Technical Note

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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 (CO_2) for contrast enhancement.**Technique:** CO_2 angiography can often produce poor image enhancement, especially in dependent vessels due to buoyancy of the gas. A new technique for premixing the CO_2 gas with the patient's blood and dispersing it into the bubble mixture before injection was developed. Comparative dynamic images showed bubble-mixed CO_2 angiography had less fragmentation, more even distribution, and more sustainability than the same volume of pure CO_2. **Conclusion:** The alteration of CO_2 gas toward a semiliquid form demonstrates an easy and reproducible concept to improve the dynamic image quality of traditional CO_2 angiography.

Keywords

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

Introduction

Carbon dioxide (CO_2) 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] CO_2'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.[1,2] If the buoyancy of CO_2 overcomes the kinetic force of blood flow, a transient vapor-lock phenomenon may result, producing fragmented CO_2 images especially in distal and low-flow arteries.[3] To solve those problems, we have developed a bubble-creating CO_2 technique by premixing the CO_2 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 CO_2's properties toward a foam-like biological CO_2 contrast agent produces a CO_2 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 CO_2 delivery system was assembled using a pure medical grade CO_2 source, gas filter, CO_2 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 is carried out by (1) withdrawing the CO_2 in one

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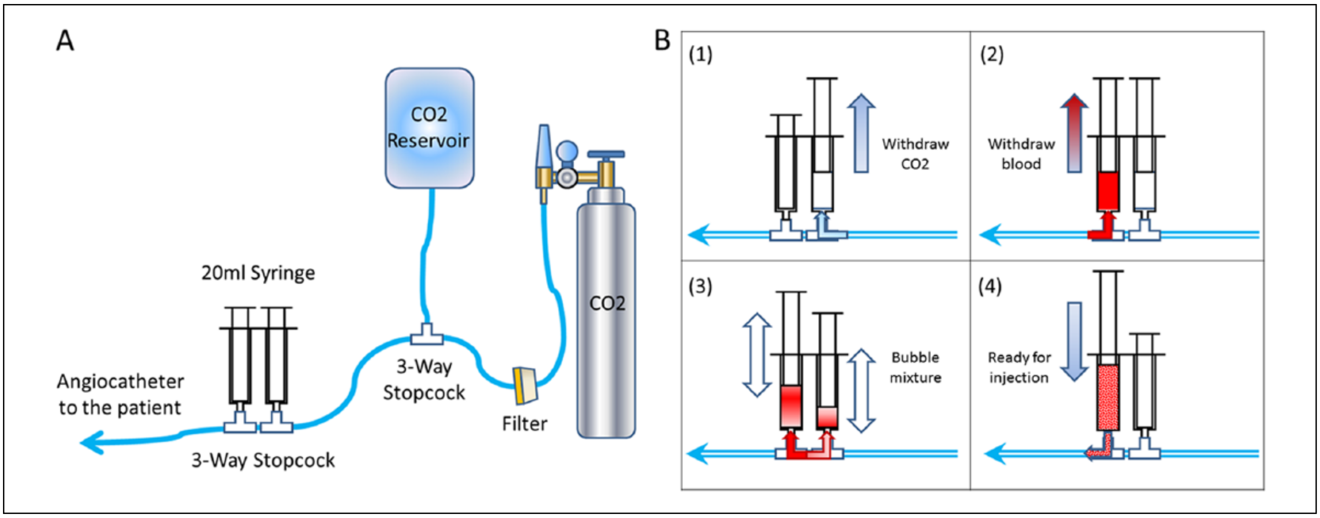

Figure 1. (A) Design of a handmade bubble-mixture CO_2 delivery system. (B) Procedures of bubble-mixture technique.

syringe, (2) withdrawing the patient's blood from the angiocatheter in the other syringe, and (3) mixing the CO_2 and blood between the 2 syringes by a dozen strokes of counterpiston motion, after which the bubble mixture of CO_2 and blood is ready for injection (Figure 1B). The volume of syringes and the ratio of blood and CO_2 can be altered according to the particular field of interest. We preferentially used 10 mL of CO_2 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 CO_2 angiography prior to percutaneous transluminal angioplasty. The same amount of 20-mL pure CO_2 and 20-mL bubble-mixed CO_2 as contrast agents were delivered for comparison. During diagnostic angiography, the pure CO_2 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 CO_2 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 CO_2 angiogram (Figure 3A) showed better visualization of the posterior tibial artery compared with the pure CO_2 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 CO_2 angiogram than the traditional pure CO_2 image (Figure 3B).

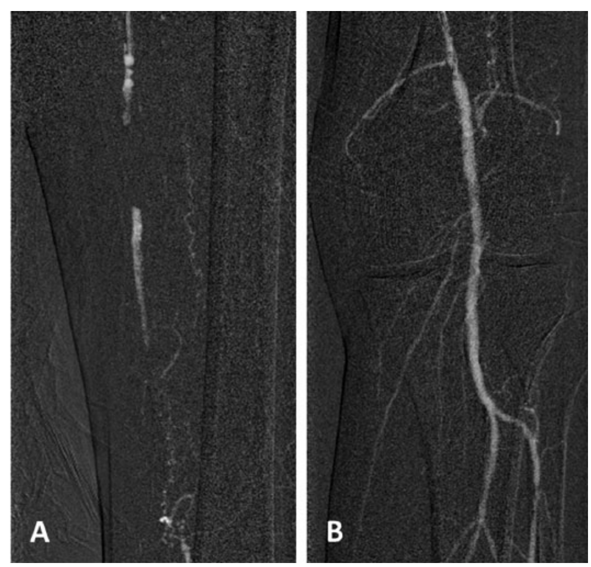

Figure 2. Digital subtraction angiography images. (A) Pure CO_2 in the proximal left superficial femoral artery (SFA) showed fragmented enhancement due to stenosis. (B) Bubble-mixture CO_2 in the distal left SFA showed good visualization of 3 tibial arteries.

Unlike pure CO_2, the bubble-mixture CO_2 was distributed more evenly and was sustained in the exact time frame comparison image (Figure 4). The bubble-mixture CO_2 image had lower enhancement contrast because it contained only 10 mL of CO_2 instead of the 20 mL in the pure CO_2 image. Subjectively, the smooth progression and even distribution of bubble-mixed CO_2 without bolus fragmentation were much like a traditional contrast angiogram.

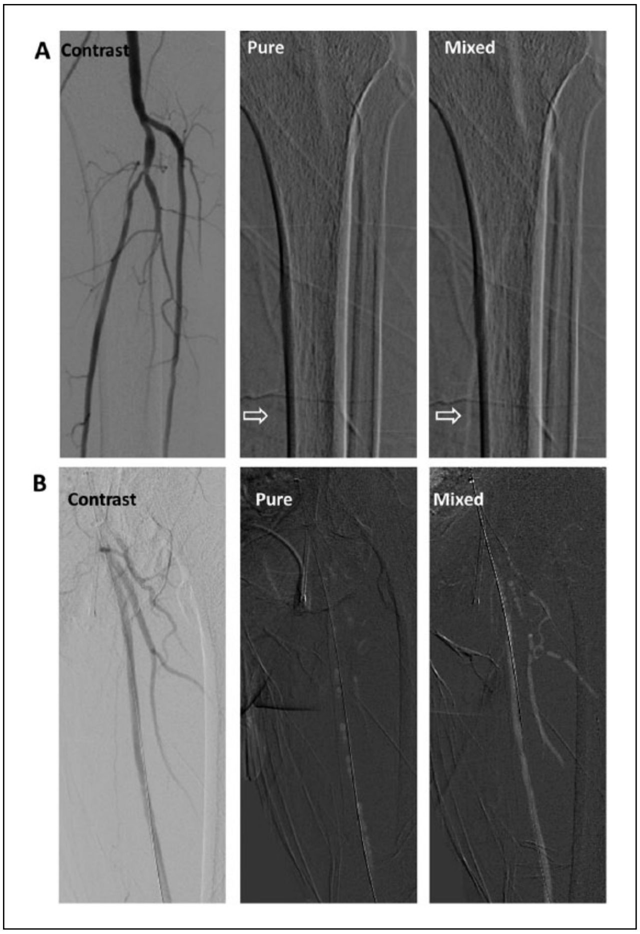

Figure 3. Comparison images of iodinated contrast, pure CO_2, and bubble-mixture CO_2. (A) Below-knee trifurcation angiography showed better visualization of the posterior tibial artery (white arrow) in bubble-mixture image than pure CO_2 image. (B) Femoral catheter CO_2 injection showed fragmented appearance of pure CO_2 image.

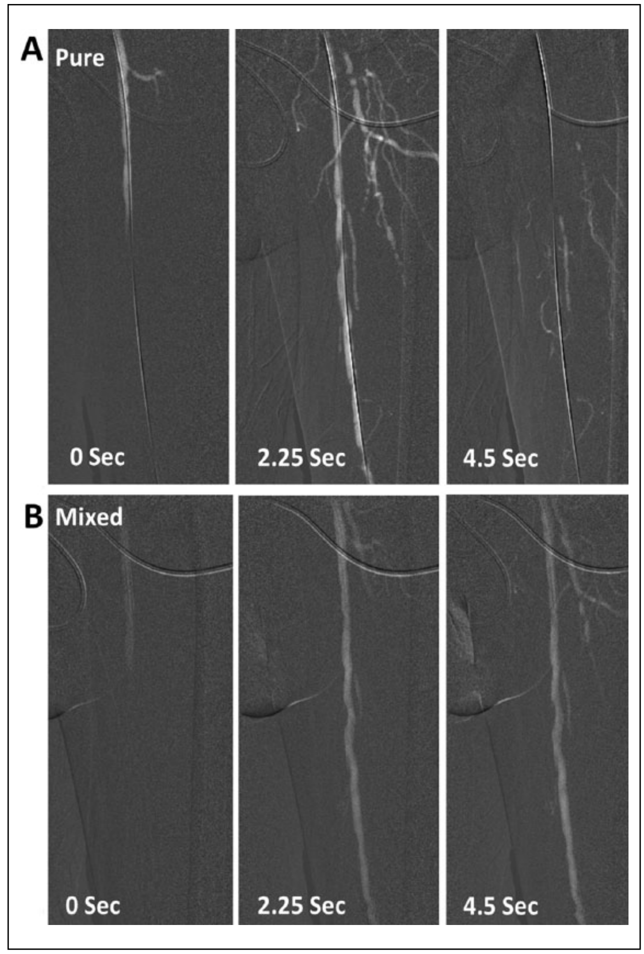

Figure 4. Exact time frame comparison of digital subtraction angiography. (A) The 20-mL pure CO_2 angiogram demonstrated bursting dynamic images that faded away quickly. (B) The 20-mL bubble-mixture CO_2 showed even distribution and more sustained dynamic images.

Discussion

The role of CO_2 angiography in the clinical field has expanded and is now used in cases involving abdominal aortic aneurysm[4–6] because it is cheap, nonallergenic, and not nephrotoxic. It is a versatile technique and a safe procedure if managed in a trained facility.[7] Prospective reports of CO_2 angiography in lower limbs compared with iodine-based contrast showed inferior image quality, especially below the popliteal level[8,9] because of the vapor-lock phenomenon in the small tibial arteries. The foaming produced by the bubble-mixture CO_2 method reduces this event and, in our preliminary study, showed benefits over pure CO_2 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 CO_2 can cause serious adverse events, such as massive bowel infarction,[10] but this is rare. Although as yet unproven, the blood-mixed CO_2 could be safer than pure CO_2 because it could decrease the amount of CO_2 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 CO_2 and blood did produce less contrast in images compared with the same volume of pure CO_2 because the negative density difference of CO_2 was the key component during DSA image acquisition. If image contrast is too low for interpretation, the proportion of CO_2 to blood can be increased. In our experience, a 1:1

blood to CO_2 ratio produced an optimal bubble foam mixture, but the ratio can be adjusted according to the images obtained.

According to Hawkins et al,[1] up to 95% of pure CO_2 is delivered in the last 0.5 seconds during a 4-second CO_2 injection because of its compressed character. With hand injection, it is hard to control the injection pressure. Once the syringe pressure meets resistance, the CO_2 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 CO_2 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 CO_2 angiography image quality and noncandidates for traditional iodine contrast, this inexpensive and easy bubble-mixture modification could serve as an alternative option in CO_2 angiography.

Declaration of Conflicting Interests

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