CO_2 Angiography in Lower Extremity Arterial Disease

Techniques for improving safety and efficacy in the use of carbon dioxide as a contrast agent for evaluation and treatment of lower extremity arterial disease.

BY JASON Q. ALEXANDER, MD

The discovery of nephrogenic systemic fibrosis associated with the use of magnetic resonance imaging contrast agents in patients with renal dysfunction has narrowed the arsenal of studies available to the vascular interventionist. Before the discovery of this entity, magnetic resonance angiography had been a valuable test in patients with risk related to more traditional liquid-based contrast. Liquid-based dyes used for both computed tomographic angiography and traditional catheter-based angiography have improved dramatically over the years. Despite the improvements in these agents, however, contrast nephropathy and dye allergies continue to plague their use, especially in an increasingly high-risk population.

Carbon dioxide (CO_2) is a nontoxic, compressible gas that has been used as a contrast agent since the early 1900s.[1,2] As a contrast agent, CO_2 does not appear to carry the risks of either contrast nephropathy or allergic reaction.[3] Since its implementation in the vascular system by Haskins in the 1970s, the use of CO_2 as a contrast agent has been validated in a number of studies.[4] It has been found to be particularly advantageous in the treatment of renal artery stenosis[5,6] and the endovascular management of infrarenal abdominal aortic aneurysms.[7] Despite these encouraging results, the adoption of CO_2 as a contrast agent in the evaluation and treatment of lower extremity arterial disease has not been as pervasive as one might expect. There seem to be two primary reasons that this may be the case. The use of a gas rather than a liquid contrast agent changes a number of elements in the process of angiography that may be unfamiliar to vascular interventional practitioners. Many practitioners express concern about the adequacy of imaging using CO_2 in the lower extremities, particularly in the distribution of the popliteal artery and below.[8,9] Published results have varied considerably with respect to the validity of imaging this anatomy.[8-10] It is possible that some of the conflicting data can be accounted for by change in technique and advancing imaging technology over time.

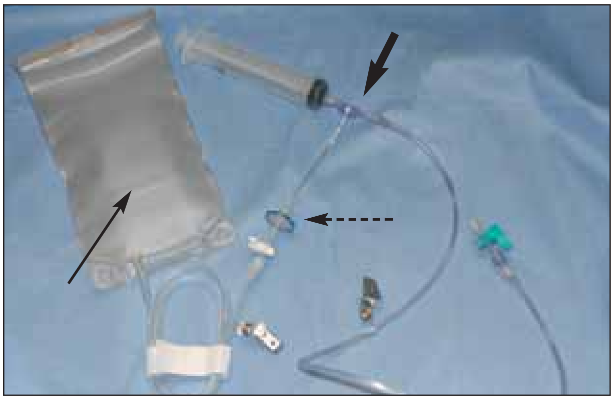

Figure 1. Example setup for CO_2 arteriography. The thin arrow points to a flaccid 1,500-mL bag with CO_2. The dotted arrow points to the 0.2-μm filter, and the thick arrow points to the injection syringe with two one-way valves to prevent inadvertent air contamination.

This article demonstrates the process for the safe administration of CO_2 as a contrast agent in the extremities. Because of the unique properties of CO_2, each step from preparation to postprocessing requires some alterations from those employed for traditional liquid contrast agents. Discussing these steps will allow us to outline the advantages and disadvantages of CO_2 as a contrast agent. Ultimately, we hope to demonstrate that CO_2 can be employed safely and easily. In addition,

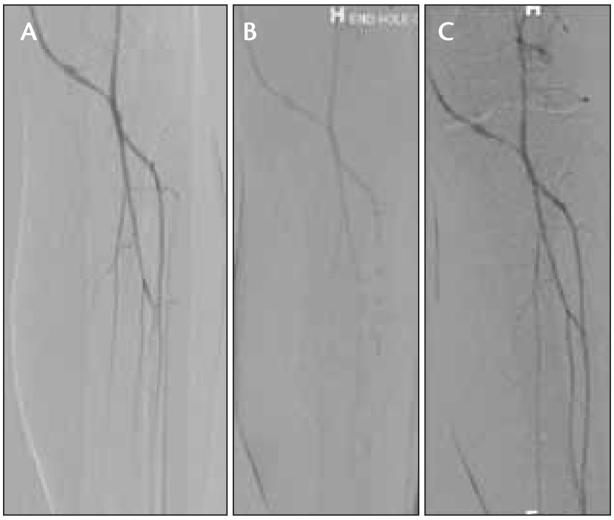

Figure 2. Injection of traditional liquid contrast dye demonstrating tibial artery runoff distal to bypass (A). Injection of CO_2 at the same level through endhole catheter (B). Improved imaging of tibial vessels with CO_2 injected through sheath (C).

the imaging in the lower extremity, even below the knee, can be quite good, limiting the need for the use of liquid-based contrast in high-risk patient populations.

PREPARATION

Angiography employing CO_2 takes advantage of many of the properties of a gas. CO_2 injected into the arterial supply displaces the blood. Imaging identifies the density difference between the gas in the blood stream and the surrounding soft tissues. More unique to CO_2 is considerable solubility that allows it to be rapidly dissolved in the blood. Furthermore, the gas benefits from its rapid first-pass clearance through the lungs. These properties limit the possibility of the dreaded complication of gas embolism. Unfortunately, other gases can quickly contaminate CO_2 if the system employed for administration is not managed stringently. Accidental contamination with air or nitrous oxide (distributed in the soft tissues during general anesthesia) can lead to poor gas clearance and the potential for end-organ ischemia.[3]

A number of different systems have been put in place to prevent contamination. CO_2 may be obtained in either individual canisters checked for purity or in more traditional cast iron receptacles. Individual canisters benefit from their tested accuracy. Traditional tanks can be used, but it is important to make sure that the system drawing off the gas is attached to a filter that will prevent contamination of particles. The filter should prevent particles of 0.2 µm or smaller from entering the system. This does not affect gas contamination but for traditional tanks prevents stagnant, solid particles such as rust from inadvertently being injected. Whichever CO_2 source is used should then be attached to a closed system on the angiography table. Most systems take advantage of a sterile bag that will limit the maximum amount of gas that is withdrawn from the tank. This bag should be purged multiple times before the final filling to prevent air contamination. The bag is then attached to a system that includes a series of one-way valves (Figure 1). This allows the proceduralist to draw up and inject CO_2 without fear of inadvertent air contamination.

Attachment to the catheter or sheath is by standard

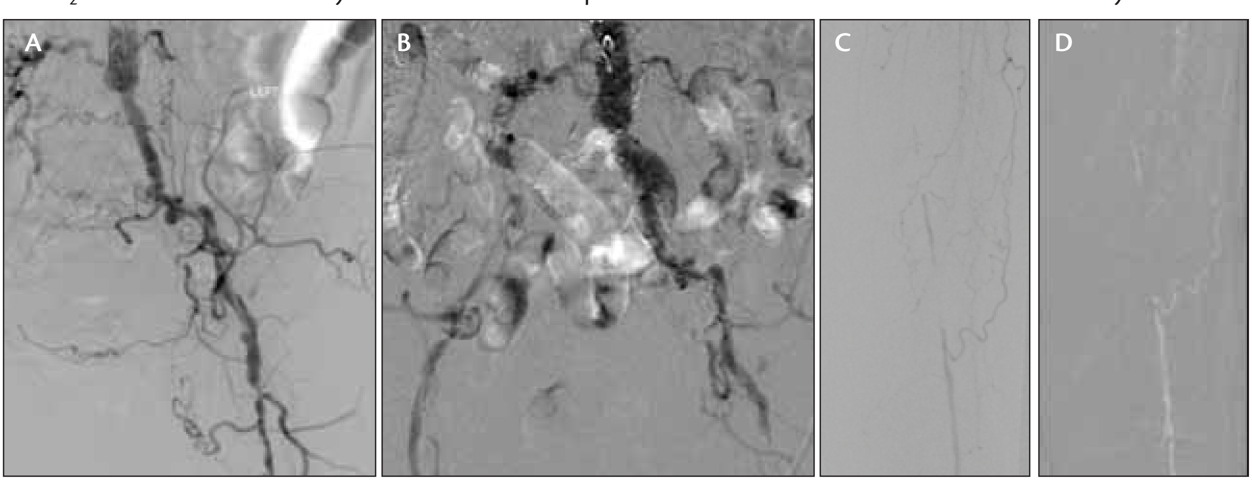

Figure 3. Liquid contrast aortogram demonstrating right common iliac artery occlusion (A). CO_2 angiogram demonstrates common iliac occlusion as well as reconstitution of the right femoral arterial system (B). Liquid contrast angiogram demonstrating occlusion at the adductor canal (C). CO_2 comparison with similar filling of large collateral demonstrating reconstitution of popliteal artery (D).

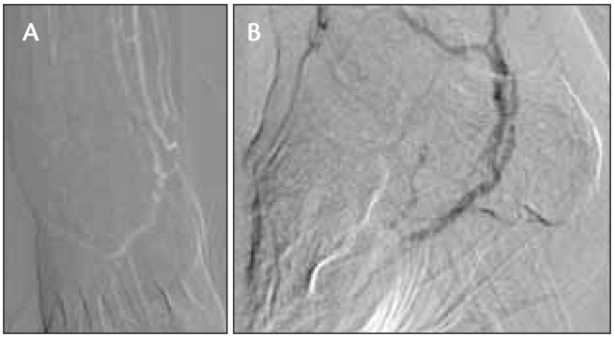

Figure 4. Anteroposterior view of the foot using CO_2 shows filling of the pedal arch from the posterior tibial artery (A). Lateral foot view shows filling of the posterior tibial artery from collaterals off of the peroneal artery in a patient with more proximal posterior tibial artery occlusion (B).

protocol of back-bleeding. Generally, we will purge the system with CO_2 multiple times before injection to clear the system as a final safety check. In my experience, flushing of the system, including the catheter or sheath, is best performed with CO_2 rather than liquid. Filling the catheter with saline will not only decrease the filling of the vessels but also seems to lead to greater patient discomfort when combined with CO_2. Directly filling syringes from the CO_2 tank or canister should be avoided. Because CO_2 is compressible, attempts to directly fill a syringe can inadvertently compress the gas, leading to a much greater quantity being withdrawn than intended. When injected, this compressed CO_2 can cause significant barotrauma due to explosive delivery. This pitfall is avoided by instead filling a sterile bag as previously mentioned. It is important, however, to avoid overfilling the bag, or the same problem can arise.

A further advantage of a closed system attached to a filled bag is the ability to quickly refill the syringe and perform multiple runs. In fact, in certain situations, CO_2 may be a faster agent to use than traditional liquid agents. Because large boluses of CO_2 can be given and reloaded by hand, it obviates the need to reset a power injector. This may come in handy, for example, in the case of ruptured abdominal aortic aneurysms when multiple rapid views of the aorta may become necessary. Furthermore, because there is no known maximum dose of CO_2, multiple images may be taken without concern about contrast load. This can be particularly useful in patients who are prone to movement during angiography. It also allows additional safety checks before interventions in patients that a proceduralist might otherwise fail to perform if limited by contrast load.

Figure 5. CO_2 imaging of a bypass graft. Angiogram shows stenosis at the proximal anastomosis as well as valve (arrow). Both areas demonstrated velocity increase on ultrasound evaluation.

INJECTION

CO_2 is usually injected through a large syringe. I tend to use a 60-mL syringe for all injections, although a full syringe is usually only needed for runs in the abdomen. CO_2 can cause discomfort when injected, and it is often beneficial to make sure that the patient is adequately medicated before injection. When evaluating the aorta, we will administer a dose of ondansetron at the beginning of the case due to the fairly frequent occurrence of nausea. In the lower extremities, injection can sometimes give the patient a somewhat shocking feeling that may prompt movement and cause imaging degradation. Several tips to prevent this include stabilizing the limb or restraining if necessary. Often, the best advice, however, is to inject at a slower rate and to allow a period of time (2–3 minutes) for CO_2 clearance between injections. Of course, fair warning to the patient about injection also cannot be understated. Finally, in extreme cases in which a patient is likely to have difficulties remaining still during the case, general anesthesia may be an option. Once again, nitrous oxide should probably be avoided as an anesthetic agent in these cases.

Multiple studies have suggested that imaging with CO_2 is limited with respect to accuracy at the popliteal artery and below. Of course, using CO_2 in the aortoiliac and femoral segments can dramatically decrease patients' exposure to liquid dye. There are, however, a number of techniques that can be employed to improve imaging below the superficial femoral artery. To begin with, it is beneficial to place the tip of your catheter or sheath as close to the imaged segment as possible. Although this may seem fairly obvious, it can sometimes mean advancing catheters or sheaths further than when using traditional contrast agents. We have also found it beneficial to use either multi-sidehole catheters or, ideally, sheaths for injection. This allows a great load of CO_2 to be quickly dispersed. Although endhole catheters often provide ade-

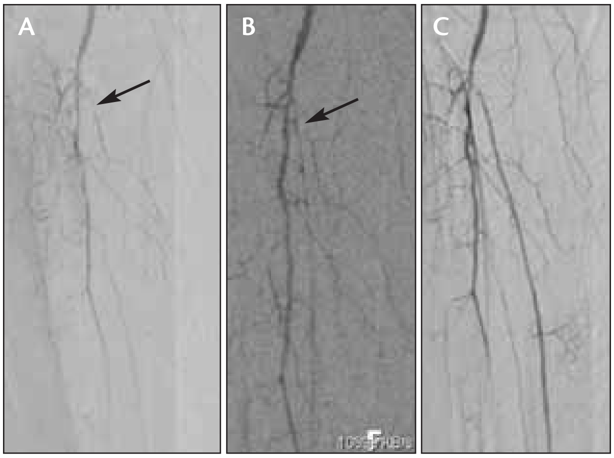

Figure 6. Liquid contrast angiogram demonstrating posterior tibial occlusion (arrow) (A). CO_2 angiogram at the same level (B). Completion angiogram following recanalization of the posterior tibial artery (C).

quate images, multi-sidehole or sheath images may be superior, usually only necessitating the time for an extra over-the-wire exchange (Figure 2). It should be pointed out, though, that the use of multi-sidehole catheters can lead to break up of the CO_2 gas during imaging. This will give the appearance of a series of CO_2 bubbles marching down the arterial anatomy. These images can still be valuable but necessitate diligent postprocessing. The best images, particularly below the knee, are obtained when a sheath can be advanced to this level. Sheath injection allows a large amount of gas to be injected and tends not to cause similar CO_2 break-up seen with multi-sidehole catheters. This does require a willingness to take the extra time to advance long sheaths as close as possible to the point of anatomic interest.

Because CO_2 is a gas, it rises in a liquid environment. To maximize contrast movement into the lower extremities, it is extremely helpful to place the patient in the Trendelenburg position. The more extreme the position, the better the imaging will be. This is particularly critical when imaging below the knee or when trying to image beyond an area of occlusion. Areas of stenoses tend not to be problematic with CO_2 because the gas is less viscous than liquid agents and will traverse areas of narrowing more easily (Figure 3).

Finally, to maximally opacify the tibial vessels, it is often beneficial to inject an intra-arterial vasodilator before CO_2 injection. Before imaging the tibial arteries, I will usually inject 150 to 200 µg of nitroglycerin. Employing these techniques, images can be obtained to the level of the pedal vessels (Figure 4). In some instances, particularly detailed anatomic features may be appreciated. Figure 5 shows a patient noted to have a mid graft velocity shift by ultrasound at the sight of a valve.

Regarding the use of CO_2 for lower extremity interventions, Haskins recommends using a specialized O-ring that allows for injection around a wire.[3] Although we have not employed this device at our institution, the potential benefit is clear. We have not appreciated any problems with air contamination when injecting through a side port of a sheath with a wire in place. Due to similar concerns about air contamination, however, we will exchange out stiff wires for softer wires before injection because of concerns that the stiffer wire will break the airtight seal in the sheath. Ultimately, even complex tibial intervention can be performed using CO_2 imaging (Figure 6).

IMAGING

Because of the quick passage of the CO_2 through the blood stream, increased frame rates are generally required to acquire pictures (7.5 frames/s is a typical setting for most systems). This leads to increased radiation dose to the patient. Furthermore, when hand injection setups are used, the proceduralist may be exposed to greater doses of radiation. This can be prevented by extending the setup away from the radiation source during injection, careful shielding, or the use of automated injectors. In fact, at our institution, the two vascular proceduralists who used CO_2 the most frequently over the last year have also had the least radiation exposure.

The same properties that allow CO_2 to be visualized can also detract from imaging when evaluating the aorta and iliac system. As previously mentioned, imaging of CO_2 depends on the density difference between the gas and surrounding soft tissues. Bowel gas will sometimes demonstrate the same density as the CO_2 and obscure pictures in the abdomen. This problem can, however, often be overcome easily by rotating the radiation source. Because CO_2 does not appear to have a maximum dose limit, the proceduralist can take multiple views without worrying about an increasing contrast load, although the patient will potentially receive a higher dosage of radiation exposure.

POSTPROCESSING

Most current angiography rooms are now set up with a CO_2 package. Elements that are critical to this package include the ability to invert color on the images and stack images. CO_2 will show up as a white agent in most imaging systems. Imaging is often adequate with this set-up. However, certain situations do arise in which inverting the color of the image provides greater clarity of the true anatomy. Bowel gas and dense plaque may obscure imaging in either a black or white color scheme. In these instances, we will view the imaging in both colors, toggling between both to obtain the best information.

Because of the transit time, CO_2 will sometimes fail to opacify the entire field during a run. Instead, the gas will march down the anatomy. This is possible even when no lesion exists. It is important to be able to stack these images to obtain a final picture that delineates the true anatomy. This is dependent on someone who feels comfortable with postprocessing software for CO_2 imaging. Stacking of images may need to be performed during the procedure to identify lesions. It is otherwise frustrating to presume normal transit of CO_2 during imaging only to discover after the procedure during postprocessing that a stenosis was present.

SUMMARY

CO_2 is a valuable alternative to traditional contrast agents for evaluating lower extremity arterial disease. This is particularly true in the patient population with renal insufficiency or known contrast allergy. To maximally optimize imaging, the proceduralist must take advantage of the special properties of CO_2. This requires alterations in angiographic techniques from contrast preparation to postprocessing. Fortunately, most of the techniques for the safe administration of CO_2 are easily learned and applied. By employing some of the strategies previously mentioned, excellent imaging of the lower extremities can be obtained.

Traditional liquid contrast agents remain the gold standard for evaluation of the lower extremities. At the present time, liquid contrast agents still demonstrate superior imaging compared to CO_2, particularly in smaller vessels below the knee. Employing CO_2 angiography, however, can allow more sparing use of liquid contrast in the azotemic patient. Furthermore, in the right circumstances, CO_2 can provide excellent imaging even at the level of the tibial and pedal vessels as well as during extensive lower extremity arterial intervention. As technology advances, this imaging will likely continue to improve making CO_2 arteriography a valuable tool in the armamentarium of the vascular interventionist when evaluating the lower extremities. ■

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