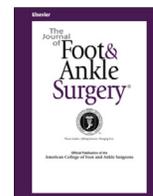




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Peripheral Vascular Disease Diagnostic Related Outcomes in Diabetic Charcot Reconstruction



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ABSTRACT

Postreconstructive outcomes were compared in diabetic patients with Charcot neuroarthropathy (CN) who had peripheral arterial disease (PAD) diagnosed with angiography versus patients who were diagnosed clinically. A retrospective review was performed of patients with diabetic CN requiring reconstruction secondary to ulceration and/or acute infection. Of the 284 patients in the CN osseous reconstruction cohort, after accounting for exclusion criteria, 59 (20.8%) patients with PAD were included in the analyses. Forty (67.8%) of these 59 patients were diagnosed with PAD clinically and 19 (32.2%) were diagnosed with the use of angiography. Bivariate analysis was used to compare outcomes between those diagnosed with PAD via angiography versus those diagnosed clinically for the following postreconstruction outcomes: wound healing, delayed healing, surgical site infection, pin tract infection, osteomyelitis, dehiscence, transfer ulcer, new site of Charcot collapse, contralateral Charcot event, nonunion, major lower extremity amputation, and return to ambulation. Bivariate analysis found return to ambulation postreconstruction ($p = .0054$) to be the only statistically significant factor. There was a trend toward significance for major lower extremity amputation, with higher rates of amputation in the clinically diagnosed PAD arm. Return to ambulation indicates improved functional outcomes. The main goal of limb salvage should be focused on improving the patient's functional performance. With significantly faster rates of return to ambulation and a trend toward decreased rates of major amputation, angiography was found to be a better assessor of PAD than clinical evaluations.

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Charcot neuroarthropathy (CN) is a joint destructive process that can lead to joint dislocation and fracturing and potentially progress to deformities, ulcerations, and limb amputation (1). Although the true etiology of CN has not yet been elucidated, peripheral neuropathy is a known associated process of CN (2). In patients with sensory loss, the

risk of developing the first foot ulcer is 7 times high than in patients with intact sensation (3). There are numerous causes of CN, but diabetes remains the most common cause. Within the diabetic population, 0.08% to 7.5% of patients will eventually be diagnosed with CN (4). Reconstructive surgery is performed with the goal of creating a plantigrade foot and ankle for ambulation, thus decreasing the risk of ulceration and amputation (5).

CN is commonly thought to be associated with good peripheral perfusion. The foot of a patient with CN is routinely characterized as having bounding pulses and exaggerated arterial blood flow (6), theorized to be associated with an inflammatory process. The inflammation results

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in increased temperature of the affected limb compared with the contralateral side, with local edema and erythema (6). Renner et al (7) theorized that hyperemia resulted in periarticular osteopenia and joint breakdown from an autonomously stimulated vascular reflex. However, peripheral arterial disease (PAD) occurs in the natural history of diabetes. PAD is defined as diminished lower extremity arterial perfusion and is associated with arteriosclerotic plaques and medial artery calcinosis (8,9). The inflammatory process and edematous nature of the foot may be false clinical indicators of peripheral perfusion. Wukich et al (10) evaluated patients with CN who had abnormal vascular examinations and found the rate of PAD to be 40% with the diagnosis of PAD made on the basis of an ankle-brachial index (ABI) of <0.9 or a toe-brachial index (TBI) of <0.7 on either extremity. These data contradict the dogma that CN is associated with well-perfused distal vasculature.

Angiography evaluates macrovascular patency, whereas clinical examinations evaluate both macrovascular and microvascular circulation. Clinical examinations demonstrate microvascular flow with the appearance of local tissue perfusion, presence of digital hair, blanchable digits, and TBIs. With the understanding that PAD is present in the CN population, we sought to compare outcomes based on diagnosis method. The postreconstruction outcomes evaluated included wound healing, delayed healing, surgical site infection, pin tract infection, osteomyelitis, dehiscence, transfer ulcer, new site of Charcot collapse, contralateral Charcot event, nonunion, major lower extremity amputation, and return to ambulation.

Patients and Methods

The Georgetown University Hospital Institutional Review Board approved the present study. During a 16-year period (1997–2013), data were collected from the records of the senior author (C.E.A.) on patients with foot and ankle CN who required osseous reconstruction. Exclusion criteria consisted of age <18 years, absent known diagnosis of diabetes mellitus, <1-year postoperative follow-up, presenting with dry gangrene, or treatment with nonsurgical management. With the above exclusion criteria, 284 patients were included in the cohort. Fifty-nine (20.8%) patients were identified with a diagnosis of PAD: 19 (6.7%) patients were diagnosed with the use of angiography and 40 (14.1%) patients were diagnosed clinically. Patients with inconclusive or incomplete data were also excluded from data analysis.

Demographic data were collected on age, sex, body mass index (BMI), glycosylated hemoglobin A1c (HbA_{1c}), diabetes mellitus, renal disease, hypertension (HTN), smoking history, and PAD. Data collected on preoperative infections included ulcer at time of presentation, preoperative soft tissue infection, and preoperative osteomyelitis. Data were collected on postreconstruction outcomes including wound healing, delayed healing, surgical site infection, pin tract infection, osteomyelitis, dehiscence, transfer ulcer, new site of Charcot collapse, contralateral Charcot event, nonunion (defined <6 months), major lower extremity amputation, and return to ambulation.

Patients were admitted to a multidisciplinary team for acute management of the foot and ankle and were treated for lower extremity infection, complex Charcot foot and/or ankle deformity, and/or ischemic changes. Patients were evaluated and additional consultations were provided based on patient-specific needs. Consulting teams included but were not limited to internal medicine, vascular surgery, podiatric surgery, orthopedic surgery, infectious disease, plastic surgery, and physical therapy. Patients had comprehensive laboratory testing, imaging, vascular evaluation, and medical management of multiple comorbidities before CN osseous reconstruction. Osseous reconstruction included internal and/or external fixation.

All vascular interventions were performed before any surgical intervention (i.e., debridement, internal fixation, external fixation, etc.) unless the patient was taken emergently. All patients were initially screened for PAD through clinical examination, noninvasive studies, and history of vascular disease. Some patients went directly to endovascular angiography, whereas others received angiography after screening positive for PAD. Our practice pattern changed with improvements and new techniques for diagnostic angiography, with a noted reduction in contrast requirements. In 2010, it became standard of care for all patients to undergo angiography before intervention for incision planning based on angiosomes. PAD was defined clinically as nonpalpable pulses, audible Doppler examination with less than triphasic signals, an ABI of <0.9, or a TBI of <0.7. PAD was defined by angiography as <3-vessel run-off after diagnostic and interventional angiographic intervention. Outcomes in the clinically diagnosed PAD arm (physical examination and noninvasive testing, n=40) were compared with outcomes in the angiographically diagnosed PAD arm (<3-vessel run-off status post attempted revascularization, n=19). Postreconstruction outcomes included wound healing, delayed healing, surgical site infection, pin tract infection, osteomyelitis, dehiscence, transfer ulcer, new

site of Charcot collapse, contralateral Charcot event, nonunion, major lower extremity amputation, and return to ambulation.

Descriptive statistics were used to describe study subjects. Continuous variables were described by means, medians, modes, and ranges (minimum–maximum). Student's *t* test was used to examine differences in the averages between the groups. Categorical variables were described by frequencies and percentages, and the χ^2 and Fisher exact (when cells had counts <5) tests as appropriate were used to compare proportions of categorical variables. Statistical significance was defined at the 5% ($p < .05$) level.

Results

There were a total of 284 patients with foot and ankle CN requiring osseous reconstruction during a 16-year (1997 to 2013) period (approximately 17.75 patients per year). Of these 284 patients, 225 (79.2%) were excluded because they did not have PAD, leaving 59 (20.8%) for these analyses. Of the 59 patients included in the final analyses, 40 (67.8%) were diagnosed with PAD clinically and 19 (32.2%) were diagnosed angiographically (Fig. 1).

Demographic data for the 59 patients (55.9% males [33/59] and 44.1% females [26/59]) diagnosed with PAD are presented in Table 1. The prevalence of PAD in the entire cohort of patients undergoing Charcot osseous reconstruction was 20.8% (59/284). All of the 59 patients had a history of diabetes complicated by CN. The mean age at time of CN osseous reconstruction was 57.9 (range 38 to 73, median 59) years. The mean BMI was 32.1 (range 20.1 to 47.7, median 32.5) kg/m². The mean HbA_{1c} was 8.8% (range 5.1% to 15%, median 9%). The prevalence of smoking history was 25.4% (15/59), and the prevalence of renal disease was 57.6% (34/59).

Descriptive statistics for the patients with PAD are given in Table 2. In the patients with PAD that was diagnosed clinically, the mean age at time of CN osseous reconstruction was 57.9 (range 38 to 71, median 59) years. The average BMI was 31.7 (range 20.1 to 40.3, median 32.5) kg/m². The mean HbA_{1c} was 8.8% (range 5.1% to 15%). The prevalence of diabetes was 100% (59/59), renal disease 60% (24/40), HTN 87.5% (35/40), and smoking history 32.5% (13/40). The rates of preoperative infection are preoperative ulcer 72.5% (29/40), soft tissue infection 20% (8/40), and osteomyelitis 27.5% (11/40). In the patients with PAD diagnosed with angiography, the mean age at time of CN osseous reconstruction was 57.8 (range 45 to 73, median 56.5) years. The average BMI was 32.9 (range 20.8 to 47.7, median 31.8) kg/m². The mean HbA_{1c} was 8.8% (range 5.7% to 12.5%). The prevalence of DM was 100% (19/19), renal disease 52.6% (10/19), HTN 73.7% (14/19), and smoking history 10.5% (2/19). The rates of preoperative infection are preoperative ulcer 78.9% (15/19), soft tissue infection 42.1% (8/19), and osteomyelitis 31.6% (6/19).

Descriptive statistics for postreconstructive outcomes for the 2 arms are given in Table 3. The postreconstruction rates for the clinically diagnosed PAD are wound healed 47.5% (19/40), delayed healing 40% (16/40), surgical site infection 50% (20/40), pin tract infection 7.5% (3/40), osteomyelitis 30% (12/40), dehiscence 10% (4/40), transfer ulcer 10% (4/40), new site of Charcot collapse 2.5% (1/40), occurrence of contralateral Charcot event 7.5% (3/40), nonunion 5% (2/40), major lower extremity amputation 42.5% (17/40), and return to ambulation 17.5% (7/40). The postreconstruction rates for the angiographically diagnosed PAD are wound healed 36.8% (7/19), delayed healing 47.4% (9/19), surgical site infection 47.4% (9/19), pin tract infection 5.3% (1/19), osteomyelitis 36.8% (7/19), dehiscence 26.3% (5/19), transfer ulcer 10.5% (2/19), new site of Charcot collapse 0% (0/19), occurrence of contralateral Charcot event 5.3% (1/19), nonunion 5.3% (1/19), major lower extremity amputation 26.3% (5/19), and return to ambulation 52.6% (10/19). Bivariate analysis revealed that return to ambulation postreconstruction ($p = .0054$) was the only statistically significant factor; all other factors were not statistically significant. There was a trend toward significance for major lower extremity amputation in the clinically diagnosed PAD arm.

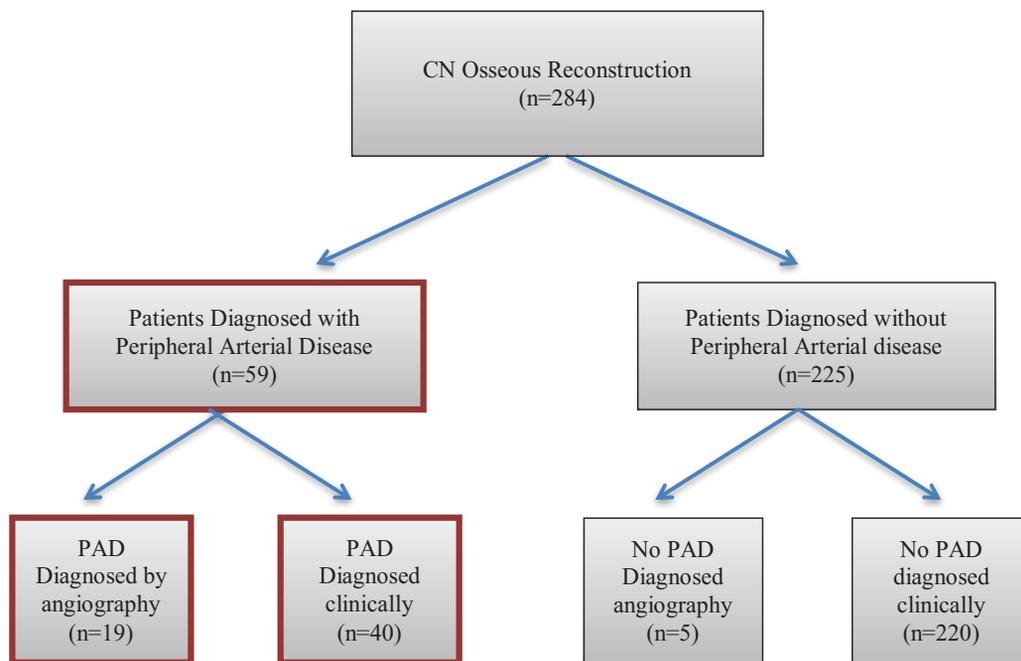


Fig. 1. Flowchart of patients.

Table 1
Demographics of patients diagnosed with peripheral arterial disease (n = 59 patients)

Male, n (%)	33 (55.9)
Female, n (%)	26 (44.1)
Age, mean (range), median, yr	57.9 (38 to 73), 59
BMI, mean (range), median, kg/m ²	32.1 (20.1 to 47.7), 32.5
HbA _{1c} , mean (range), median, %	8.8 (5.1 to 15), 9
Diabetes mellitus, n (%)	59 (100)
Charcot neuroarthropathy, n (%)	59 (100)
Renal disease, n (%)	34 (57.6)
Smoker, n (%)	15 (25.4)

Abbreviations: BMI, body mass index; HbA_{1c}, glycosylated hemoglobin.

Subanalysis on postreconstruction return to ambulation was performed for vascular intervention and number of vessel run-off postreconstruction (Table 4).

The patients who returned to ambulation postreconstruction had a 20% (2/10) rate of vascular intervention, 40% (4/10) of the patients had 2-vessel run off, 50% (5/10) had 1-vessel run-off, and 10% (1/10) had 0-vessel run-off. Patients who did not return to

ambulation postreconstruction had a rate of 33.3% of vascular intervention, 22.2% (2/9) of patients had 2-vessel run-off, 77.8% (7/9) had 1-vessel run-off, and 0% had 0-vessel run-off. There was no statistical difference between vascular intervention or number of vessel run-off between those who returned to ambulation and those who did not.

The percentages of vessels affected by PAD in the angiographically diagnosed arm of CN osseous reconstruction are presented in Table 5. Distal vessels (anterior tibial, peroneal, posterior tibial arteries) were found to have higher rates of PAD than proximal vessels (superficial femoral and popliteal arteries): anterior tibial artery 52.6% (10/19), peroneal artery 52.6% (10/19), and posterior tibial artery 68.4% (13/19) versus superficial femoral artery 10.5% (2/19) and and popliteal artery 10.5% (2/19).

When PAD was diagnosed with angiography, the angiography performed was categorized into interventional versus diagnostic (Table 6). Vascular intervention was performed in 26.3% (5/19) of the patients with PAD diagnosed by angiography. The intervention included both 21.2% (4/19) endovascular intervention and 5.3% (1/19) bypass intervention. The endovascular intervention performed was

Table 2
Descriptive statistics for PAD (bivariate analysis) (n = 59 patients)

	PAD Diagnosed Clinically (n = 40)	PAD Diagnosed Angiographically (n = 19)	p Value
Age, mean (range), median, yr	57.9 (38 to 71), 59	57.8 (45 to 73), 56.5	.9640
BMI, mean (range), median, kg/m ²	31.7 (20.1 to 40.3), 32.5	32.9 (20.8 to 47.7), 31.8	.5315
HbA _{1c} , mean (range), %	8.8 (5.1 to 15)	8.8 (5.7 to 12.5)	.9774
Diabetes mellitus, n (%)	40 (100)	19 (100)	>.99
Renal (CKD + ESRD), n (%)	24 (60)	10 (52.6)	.5925
HTN, n (%)	35 (87.5)	14 (73.7)	.1863
Smoker, n (%)	13 (32.5)	2 (10.5)	.1096
Preoperative infection			
Ulcer at time of presentation, n (%)	29 (72.5)	15 (78.9)	.7529
Soft tissue infection, n (%)	8 (20)	8 (42.1)	.0743
Osteomyelitis, n (%)	11 (27.5)	6 (31.6)	.7465

Abbreviations: BMI, body mass index; CKD, chronic kidney disease; ESRD, end-stage renal disease; HbA_{1c}, glycosylated hemoglobin; HTN, hypertension; PAD, peripheral arterial disease.

Table 3
Descriptive Statistics for Postreconstruction Outcomes in PAD (Bivariate Analysis) (N = 59 Patients)

Outcome, n (%)	PAD Diagnosed Clinically (n = 40)	PAD Diagnosed by Angiographically (n = 19)	p Value
Wound healed	19 (47.5)	7 (36.8)	.4410
Delayed healing	16 (40)	9 (47.4)	.5925
Surgical site infection	20 (50)	9 (47.4)	.8502
Pin tract infection	3 (7.5)	1 (5.3)	>.99
Osteomyelitis	12 (30)	7 (36.8)	.6437
Dehiscence	4 (10)	5 (26.3)	.1368
Transfer ulcer	4 (10)	2 (10.5)	>.99
New site of Charcot collapse	1 (2.5)	0 (0)	>.99
Contralateral Charcot event	3 (7.5)	1 (5.3)	>.99
Nonunion	2 (5)	1 (5.3)	>.99
Major lower extremity amputation	17 (42.5)	5 (26.3)	.2297
Return to ambulation	7 (17.5)	10 (52.6)	.0054

Abbreviation: PAD, peripheral arterial disease.

Table 4
Subanalysis for returned to ambulation (n = 19 patients)

	Patient Returned to Ambulation (n = 10)	Patient Did Not Return to Ambulation (n = 9)	p Value
Vascular intervention, n (%)	2 (20)	3 (33.3)	.6285
2VRO, n (%)	4 (40)	2 (22.2)	.6285
1VRO, n (%)	5 (50)	7 (77.8)	.2101
0VRO, n (%)	1 (10)	0 (0)	>.99

Abbreviation: VRO, vessel run-off.

Table 5
Distribution of named vessels affected by peripheral arterial disease from angiography post intervention (n = 19 patients)

Vessel, n (%)	Vessel Affected by PAD
Superficial femoral artery	2 (10.5)
Popliteal artery	2 (10.5)
Anterior tibial/dorsalis pedis artery	10 (52.6)
Peroneal artery	10 (52.6)
Posterior tibial artery	13 (68.4)

Abbreviation: PAD, peripheral arterial disease.

Table 6
Angiography performed categorized into vascular intervention and solely diagnostic (n = 19 patients)

	PAD Diagnosed by Angiography, n (%)
Endovascular intervention	4 (21.2)
Bypass	1 (5.3)
No vascular intervention	14 (73.7)
Diagnostic angiography	11 (57.9)
Diagnostic angiography for free flap planning	1 (5.3)
Diagnostic angiography due to previous bypass	2 (10.5)

Abbreviation: PAD, peripheral arterial disease.

1. Balloon angioplasty to superficial femoral artery
2. Balloon angioplasty to posterior tibial artery
3. Balloon angioplasty to anterior tibial artery and peroneal artery
4. Stent placement in the superficial femoral artery

The bypass performed was a superficial femoral artery–to–peroneal artery bypass. No vascular intervention was performed on 73.7% (14/19) of the patients with PAD diagnosed with angiography,

Table 7
Intact inframalleolar flow in patients diagnosed with PAD with angiography postintervention (n = 19 patients)

Angiography diagnosed PAD	0VRO	1VRO	2VRO
Run off	1 (5.3)	12 (63.2)	6 (31.6)

Abbreviation: PAD, peripheral arterial disease; VRO, vessel run-off.

categorized into 57.9% (11/19) diagnostic angiography, 5.3% (1/19) diagnostic angiography for free flap planning, and 10.5% (2/19) diagnostic angiography as a result of previous bypass.

Number of vessel run-off in the angiographically diagnosed PAD arm is given in Table 7. Zero-vessel run-off was present in 5.3% (1/19) of patients, 1-vessel run-off was present in 63.2% (12/19) of patients, and 2-vessel run-off was present in 31.6% (6/19) of patients.

Descriptions of anatomical location of CN, type of hardware used in CN osseous reconstruction, and type of osseous reconstruction performed are given in Table 8. Bivariate analysis revealed that midfoot collapse occurred at significantly higher rates in the angiographically diagnosed PAD arm and pantalar fusion was performed at significantly higher rates in the clinically diagnosed PAD arm; all other factors were not statistically significant.

Discussion

Despite the connection between PAD and CN, there is limited published data available on the subject. Therefore, when considering vascular assessment in CN, clinicians largely depend on the literature available for diabetic patients as a proxy. When evaluating the standard of care for the diagnosis of PAD, the methods varied. Depending on the provider, the provider's specialty, geographic location, standard of care, and many other factors, the clinician's physical evaluation of PAD will vary. The diabetic population introduces further discrepancy in opinions on the validity of noninvasive diagnostic modalities for PAD. This is largely due to medial artery calcinosis, which occurs in the natural history of diabetes mellitus. Medial artery calcinosis results in less compressible/rigid vessels, causing lower sensitivities to pedal pulse palpation and ABI readings (10,11). TBIs are less susceptible to medial artery calcinosis compared with the level of the ankle and therefore are theorized to be more reliable indexes than ABIs in diabetic patients (12). There are varying opinions on the reliability of ABIs and TBIs. Wukich (12) found that the combination of ABIs and TBIs in patients with diabetes improved the ability to diagnose PAD, whereas Hyun et al (13) advocates for relying on TBI results, in the setting of elevated ABIs, due to the limitations of ABI predictive values in the diabetic population. Stoekenbroek et al (14) found that TBIs did not result in earlier detection of PAD in diabetic patients compared with the use of ABIs. Boulton et al (2) advocate for pulse palpation and Doppler examination for the diagnosis of PAD in the diabetic population, using audio assessment to classify the waveform as opposed to pressures. Other investigators have found Doppler examination prone to high false-positive rates with low specificity and overall low accuracy rates (15). There is no true standard for diagnosing PAD within the diabetic population via clinical examinations.

Noninvasive imaging can be an intermediate between clinical examinations and invasive angiography (diagnostic or intervention). The accuracy of computed tomography-angiography is similarly affected by calcified smaller vessels (16). Magnetic resonance angiography (MRA) images can be difficult to assess in the presence of stents due to image artifact, and MRA cannot be performed in patients with implanted devices, pacemakers, defibrillators, or metal aneurysm clips because of the MRA magnetic field (17). Although each individual test has its inaccuracies, the combination of the clinical techniques creates a larger scope of the vascular status.

Table 8
Description of anatomical location of CN, type of hardware used in CN osseous reconstruction, and type of osseous reconstruction performed

	Entire CN cohort (N = 59), n (%)	PAD Diagnosed Clinically (n = 40), n (%)	PAD Diagnosed Angiographically (n = 19), n (%)	p Value
Anatomical location of CN				
Forefoot collapse	8 (13.6)	7 (17.5)	1 (5.3)	.4165
Midfoot collapse (TMTJ + CNJ)	31 (52.5)	17 (42.5)	14 (73.7)	.0250
Hindfoot collapse (TNJ+CCJ+STJ)	14 (23.7)	11 (27.5)	3 (15.8)	.5138
Rearfoot collapse (AJ + calcaneus)	23 (39)	15 (37.5)	8 (42.1)	.7347
Type of hardware used in the CN osseous reconstruction				
External fixation	37 (62.7)	28 (70)	9 (47.4)	.1640
Screws/plates	1 (23.7)	6 (15)	8 (42.1)	.0501
Beaming	1 (1.7)	0 (0)	1 (5.3)	.3220
Intramedullary nailing	7 (11.9)	7 (17.5)	0 (0)	.0846
Type of Charcot reconstruction				
Exostectomy	20.3 (12)	8 (20)	4 (21.1)	>.99
Midfoot arthrodesis	20 (33.9)	10 (25)	10 (52.6)	.0717
Subtalar joint arthrodesis	1 (1.7)	1 (2.5)	0 (0)	>.99
Triple arthrodesis (STJ, CCJ, TNJ)	3 (5.1)	2 (5)	1 (5.3)	>.99
TTC arthrodesis	3 (5.1)	1 (2.5)	2 (10.5)	.2402
TC arthrodesis + talectomy	1 (1.7)	1 (2.5)	0 (0)	>.99
AJ arthrodesis	8 (13.6)	7 (17.5)	1 (5.3)	.4165
Pantalar fusion (TTC + STJ, CCJ, TNJ)	15 (25.4)	14 (35)	1 (5.3)	.0227

Abbreviations: AJ, ankle joint; CCJ, calcaneocuboid joint; CNJ, cuneonavicular joint; STJ, subtalar joint; TC, tibiocalcaneal; TTC, tibiototalcaneal; TMTJ, tarsometatarsal joint; TNJ, talonavicular joint.

Contrast angiography remains the gold standard for defining normal macrovascular anatomy and diagnosing vascular pathology (18). Angiography provides an arterial map indicative of perfusion, from dye injected into the vessel, assessed radiographically. There are limitations with angiography; digital subtraction angiography may result in difficult visualization of distal vessels, which are the main indicators of peripheral vascular disease (19). The effects of contrast dye can cause acute kidney issues and can have more severe side effects in patients with chronic kidney disease or renal insufficiency (18), potentially leading to end-stage renal disease. Hydration is required to help prevent this (18). Also, contrast reactions are possible.

Although the standard of care at the Georgetown Limb Salvage Service in assessing for PAD is palpation of pulses, Doppler examination, and ABIs, the authors acknowledge the limitation of these methods, especially within the diabetic population. The arm of patients with clinically diagnosed PAD in this study represents a real-world assessment of perfusion to the lower extremity.

Typical revascularization for infrainguinal PAD is typically done through percutaneous transluminal versus balloon angioplasty via an antegrade technique (6). Pedal access is a technique typically used in the setting of failed crossing of the occlusion with antegrade intraluminal access, and it is performed under ultrasound or fluoroscopic guidance (20). In a comparison of the technical success of infrainguinal intervention, antegrade revascularizations success rates ranged from 56% to 97% compared with the retrograde revascularization success rate, which was 89% (20). Pedal access, although more successful in reestablishing in-line flow, has the risk of thrombosis or dissection of the pedal access vessel with potential ischemic complications (20).

The purpose of this study was to evaluate the accuracy of clinical diagnosis of PAD against the gold standard of angiography. There was no statistically significant difference between the 2 arms in wound healing, delayed healing, surgical site infection, pin tract infection, osteomyelitis, dehiscence, transfer ulcer, new site of Charcot collapse, contralateral Charcot event, nonunion, and major lower extremity amputation. There was a trend toward significance in the rate of major lower extremity amputation. The patients diagnosed based on angiography had a trend toward a lower rate of major amputation compared

with the patients diagnosed clinically. The only factor found to be statistically significant was return to ambulation. Patients diagnosed with PAD on angiography were statistically more likely to return to ambulation than were the patients with PAD diagnosed clinically. This may reflect the advantage of immediate intravascular intervention available with angiography. However, of the 19 patients who received angiography, only 4 received an intervention. Of note, a subgroup analysis of these 4 patients failed to show a difference in ambulation compared with those not receiving angiographic intervention. Data from an unpublished analysis of PAD in below knee amputees showed a significant decrease in postamputation ambulation rates in patients with occluded popliteal arteries. All of the data together suggest that whereas surgical outcomes (i.e., healing, infection, dehiscence) may not depend on a robust blood supply, functional outcomes (i.e., ambulation) necessitate adequate perfusion of the distal limb.

The limb salvage team has an aggressive approach to these high-risk patients, including medical optimization from multiple services, radical surgical correction of the deformity, and a range of soft tissue coverage techniques including free flaps. With the aggressive treatment in both of the high-risk patient arms, there were similar outcomes except for return to ambulation and a trend toward major amputation. Return to ambulation indicates improved functional outcomes. With a shift in limb salvage to functional limb salvage, this outcome is crucial to a patient's ability to perform day-to-day activities and to remain active within his or her home and community. The main goal of limb salvage should be focused on improving the patient's functional performance (21).

The statistical difference between clinically diagnosed and angiographically diagnosed PAD could be due to patient selection bias, with angiography performed on those most likely to have clinical success. However, when comparing the 2 cohorts for anatomical location of CN breakdown, type of hardware used in the CN osseous reconstruction, and type of osseous reconstruction performed, there was only a statistically significant difference between midfoot collapse and pantalar fusion between the 2 arms. Midfoot collapse did occur at significantly higher rates in the angiographically diagnosed PAD arm, and pantalar fusion was performed at significantly higher rates in the clinically diagnosed PAD arm. There was no statistically significant difference between the remaining factors. Pantalar fusion is an extremely

aggressive surgical reconstruction option and could indicate a selection bias away from those with angiographically confirmed PAD, because of expected poor outcomes. Alternatively, the difference could be due to the small sample size of each arm. Because PAD is an infrequent diagnosis among patients receiving Charcot reconstruction, a larger cohort in a prospectively observed study may be necessary to avoid a type II error. Finally, because this is a retrospective study, this cohort may be biased toward patients more likely to have optimal outcomes.

Angiography could have additionally served as an important exclusionary procedure in identifying those patients unlikely to heal postreconstruction. Although not captured within our study, angiography may be a useful tool in identifying those patients unlikely to heal well postreconstruction and instead divert them to major lower extremity amputation, saving the patient time and frustration and accelerating their time to rehabilitation and return to ambulation.

Angiography is the gold standard for evaluating the larger named vessels and angiosome level tissue perfusion (21), but there are limitations in evaluating small vessel perfusion. In the diabetic patient, PAD represents macrovascular and microvascular disease, which is beyond the ability of current angiographic methods to fully assess. Clinical examinations were able to identify high-risk patients, given the similar rates of transfer ulceration, recurrence of Charcot, development of new Charcot breakdown, and major lower extremity amputation compared with angiography diagnosis. However, with a trend toward decreased rates of major amputation and significantly faster rates of return to ambulation, angiography was found to be a better assessor of PAD than clinical evaluations.

In conclusion, return to ambulation, a proxy for functional limb salvage, was the only statistically significant outcome between the clinically diagnosed and angiographically diagnosed PAD ($p = .0054$). With the main goal of functional limb salvage within this high-risk population, angiography as a diagnostic modality has increased rates of return to ambulation. When assessing the risks and benefits of angiography, the benefit of improved functional outcomes advocates for its use as a diagnostic and interventional modality despite the risks. The main goal of limb salvage should not be focused on sparing the foot but on return to function. We believe that angiography provides better diagnosis of PAD in this high-risk population. The clinician who is contemplating a Charcot reconstruction or is faced with post-Charcot reconstruction complications should have a low threshold for pursuing angiography to best pursue functional limb salvage.

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