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Technical Success and Clinical Outcomes of Pedal Serration Angioplasty for Chronic Limb-Threatening Ischemia

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Abstract

Purpose: Patients with pedal artery occlusive disease have limited options when presenting with chronic limb-threatening ischemia (CLTI). Serration angioplasty (SA) has demonstrated less recoil and improved freedom from reintervention compared with plain old balloon angioplasty within the tibial vessels. We aimed to identify the technical feasibility and clinical outcomes of SA within the pedal (inframalleolar) vasculature in patients with CLTI.

Materials and Methods: Patient with SA of the pedal vasculature for CLTI from January 01, 2021 to March 31, 2023 were included in this multicenter retrospective study. Pedal vessels were defined as any inframalleolar vessel distal to the talocrural joint. Patient demographics, anatomic and technical details, acute procedural outcomes, and outcomes at the most recent follow-up were collected for analysis. The primary endpoint was technical success, defined as SA with <50% residual target vessel stenosis. Secondary endpoints included freedom from vessel injury, amputation-free survival, clinically-driven target lesion revascularization (CD-TLR), composite major adverse limb events (MALEs), wound healing rate, and improvement in wound, ischemia, and foot infection (WIfI) clinical stage at the most recent follow-up.

Results: Of the identified 45 patients managed with pedal SA, median pre-intervention Rutherford classification was 5, and 91.9% of patients had concomitant below-the-knee tibial artery intervention. The most commonly treated artery was the dorsalis pedis (59.2%), with a median diameter SA of 2.5 mm. Residual stenosis was <50% in 93.3% of cases and <30% in 82.2%. Freedom from vessel injury was 93.3% (1 immediate occlusion and 2 bail-out stents). Six-month freedom from major amputation was 93.3%, freedom from pedal CD-TLR was 93.3%, and freedom from MALE was 80.0%. At a median follow-up of 163 days, 48.7% of patients had complete wound healing, with the total frequency of either healed or improving wounds of 79.5%.

Conclusion: Serration angioplasty of the inframalleolar vasculature in patients with CLTI had high rates of technical success with a low incidence of vessel injury. At a median follow-up of 5.4 months, wound healing was ahead of previously published studies on inframalleolar intervention.

Clinical Impact

This represents the largest series of a specialty balloon used to treat pedal occlusive disease in chronic limb-threatening ischemia patients. As the rate of pedal intervention increases, using new technology to safely achieve luminal gain is crucial for both short- and long-term limb salvage.

Keywords

pedal angioplasty, serration angioplasty, chronic limb-threatening ischemia, inframalleolar

Introduction

Chronic limb-threatening ischemia (CLTI) represents one of the highest-risk patient populations for major limb loss, with estimated 4-year amputation rates for patients with Rutherford class 5 and class 6 ischemia of 35.3% and 67.3%, respectively.[1,2] Within this high-risk population, patients with poor pedal outflow, or concomitant pedal artery occlusive disease, have the worst outcomes. A recent study by Vacirca et al[3] found that in patients with CLTI, lack

of a patent pedal artery was associated with a two-fold higher risk of major amputation.

Concomitant revascularization of the inframalleolar vasculature may confer some benefit in terms of amputation-free survival and rates of wound healing. Within the RENDEZVOUS registry, patients who had concomitant pedal artery revascularization (PAR) had higher rates of wound healing and shorter time to wound healing compared with those who did not.[4] Serration angioplasty (SA) with the Serranator balloon has some technical advantages compared with plain old balloon angioplasty (POBA). In the Prelude BTK study, 6-month freedom from clinically-driven target lesion revascularization (CD-TLR) after SA of the tibial vessels was 97.7%, higher than traditionally noted with POBA.[5] A recent study by Fereydooni et al[6] demonstrated lower recoil following SA when compared with POBA. Despite potential advantages of this technology in the tibial vessels, there has been little to no investigation of feasibility or outcomes of specialty balloon angioplasty within the pedal vessels. Thus, we examined the technical success and clinical outcomes of SA within the inframalleolar vasculature for patients with CLTI.

Materials and Methods

This was an investigator-initiated, industry-supported, multi-institutional retrospective study of patients who underwent SA below the ankle for the indication of CLTI. The Institutional Review Board's approval was granted prior to study commencement, with minimal risk. Patients who underwent lower extremity angioplasty with SA were reviewed by the individual investigator. Inclusion criteria were any patients aged 18 to 90 years old who underwent SA within a pedal vessel for CLTI. The pedal vessel was defined as either the dorsalis pedis or common plantar artery distal to the location where the anterior tibial artery or posterior tibial artery, respectively, crosses the talocrural joint (Figure 1), or branches of the plantar artery, including the medial and lateral plantar artery, or the deep plantar connection between the dorsalis pedis and lateral plantar vessels. Any patients treated with SA for acute limb ischemia or aneurysm pathology were excluded. Patients with pedal angioplasty with plain balloon technology only, and patients with less than 30-day follow-up data available were excluded.

Patient's demographic, anatomic, technical, and outcome data were collected and managed by the principal investigator using REDCap (Research Electronic Data Capture).[7,8] Demographic data included sex, age, body mass index (BMI), comorbid conditions, presenting vascular findings including Rutherford classification, ankle-brachial index (ABI), and toe-brachial index (TBI), as well as the Society for Vascular Surgery (SVS) Lower Extremity Threatened Limb WIfI (wound, ischemia, and foot infection) clinical stage, and prior ipsilateral vascular interventions. Anatomic data at the index angiogram included assessments of pedal disease with the pedal runoff score and Kawarada classification.[9,10] Concomitant interventions including inflow and tibial adjunctive procedures, use of drug-coated or drug-eluting technology in proximal vascular beds, and concomitant atherectomy use were recorded in the database. Imaging used to guide therapy during the index procedure included both angiogram and intravascular ultrasound (IVUS) when utilized by the investigator. These modalities were used to asses pedal lesion anatomy including lesion location, length, reference vessel diameter and degree of stenosis, presence of chronic total occlusion (CTO), and degree of calcification (either present or severe). Adjunctive pedal treatment including concomitant atherectomy, pre-dilation, and number of inflations per lesion were recorded. Immediate outcomes included residual vessel stenosis by visual estimate, post-treatment pedal runoff score, and vessel injury defined as embolization, perforation, immediate occlusion, or dissection requiring bail-out stent. These outcomes were assessed by primary angiography, with adjunctive IVUS at discretion of the investigator. Follow-up outcomes included ipsilateral reintervention, ipsilateral pedal reintervention, freedom from major amputation, wound healing at the most recent follow-up (healed, improved, unchanged, worsened), Rutherford classification, and WIfI clinical stage at the most recent follow-up.

The primary study endpoint was less than 50% residual stenosis at case completion. Secondary endpoints included freedom from vessel injury, defined as lack of vessel

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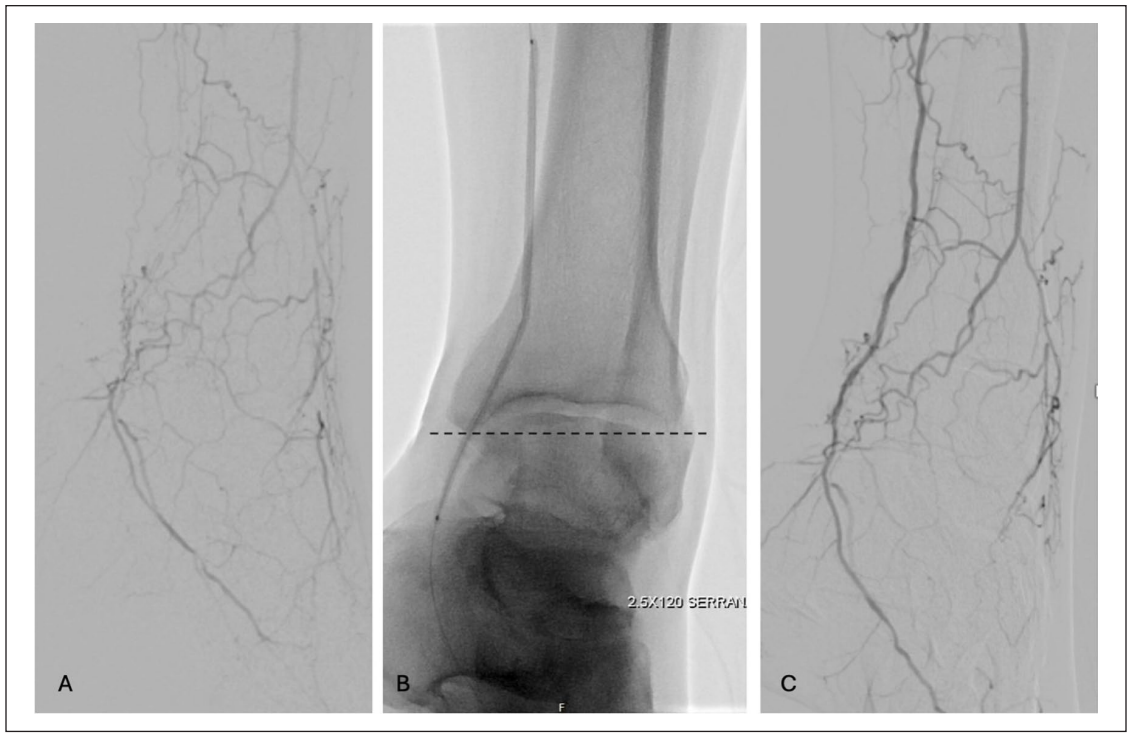

Figure 1. Example of inframalleolar serration angioplasty. Pre-intervention angiogram (A). Serration angioplasty with talocrural joint marked (hash line) (B). Post-serration angioplasty (C).

perforation, immediate occlusion, embolization, or bail-out stenting. Other secondary endpoints were amputation-free survival at 6 months, major adverse limb events (MALEs) at 6 months (major amputation, loss of patency, or need for pedal reintervention), clinically-driven target vessel revascularization (CD-TVR) at 3 and 6 months post-index procedure, change in the SVS WIfI clinical stage from pre-procedure to the most recent follow-up, and the number of wounds both healed and healing at the most recent follow-up visit. Loss of patency at follow-up was defined as either >50% stenosis or occlusion of the treated pedal segment, as seen on follow-up angiogram or duplex ultrasound (when available), according to site-specific ultrasound protocols.

Data from all sites were pulled and analyzed as aggregated information. Descriptive statistics for the entire group of patients were given for all variables: frequencies and percentages for dichotomous or categorical variables; medians and interquartile ranges (IQRs; presented as 25th and 75th percentiles) for numerical information that did not meet normality assumption. Subsequent statistical analysis was performed for patients with and without ≥50% stenosis, clinically-driven target pedal lesion revascularization, MALEs, and complete wound healing at follow-up using a Pearson's chi-squared, Fisher's exact, or Mann-Whitney U test that applied. Patients who underwent major amputation were considered to have infinite time to wound healing endpoint. In addition, a Cox regression analysis with backward, stepwise selection was employed to identify risk factors of MALE at 180 days, and a hazard ratio (HR) with a 95% confidence interval (CI) was reported for each identified risk factor. All hypotheses were tested with a two-sided alpha level of 0.05, and test results with a p-value <0.05 were deemed statistically significant. All statistics were performed in SPSS version 29 (International Business Machines, Armonk, New York, 2022).

Procedure Technique

Access technique included contralateral femoral and ipsilateral antegrade femoral. Patients received heparin bolus or equivalent anticoagulation per site and investigator protocol. Treatment of concomitant above-the-knee and below-the-knee tibial disease was performed at the investigator's discretion and recorded. For treatment of the pedal vessels, pre-treatment was performed if felt necessary by the investigator. This included pre-dilation with plain balloon, atherectomy, or both. The Serranator balloon, ranging from 2.5 to 3.5 mm in diameter, was then advanced into the pedal vessel. Although this was a retrospective study, the majority of investigators utilized a similar inflation strategy: 2 atmospheres (atm) for 20 to 40 seconds, then inflation to 4 atm for 20 to 40 seconds, and inflation to nominal pressure (6 atm). Recommended balloon inflation time was 2 to 3 minutes. Final inflation pressure and treatment time were noted. If there was significant residual stenosis, investigators

Table 1. Patient Demographics and Clinical Presentation.

Variable	
Male sex, n (%)	36 (80.0)
Age in years, median (IQR)	70 (60–79)
Rutherford classification, n (%)	
4	6 (13.3)
5	29 (64.4)
6	10 (22.2)
BMI (kg/m^2), median (IQR)	26.7 (23.4–30.7)
Hypertension, n (%)	40 (88.9)
Hyperlipidemia, n (%)	40 (88.9)
CAD, n (%)	19 (47.5)
Any tobacco use, n (%)	17 (45.9)
DM, n (%)	32 (71.1)
IDDM	21 (65.6)
CKD, n (%)	19 (43.2)
ESRD, n (%)	5 (11.4)
ABI (n=22), median (IQR)	0.8 (0.5–1.0)
TBI (n=12), median (IQR)	0.2 (0.1–0.4)
WIfI clinical stage (n=39), median (IQR)	3 (2–4)
Prior target limb revascularization, n (%)	22 (48.9)
Prior target limb pedal revascularization, n (%)	3 (6.7)

Abbreviations: IQR, interquartile range; BMI, body mass index; CAD, coronary artery disease; DM, diabetes mellitus; IDDM, insulin-treated diabetes mellitus; CKD, chronic kidney disease; ESRD, end-stage renal disease; WIfI, wound, ischemia, and foot infection clinical stage.

Table 2. Anatomic and Technical Details.

Variable	
Ipsilateral antegrade access, n (%)	27 (60.0)
Number of patent tibial vessels, median (IQR)	1 (1–2)
Index pedal runoff score, median (IQR)	9 (8–10)
Kawarada classification, n (%)	
1	4 (8.9)
2A	11 (24.4)
2B	15 (33.3)
3	15 (33.3)
Any pedal calcification, n (%)	37 (84.1)
Severe pedal calcification (n=37), n (%)	26 (57.8)
Pedal CTO, n (%)	18 (40.0)
Pedal pre-treatment stenosis, median (IQR)	87 (80–100)
Concomitant above-the-knee treatment, n (%)	11 (25.0)
Concomitant below-the-knee treatment, n (%)	41 (91.1)
BTK final stenosis (n=38), median (IQR)	10 (0-20)
Pedal pre-dilation, n (%)	24 (54.5)
Pedal atherectomy, n (%)	12 (26.7)
Pedal serration angioplasty diameter (mm), median (IQR)	2.5 (2.5–3)
Inflation pressure (atm; n=34), median (IQR)	6 (6–8)
Second serration inflation in target vessel, n (%)	10 (22.7)
Concomitant IVUS, n (%)	12 (26.7)

Abbreviations: IQR, interquartile range; CTO, chronic total occlusion; atm, atmosphere; IVUS, intravascular ultrasound.

could choose to perform a second inflation of the same lesion with the same Serranator balloon, increase Serranator balloon diameter, or treat with a plain balloon. Any flow-limiting dissection or vessel injury was managed at the discretion of the treating investigator.

Results

A total of 45 patients underwent SA within the pedal vasculature for CLTI during January 01, 2021 to March 31, 2023 were identified. Patients were predominantly male (n=36, 80%) with a median age at time of procedure of 70 years (IQR 60–79). The majority of the patients were Rutherford classification 5 (n=29, 64.4%) with 6 patients (13.3%) presenting with Rutherford class 4 ischemia and 10 patients (22.2%) presenting with Rutherford class 6 ischemia. The most common comorbid conditions included hypertension (88.9%), hyperlipidemia (88.9%), and diabetes mellitus (71.1%). Pre-operative WIfI clinical stage was available in 39 patients (86.7%) with a median of 3 (IQR 2–4). A history of prior target limb revascularization was present in 22 (48.9%) and 3 (6.7%) had prior pedal revascularization. Additional demographic information is available in Table 1.

Most patients (60%) underwent intervention via antegrade approach. Median number of patent tibial vessels prior to intervention was 1 (IQR 1–2). Median pedal runoff score was 9 (IQR 8–10). Pedal vessel calcification was described as severe in 26 (57.8%), and 18 (40%) patients had a CTO within the pedal vessels. Additional anatomic and technical details are noted in Table 2. Concomitant treatment of above-the-knee disease occurred in 11 (25%) patients and below-the-knee disease in 41 (91.1%). Four patients (8.9%) had treatment limited to the pedal vessels. Within the pedal vessels, 24 (54.5%) required pre-dilation with plain balloon, and 12 (26.7%) had concomitant atherectomy. A total of 49 infra-malleolar vessels were treated, with 4 patients undergoing SA in more than one pedal vessel (Figure 2). The majority of interventions occurred in the dorsalis pedis artery (59.2%). Median SA diameter was 2.5 mm with 11 patients undergoing SA at 3.0 mm and 5 patients undergoing SA up to 3.5 mm in diameter. Following initial SA, 16 patients received additional angioplasty in the same target lesion for residual stenosis (35.6%). Of these, 4 patients were treated with POBA, 12 patients underwent repeat SA, and 3 of those patients involved larger diameter serrated balloons. Twelve patients (26.7%) had IVUS within the pedal vessels during the index procedure for additional image guidance.

Following pedal SA, median residual stenosis was 13% (IQR 1%–20%). Three patients had residual stenosis of 50% or greater by visual estimate (including one patient with immediate vessel occlusion), and 8 patients had residual stenosis of

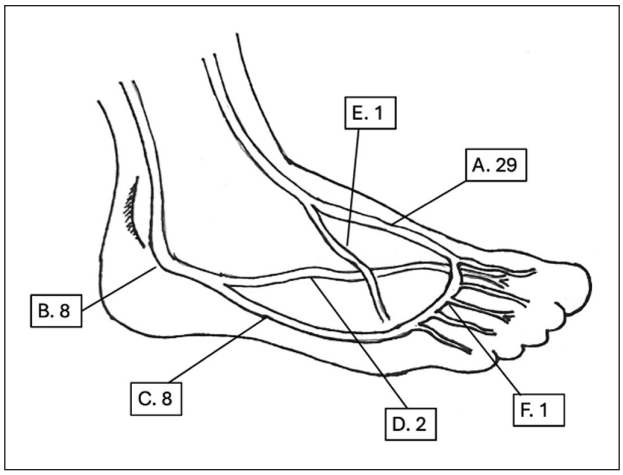

Figure 2. Location of pedal serration angioplasty. (A) Dorsalis pedis, (B) common plantar, (C) lateral plantar, (D) medial plantar, (E) lateral tarsal, (F) deep plantar.

Table 3. Procedural and Clinical Outcomes.

Variable	
Final pedal vessel stenosis (%), median (IQR)	13 (1–20)
Residual stenosis, <50%, n (%)	42 (93.3)
Residual stenosis, <30%, n (%)	37 (82.2)
Bail-out stent, n (%)	2 (4.4)
Freedom from vessel injury, n (%)	42 (93.3)
Final pedal runoff score, median (IQR)	7 (4–8)
Time to follow-up (days), median (IQR)	163 (89–334)
Any reintervention, n (%)	15 (34.9)
Pedal reintervention, n (%)	7 (15.6)
Follow-up imaging stenosis % (n=14), median, IQR	22.5 (0.0–82.5)
Major amputation, n (%)	3 (6.6)
WIfI improvement, n (%)	24 (72.7)
Wound healed (n=39), n (%)	19 (48.7)
Wound healed + improved (n=39), n (%)	31 (79.5)

Abbreviations: IQR, interquartile range; WIfI, wound, ischemia, and foot infection clinical stage.

30% or greater. Freedom from vessel injury was 93.3% (n=42), with 1 patient (noted above) experiencing immediate vessel occlusion, and 2 patients with a residual pedal dissection that required use of a bail-out stent. One patient was treated with a self-expanding tacking stent, and the other with a balloon-expandable coronary stent. Of the two, 1 patient went on to heal their wound, and the other had a residual wound at the most recent follow-up and declined further intervention. There were no instances of vessel perforation or distal embolization. Additional outcome details are noted in Table 3.

Over the length of the study period, 7 (15.6%) patients required CD-TLR within the pedal vessels. Rates of CD-TLR at 3 months were 2.2% and at 6 months were 6.7%, for a 6-month freedom from CD-TLR rate of 93.3%. Patients with a lower final post-SA diameter stenosis were associated with a lower rate of CD-TLR (median 10% vs median 30% for those with and without freedom from CD-TLR, p=0.021). Follow-up imaging (either angiography or duplex) was available in 14 patients at a median of 112 days from the index procedure, with a median follow-up stenosis of 22.5% (IQR 0.0–82.5) (Table 3). Nine patients had follow-up stenosis of < 50%, and 8 had follow-up stenosis of <30%, with 3 having met criteria for composite MALE with a restenosis of ≥50%.

A total of 12 patients with MALEs were identified, including three patients who went on to below-the-knee amputation, for an overall MALE rate of 26.7%. Rate of MALE at 6 months was 20%. Table 4 shows that patients with Rutherford 4 or 6 disease, index pedal runoff score, and severe calcification were associated with patients with MALE. Procedural details associated with MALE included higher residual pedal stenosis following SA (median 40% vs median 10%, p<0.001), and worse final pedal runoff score (median 8 vs 7, p=0.005). A worse final total pedal runoff score (HR 5.5, 95% CI 1.8 – 16.8, p=0.003) and CTO (HR 4.7, 95% CI 0.9-24.7; p=0.067) were risk factors of 180-day MALE in the Cox regression model.

The SVS WIfI clinical stage improved in 72.7% of patients, with most patients having either WIfI clinical stage 0 (n=6, 17.6%) or 1 (n=15, 44.1%) at a median follow-up for the entire cohort of 163 days. Complete wound healing occurred in 19 of 39 patients (48.7%) during follow-up, with an additional 12 patients noting wound improvement for a wound healing/healed rate of 79.5%. Median follow-up for patients with healed wounds was 192 days. Patients with wounds healed were less likely to have coronary artery disease (27.8% in healed wounds vs 62.5% in non-healed wounds, p=0.042). Need for any ipsilateral reintervention was associated with a lower rate of wound healing at follow-up (52.6% in unhealed vs 11.1% in healed, p=0.007).

Discussion

In this series of 45 patients treated with SA within the pedal vessels, overall results of the procedure were good, with 93.3% of patients having <50% residual stenosis following intervention, and 82.2% having <30% residual stenosis. Rates of vessel injury were low, with 2 cases of stent placement below the ankle, and freedom from vessel injury of 93.3%. This represents the largest clinical case series of specialty angioplasty within the pedal vessels, with the smallest delivered balloon diameter of 2.5 mm, and 16 patients undergoing SA with either a 3.0 or 3.5 mm balloon. This resulted in a low rate of residual stenosis, with no incidence of vessel perforation, rupture, or distal embolization.

Table 4. Factors Associated With Major Adverse Limb Events at the Most Recent Follow-up.

Variable	Male		p value
	No (n=33)	Yes (n=12)	
Female sex, n (%)	6 (18.2)	3 (25)	0.682
Pre-operative Rutherford classification (%)			0.016
4	2 (6.1)	4 (33.3)	
5	25 (75.8)	4 (33.3)	
6	6 (18.2)	4 (33.3)	
Tobacco use, n (%)	14 (48.3)	3 (37.5)	0.701
Diabetes mellitus, n (%)	22 (66.7)	10 (83.3)	0.460
Chronic kidney disease, (n=44) n (%)	16 (48.5)	3 (27.3)	0.301
Prior target limb revascularization, n (%)	19 (57.6)	3 (25)	0.027
Prior pedal revascularization, n (%)	2 (6.1)	1 (8.3)	1.000
ATK inflow treated, n (%)	7 (21.9)	4 (33.3)	0.457
BTK inflow treated, n (%)	30 (90.9)	11 (91.7)	1.000
BTK final diameter stenosis (n=38), median (IQR)	10 (0–20)	10 (10–35)	0.309
Initial pedal runoff score, median (IQR)	9 (5–10)	10 (9–10)	0.007
Pedal CTO, n (%)	12 (36.4)	6 (50)	0.499
Severe calcification (n=37), n (%)	15 (57.5)	11 (100)	0.015
Percent final post-serration angioplasty stenosis, median (IQR)	10 (0–20)	40 (20–40)	<0.001
Final pedal runoff score, median (IQR)	7 (2– 7)	8 (7–8)	0.005

Abbreviations: IQR, interquartile range; CTO, chronic total occlusion; ATK, above-the-knee; BTK, below-the-knee.

Overall follow-up was slightly less than 6 months, and 48.7% of the patients with wounds had achieved complete wound healing at a median of 192 days, with almost 80% having either completely healed or healing wounds. Over the study period, the rate of clinically-driven pedal lesion revascularization was 6.7% at 6 months.

Pedal disease is known to play a major role in CLTI, and poor pedal runoff is associated with lower rates of wound healing and higher incidence of limb loss.[3,10] A recent study of infrageniculate intervention in patients without a patent pedal artery identified that compared to patients with patent pedal vessels, lack of pedal runoff was associated with significantly lower limb salvage rates.[3] With use of SA, we were able to achieve freedom from major amputation at 6 months of 93.3%. In the original study outlining the classification scheme of pedal blood flow by Kawarada et al, patients with persistent poor pedal outflow (type III) in the pedal arch had lower rates of wound healing at follow-up. Recent studies that examined the impact of pedal runoff score on both infrageniculate and inframalleolar interventions found that a final pedal runoff score of <7 was associated with higher rates of wound healing and better amputation-free survival.[11,12] Similarly, we found that a lower pedal runoff score (median 7 for freedom from MALE vs 8 for patients with MALE) at completion was associated with higher freedom from MALEs at follow-up.

Previous studies have highlighted both the feasibility of PAR and its impact on wound healing and freedom from major amputation. In 2012, Manzi published on outcomes of 135 patients treated with pedal revascularization with a pedal-plantar loop technique, with improved transcutaneous oxygen compared with patients without pedal revascularization.[13] In the Rendezvous registry, patients who had pedal artery angioplasty had higher rates of wound healing (43.8% wound healing at 6 months with pedal angioplasty compared with 31% without) and shorter time to wound healing.[4] In our own series, at a median of 192 days, 48.7% had complete wound healing. A notable difference in the Rendezvous registry was the use of smaller diameter balloons, limited to 2.0 mm. In comparison, in this series, the smallest utilized Serranator balloon was 2.5 mm. Other comparative outcomes of pedal intervention include a matched cohort of CLTI patients with and without pedal revascularization.[14] In that study, patients with pedal revascularization had higher freedom from major amputation at 1 year (96.3% vs 84.2% without pedal revascularization). These results are in-line with our own freedom from major amputation rate of 93.3%.

There are several different technical considerations in pedal artery angioplasty. Patients with advanced tibial or pedal disease often have significant vessel calcification, which can make delivery of both plain and specialty balloons difficult. In our study, 84.1% of patients had noted pedal calcification, with 57.8% described as severe. One described technique for severely calcified tibial and pedal vessels is the PIERCE (percutaneous direct needle puncture of calcified plaque) technique, with intraluminal cracking via percutaneous needle.[15] Orbital atherectomy in the pedal vessels as a bail-out strategy has been described in limited case series, with similar 6-month freedom from CD-TLR

(91.7%).[16] In our study, the majority of patients were able to be treated either without pre-dilation (33.3%), or with plain balloon (54.5%) prior to delivery of SA. Of the 12 patients who had concomitant atherectomy, the majority of these were orbital (9 patients). The unique features of the Serranator balloon allow for a high amount of force to be directed at the calcific burden via the serrated point tips on the balloon, despite modest inflation pressures, as seen in our series.

Previous studies have identified features of SA that may confer benefit to patients in difficult pedal anatomy. Durability of treatment, particularly in below-the-knee tibial and pedal vessels, is limited regardless of treatment modality. However, in the prospective, multicenter Prelude BTK study, 6-month freedom from CD-TLR was 97.7%.[5] Other considerations for healing of ischemic wounds include improved volume flow of blood to the affected tissue. In a comparison of patients treated with POBA or SA within the tibial vessels, SA was noted to have lower residual stenosis, at lower atmospheric pressure, and calculated flow rates of over 200% higher than POBA when comparing pre-treatment to post-treatment flow via core laboratory.[17] Particularly in vascular beds where there are no or limited options for stenting, lesion recoil can limit the impact and durability of endovascular intervention. A recent study by Fereydooni et al[6] demonstrated that on-table recoil of SA-treated infrapopliteal lesions was lower than POBA. In our own study, we found low rates of vessel injury, at low inflation pressures of 6 atm, with good freedom from pedal reintervention.

Previous studies have examined potential risk factors for failure of both tibial and pedal revascularization. The medial arterial calcification (MAC) score has been previously associated with risk of major amputation in patients with CLTI.[18] Cheun et al[19] compared blinded pedal MAC scores to outcome in patients undergoing isolated inframalleolar interventions. Patients with worse MAC scores had lower rates of amputation-free survival at follow-up. In our own study, severe pedal calcification was more often seen in patients with MALEs (100% in patients with MALE vs 57.7% in patients without, p=0.015). A similar study identified lack of target vessel outflow, occluded pedal arch, and higher MAC score with technical failure of pedal revascularization.[20] Our study included 2 patients who required pedal stenting for significant dissection: one self-expanding stent and one balloon-expandable stent. A prior study identified limitations of below-the-ankle angioplasty and stenting, with 1-year target vessel patency of 50.4%.[21] Interestingly, in this study, balloon-expandable stents were associated with lower rates of restenosis despite a high rate (5 of 11 stents) of stent deformity or fracture on follow-up.

This study is not without some noteworthy limitations. Given the retrospective nature of the study, it is subject to both recall bias and non-uniform data collection, as noted by low rates of preoperative toe-brachial indices, among other factors. Most importantly, we were unable to adjudicate the pre-angioplasty and post-angioplasty stenosis with the assistance of a Core lab. While this would be particularly helpful given the unique nature of this procedure, as well as support from industry, the retrospective nature of the study, and non-standardized collection of angiographic images, limited further imaging review. However, the impact of significant residual stenosis with worse clinical outcomes suggests some correlation between radiographic visual estimate and true stenosis. Finally, patient follow-up through the study was irregular, which impacts accurate recording of time to wound healing in our Rutherford 5 and 6 patients. Measurement of recurrent stenosis within the pedal vessels was not uniform (based on both duplex and any follow-up angiogram for reintervention). Nevertheless, we feel this first-of-its-kind study adds to the growing body of evidence on the impact and potential future options in treating pedal artery occlusive disease.

Conclusion

This investigator-initiated, industry-supported multi-institutional retrospective study is the largest study to date that demonstrates use of a specialty balloon for inframalleolar vascular angioplasty. Overall technical success was high, with low rates of vessel injury and need for bail-out stenting. The ability to achieve safe and durable results following endovascular intervention is critical for successful limb salvage in patients with CLTI. Patients with concomitant pedal artery disease are known to have some of the worst outcomes in this cohort. Here we demonstrate the ability to safely dilate these vessels up to diameters of 3.5 mm at low atmospheric pressure, with freedom from major amputation of >93% at 6 months and almost half of the wounds completely healed. As this technology continues to advance, more study to further evaluate both short-term and long-term outcomes is warranted.

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Ethical Considerations

The institutional review board's approval was granted prior to study commencement, with minimal risk.

Consent to Participate

Given minimal risk based on the retrospective nature of the study, the institutional review board waived informed consent to participate.

Consent for Publication

Not applicable

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Data Availability Statements

The data sets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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