femoropopliteal CTO interventions.

2. CTO crossing techniques

2.1. Antegrade crossing

Antegrade CTO crossing involves approaching a lesion from the proximal cap, which can be achieved by intimal or subintimal tracking (Fig. 1). Intimal tracking utilizes a soft-tipped hydrophilic guidewire initially to traverse microchannels with gradual escalation of guidewire tip load with the support of microcatheter, as needed, with the goal of using the safest guidewire to minimize the risk of perforation [7,8]. Subintimal tracking involves creating a blunt dissection between the anatomical planes of a vessel using a looped hydrophyllic guidewire and continuing to advance until it spontaneously re-enters the true lumen distal to the occlusion.

Special re-entry techniques and devices can be used to facilitate antegrade subintimal tracking, when the guidewire fails to cross using the above single wire techniques or inadvertently enters the subintimal tissue. The subintimal tracking and re-entry (STAR) technique involves advancement of the subintimal guidewire until it spontaneously or intentionally (mini-STAR technique) enters the true lumen. A variant of STAR, contrast-guided STAR technique, involves injecting contrast through the subintimal layer to adequately visualize the dissection plane and facilitate guidewire passage [11,12]. Re-entry can also be achieved using specialized devices, which will be discussed separately.

Knowing the location of guidewire tip and direction in which the wire should be advanced is important for procedural success, which can be achieved using imaging devices. For example, when the side branch is located near the proximal end of CTO, intravascular ultrasound (IVUS) catheter can be inserted in the side branch to locate and track luminal passage of the guidewire. Nevertheless, inadvertent subintimal passage of the guidewire is possible in tortuous and heavily calcified lesions. In such a case, guidewire re-entry into the true lumen is difficult due to higher resistance of the intimal plaque than the subintimal tissue, often requiring device-guided re-entry.

2.2. Retrograde crossing

The distal end of CTO is exposed to lower flow pressure from collateral circulation and is often tapered with a softer cap, which renders guidewire penetration relatively easier compared to the proximal cap [13]. The retrograde approach (Fig. 2) is useful in the setting of unsuccessful antegrade crossing, long occlusion, severe calcification or tortuosity and ambiguous proximal cap. After successfully penetrating the distal cap, intimal plaque tracking is attempted by advancing a guidewire through the occlusion, similar to the antegrade crossing approach described earlier. After retrograde access via collaterals, the retrograde wire is usually snared or externalized to form a loop and deliver balloons and devices. If the retrograde crossing technique fails, then another guidewire could be advanced antegrade through the proximal cap. In this case, the antegrade guidewire could be advanced towards the opposing channel using retrograde guidewire as a landmark, a technique known as kissing wire cross [7,8]. Alternatively, antegrade balloon dilatation could be used to expand the antegrade channel or disrupt the dissection planes, thereby facilitating the retrograde guidewire passage through intima towards the antegrade guiding catheter [8]. In the case when retrograde guidewire inadvertently (or intentionally) enters the subintimal tissue, specific dissection/re-entry techniques could be used. Using controlled antegrade and retrograde subintimal tracking (CART), a guidewire is advanced using antegrade approach through the proximal true lumen and then into the subintimal tissue. Subsequently, a balloon is advanced in retrograde fashion into the subintimal space and is inflated to expand the subintimal space. This allows the antegrade guidewire to cross through the CTO and advance into the true lumen.

Using CART technique can be sometimes challenging, because it may require multiple low-pressure small balloon inflations or a passage of

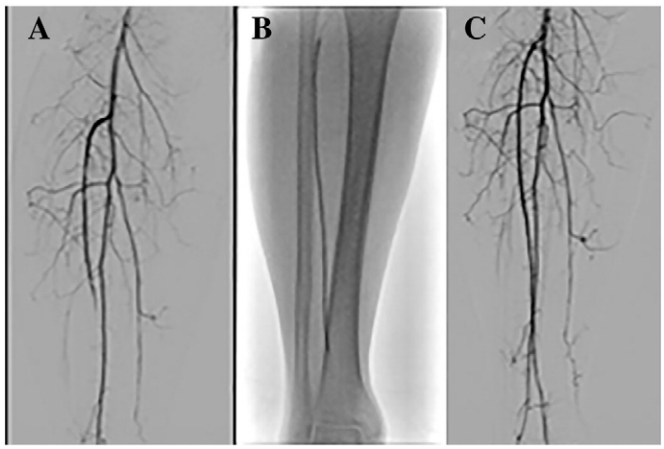

Fig. 1. Angiographic image of anterior tibial artery occlusion (A) that was crossed antegrade and treated with balloon angioplasty (B) with excellent angiographic result (C).

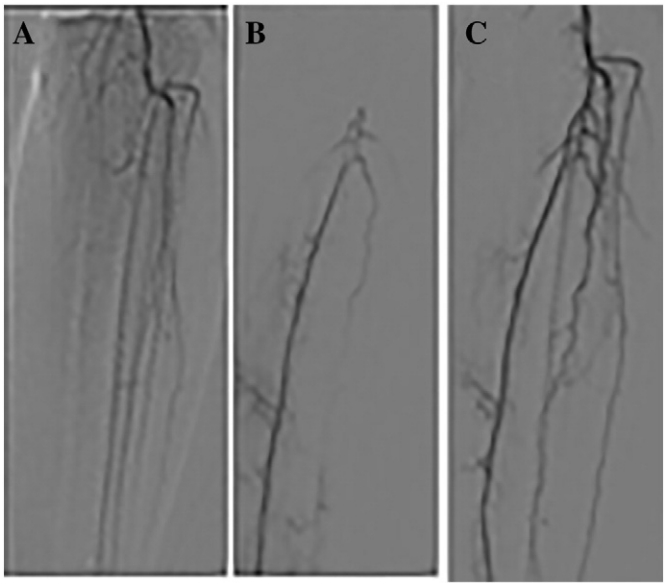

Fig. 2. Angiographic image of posterior tibial artery occlusion (A) that was crossed retrograde via transpedal access (B) with excellent angiographic result following angioplasty (C).

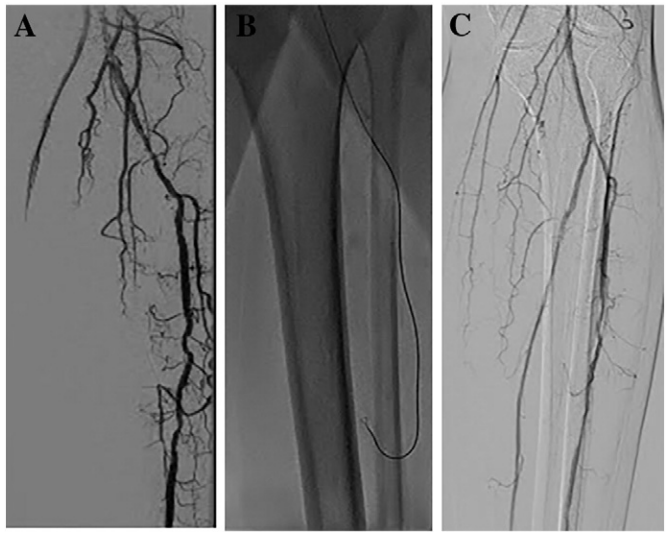

Fig. 3. Angiographic image of peroneal artery occlusion (A) that was crossed using a transcollateral approach (B) with excellent angiographic result following angioplasty (C).

larger diameter balloons through the vessel in retrograde fashion [8]. The reverse CART technique uses similar approach as CART technique, except that a balloon is advanced over the antegrade guidewire. The balloon is inflated to expand the proximal part of occlusion to facilitate the retrograde guidewire entry into the true lumen [7,8,14]. In femoropopliteal CTO lesions, the retrograde approach is usually attempted under fluoroscopic or ultrasound guidance by entering the popliteal artery, which may require prone patient positioning or a tibiopedal artery which can be accessed supine. The retrograde approach is commonly used in a case of failed antegrade approach or when femoral artery is inaccessible [15,16]. Noory et al. evaluated acute procedural and clinical success of retrograde popliteal approach after failed antegrade attempt to treat superficial femoral artery (SFA) and proximal popliteal artery CTOs. Fifty five out of 56 patients underwent successful transpopliteal intervention. The procedural outcome was mostly safe with 6 complications including an arteriovenous fistula and a popliteal artery occlusion [16]. Matsi et al. evaluated the impact of percutaneous transluminal angioplasty on 117 CTO lesions: 89 using antegrade femoral and 28 using retrograde transpopliteal access. Authors reported no statistically significant differences in complications, primary success rates and long-term complications between both techniques [17]. More recently, transpedal access has emerged as a safe and feasible approach for retrograde crossing [18]. In addition to providing an alternative access option for the retrograde approach, transpedal access has gained tremendous traction as a primary access point for complex revascularization.

2.3. Transcollateral crossing

Transcollateral approach (Fig. 3) can be used when there is a flush proximal occlusion, failure to penetrate proximal cap, presence of collaterals at the site of occlusion, or complications from antegrade approach. In a case when tibiopedal or popliteal arteries cannot be used, well-developed collateral vessels can be engaged to reach the distal reconstituted femoropopliteal segment to then engage the distal CTO cap in a retrograde fashion. Multiple cases of successful use of transcollateral approach have been previously reported [19–21]. Transcollateral approach does not require additional access and precludes the need for prone patient positioning. The limitations of this technique are absence of well-developed collaterals, severe angulation or tortuosity of collateral vessels, and use of long support catheters that could cause friction and damage within the vessel wall. In addition, frequent catheter maneuvering may cause collateral vessel spasm requiring administration of vasodilating drugs. Complications such as dissection, perforation, or acute collateral vessel closure could lead to serious manifestations of critical limb ischemia or limb loss. Use of floppy-tipped hydrophyllic guidewires to engage collaterals can minimize the risk of vessel trauma. Thus, the transcollateral approach could be a useful alternative to conventional CTO crossing approaches with additional operator experience.

3. CTO crossing devices

Various CTO crossing devices have been studied in enhancing successful revascularization of femoropopliteal CTOs. These can be primarily divided into fluoroscopy-guided and intravascular imaging-guided devices (Table 1).

3.1. Fluoroscopy guided

3.1.1. Frontrunner

Frontrunner XP (Cordis, Freemont, CA) catheter, a CTO crossing device, utilizes controlled blunt microdissection strategy (Fig. 4). This device performs microdissection of an atherosclerotic plaque and creates fracture planes using a pair of miniature hinged jaws at the distal tip to penetrate the fibrous CTO cap and creates a channel for guidewire passage. Frontrunner XP is commonly used with a microguide catheter, which provides support to the distal end to enable guidewire placement after CTO crossing [2,22,23]. Charalambous et al. assessed the safety and efficacy of the Frontrunner XP CTO catheter in long (>10 cm) and complex (TASC B, C or D) SFA lesions. Out of 76 CTO lesions, 26 failed the initial CTO guidewire passage [24]. Frontrunner XP catheter was successfully able to cross the lesion in 17 out of 26 lesions with no major complications, increasing the overall technical success rate to 88.12%. The failure of Frontrunner XP was due to inability to cross the lesion or re-enter the true lumen after subintimal passage. Similarly, Mossop et al. prospectively investigated the efficacy and safety of blunt microdissection technique using the prototype controlled microdissection catheter in 44 symptomatic peripheral (including 17 femoropopliteal) CTOs after failure to cross the lesions using conventional guidewire and catheter [25]. Out of 17 femoropopliteal CTOs, 16 were successfully crossed using the controlled microdissection catheter with residual <30% stenosis and without any procedural or immediate

Table 1
Literature summary on CTO crossing devices.

CTO crossing devices	Reference number	Number of lesions intervened (n)	CTO crossing success; n (%)	Device related major/minor complication rate; n (%)
Fluoroscopy guided				
Frontrunner	26	26	17 (65.4)	2 (7.7)
	27	17	16 (94.1)	0
	28	22	21 (95.5)	0
Crosser	33	36	23 (63.8)	0
	34	85	71 (83.5)	0
Wildcat	38	84	75 (89.2)	4 (4.8)
Viance	40	58	51 (87.9)	1 (1.7)
	41	26	23 (88.4)	0
	42	45	38 (84.4)	0
TruePath	44	85	65 (76.5)	1 (98.6)
	45	13	10 (77.0)	0
Intravascular imaging guided				
Ocelot	49	100	97 (97.0)	2 (2.0)
	50	33	31 (94.0)	0

CTO – chronic total occlusion.

post-procedural complications. Shetty et al. retrospectively assessed the safety and efficacy of Frontrunner XP catheter in patients with critical limb ischemia and TASC Type D femoropopliteal lesions (mean occlusion length 18 cm and 86.4% with mild calcification) [26]. Attempts of crossing with conventional guidewire failed in 22 out of 33 cases. Frontrunner XP catheter successfully facilitated the guidewire passage in 21 out of 22 lesions with 95.5% success rate. Thus, the above data shows that Frontrunner XP catheter is a useful tool in crossing complex femoropopliteal CTO lesions after failure of initial guidewire use.

3.1.2. Crosser

Crosser system (Bard, Murray Hill, NJ) consists of a generator, transducer, foot switch and a disposable catheter (Fig. 5). The device uses high frequency mechanical vibrations at approximately 20,000 cycles per second to a depth of 20 μm [2,27,28]. The vibration energy is transferred from the core wire to the titanium tip of the catheter, thus creating a cavitational and vibrational effect, which help penetrate through the CTO. Cases of successful Crosser use to treat challenging peripheral

Fig. 4. Frontrunner catheter with miniature hinged jaws (Image provided courtesy of Cordis, Freemont, CA).

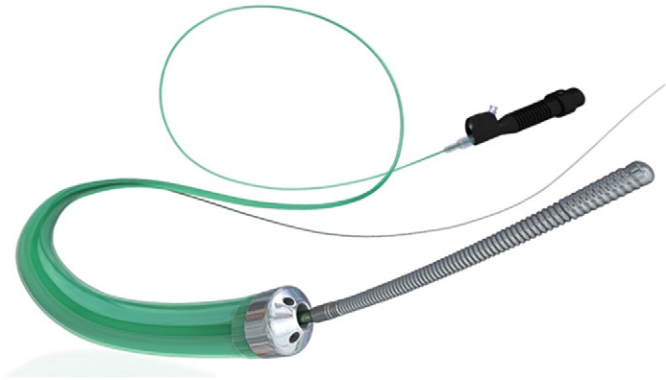

Fig. 5. Crosser catheter (Image provided courtesy of Bard, Murray Hill, NJ).

CTO lesions have been previously reported [28–30]. Earlier single center studies reported moderate success rates of Crosser catheter in femoropopliteal lesions. Staniloae et al., using data from a single center registry, reported the success rates and safety of using Crosser system in treating peripheral CTOs [31]. Out of 56 patients with 73 CTOs, 36 lesions were in femoropopliteal segments. All lesions were TASC B, C or D type and 52.1% had moderate to severe calcification. The efficacy endpoint, defined as successful intraluminal delivery of the wire into the distal vessel by use of Crosser, was achieved in 63.8% of femoropopliteal CTOs with no Crosser related perforations. The PATRIOT trial, a prospective multi-center study, evaluated the angiographic and functional outcomes of the Crosser system in infrainguinal CTOs [32]. Out of 85 total participants with CTOs (mean length 117.5 ± 84 mm), 71 had femoropopliteal lesions; 55.7% lesions had unfavorable morphology (blunt or eccentric), and 54.8% lesions were severely calcified. Primary safety endpoint of freedom from clinically significant perforation at 30 days was 98.8%. Primary clinical efficacy endpoint defined as the advancement of Crosser catheter into or through CTO with successful passage of guidewire into the distal true lumen was 83.5%. Of all the successful cases, only 1 case required repeat percutaneous transluminal angioplasty and 5 cases of clinically non-significant perforations were attributed to the Crosser catheter. Thus, these data show acceptable safety and efficacy of Crosser catheter in crossing long and calcified guidewire resistant femoropopliteal CTOs.

3.1.3. Wildcat

The Wildcat catheter (Avinger, Redwood city, CA), approved for use as a support catheter, is designed to penetrate and traverse through CTOs (Fig. 6). The catheter is hydrophilic coated, and consists of a proximal handle that allows device manipulation and the distal tip that contains spiral wedges. The tip can be configured in passive (counterclockwise rotation) or active (clockwise rotation) modes. The passive mode is initially used, but if it fails to traverse the cap, then the more aggressive active mode is configured with spiral wedges exposed out of the catheter tip [33–36]. Wildcat can be used with a snap-on motorized juicebox accessory system, which enables automatic hands-free rotation of the distal tip, thus allowing enhanced tactile feedback during intervention. Cases of successful SFA CTO intervention with Wildcat catheter have been reported [33,34]. The prospective, nonrandomized CONNECT trial assessed the safety and efficacy of Wildcat device in crossing femoropopliteal CTOs (1–30 cm long) [36]. Out of 88 patients enrolled, Wildcat catheter was used in 84 patients. At baseline, 53.4% lesions had moderate calcification, 88.6% were de novo and 85.2% were in SFA. The primary efficacy endpoint was met with 89.2% success rate and the primary safety endpoint was met with 95.2% safety rate. Four clinically significant perforations were reported for which no remedial or rescue interventions were required. Of the 75 patients in whom Wildcat was successfully crossed, only 12 cases required use of re-entry device. Hence, in majority of the cases, Wildcat was predictable

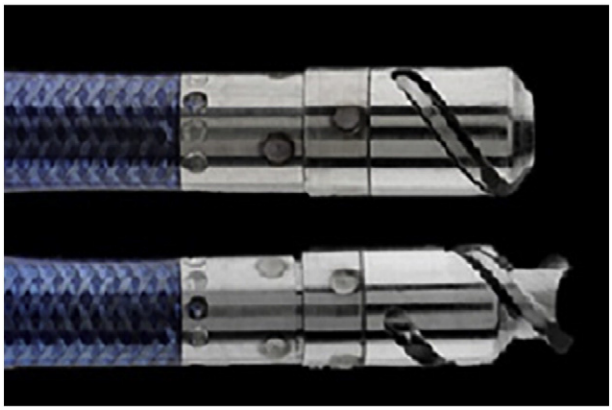

Fig. 6. Wildcat catheter (Image provided by courtesy Avinger, Redwood city, CA).

in crossing through to the distal end of CTO. Despite the encouraging results of CONNECT trial, prospective studies focused on long term outcomes and comparing Wildcat with other crossing devices would be useful.

3.1.4. Viance

Viance catheter system (Covidien, Mansfield, MA) is commonly used for peripheral CTO intervention (Fig. 7). The catheter has a rounded blunt tip distally, and the adjustable torque handle delivers 1:1 torque with manual external control of spin speed transmitted to the distal tip. Forward push and fast spin technique allows the device to pass through CTO via true lumen or subintimal channel [37,38]. Banerjee et al., using data from the XLPAD registry, evaluated the procedural success and complications of Viance catheter in peripheral CTO interventions, including femoropopliteal lesions [38]. Out of 58 CTOs (81% severely calcified, average CTO length 132 mm, 55.2% TASC C or D), 40 were femoropopliteal. Technical success, defined as guidewire placement beyond the distal CTO cap in the true lumen, was 87.9%, whereas the procedural success, defined as successful CTO revascularization with a <30% residual stenosis, was 86.2%. Initial Viance catheter crossing resulted in 95.8% technical success rate. After unsuccessful initial guidewire crossing, the technical success rate of Viance catheter was 50%. At 30 days, there were 3 major adverse events (2 patients with repeat target limb revascularization and 1 patient with surgical revascularization). There was significant improvement in ABI at 30 days compared with baseline (0.72 ± 0.3 to 0.84 ± 0.16). Sethi et al. reported the use of crossing devices in peripheral CTO (total 37 lesions including 8 popliteal) intervention in patients with critical limb ischemia or severe claudication [39]. Out of 26 lesions crossed successfully, 23 were crossed via true lumen using Viance, whereas 1 was crossed subintimally, resulting in 88% technical and 92% procedural success rate. Peripheral facilitated antegrade steering technique in chronic total occlusions (PFAST-CTO) trial assessed the safety and efficacy of Viance catheter with or without use of re-entry catheter [40,41]. A total of 66 patients with infrainguinal lesions (65% SFA, mean length 19.5 cm and 42% moderate to severely calcified) were enrolled. The Viance catheter was used alone in 45 patients. The technical success rate of CTO crossing using Viance catheter, when used alone, was 84% (38 out of 45). Only 2 major adverse events were observed at 30 days among all patients. Thus, the above data demonstrates efficacy and safety of Viance crossing system in the presence or absence of re-entry devices in peripheral CTO intervention.

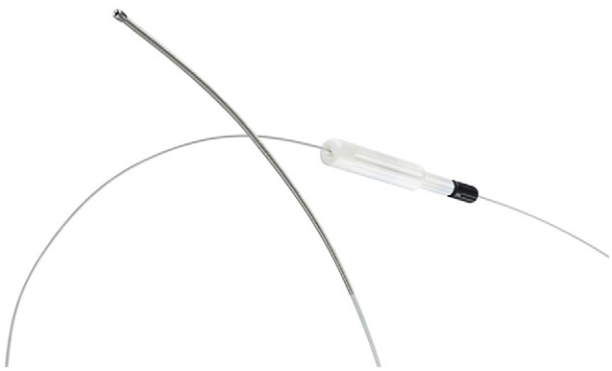

Fig. 7. Viance catheter (Image provided by courtesy Covidien, Mansfield, MA).

3.1.5. TruePath

A recent novel device, TruePath intraluminal crossing system (Boston Scientific Corporation, Natick, MA), consists of a diamond coated radiopaque distal tip mounted onto a hydrophilic wire connected to the motor housing unit (Fig. 8). The distal tip rotates at ~13,000 rpm to create a channel through the CTO lesion and can bend 15 degrees to avoid side branches and need for subintimal re-entry [42,43]. The ReOpen study was a prospective multicenter open labelled trial to assess safety and efficacy of TruePath [42]. Out of 85 CTOs, 67 were located in femoropopliteal vessels. The mean lesion length was 166.5 mm and 80% lesions were moderate to severely calcified. TruePath could not be crossed in 15 out of 85 lesions. The primary efficacy measure of successful advancement of TruePath into or through the CTO and subsequent distal vessel guidewire positioning was 76.5% (n = 65). The primary safety measure of freedom from clinical perforation through 30 days was 98.6% (n = 69). The technical success (ability of TruePath to cross by itself or with conventional guidewire to facilitate crossing of the target occlusion) was 81.1%, and procedural success (technical success and <50% residual stenosis) was 82.4% (n = 70). Thus, ReOpen trial demonstrates that TruePath is safe and effective in crossing CTOs. Banerjee et al. reported 6-month outcomes and success rates of True Path use using a much smaller sample from the XLPAD registry data [43]. Out of 13 CTOs (majority with TASC type C/D) with initial unsuccessful guidewire passage attempts, 12 were in femoropopliteal segments. The mean lesion and CTO length were 169.8 mm and 128.1 mm respectively. The CTO revascularization was successful in all patients, whereas, technical success (placement of guidewire beyond distal cap) was achieved in 10 patients. Only 1 patient required repeat revascularization in 6 month follow-up. The above findings indicate that TruePath device is a useful alternative in crossing femoropopliteal CTO.

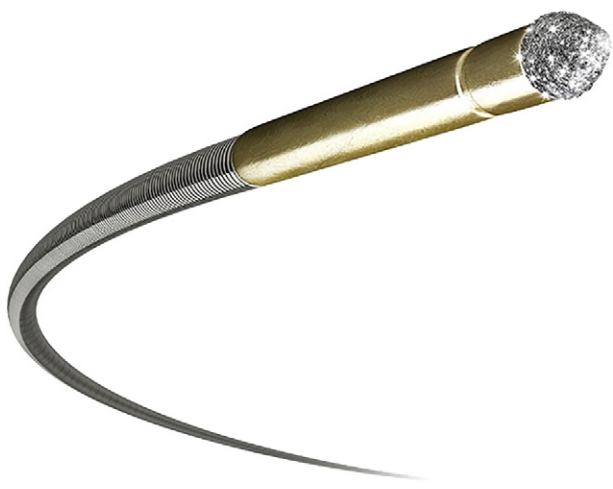

Fig. 8. Truepath catheter (Image provided by courtesy Boston Scientific Corporation, Natick, MA).

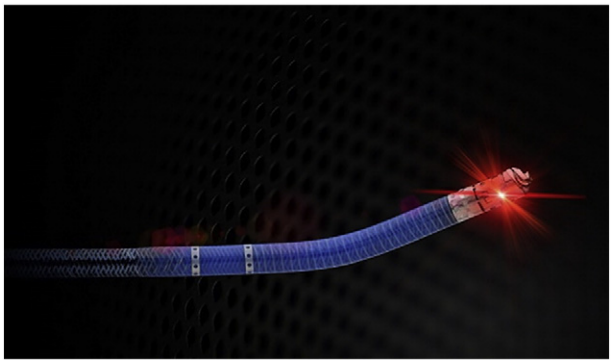

Fig. 9. Ocelot system (Image provided by courtesy Avinger Inc., Redwood City, CA).

Table 2
Literature summary on CTO re-entry devices.

CTO re-entry devices	Reference number	Number of lesions intervened (n)	CTO crossing success; n (%)	Device related major/minor complication rate; n (%)
Fluoroscopy guided				
Outback	53	118	108 (91.5)	13 (11.0)
	54	10	8 (80.0)	0
	56	26	26 (100)	0
Enteer	43	21	18 (85.7)	0
OffRoad	59	92	78 (84.8)	3 (3.3)
Intravascular imaging guided				
Pioneer	63	21	20 (95.0)	0

CTO – chronic total occlusion.

3.2. Intravascular imaging guided

3.2.1. Ocelot

Optical coherence tomography (OCT) uses infrared light, which provides high resolution cross-sectional images (4–15 μm). At such a high resolution, OCT could help assess lesion length, vessel wall layers, fibrous cap thickness and atherosclerotic plaque morphology. In addition, OCT may help determine stent length accurately and limiting inadequate stent expansion or incomplete stent strut apposition. OCT use could help visualize collagen, calcium and microchannels within CTO, which may assist in guidewire passage through the lesion [44–46]. The Ocelot system (Avinger Inc., Redwood City, CA) uses OCT to assist in orientation and navigation of catheter in peripheral CTO intervention (Fig. 9). In contrast to the stand alone diagnostic OCT catheter, Ocelot provides real time images while guiding therapeutic intervention across CTO. The CONNECT II trial, a prospective, nonrandomized, multicenter study, assessed the safety and efficacy of Ocelot catheter in femoropopliteal CTO interventions [47]. Of 100 patients who underwent the intervention, 98 patients had a complete 30 day follow-up. In terms of the safety endpoint, 2 patients experienced 30 day major adverse event of vessel perforation related to Ocelot catheter. The primary effectiveness endpoint (distal placement of guidewire into the true lumen), was met in 97% of patients. Ankle brachial index at discharge and 30 days post procedure improved significantly compared with baseline. Schwindt et al. reported the initial European experience in using Ocelot catheter in 33 patients with SFA lesions [48]. All patients achieved the key safety measure of freedom from procedural major adverse events. The key efficacy measure (successful CTO crossing) was achieved in 31 out of 33 patients (94%); 5 out of 31 lesions crossed successfully (16.1%) required the use of re-entry device. Importantly, the physician feedback in using Ocelot was positive with an 86% average rating of excellent or good in terms of catheter trackability, pushability, tip deflection, ability to stay in true lumen and catheter tip visibility. Furthermore, the Ocelot success rates will likely increase with more experience with the device as illustrated in CONNECT II. Therefore, Ocelot could be a useful adjunctive tool to cross femoropopliteal CTOs, with direct visualization using OCT imaging.

4. Re-entry devices

Many re-entry devices have been evaluated for successful linking of the subintimal plane to the true distal reconstituted lumen beyond the CTO. These can also be classified as fluoroscopy-based or intravascular imaging based devices (Table 2).

4.1. Fluoroscopy guided devices

4.1.1. Outback

Outback (Cordis Corporation, Fremont, CA) is a single-lumen catheter used as a re-entry tool with a hollow curved needle at its tip for distal true lumen re-entry under fluoroscopic guidance during subintimal angioplasty (Fig. 10). A radiopaque marker that appears as "L" or "T" under orthogonal fluoroscopic projections is used to ensure correct alignment of the catheter to the artery. The guidewire is then advanced into the distal true lumen and the Outback catheter is removed [49–51]. Several studies have assessed the efficacy and success rates of Outback catheter re-entry in femoropopliteal interventions. Hausegger et al. reported 80% success rate using Outback catheter in 10 femoropopliteal CTO lesions with no procedural complications [52]. Setacci et al., in a study of 24 patients with critical limb ischemia with SFA CTO lesions (TASC C and D, lesion length > 15 cm) reported a 79% technical success rate (≤50% stenosis) and 1 case of vessel perforation associated with use of Outback catheter [53]. The technical failure in the above studies was largely due to lesion calcification and there were no other devices used for comparison. Gandini et al., in 52 patients with SFA TASC II type D CTO lesions, compared the conventional re-entry technique without Outback use (n = 26) and re-entry technique with Outback use (n = 26) [54]. The success rate (defined as planned in-target re-entry within 5 cm) was 100% with Outback use compared with 42.3% using conventional re-entry techniques. The mean procedural (36 ± 9.4 vs 55.4 ± 14.2) and fluoroscopy time (29.8 ± 8.9 vs 39.6 ± 13.9) were significantly lesser with Outback use. No major peri or post procedural complications were reported with either group. Bausback et al. retrospectively evaluated the long-term clinical results of Outback catheter in femoropopliteal CTO interventions [51]. The study included 113 patients with severe claudication or critical limb ischemia with 118 lesions (mean length 192.3 ± 91.7 mm), of which 93.7% were TASC II C and D and 89.7% lesions had moderate or severe calcification. Technical success (successful recanalization with use of Outback catheter) rate was

Fig. 10. Outback catheter (Cordis Corporation, Fremont, CA).

Fig. 11. Enteer re-entry system (Image provided by courtesy Covidien, Manfield, MA).

Fig. 12. OffRoad catheter (Image provided by courtesy Boston Scientific, Natick, MA).

91.5%, and the rate of successfully recanalized arteries (unrestricted flow to the femoropopliteal segment regardless of residual stenosis) was 90.7%. Rates of target vessel perforation, pseudoaneurysm or minor bleeding and thrombotic re-occlusion < 30 days after procedure were 4.2%, 5.1% and 1.7% respectively. After 12 months, the ABI improved from 0.53 ± 0.25 at baseline to 0.87 ± 0.24. Primary patency (defined as permanent patency during the entire period) rates were 80.5%, 56.7% and 31.2% at 6, 12 and 24 months follow-up. The limb salvage rate in patients with CLI was 86.2%. Thus, the Outback catheter remains a very useful adjunctive tool in subintimal approach for CTO interventions.

4.1.2. Enteer

Enteer re-entry system (Covidien, Manfield, MA) is part of the Viance crossing system that facilitates re-entry of the crossing catheter into the distal true lumen in peripheral CTO interventions (Fig. 11). Enteer consists of a guidewire and flat shaped balloon with 2 side exit ports; upon inflation, one exit port orients towards the true lumen and the other towards the adventitia. The guidewire has a radiopaque segment with distal bend and tapered tip [37]. Different sized balloons are used for above and below knee interventions. The catheter's flat shape self-orients in the subintimal space to enable re-entry into the distal true lumen [37,41]. The use of Enteer re-entry system was demonstrated in PFAST-CTO trial in which 21 out of 66 cases required the use of re-entry system with Viance catheter. The technical success in cases using Enteer catheter was 86% (18/21 patients). There were only 2 patients with major adverse events throughout the trial [42,43]. Banerjee et al., using XLPAD registry data, assessed the efficacy and safety of Viance catheter in patients with complex CTO lesions [38]. Out of 7 cases in which Viance entered the subintimal space, re-entry was successful in 5 cases (71.4%) using Enteer device. Thus, Enteer re-entry system could be successfully used to facilitate guidewire passage into the distal true lumen.

4.1.3. OffRoad

OffRoad catheter (Boston Scientific, Natick, MA), originally proposed as SPOT catheter (S.I. Therapies, Caesarea, Israel), is fluoroscopically guided with conical shaped positioning balloon at its distal tip and microcatheter lancet (Fig. 12). The balloon has a flexible neck with radiopaque band within its body that acts as a fluoroscopic marker. The microcatheter lancet is a single lumen hypotube with lancet tip. The OffRoad catheter is advanced into the subintimal channel and the balloon is inflated distal to the lesion and oriented towards the true lumen. Subsequently, the microcatheter is advanced coaxially in the inner lumen of the balloon catheter through the distal end [55,56]. Airoldi et al. reported the first use of OffRoad catheter in 6 patients with SFA CTOs after an initially failed attempt of antegrade recanalization [55]. Successful re-entry into the true lumen was obtained in five patients. At 30 days follow-up, the SFA was patent in all patients. The Re-Route trial assessed the safety and technical success rates of OffRoad catheter system in femoropopliteal CTO interventions [57]. Out of 92 patients (or lesions), 53% had moderate to severe calcification with mean lesion length of 175.12 mm. The primary effectiveness endpoint, technical success (defined as placement of a guidewire in the distal true lumen) was 84.8%. The 30 day device related major adverse event rate was 3.3% with no device related dissections, perforations or target lesion revascularizations due to complications. The above data indicates that OffRoad is an effective re-entry tool in femoropopliteal CTO interventions.

4.2. Intravascular imaging guided devices

4.2.1. Pioneer

Initially approved as CrossPoint TransAccess catheter, the first FDA approved catheter designed for re-entry, the device was subsequently renamed Pioneer catheter (Volcano corp., San Diego, CA). Pioneer contains intravascular ultrasound (IVUS) and a curved retractable nitinol hollow core needle at the distal tip (Fig. 13). The catheter is placed in the subintimal space just distal to CTO. Subsequently, the needle is positioned and deployed towards the true lumen under IVUS guidance at a controlled depth. An exchange 0.014″ guidewire is passed through the needle and placed in the distal true lumen [49,50,58]. Successful and safe use of Pioneer catheter using subintimal technique has been previously reported in cases of SFA CTO intervention [59,60]. A single center retrospective study of 21 patients with common iliac artery and SFA CTO lesions assessed the safety and efficacy of Pioneer catheter. The procedure was successful in 20 out of 21 patients (95%) with subintimal technique using Pioneer catheter. There were no complications related to the use of Pioneer catheter [61]. Jacobs et al., using a single center registry, reported re-entry use in infrainguinal CTO lesions; out of 87 CTOs, 29 involved SFA [58]. The Pioneer catheter was used in 3 SFA CTOs with no device associated complications. Prospective studies with follow-up data would help assess the long term outcomes of Pioneer catheter use in femoropopliteal CTO intervention.

5. Summary

The field of peripheral CTO intervention is dynamic and novel CTO revascularization strategies, crossing devices, and re-entry techniques are rapidly emerging. With use of these techniques and adjunctive tools, complex femoropopliteal CTOs are becoming more amenable to endovascular intervention. In addition, the novel techniques and tools could help circumvent the need for surgical bypass in high risk patients, decrease the procedural time and minimize contrast volume use and radiation exposure. Prospective trials comparing the efficacy and safety of these adjunctive tools would further help identify appropriate clinical settings for use and reinforce their utility in complex femoropopliteal interventions.

Fig. 13. Pioneer catheter (Image provided by courtesy Volcano corp, San Diego, CA).

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