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Can CO_2 Be a Savior for Endovascular Aneurysm Repair Candidates with Renal Dysfunction? Critical Tips for Safe CO_2 Angiography

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Abdominal aortography is performed to guide endovascular aneurysm repair (EVAR), but the use of iodinated contrast medium (ICM) may cause contrast-induced nephropathy (CIN), particularly in patients with preexisting kidney dysfunction [1]. Progressive decline in kidney function following EVAR increases morbidity, mortality, length of hospitalization, and cost [2-5]. The only absolute prevention of CIN is to avoid the use of ICM. CO_2 has been used as an alternative to ICM for EVAR procedures and other endovascular interventions [6-8]. CO_2 digital subtraction angiography (CO_2 DSA) can provide much of the necessary vascular information that can be derived from catheter angiography with ICM.

I read with great interest the article by Cuen-Ojeda et al. [9] entitled “Percutaneous Endovascular Aortic Aneurysm Repair with INCRAFT Endograft Guided by CO_2 Digital Subtraction Angiography in Patients with Renal Insufficiency” published in the March 2020 issue of *Vascular Specialist International*. That article reported for the first time the use of CO_2 DSA to guide percutaneous EVAR (PEVAR) with the INCRAFT™ AAA Stent Graft System (Cordis, Bridgewater, NJ, USA) in three patients with renal insufficiency. In the study, the authors found no evidence of deterioration of kidney function at a 6-month follow-up following CO_2-guided PEVAR. This is a timely article, as CO_2-EVAR is increasingly being performed for the prevention of CIN in patients with renal insufficiency.

The authors provided a brief description of the technique and equipment used for CO_2 DSA during PEVAR but did not describe the safe use of CO_2 and the imaging techniques that are essential for obtaining a successful angiogram. In the section “Techniques for CO_2 DSA and PEVAR”, there are four important points that need the reader’s attention. First, it is not clear how the use of the “UHI-4 high flow insufflation unit (Olympus, Tokyo, Japan)” prevented air contamination and explosive gas delivery. In this study, a 60-mL syringe was used for injection of 40 mL of CO_2 over 2.5 seconds. When a hand-held syringe method is used, the proper technique of CO_2 delivery should be used to prevent air contamination and explosive delivery. A stopcock should be placed on the tip of a Luer-Lock syringe. If a CO_2-filled syringe is inadvertently left open on the procedure table for some time before injection, the CO_2-filled syringe becomes contaminated with less soluble air. Once the syringe has been filled with CO_2 from the CO_2 cylinder at very high pressure, the stopcock of the syringe is quickly opened and then closed to reduce the pressure in the syringe before connecting it to the catheter. Two other CO_2 delivery systems used in the United States are the plastic bag system (Custom Waste Bag Kit; Merit Medical, South Jordan, UT, USA) (Fig. 1) and CO_2MMANDER System with AngiAssist (AngioAdvancements, LLC, Fort Myers, FL, USA) (Fig. 2). The correct use of the bag system can prevent air contamination and the delivery of excessive volumes. The CO_2MMANDER system with AngiAssist is an FDA-approved CO_2 delivery system allowing safe delivery of CO_2 in a nonexplosive fashion. Second, I note that a 5-Fr pigtail catheter was used for CO_2 delivery. The end-hole catheter, even a microcatheter, can be used for CO_2 delivery for abdominal aortic DSA and for selective and superselective DSA. It can not only produce a continu-

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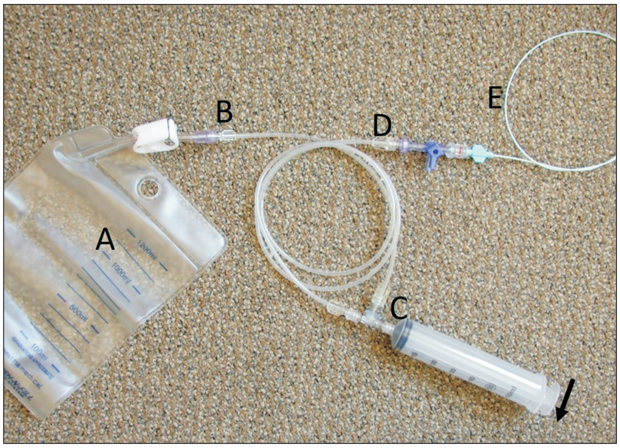

Fig. 1. Plastic bag delivery system for CO_2 digital subtraction angiography (DSA). The 1,000 mL bag (A) should be filled with CO_2 and emptied three times to remove residual air. The CO_2-filled bag is connected to the 100-cm long delivery system (B) with two one-way check vales (C), a distal one-way check valve (D), and a distal three-way stopcock connecting to the catheter (E). A 30-mL or 60-mL syringe with Luer-Lock tip is connected to the T-fitting with the two check valves (C). After checking for a gas leak by pulling the syringe plunger back, the tube from the bag is unclamped for aspiration and injection of CO_2. The distal three-way stopcock allows for purging of the delivery system with CO_2 and injection of heparinized saline or iodinated contrast medium into the catheter. If used correctly, this system is safe and easy to use for CO_2 DSA.

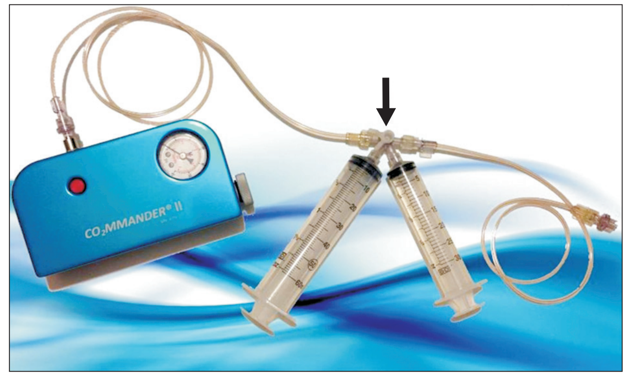

Fig. 2. CO_2MMANDER ELITE and AngiAssist (AngioAdvancements; LLC, Fort Myers, FL, USA). This FDA-approved portable CO_2 delivery system containing a medical grade CO_2 cylinder (10,000 mL CO_2) allows gas delivery at low pressures through the AngiAssist. The K-valves (arrow) of the AngiAssist control the direction of gas flow from the CO_2MMANDER to the 60-mL reservoir syringe and then to the 30-mL injection syringe. This system eliminates air contamination of CO_2 being injected and explosive CO_2 delivery.

ous gas column at the injection site but also allows selective catheterization of the aortic branches. Third, the authors described that “a 10°-15° left anterior oblique projection was obtained to localize the origin of the renal arteries” but do not explain why the projection angles were necessary nor state whether the C-arm was angled or the left side of the patient was elevated. As the right renal artery tends to be more anterior than the left renal artery at their origins of the aorta, CO_2 abdominal aortography is performed in the supine position to visualize the right renal artery. If the left renal artery is not seen due to its posterolateral origin in the supine position, elevating the left side usually fills the left renal artery with CO_2. Fourth, it is not clear whether CO_2 injections were separated by 2-3 minutes to allow complete absorption of the gas before a subsequent injection. When a large CO_2 bubble is trapped in an AAA, the gas bubble is absorbed much slower because of its smaller surface area, resulting in replacement of the CO_2 bubble with less soluble nitrogen and oxygen. Subsequent occlusion of the inferior mesenteric artery originating from the AAA with the nitrogen and oxygen bubbles can cause colonic ischemia due to its poor solubility.

Several additional points are critical for obtaining a safe CO_2 angiogram. First, only medical-grade CO_2 should be used. Second, CO_2 tanks should not be connected directly to the catheter placed in the patient. Third, CO_2 should not be delivered at high pressures to avoid explosive delivery. Fourth, CO_2 should not be injected in the arterial circulation above the diaphragm.

The purpose of CO_2 DSA during EVAR is to localize the renal arteries, aortic bifurcation, and iliac arteries before and to perform a completion angiogram after EVAR. Regardless of which AAA endograft is used, the technique for CO_2 DSA is similar: CO_2 can be delivered through the introducer preloaded with a stent graft (Fig. 3) [10]. After purging the main body graft with 20 mL of CO_2 before insertion into the femoral artery, it is then advanced to the level of the first lumbar body, and CO_2 is injected through the side port of the sheath to visualize the renal artery. CO_2 is injected through the side port of the femoral introducer to visualize the aortic bifurcation and iliac arteries in the ipsilateral posterior oblique projection. Completion DSA (Fig. 4) is performed with the injection of CO_2 through a 4-Fr endhole catheter at the level of the renal artery and bifurcation of the stent graft. A 4-Fr or 5-Fr Cobra catheter can also be introduced from the contralateral femoral artery for CO_2 delivery at the level of the first lumbar spine to visualize the renal artery (Fig. 5) [4].

In the discussion, the authors gave a brief comment on the flow dynamics and radiopacity of CO_2, stating that “CO_2 gas displaces blood within the blood vessels, thus serving as negative contrast agent”. I think a further discussion on this

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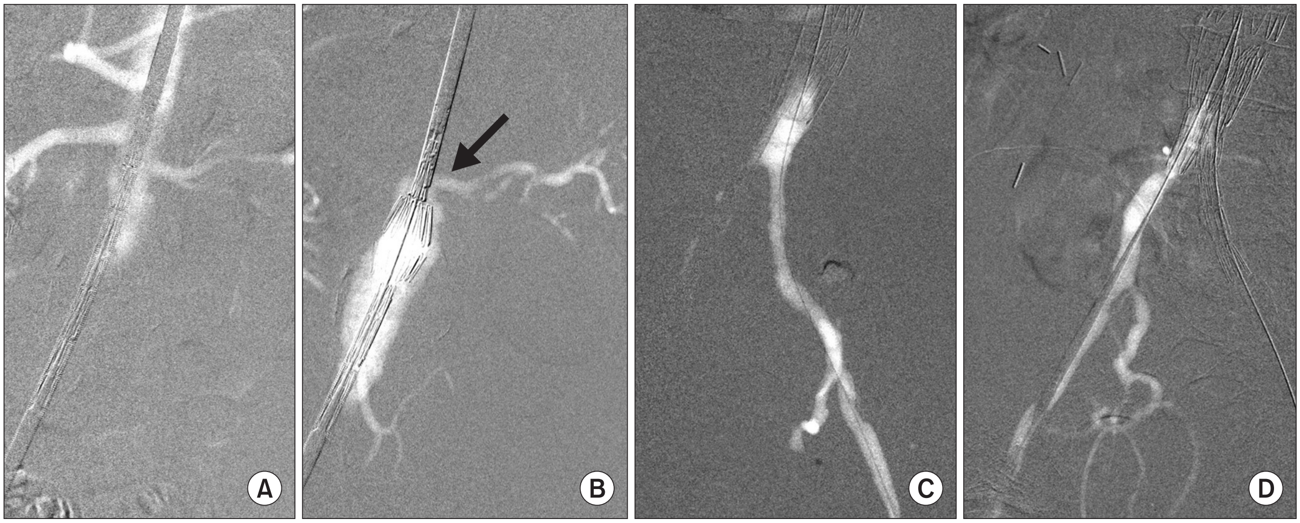

Fig. 3. CO_2-endovascular aneurysm repair with Zenith Flex AAA Endovascular Graft (Cook Medical, Bloomington, IN, USA) in a patient with chronic renal insufficiency and a 5.5 cm infrarenal AAA. (A) Abdominal digital subtraction angiography (DSA) with the injection of 40-mL CO_2 through the connecting tube of the hemostatic valve of the endograft with the patient's left side slightly elevated. The celiac and superior mesenteric arteries fill well with buoyant CO_2. In addition, the left renal artery fills well with CO_2 due to its elevation. The right renal artery is absent from a prior nephrectomy. (B) After deploying the first two covered stents, CO_2 DSA shows the position of the gold markers just below the left renal artery (arrow). (C) Injection of 20-mL of CO_2 through the connecting tube of the hemostatic valve (RAO). The hypogastric and common iliac arteries fill with CO_2. (D) Injection of 20-mL of CO_2 through the right femoral sheath (left anterior oblique) fills the hypogastric and common iliac arteries with CO_2.

aspect of CO_2 is needed to help optimize the technique for CO_2 imaging. Unlike iodinated contrast media, CO_2 does not mix with blood, rather it displaces blood and produces undiluted negative contrast (radiolucent due to a low atomic number of CO_2). When injected into the femoral artery in the patient with peripheral arterial occlusive disease, CO_2 cannot be diluted by collateral blood flow since the gas is immiscible with blood, and forms small bubbles which can be added together by the DSA stacking software, resulting in a composite continuous gas column for a diagnostic image. Motion is a problem inherent in the digital subtraction technique, as any movement between the baseline image and CO_2 image degrades the information obtained. Respiratory motion and peristalsis are significant problems in the evaluation of the abdominal aorta and its branches. Post-processing with a new mask usually makes the CO_2 image better. The imaging stacking program should be used to create a complete angiogram when the undulating common and external iliac arteries fail to fill with CO_2 due to gas breakup.

In summary, the authors are to be commended for performing CO_2-guided PEVAR in three patients with renal dysfunction to prevent CIN. The lack of "increased serum creatinine or decreased glomerular filtration rate" during the 6-month follow-up in this study suggests that CO_2 may be more suitable for EVAR candidates with renal dysfunc-

Fig. 4. Completion CO_2 digital subtraction angiography (DSA). (A) The injection of 30-mL CO_2 just below the left renal artery (arrow) through a 5-Fr Cobra catheter showing the patency of the left renal artery and the position of the main graft without endoleak. (B) The injection of 30-mL CO_2 in the main body shows the main body and both iliac limbs. There is no endoleak. The inferior mesenteric artery (arrow) arising from the excluded sac fills with CO_2 through the anastomosis between the middle colic artery of the superior mesenteric artery and the left colic artery of the inferior mesenteric artery.

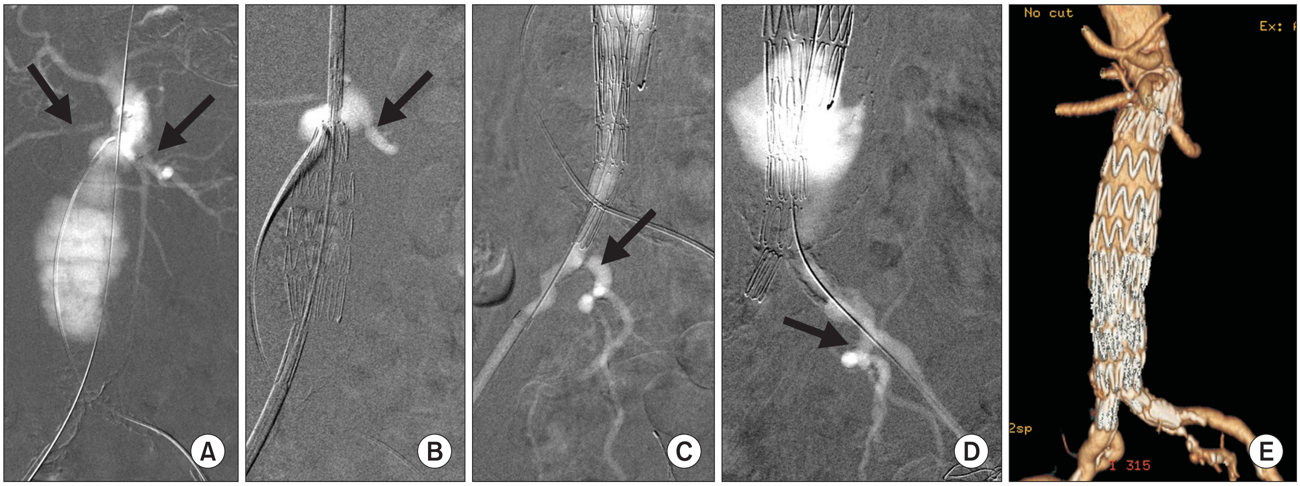

Fig. 5. CO_2-endovascular aneurysm repair (EVAR) using Zenith Flex Endograft in a 70-year-old man with a ruptured 7-cm diameter infrarenal AAA with a large retroperitoneal hematoma. (A) CO_2 digital subtraction angiography (DSA) with slight elevation of the left side and the injection of CO_2 (20 mL/sec×2 sec) at the level of L1-2 vertebral junction through a 4-Fr Glidecath from the left femoral approach. The right and left renal arteries fill with CO_2 (arrows). CO_2 refluxes and fills the superior mesenteric and celiac arteries. (B) After deploying the first two covered stents of the main body, the injection CO_2 shows filling of the left renal artery (arrow). (C) After identifying the origin of the right hypogastric artery with the injection of CO_2 through the right femoral sheath, the right iliac limb was deployed just above the hypogastric artery (left anterior oblique, arrow). (D) The injection of CO_2 through the left femoral sheath fills the common and internal iliac (arrow) arteries. CO_2 refluxes into the aneurysm. Completion CO_2 DSA with injection of CO_2 at the level of the renal artery through an angled Glidecath showed the position of the endograft and the renal arteries. There was no endoleak (not shown). (E) Volume rendered computed tomography angiography after EVAR showing AAA endograft with patent bilateral renal and hypogastric arteries.

tion. Based on this study, further prospective trials of EVAR with ICM or CO_2 in patients with renal dysfunction are needed to determine the long-term beneficial effects of CO_2.

CONFLICTS OF INTEREST

The author has nothing to disclose.

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