A Novel Bubble-Mixture Method to Improve Dynamic Images in Carbon Dioxide Angiography

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Abstract

**Purpose:** To present a novel method of preparing carbon dioxide (CO₂) for contrast enhancement. **Technique:** CO₂ angiography can often produce poor image enhancement, especially in dependent vessels due to buoyancy of the gas. A new technique for premixing the CO₂ gas with the patient’s blood and dispersing it into the bubble mixture before injection was developed. Comparative dynamic images showed bubble-mixed CO₂ angiography had less fragmentation, more even distribution, and more sustainability than the same volume of pure CO₂. **Conclusion:** The alteration of CO₂ gas toward a semiliquid form demonstrates an easy and reproducible concept to improve the dynamic image quality of traditional CO₂ angiography.

Keywords

carbon dioxide, catheterization, peripheral angiography, digital subtraction angiography, endovascular techniques, renal insufficiency

Introduction

Carbon dioxide (CO₂) angiography has shown its benefit in treating patients with chronic kidney disease (CKD) and iodine allergy because of its lack of nephrotoxicity and allergic reactions.¹ CO₂’s buoyancy and solubility cause it to fill nondependent parts of vessels and displace blood volume rather than mixing with the blood. If the target vessels are located in dependent areas, such as the lower limb, it can be difficult to produce a good image unless selective injection and elevated posture are used.¹² If the buoyancy of CO₂ overcomes the kinetic force of blood flow, a transient vapor-lock phenomenon may result, producing fragmented CO₂ images especially in distal and low-flow arteries.³ To solve those problems, we have developed a bubble-creating CO₂ technique by premixing the CO₂ gas with the patient’s blood before injection. The serum proteins act as natural foaming agents and create a fine bubble mixture. This alteration of CO₂’s properties toward a foam-like biological CO₂ contrast agent produces a CO₂ digital subtraction angiogram (DSA) that is more evenly distributed without fragmentation, resembling a traditional iodine-contrast angiogram.

Technique and Design of the Bubble System

A handmade CO₂ delivery system was assembled using a pure medical grade CO₂ source, gas filter, CO₂ reservoir with an empty blood bag, three 3-way stopcocks, and two 20-mL syringes (Figure 1A). The whole system was kept in closed circuit at all times, and a water-sealed deairing procedure was done at initial use to avoid any chance of air contamination. After connecting the system to a patient’s arterial sheath for angiography, the bubble-creating procedure was carried out by (1) withdrawing the CO₂ in one
syringe, (2) withdrawing the patient’s blood from the angiocatheter in the other syringe, and (3) mixing the CO₂ and blood between the 2 syringes by a dozen strokes of counterpiston motion, after which the bubble mixture of CO₂ and blood is ready for injection (Figure 1B). The volume of syringes and the ratio of blood and CO₂ can be altered according to the particular field of interest. We preferentially used 10 mL of CO₂ and 10 mL of blood for lower extremity angiography. Heparin should be given routinely prior to this procedure to prevent blood clotting.

All procedures were performed in a hybrid suite equipped with the Artis Zeego (Siemens Healthcare Sector, Forchheim, Germany). The technique is demonstrated in an 80-year-old man with chronic renal insufficiency (CKD stage IV), iodine contrast allergy, and a left superficial femoral artery (SFA) lesion undergoing CO₂ angiography prior to percutaneous transluminal angioplasty. The same amount of 20-mL pure CO₂ and 20-mL bubble-mixed CO₂ as contrast agents were delivered for comparison. During diagnostic angiography, the pure CO₂ subtracted images showed fragmented enhancement of the distal SFA (Figure 2A). After the catheter was placed more distally, the bubble-mixture technique was initiated, producing a smooth progression of CO₂ and good visualization of the three distal tibial arteries (Figure 2B). In another 70-year-old patient at CKD stage IV, an additional iodinated contrast image was added for reference (Figure 3). The bubble-mixture CO₂ angiogram (Figure 3A) showed better visualization of the posterior tibial artery compared with the pure CO₂ image in the below-knee trifurcation angiogram. A comparison series from the SFA after balloon angioplasty also showed much less “fragmentation” in the bubble-mixed CO₂ angiogram than the traditional pure CO₂ image (Figure 3B).

Figure 1. (A) Design of a handmade bubble-mixture CO₂ delivery system. (B) Procedures of bubble-mixture technique.

Figure 2. Digital subtraction angiography images. (A) Pure CO₂ in the proximal left superficial femoral artery (SFA) showed fragmented enhancement due to stenosis. (B) Bubble-mixture CO₂ in the distal left SFA showed good visualization of 3 tibial arteries.

Unlike pure CO₂, the bubble-mixture CO₂ was distributed more evenly and was sustained in the exact time frame comparison image (Figure 4). The bubble-mixture CO₂ image had lower enhancement contrast because it contained only 10 mL of CO₂ instead of the 20 mL in the pure CO₂ image. Subjectively, the smooth progression and even distribution of bubble-mixed CO₂ without bolus fragmentation were much like a traditional contrast angiogram.
Discussion

The role of CO₂ angiography in the clinical field has expanded and is now used in cases involving abdominal aortic aneurysm because it is cheap, nonallergenic, and not nephrotoxic. It is a versatile technique and a safe procedure if managed in a trained facility. Prospective reports of CO₂ angiography in lower limbs compared with iodine-based contrast showed inferior image quality, especially below the popliteal level because of the vapor-lock phenomenon in the small tibial arteries. The foaming produced by the bubble-mixture CO₂ method reduces this event and, in our preliminary study, showed benefits over pure CO₂ in terms of image quality in lower extremity angiography. However, this technique still needs to be explored in other areas, such as aortic angiography.

The use of pure CO₂ can cause serious adverse events, such as massive bowel infarction, but this is rare. Although as yet unproven, the blood-mixed CO₂ could be safer than pure CO₂ because it could decrease the amount of CO₂ used and the incidence of transient gas embolic events caused by the vapor-lock phenomenon. On the other hand, air contamination may come from any unlocked connector in our system, so it is important to maintain a closed system during manipulation. We suggest deairing the system in a water basin at all times.

The mixture of CO₂ and blood did produce less contrast in images compared with the same volume of pure CO₂ because the negative density difference of CO₂ was the key component during DSA image acquisition. If image contrast is too low for interpretation, the proportion of CO₂ to blood can be increased. In our experience, a 1:1

Figure 3. Comparison images of iodinated contrast, pure CO₂, and bubble-mixture CO₂. (A) Below-knee trifurcation angiography showed better visualization of the posterior tibial artery (white arrow) in bubble-mixture image than pure CO₂ image. (B) Femoral catheter CO₂ injection showed fragmented appearance of pure CO₂ image.

Figure 4. Exact time frame comparison of digital subtraction angiography. (A) The 20-mL pure CO₂ angiogram demonstrated bursting dynamic images that faded away quickly. (B) The 20-mL bubble-mixture CO₂ showed even distribution and more sustained dynamic images.
blood to CO₂ ratio produced an optimal bubble foam mixture, but the ratio can be adjusted according to the images obtained.

According to Hawkins et al., up to 95% of pure CO₂ is delivered in the last 0.5 seconds during a 4-second CO₂ injection because of its compressed character. With hand injection, it is hard to control the injection pressure. Once the syringe pressure meets resistance, the CO₂ can be delivered explosively, subsequently causing massive air embolism. In our experience, this explosive delivery did not happen with the semiliquid modification. Currently, bubble-mixture CO₂ angiography has many limitations; notably, it can be created for only hand injection instead of power injector. Owing to our small patient experience, further studies should be carried out to determine safety and validity.

**Conclusion**

In patients with poor pure CO₂ angiography image quality and noncandidates for traditional iodine contrast, this inexpensive and easy bubble-mixture modification could serve as an alternative option in CO₂ angiography.

**Declaration of Conflicting Interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Funding**

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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