Can CO₂ Be a Savior for Endovascular Aneurysm Repair Candidates with Renal Dysfunction? Critical Tips for Safe CO₂ 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. CO₂ has been used as an alternative to ICM for EVAR procedures and other endovascular interventions [6-8]. CO₂ digital subtraction angiography (CO₂ 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 CO₂ 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 CO₂ 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 CO₂-guided PEVAR. This is a timely article, as CO₂-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 CO₂ DSA during PEVAR but did not describe the safe use of CO₂ and the imaging techniques that are essential for obtaining a successful angiogram. In the section “Techniques for CO₂ 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 CO₂ over 2.5 seconds. When a hand-held syringe method is used, the proper technique of CO₂ 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 CO₂-filled syringe is inadvertently left open on the procedure table for some time before injection, the CO₂-filled syringe becomes contaminated with less soluble air. Once the syringe has been filled with CO₂ from the CO₂ 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 CO₂ 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 CO₂MMANDER System with AngiAssist (AngioAdvanceds, 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 CO₂MMANDER system with AngiAssist is an FDA-approved CO₂ delivery system allowing safe delivery of CO₂ in a nonexplosive fashion. Second, I note that a 5-Fr pigtail catheter was used for CO₂ delivery. The end-hole catheter, even a microcatheter, can be used for CO₂ delivery for abdominal aortic DSA and for selective and superselective DSA. It can not only produce a continua-
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In the discussion, the authors gave a brief comment on the flow dynamics and radiopacity of CO\textsubscript{2}, stating that “CO\textsubscript{2} gas displaces blood within the blood vessels, thus serving as negative contrast agent”. I think a further discussion on this

Several additional points are critical for obtaining a safe CO\textsubscript{2} angiogram. First, only medical-grade CO\textsubscript{2} should be used. Second, CO\textsubscript{2} tanks should not be connected directly to the catheter placed in the patient. Third, CO\textsubscript{2} should not be delivered at high pressures to avoid explosive delivery. Fourth, CO\textsubscript{2} should not be injected in the arterial circulation above the diaphragm.

The purpose of CO\textsubscript{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\textsubscript{2} DSA is similar: CO\textsubscript{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\textsubscript{2} before insertion into the femoral artery, it is then advanced to the level of the first lumbar body, and CO\textsubscript{2} is injected through the side port of the sheath to visualize the renal artery. CO\textsubscript{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\textsubscript{2} through a 4-Fr end-hole 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\textsubscript{2} delivery at the level of the first lumbar spine to visualize the renal artery (Fig. 5) [4].
aspect of CO2 is needed to help optimize the technique for CO2 imaging. Unlike iodinated contrast media, CO2 does not mix with blood, rather it displaces blood and produces undilated negative contrast (radiolucent due to a low atomic number of CO2). When injected into the femoral artery in the patient with peripheral arterial occlusive disease, CO2 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 CO2 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 CO2 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 CO2 due to gas breakup.

In summary, the authors are to be commended for performing CO2-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 CO2 may be more suitable for EVAR candidates with renal dysfunc-

Fig. 3. CO2-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 CO2 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 CO2. In addition, the left renal artery fills well with CO2 due to its elevation. The right renal artery is absent from a prior nephrectomy. (B) After deploying the first two covered stents, CO2 DSA shows the position of the gold markers just below the left renal artery (arrow). (C) Injection of 20-mL of CO2 through the connecting tube of the hemostatic valve (RAO). The hypogastric and common iliac arteries fill with CO2. (D) Injection of 20-mL of CO2 through the right femoral sheath (left anterior oblique) fills the hypogastric and common iliac arteries with CO2.

Fig. 4. Completion CO2 digital subtraction angiography (DSA). (A) The injection of 30-mL CO2 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 CO2 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 CO2 through the anastomosis between the middle colic artery of the superior mesenteric artery and the left colic artery of the inferior mesenteric artery.
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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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**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.
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