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Automated Carbon Dioxide Angiography for the Evaluation and Endovascular Treatment of Diabetic Patients With Critical Limb Ischemia

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Abstract

Purpose: To test the safety, efficacy, and diagnostic accuracy of automated carbon dioxide (CO_2) angiography (ACDA) for the evaluation of diabetic patients with critical limb ischemia (CLI) and baseline renal insufficiency and compare ACDA with iodinated contrast medium (ICM) during endovascular treatment. **Methods:** From November 2014 to January 2015, 36 consecutive diabetic patients (mean age 74.8±5.8 years; 27 men) with stage ≥3 chronic kidney disease (CKD ≥3) and CLI underwent lower limb angiography with both CO_2 and ICM followed by balloon angioplasty in a prospective single-center study. The primary outcome measure was the safety and efficacy of ACDA as the exclusive agent to guide angioplasty in this cohort. The secondary outcomes were the safety and diagnostic accuracy of ACDA injection as compared with ICM digital subtraction angiography (DSA) for invasive evaluation of these patients. **Results:** ACDA safely and effectively guided angioplasty in all patients without complications. Transcutaneous oxygen pressure improved from 11.8±6.3 to 58.4±7.6 mm Hg ($p<0.001$). There were no complications related to ACDA during diagnostic imaging and no significant changes in the estimated glomerular filtration rate from baseline to 24 hours (44.7±13.3 vs 47.0±0.8 mL/min/1.73 m^2; nonsignificant). The diagnostic accuracy of CO_2 was 89.8% (sensitivity 92.3%; specificity 75%; positive predictive value 95.5%; negative predictive value 63.1%). There was no statistically significant difference in the qualitative diagnostic accuracy between the media ($p=0.197$). **Conclusion:** ACDA is an accurate, safe, and effective technique that can be utilized to guide endovascular interventions in diabetics with CLI and baseline CKD ≥3. Larger multicenter randomized studies are needed to validate these results.

Keywords

angioplasty, automated carbon dioxide angiography, chronic kidney disease, contrast media, critical limb ischemia, diabetic foot, endovascular interventions, iodinated contrast, pedal arteries, transcutaneous oxygen pressure

Introduction

Peripheral artery disease (PAD) affects 12% of the adult population and 20% of those older than 70 years. Its incidence, and that of critical limb ischemia (CLI), continues to increase, thanks to the epidemic of obesity and diabetes mellitus caused by calorie-rich diets and sedentary lifestyles, combined with hypertension and failed attempts at decreasing tobacco use.[1–4] In diabetic patients, the risk of PAD is 3- to 4-fold higher, and it tends to be more aggressive, with a major amputation rate 5 to 10 times higher than in patients without diabetes. Typical infrapopliteal disease in diabetics is characterized by long, multilevel disease involving all 3 infrapopliteal vessels.[5,6] Patients tend to have concomitant coronary and advanced kidney disease,[7,8] which places them at increased risk of adverse events, particularly contrast-induced nephropathy (CIN) after traditional fluoroscopically guided endovascular interventions.

Revascularization constitutes the mainstay of therapy for CLI patients, and the endovascular approach is becoming standard as it provides good technical results and favorable clinical outcomes while being less invasive and applicable

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to a broader set of patients, including those with poor surgical risk or short life expectancy.[9,10] The goals of treatment include pain control, limb salvage, wound healing, maintenance of ambulatory status, improvement in quality of life, and reduction of major adverse cardiovascular events, including avoidance of major amputation.[7,8]

Digital subtraction angiography (DSA) with iodinated contrast media (ICM) remains the most commonly used invasive imaging technique for diagnostic and interventional vascular procedures. However, this approach is well known to be associated with an increased risk of CIN among diabetic patients with baseline kidney disease.[11,12] The incidence of CIN in patients with baseline chronic kidney disease (CKD) undergoing peripheral interventions has been reported at 5.1%.[13]

In an effort to decrease procedure-related complications, such as CIN and allergic reactions, several studies have focused on the potential benefits of carbon dioxide (CO_2) as a contrast agent during invasive diagnostic procedures in the lower limbs.[12–17] Minor complications from CO_2 angiography and interventions have been described, including leg pain, abdominal pain, diarrhea, and even rare lethal complications, such as nonobstructive mesenteric ischemia. A recent study compared the safety and efficacy of CO_2 and ICM in the angiographic evaluation of PAD patients using an automated CO_2 injector with selective and superselective injections, showing that this strategy was safe and efficacious for diagnostic purposes.[18] However, no studies have been published addressing this issue in diabetic CLI patients with concomitant advanced CKD (stage ≥3).

The aim of this prospective, single-center, single-arm study was to report our preliminary experience with automated carbon dioxide angiography (ACDA) during the endovascular treatment of diabetic CLI patients with advanced kidney disease and to evaluate its diagnostic accuracy vs ICM DSA.

Methods

Study Design

From November 2014 to January 2015, a prospective single-center study enrolled 36 consecutive diabetic patients with CKD ≥3 [estimated glomerular filtration rate (eGFR) ≤60 mL/min/1.73 m^2] who had a clinical diagnosis of CLI based on the presence of nonhealing pedal ulcers and/or gangrene (Rutherford category 5/6) and severely abnormal transcutaneous oxygen pressure ($TcPO_2$ ≤30 mm Hg). Patients were ineligible if they had severe chronic obstructive pulmonary disease (1-second forced expiratory volume <50% of predicted during spirometry or stages III and IV of the GOLD classification[19]) or previous adverse reaction to ICM or CO_2. The baseline demographics of the study cohort are summarized in Table 1. The lesion distribution included 14 (39%) patients with superficial femoral artery (SFA) disease, 17 (47%) patients with popliteal disease, and 33 (92%) with below-the-knee disease. The study protocol was in accord with the Declaration of Helsinki and approved by the local institutional review board. All patients provided informed consent before the procedure.

Table 1. Demographics and Baseline Clinical Conditions.[a]

Age, y	74.8±5.8 (55–83)
Men	27/36 (75)
Comorbidities	
Diabetes	36/36 (100)
Coronary artery disease	19/36 (53)
Dyslipidemia	11/36 (30)
Hypertension	24/36 (67)
Dialysis	6/36 (17)
Baseline parameters	
Creatinine, mg/dL	2.3±0.8
Systolic blood pressure, mm Hg	151.5±28.9
eGFR, mL/min/1.73 m^2	44.7±13.3
$TcPO_2$, mm Hg	11.8±6.3
Rutherford category	
5	25/36 (69)
6	11/36 (31)

Abbreviations: eGFR, estimated glomerular filtration rate, $TcPO_2$, transcutaneous oxygen pressure.
[a]Continuous data are presented as the means ± standard deviation (range if available); categorical data are given as the counts/sample (percentage).

Angioplasty Procedure

All patients were pretreated with aspirin (75–160 mg) and ticlopidine (500 mg) or clopidogrel (300 mg). An infusion of 0.9% normal saline solution at 1 mL/kg/min was begun 1 hour before the procedure and continued until 6 hours after the procedure. Intravenous sedatives or analgesics were withheld to avoid masking a patient's reaction to the injection of CO_2. After local anesthesia, antegrade access in the common femoral artery (CFA) was obtained under ultrasound guidance (9-MHz linear probe, GE Logic E9; General Electric Medical Systems, Milwaukee, WI, USA), and a 6-F, 11-cm end-hole introducer sheath (Radifocus; Terumo, Tokyo, Japan) was advanced. Patients were anticoagulated with a 5000-unit bolus of intravenous unfractionated heparin. Diagnostic angiography through the CFA sheath as described below was performed in all patients, with CO_2 followed by ICM; balloon angioplasty was then carried out during the same session. Patients complaining of pain during the procedure received 10 mL of 2% intra-arterial lidocaine. All the revascularization procedures were performed exclusively with CO_2 guidance.

Angiography

All angiograms were captured using the Integris Allura 12 DSA system (Philips Medical Systems, Best, the Netherlands). For CO_2 angiography, the patient was placed

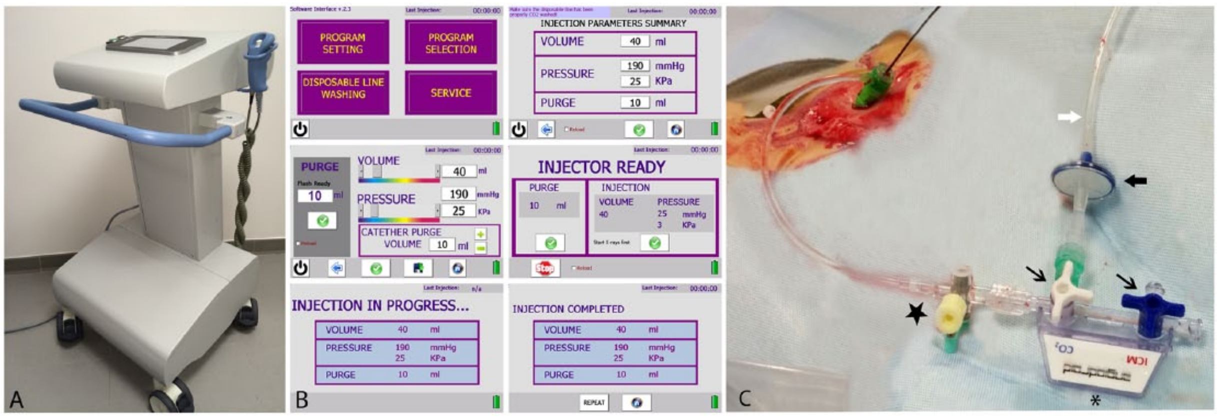

Figure 1. (A) The Angiodroid automatic CO_2 injector. (B) The different screens of the touch control panel, through which one sets up CO_2 volume, injection pressure and rate, and the automatic purifying catheter function. (C) The 6-F antegrade sheath in place with a wire through it. The star shows the side arm of the sheath, which is connected to a white 3-way stopcock (arrow) and a blue 2-way stopcock (arrow) labeled CO_2 and iodinated contrast medium (ICM), respectively, to switch modalities. The white arrow is the connecting tubing from the CO_2 injector and the black thick arrow is a transducer protector, which acts as an antibacterial filter.

in a modified Trendelenburg position with the aid of a 30° transparent rubber wedge. The automatic, digital Angiodroid injection system (Angiodroid SRL, Bologna, Italy; Figure 1) was connected to the sidearm of the sheath. Initially, 10 mL of CO_2 was injected to fill the tubing with gas and eliminate the air. Then by appropriate manipulation of the stopcocks, the sheath is back-bled through its sidearm, and the CO_2 was injected, creating a blood-CO_2 interface without any air in the system. The injection pressure was set at 20 mm Hg over the patient's systolic blood pressure for each injection at each arterial segment. To avoid gas fragmentation and trapping, the catheter was purged prior to each injection and delivery was in a continuous, controlled fashion.

For ICM angiography, a Medrad Mark V Provis injector (Bayer HealthCare, Whippany, NJ, USA) was connected to the sheath sidearm to inject 9 mL of a 50% solution of the nonionic isosmolar contrast medium (Iodixanol, 270 mg I/mL) at a rate of 3 mL/s for each injection. A frame rate of 3 frames per second was utilized during image acquisition.[20]

All angiograms were captured and analyzed in 5 predefined segments: proximal femoral (including the CFA, proximal to the mid SFA, and profunda); distal femoral (from mid SFA to P1 segment of the popliteal); infragenicular (from the P2 segment of the popliteal to the proximal third of the tibial arteries); distal tibial (from mid-calf to ankle); and pedal (below the ankle). The pedal territory was studied in two distinct projections (lateral and anteroposterior).

Accuracy of CO_2 Angiograms

Philips proprietary postprocessing software was utilized to render high-quality images after CO_2 angiography, which were evaluated and compared independently by 2 experienced operators blinded to the ICM images and not involved in the angioplasty procedure. Diagnostic accuracy was scored according to 4 predefined categories:

1. Excellent: All images were of sufficiently high quality to establish the diagnosis and set up the revascularization without the need for further imaging studies.
2. Good: All images were adequate to establish the diagnosis and guide the treatment; however, complementary images with ICM would be needed prior to the intervention.
3. Poor: All images were insufficient or required the use of intravenous sedation/analgesia or the need to completely repeat the angiographic acquisition with ICM.
4. Unacceptable: Images were not obtained as the procedure had to be cancelled secondary to uncontrollable pain or movement.

After diagnostic angiography and endovascular treatment, the patients were followed at 24 hours, 1 week, and 30 days. Procedure-related adverse events and clinical outcomes were recorded.

Outcome Measures

The primary outcome was the safety of automated CO_2 angiography (ACDA) and its utility as the exclusive agent to guide balloon angioplasty. Safety was defined as freedom from procedure-related complications at 24 hours and 1 week. Procedure-related complications were the occurrence of nonocclusive mesenteric ischemia, prolonged hospitalization (>24 hours) as the result of the ACDA-guided intervention (eg, hematomas, pseudoaneurysms, perforations, or the need for transfusions potentially associated with sudden motions induced by the CO_2 injection), and acute renal failure (an increase in serum creatinine >0.5 mg/dL from baseline owing to the need for larger volumes of ICM).

Efficacy was defined as a composite of procedure success [ability to cross and treat the lesion(s) with restoration of brisk antegrade flow through the treated artery, no evidence of flow-limiting dissection, and/or a residual stenosis <30%, as estimated by the 2 independent observers] and 30-day improvement in $TcPO_2$ to >40 mm Hg.

The safety and diagnostic accuracy of ACDA injection was compared with ICM DSA; in this regard, safety was defined as freedom from major CO_2 injection–related complications (intractable limb pain, abdominal pain, and diarrhea) during the diagnostic imaging portion of the procedure. Diagnostic accuracy was evaluated as described previously. Other outcomes included amputation-free survival.

Statistical Analysis

Continuous data are presented as the means ± standard deviation; categorical data are given as the counts (percentage). Variables of diagnostic accuracy were compared using a Kruskal-Wallis test. The interobserver coefficient of variability (κ) was calculated to determine if there were significant differences in interpretation among the operators. Calculations of sensitivity, specificity, positive and negative predictive values, as well as accuracy, were performed using standard formulas. The significance of changes in eGFR and $TcPO_2$ mean values was tested using a Student *t* test or the Mann-Whitney *U* test as appropriate. All tests were 2-sided. Rates of amputation-free survival were estimated using the Kaplan-Meier method. The threshold of statistical significance was $p<0.05$. Analyses were performed using SPSS software (version 16.0; SPSS Inc, IBM Corporation, Somers, NY, USA).

Results

The primary efficacy endpoint was achieved in all patients (Figure 2); all procedures were completed successfully and the $TcPO_2$ improved from 11.8±6.3 to 58.4±7.6 mm Hg ($p<0.001$). There were no intraprocedural complications due to the use of CO_2 during the revascularization procedure. There were no procedure-related complications recorded at 24 hours or 1 week, so the primary safety endpoint was achieved in 100% of patients. The eGFR at baseline (44.7±13.3 mL/min/1.73 m^2) rose to 47.0±0.8 mL/min/1.73 m^2 24 hours post intervention ($p>0.05$). An average of 6 ICM injections was used per patient, for a per-patient average of only 54 mL of ICM owing to the use of CO_2.

In the accuracy assessment, the most common factor that interfered with the quality of either imaging method was motion artifact introduced by the involuntary movement of limbs and/or feet during injections, which in some cases resulted in the need for additional images. Eleven (30%) patients treated with ACDA complained of pain during CO_2 injections, which resulted in motion artifact in 6 (17%) patients. Lidocaine was given during the repeat image acquisition, with excellent results (Figure 3). In all the 11 cases, the systolic blood pressure was between 160 and 180 mm Hg; the corresponding CO_2 injection pressure of 180 to 200 mm Hg may have caused distention of the adventitial receptors. However, there was no statistically significant difference ($p>0.05$) compared with the blood pressure measurements among the patients who did not experience pain.

There was also no statistically significant difference ($p=0.197$) in qualitative diagnostic accuracy between the images rated "excellent" with ACDA (39%) or ICM (50%). The κ coefficient was 0.89, consistent with very low interobserver variability (Figure 4, Table 2). The overall diagnostic accuracy of ACDA was 89.8% (sensitivity 92.3%; specificity 75%; positive predictive value 95.5% and negative predictive value 63.1%). Table 3 gives the values per limb segment.

There were no major amputations during follow-up, resulting in a limb salvage rate of 100% in this cohort. There were 14 (39%) minor amputations, resulting in a minor amputation–free survival estimate of 61.1% by Kaplan-Meier analysis (Figure 5). At follow-up, the ulcers and surgical incisions had healed satisfactorily in this subgroup.

CO_2 Injection Pressure and Volumes

Mean systolic blood pressure was 151.5±28.8 mm Hg and the average CO_2 injection pressure was 171.1±24.3 mm Hg. The injected CO_2 volumes varied according to the arterial segments being studied (Figure 6, Table 4). The total average volume of CO_2 used for diagnostic imaging was 395.3±114.6 mL. After the intervention, ACDA was repeated only on the treated segment, using the same volume of CO_2 per segment (Figures 7 and 8).

Discussion

As previously demonstrated with the use of different ICM,[21] the most common factor that hinders the diagnostic quality of peripheral angiography among patients with diabetes and CLI is the motion artifact introduced by leg and foot movement, which in our experience also holds true for CO_2 angiography.

The advantages of CO_2 as a contrast medium for intravascular images include its lack of inherent nephrotoxicity

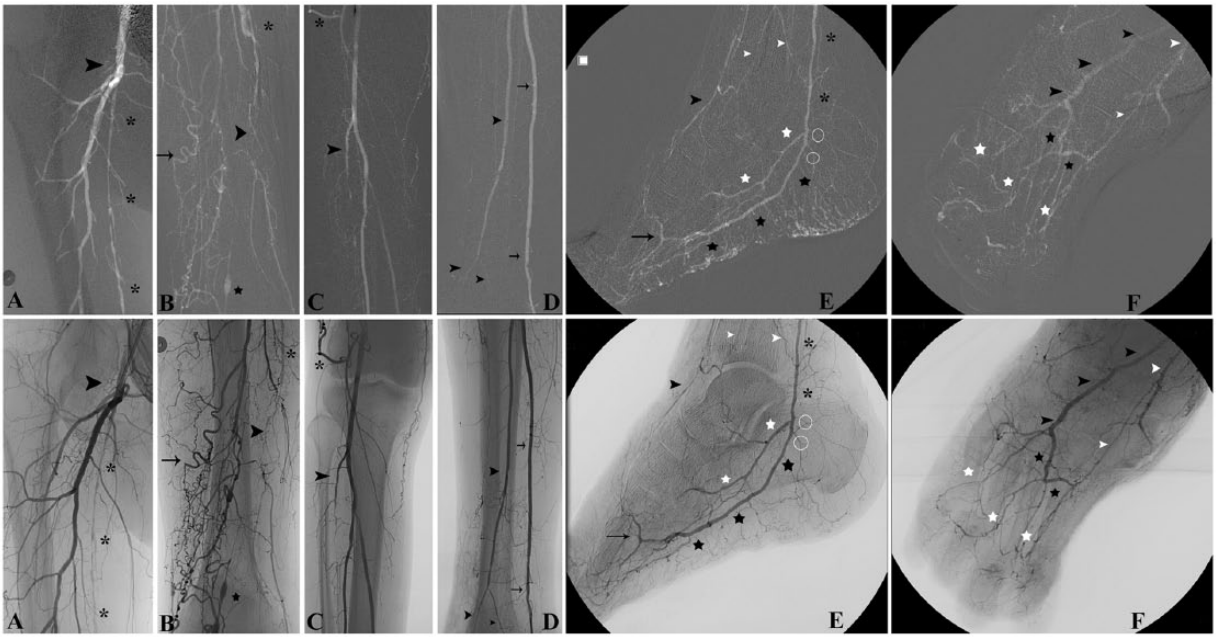

Figure 2. Representative diagnostic angiography with CO_2 and iodinated contrast medium (ICM). (A) Injection through the 6-F antegrade sheath shows the femoral bifurcation (arrowhead) and diffuse stenosis of the superficial femoral artery (SFA, *). (B) SFA stenosis (*), occlusion of the middle segment of the SFA (arrowhead), and reconstitution in the proximal popliteal artery (★). Notice the collateral from the profunda (arrow). (C) Infrapopliteal segment showing occlusion of the anterior tibial artery (arrowhead) and patency of the tibioperoneal trunk, peroneal, and posterior tibial (PT) arteries. Notice the collateral above the knee (*). (D) Patency of the peroneal artery (arrowhead) and the lateral calcaneal branch (small arrowhead) and patency of the PT (arrows). (E) Lateral view of the foot. Patent distal PT and common plantar arteries (*); patent lateral plantar (LP, black star) and medial plantar (MP) (white star) arteries. Patent plantar arch (arrow). In the dorsal circulation, the thin and distally occluded dorsalis pedis is shown (arrowhead). Notice the calcaneal branches (white circle). (F) Anteroposterior view of the foot. Patent LP (black arrowhead), plantar arch (black star), MP (white arrowhead) arteries are seen. The white stars denote the metatarsal branches.

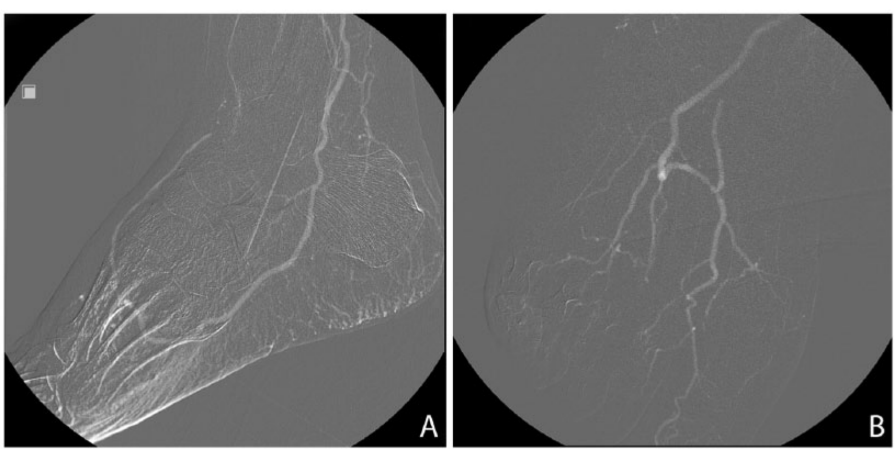

Figure 3. CO_2 angiography and motion artifact. (A) Laterolateral view of the foot with motion artifact: good evaluation of the dorsalis pedis and plantar arteries but poor evaluation of the plantar arch and the forefoot. (B) Anteroposterior view of the foot in the same patient after administering 10 mL of 2% lidocaine intra-arterially; note the good evaluation of the pedal arteries, plantar arch, and metatarsal branches.

Table 2. Qualitative Diagnostic Accuracy.

	Contrast Medium	
Score	CO_2[a,b]	ICM[a,b]
Excellent	14/36 (39)	18/36 (50)
Good	16/36 (44)	16/36 (44)
Poor	6/36 (17)	2/36 (6)
Unacceptable	0/74	0/74

Abbreviations: CO_2, carbon dioxide; ICM, iodinated contrast medium.
[a]Data are presented as the count/sample (percentage).
[b]p=0.197, κ=0.890.

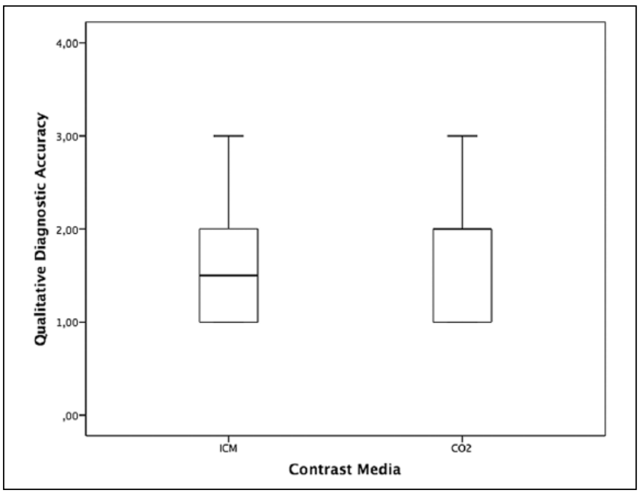

Figure 4. Qualitative diagnostic accuracy of both contrast media. 1 = excellent, 2 = good, 3 = poor, 4 = unacceptable.

Table 3. Quantitative Diagnostic Accuracy.

	ATK, %	BTK, %	BTA, %	Overall, %
Sensitivity	96.8	93.3	86.6	92.3
Specificity	80.0	83.3	66.6	75.0
PPV	96.8	96.5	92.8	95.5
NPV	80.0	71.4	50.0	63.1
Accuracy	94.4	91.7	83.3	89.8

Abbreviations: ATK, above the knee; BTA, below the ankle; BTK, below the knee; NPV, negative predictive value; PPV, positive predictive value.

and anaphylactic potential, rendering it a desirable agent for evaluating patients with renal dysfunction.[16,17,22–24] Several studies have endorsed the use of CO_2 as an adequate alternative to ICM agents in supragenicular vessels.[12–14] However, the diagnostic accuracy to image infrapopliteal vessels has been reported to drop by about 50%,[25–27] in contrast with our 89.8% accuracy among patients with the most severe form of infrapopliteal arterial disease. This difference might be at least in part explained by our use of an automated injector (hand injections were utilized in the

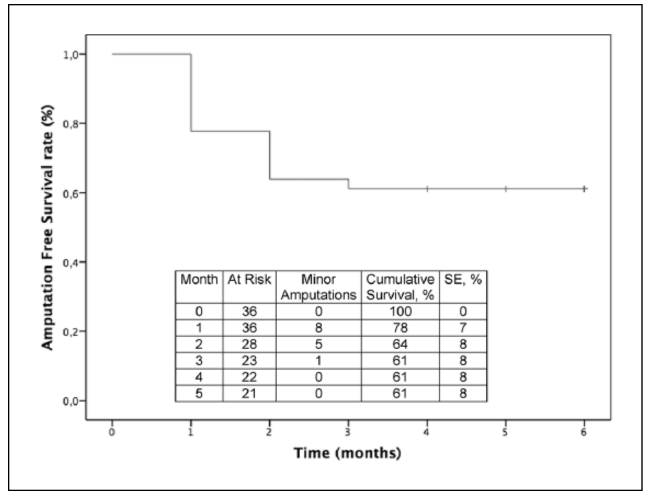

Figure 5. Kaplan-Meier plot of 6-month amputation free survival. SE, standard error.

Figure 6. Injected CO_2 volumes per arterial segment.

Table 4. Injected CO_2 Volumes per Arterial Segment.

Arterial Segment	CO_2 Volume, mL[a]
Proximal femoral	46.3±13.3
Distal femoral + P1	50.0±15.6
Genicular (P2, P3) + proximal tibial	66.9±19.6
Mid + distal tibial	72.1±24.7
Foot (lateral)	76.4±21.6
Foot (anteroposterior)	83.6±19.6

Abbreviations: CO_2, carbon dioxide; P, popliteal.
[a]Data presented as mean ± standard deviation.

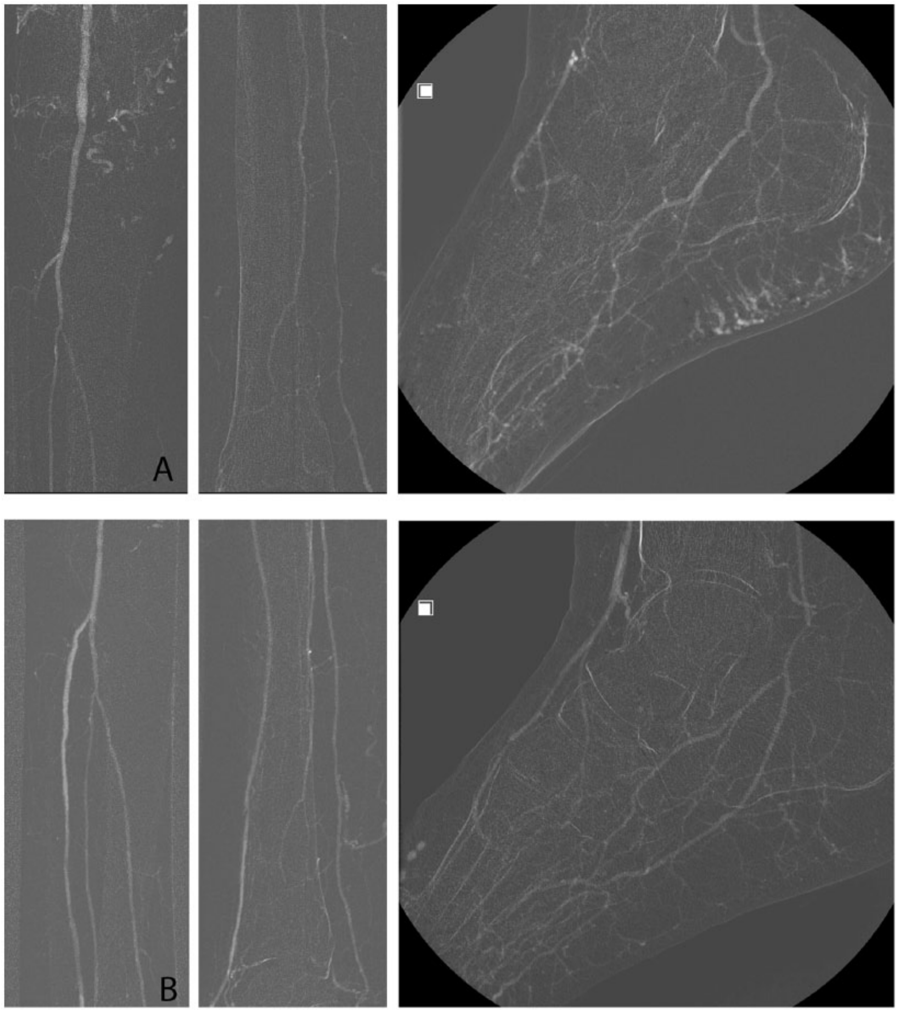

Figure 7. (A) Pre– and (B) post–CO_2-guided revascularization. (A) Patent popliteal artery. Occlusion of the anterior tibial (AT) and diffuse stenosis of the posterior tibial (PT) arteries. In the foot, distal occlusion of the dorsalis pedis (DP) and occlusion of the lateral plantar (LP) arteries. The medial plantar (MP) artery is patent. (B) Patent popliteal, AT, PT, peroneal, DP, LP, and MP arteries with direct blood flow to the forefoot after complete revascularization.

referenced studies). Hand injection may foster the natural tendency to accelerate the injection as the plunger approaches the end of the syringe, when there is less resistance to the force applied by the operator.

High-quality images of the infrapopliteal and inframalleolar arteries are of paramount importance in CLI patients in order to adequately set up the revascularization strategy, while low-quality arteriograms lead to repeated contrast injections and higher doses of radiation, thus increasing the risk of complications.[21] In the study by Fujihara et al,[13] they had 17.3% complications, of which 15.3% were minor and included transient leg or abdominal pain and diarrhea. However, they had 2 cases of nonobstructive mesenteric ischemia, a rare but lethal sequela. Of note, their study was performed using manual injections. More recent studies have advocated the use of automated CO_2 injectors, which eliminate the inaccuracy of hand-held injections. A recently published study[18] compared ICM and ACDA angiography using the Angiodroid system for diagnostic purposes in patients with lower limb arterial disease. The authors obtained high-quality images with excellent accuracy (96.9%) and found no statistically significant differences between CO_2 and ICM when performing selective and superselective angiograms with a straight 4-F catheter placed at the common iliac, common femoral, or popliteal arteries. However, only 5% of their patients had advanced CLI (Rutherford 5). Our series involved diabetic CLI patients with advanced CKD using injections from the ipsilateral CFA. Even though our patients had more complex tibiopedal lesions and therefore we included 2 projections

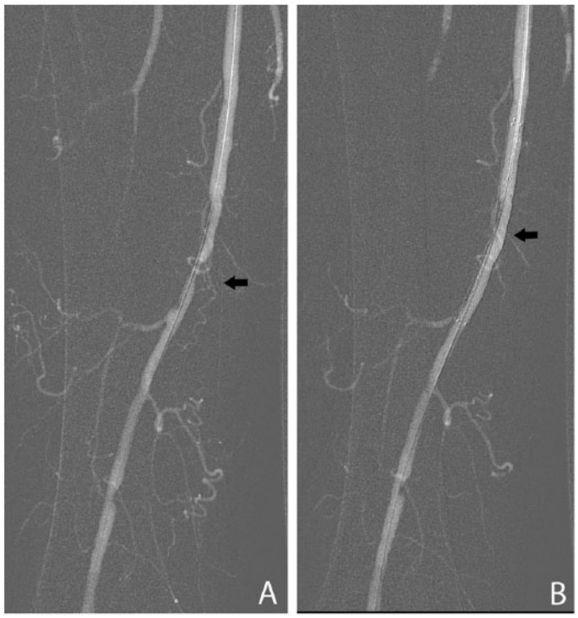

Figure 8. (A) Pre– and (B) post–CO_2-guided revascularization with guidewire in place. (A) Distal superficial femoral artery to P1 segment stenosis (arrow). (B) CO_2 angiogram performed after stent deployment (arrow) with wire in place. The guidewire and stent do not interfere with arterial assessment.

of the inframalleolar arteries, we found a comparable overall diagnostic accuracy of 89.8% for ACDA. While the selective and superselective approach allows the use of smaller CO_2 volumes (240 vs 395 mL), it has been shown that a single dose of up to 1.6 mL/kg results in no changes in cardiopulmonary parameters and can subsequently be repeated at 30- to 60-second intervals (to allow clearance by the lungs) without increased complications.[28]

When CO_2 is injected, it has the potential to fragment into random bubbles depending on how it is delivered. To avoid this, the catheter should be purged prior to injection and continuous, controlled delivery of the volume of choice should be performed. Although trapping is exceedingly rare, it can be exacerbated by the rapid administration of excessive volumes of CO_2, which can be caused by one exceptionally large injection (rare) or by multiple small and repetitive deliveries without allowing enough time between injections (30–60 seconds) for the CO_2 to dissolve. Due to the tendency of CO_2 to reflux (travel cranially), it is prudent to avoid intra-arterial injections above the diaphragm. Similarly, to reduce the possibility of central cerebral reflux, the patient can be placed in the Trendelenburg position. In fact, it is good practice to refrain from arterial delivery of CO_2 if the patient's head is elevated.

In our patient cohort, the incidence of poor diagnostic accuracy with CO_2 angiography was low (17%). The image degradation was secondary to motion artifact introduced as reaction to the pain caused by the injection, resulting in the need to repeat the angiography in the specific arterial segment. In these instances, treatment with intra-arterial lidocaine resulted in complete resolution of the patient's symptoms and lack of further motion during repeat sequences. Our observations suggest that the systolic blood pressure should ideally be kept at or below 140 mm Hg (which would generate a CO_2 injection pressure not higher than 160 mm Hg) in order to decrease the incidence of pain and therefore motion; however, this was not statistically proven.

To the best of our knowledge, no other study has evaluated the safety and efficacy of CO_2 angiography–guided endovascular interventions in a cohort solely comprised of diabetic patients with advanced CLI and CKD. Larger multicenter studies should be conducted to determine the ability to extrapolate our results. However, based on available literature and our experience with this complex subset of critically ill patients with severe comorbidities, it would appear safe to say that ACDA can be utilized to guide complex peripheral interventions, significantly decreasing (if not eliminating) the need to use iodinated contrast in patients with contrast allergies or compromised renal function at baseline.

Limitations

The ability to extrapolate our results has several limitations. First, it is an observational study of consecutive patients with diabetes and CLI who were treated in a high-volume referral center, dedicated to treating this subset of patients. Second, the sample size was small (given the fact that we recruited only those patients who had diabetes, advanced CLI, and at least grade 3 CKD). Third, all CO_2 injections were performed from the ipsilateral antegrade CFA sheath, leading to a larger volume of CO_2 and potential degradation of the inframalleolar images. It is likely that using superselective techniques would help decrease the CO_2 volumes, improve the diagnostic quality and accuracy even further, and result in an even lower percentage of patients that require repeat sequences due to motion artifact caused by pain.

Conclusion

Antegrade arterial access and ACDA performed from the ipsilateral CFA is a safe and efficient technique to guide endovascular interventions such as balloon angioplasty in diabetic CLI patients with advanced CKD. It provides good diagnostic accuracy even in patients with complex anatomy and comorbidities and represents a viable option to significantly reduce (or eliminate) the use of iodinated contrast among patients with baseline renal failure. Combining this strategy with superselective techniques for below-the-knee interventions could potentially lead to even better results. Larger multicenter, randomized studies are needed to generalize these conclusions.

Declaration of Conflicting Interests

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