

Catheter-less angiography for endovascular aortic aneurysm repair: A new application of carbon dioxide as a contrast agent

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Objective: Avoidance of nephrotoxic contrast agents during endovascular repair of abdominal aortic aneurysms (EVAR) may reduce the incidence of renal dysfunction following the procedure. Carbon dioxide (CO₂) angiography is a safe alternative to iodinated contrast media vastly under-utilized by vascular surgeons. We herein describe our experience with a simple angiographic technique using CO₂ for EVAR guidance that does not require a separate angiographic catheter.

Methods: Eighteen patients underwent EVAR using angiography with CO₂ delivered through the endograft sheath. The renal and hypogastric arteries were localized for endograft deployment exclusively with CO₂ in all patients. Completion angiography was done with CO₂ in all patients and an additional angiogram with iodinated media was done in 13 cases.

Results: All endograft deployments were done successfully with CO₂ angiography injected through the endograft delivery systems and femoral access sheaths. Additional iodinated media completion angiography did not modify the procedure in any case. All patients were discharged within two days after surgery. There were no ischemic or systemic complications related to CO₂ administration. Follow-up CT-scan revealed well positioned endografts with the expected patent renal and hypogastric arteries in all patients, and no additional endoleaks. No significant deterioration in renal function occurred in any case.

Conclusion: Carbon dioxide angiography conducted through the endograft delivery sheath is reliable for endograft deployment, safe, non-toxic and inexpensive. In addition, it may expedite EVAR by eliminating a number of angiographic catheter placements and exchanges during the procedure. This favorable experience warrants further utilization of this technique. (*J Vasc Surg* 2008;48:527-34.)

A gradual deterioration in renal function commonly follows endovascular infra-renal abdominal aortic aneurysm repair (EVAR). The patho-physiology of renal dysfunction following EVAR is probably multi-factorial, and currently not well understood. The use of iodinated contrast agents during transluminal intervention is likely one of the main factors related to renal dysfunction following EVAR.¹ The frequent deterioration in renal function after EVAR warrants the implementation of methods that may reduce its incidence or progression. Avoidance of iodinated contrast material, mainly in patients with pre-existing renal insufficiency or allergy to iodinated media, could, therefore, be helpful in reducing the overall deterioration of renal function and potential allergic reactions following EVAR.

The use of carbon dioxide (CO₂) as contrast media for intra-operative angiography during EVAR has been shown to be a safe and technically viable alternative to iodinated contrast agents.^{2,3}

Carbon dioxide lacks nephro-toxicity, is not allergenic, and when used with appropriate digital subtraction angiographic (DSA) technique provides excellent angiographic

images of the abdominal aorta and its branches.⁴ A unique physical property of CO₂ is its extremely low viscosity (less than 400 times that of iodinated contrast material). This unique feature allows effective, high volume injection rates of CO₂ through extremely small spaces, such as those existing between the components of coaxial transluminal devices.⁵ Taking advantage of this physical property, we have developed a new technique for intra-operative angiography with CO₂ during EVAR which eliminates the need for the use of an angiographic catheter to visualize the critical branches of the aorta such as the renal and hypogastric arteries, and may expedite the procedure. Our experience with this technique using CO₂ angiography for EVAR demonstrates its safety and reliability as a guiding method for endovascular aortic endograft deployment.

PATIENTS AND METHODS

Between Aug 2007 and Feb 2008, 18 consecutive patients (mean age 71 years, 17 males) underwent EVAR with the Zenith Flex Endovascular Graft (Cook Inc., Bloomington, Ind) using CO₂ as a contrast agent to localize the renal and hypogastric arteries before deploying the main body of the endograft and iliac limbs. In all procedures, CO₂ was delivered through the purging port of the hemostatic valve of the main body and iliac limb delivery sheaths of the endograft (Fig 1). Completion aortography was performed with CO₂ in all patients. In 13 of these patients, to ascertain the CO₂ findings, an additional completion aortogram was done with 30 to 100 milliliters (mean of 44 milliliters) of iodixanol 270 milligrams of

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Competition of interest: none.

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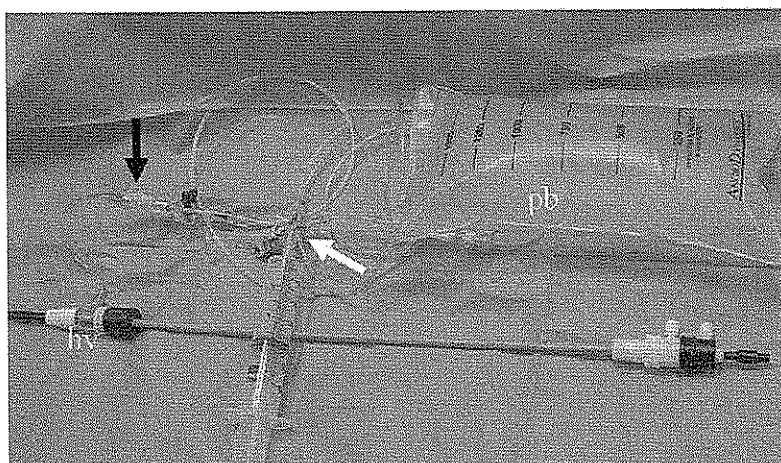


Fig 1. The carbon dioxide (CO₂) delivery system. The system includes a 1500 cc plastic bag (pb) with a one-way stopcock and gas fitting (Angioflush 111 fluid collection bag, AngioDynamics, Inc., Queensbury, NY), three one-way check valves and an O-ring gas fitting (arrowhead), which connects the bag and the delivery system (AngioFlush 111 fluid management system, AngioDynamics, Inc), and a luer-lock syringe connected to the delivery port with a check-valve (white arrow). The delivery system is connected to the connecting tube (black arrow) of the CAPTOR hemostatic valve (hv) of the main body delivery system of Zenith Flex AAA Endovascular Graft (Cook Inc., Bloomington, Ind).

iodine (mgI)/mg (Visipaque, GE Healthcare, Princeton, NJ). Iodinated contrast was not used for vessel localization or graft deployment in any case. Additional procedures, planned preoperatively, were done in seven patients including five hypogastric artery embolizations, one inferior mesenteric artery embolization and one crossover external iliac to external iliac bypass. The mean, preoperative infrarenal aortic aneurysm diameter was 57 millimeters (range, 45-75 millimeters). The common iliac arteries were aneurysmal in 10 patients, bilaterally in nine cases. In addition, 2 of those 10 patients had a hypogastric artery aneurysm. The mean serum creatinine levels measured before surgery in 17 of these patients was 1.16 mg/100 mls. Before EVAR, four patients had renal insufficiency, and one patient was on dialysis (this patient's creatinine level was not considered for the mean). Patients were followed after EVAR at 1, 6, and 12 months, and yearly thereafter with CT-scan imaging and additional abdominal ultrasonography for patients with elevated creatinine.

Pre-procedural imaging and endograft selection. Preoperative imaging evaluation of the aneurysm for endovascular intervention was done with thin-slice computerized tomography scanning (CT-scan) and three-dimensional reconstruction (3D-CT-scan) of the abdominal aorto-iliac segment.

We routinely used 3D-CT-scan reconstruction programs that allow precise cross-sectional measurement of aortic diameters and centerline luminal distances. With this imaging reconstruction technique, we acquired accurate information of the patency and location of the origins of the visceral, renal, and hypogastric arteries to select the appropriate endograft based on the manufacturer's recommendations. In addition, this preoperative knowledge facilitates

the intraoperative localization of these vessels for deployment of the endograft in its intended position. In four patients with preoperative significant renal insufficiency an unenhanced CT-scan followed by intraoperative CO₂ angiography was done for endograft selection and deployment.

Interventional technique. This technique was done using fixed C-arm fluoroscopic imaging (AXIOM Artis dTA, Siemens AG, Muenchen, Germany) and Zenith Flex aortic endografts (Cook Medical Inc, Bloomington, Ind). However, we believe the same technique can be used with other fixed fluoroscopic equipment and other commercially available aortic endografts. We have not used a portable C-arm for this technique. But they may not be adequate for CO₂ imaging purposes.

After induction of the anesthetic technique, patients were placed supine with a slight elevation of the feet. This position facilitates distal propagation of the CO₂ bubble and prevents potential proximal propagation of the gas bubble, which can occur if the head is at a higher level than the point of injection. Apnea is maintained during all angiographic image acquisitions to minimize motion artifact.

The femoral arteries are dissected through small oblique incisions parallel to the inguinal ligaments and centered over the femoral arteries. The femoral arteries are dissected just distal to the inguinal ligament and controlled with vessel loops. If the femoral artery length is not adequate for control proximal and distal to the intended arteriotomy site, the dissection is extended to the femoral artery bifurcation, controlling the superficial and profunda femoral arteries individually.

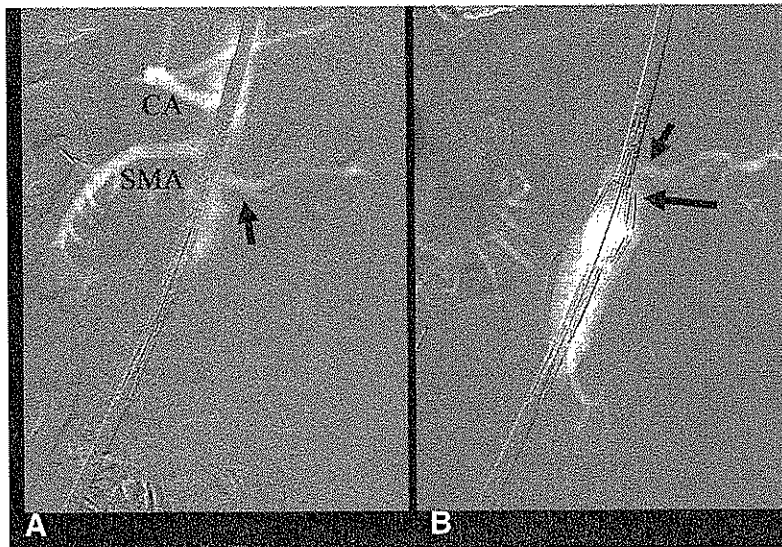


Fig 2. Deploying the first two covered stents of the main body. **A,** After advancing the main body delivery system just proximal to the left renal artery, digital subtraction angiographic (DSA) is obtained with the injection of 30-cc of carbon dioxide (CO_2) through the connecting tube of the hemostatic valve (the patient's left side was elevated to 8°). There is excellent filling of the celiac (CA) and superior mesenteric (SMA) arteries and left renal artery (arrow). The level of the left renal artery is marked on the fluoroscopy monitor by a marker pencil. Right renal artery is absent from a nephrectomy. **B,** Using the landmark, the system is retracted until the four gold radiopaque markers of the proximal graft material is at least 2 mm from the renal artery. The first two covered stents are deployed by withdrawing the sheath, and repeat CO_2 digital subtraction angiographic (DSA) demonstrates the position of the gold markers (longer arrow) inferior to the left renal artery (shorter arrow). Then deployment is proceeded until the contralateral limb is fully deployed.

An 18-gauge entry needle is used for direct, retrograde puncture of the femoral arteries. A stiff shaft guidewire (Terumo Medical Co, Somerset, NJ) is advanced through the iliac artery and into the thoracic aorta under fluoroscopic guidance on the side selected for delivery of the main body of the endograft, generally the right. The needle is withdrawn, and a 9F, 11-cm long sheath is advanced over the wire into the femoral-iliac artery. A 9F sheath is also placed in the contralateral femoral artery in a standard fashion. Using a 65-cm long angled tip glide catheter (Terumo Corp Somerset, NJ), the guidewire is exchanged for a Lunderquist Extra Stiff Guidewire (Cook Medical Inc, Bloomington, Ind) or similar wire, and its tip placed in the proximal descending thoracic aorta. The position of the outer end of the Lunderquist wire is marked on the table, to prevent excessive advancement of the wire into the arch during the procedure. The delivery system of the main body of the endograft is brought into the field and flushed with saline according to manufacturer's recommendations. The contra-lateral docking limb of the endograft is oriented under fluoroscopy to its intended position. The patient is given systemic heparin. The 9F sheath is removed, and the delivery system sheath of the endograft main body is advanced over the extra-stiff wire until the grey dilator tip is introduced into the femoral artery leaving the edge of the outer sheath about one centimeter outside the arteriotomy. The CO_2 delivery system (Angio Flush III Contrast Man-

agement System, Angio Dynamics Inc, Queensbury, NY) is connected to the side port of the endograft (Fig 1). About 20-milliliters of CO_2 are injected with a 60-milliliter syringe holding pressure in the plunger until the gas is heard and seen bubbling as it exits between the sheath and the grey dilator. At this point, a marked reduction in resistance is felt in the plunger and the delivery sheath is immediately advanced into the artery. This indicates that the fluid contained in the delivery sheath has been displaced by the CO_2 gas bubble which now occupies most of its lumen. This purging maneuver facilitates smooth, non-explosive CO_2 delivery during intravascular angiographic injection, and prevents air contamination of the delivery sheath while it remains outside the vascular lumen. The endograft is advanced under fluoroscopy to the level of the first lumbar inter-vertebral space.

Ventilation motion is held and, using the CO_2 subtraction settings, an angiogram is obtained using 40-milliliters of CO_2 hand injected in approximately 2 seconds. The renal arteries are visualized and the optimal subtraction image is stored for guidance during endograft deployment (Fig 2). If a renal artery is not well visualized, the table is tilted to elevate the kidney which will facilitate passage of CO_2 into the renal artery. It is important to remember that the CO_2 bubble generated by syringe injection is highly buoyant and tends to accumulate in the most anterior portion of the arterial segment. Since the renal artery

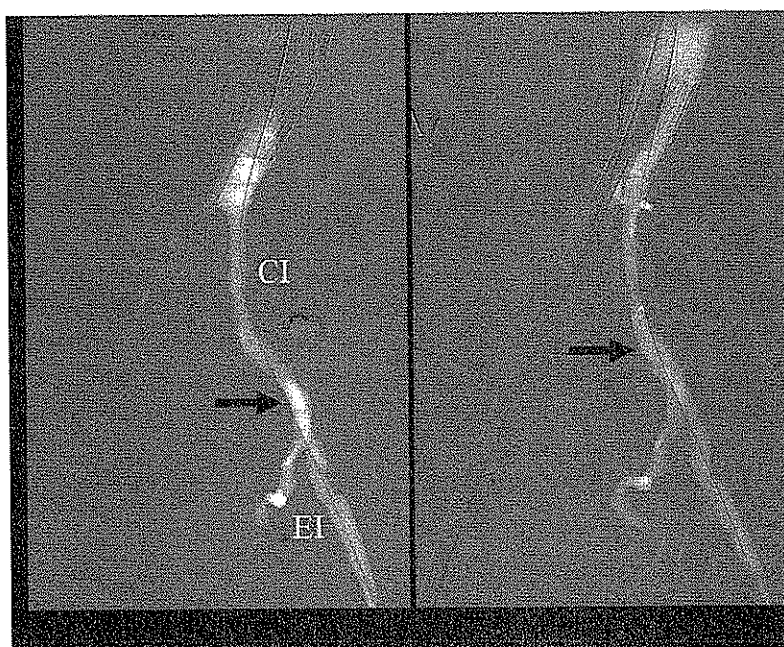


Fig 3. Deploying the iliac leg graft. After cannulation of the contralateral limb, the suprarenal stent is deployed and the contralateral guidewire is advanced into the thoracic aorta. The contralateral iliac leg that was prepped with saline solution and primed with carbon dioxide (CO_2), is introduced into the external iliac artery. **A,** Digital subtraction angiographic (DSA) is performed in the right anterior oblique projection with the injection of 20-cc of CO_2 through the connecting tube of the hemostatic valve. There is excellent filling of the common iliac (CI) and external iliac (EI) arteries, and the origin of the hypogastric artery (arrow). The level of the hypogastric artery is identified on the fluoroscopy monitor by a marker pencil. **B,** After deploying the iliac leg graft, repeat CO_2 DSA confirmed the position of the graft (arrow) above the origin of the hypogastric artery.

origins are often posteriorly located, table tilting may be necessary to allow CO_2 entry into the renal arteries in some patients. The main body of the graft is deployed in a routine fashion based on this angiogram. Next, the contra-lateral docking limb is retrogradely cannulated with a soft shaft guidewire with the aid of an angled glide catheter or other shaped catheter if necessary. Once a stiff guide wire is in place through the contra-lateral docking limb, a retrograde angiogram is obtained in an anterior oblique projection, injecting 30-mls of CO_2 through the contra-lateral femoral artery 9F sheath. Prior to injection, the sheath is purged with 5 to 10-mls of CO_2 . This angiogram allows localization of the origin of the hypogastric artery (Fig 3). The contra-lateral limb of the graft is then deployed in a standard fashion proximal to the take-off of the hypogastric artery. The delivery sheath of the main body of the graft is removed, and the ipsilateral limb sheath advanced over the stiff guide wire and the vessel loops tightened at the level of the gray dilator to prevent bleeding, since this second sheath is a smaller diameter. The ipsilateral limb sheath is purged with saline and CO_2 just before entering the artery in a similar fashion as done with the main body delivery system. Because of its smaller size, less CO_2 volume is necessary for purging (15-20 mls). The ipsilateral limb sheath is advanced distal to the estimated level of the hypogastric artery, and an angiogram in the anterior

oblique projection obtained by hand injection of 30 mls of CO_2 (Fig 4). The hypogastric artery is located and the ipsilateral limb is deployed in a standard fashion. Alternatively, instead of injecting CO_2 through the ipsilateral limb delivery sheath, a 16F sheath may be temporarily placed in the ipsilateral, external iliac artery for angiographic purposes, and then removed. Once the endograft is deployed and shaped with a compliant balloon, a completion angiogram is done with a 5F angled glide end-hole catheter used during the procedure, placed at the level of the renal arteries. The catheter is connected to the syringe-delivery system and purged with 5-mls of CO_2 . A standard anterior-posterior angiogram is obtained with 40-mls of CO_2 including the renal and hypogastric artery origins in the field. The subtraction sequence is held to allow late opacification of the lumbar and inferior mesenteric arteries. Additional injections may be done with the catheter in different positions if there is any suggestion of endoleak or other potential problem (Fig 5).

Once a satisfactory angiogram is obtained, the procedure is completed in a standard fashion.

RESULTS

The renal and hypogastric arteries were identified with CO_2 angiography for endograft deployment without the aid of iodinated contrast angiography in all cases. The

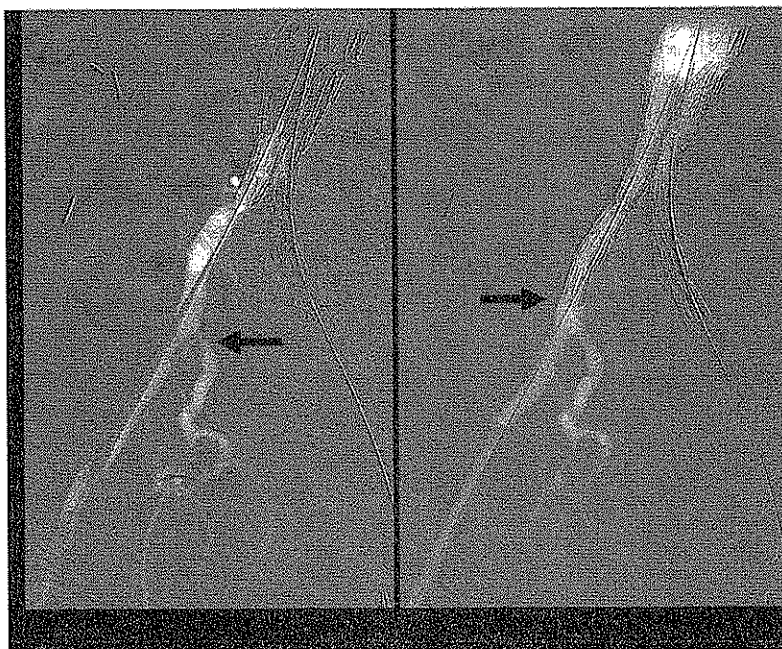


Fig 4. Deploying the ipsilateral iliac leg. After deploying the ipsilateral limb of the main body, the ipsilateral iliac leg graft that has been prepped with normal saline and primed with carbon dioxide (CO_2), is introduced into the external iliac artery. A, Digital subtraction angiographic (DSA) is performed in the left anterior oblique projection with the injection of 20-cc of CO_2 through the connecting tube of the hemostatic valve. There is excellent filling of the common and external iliac arteries and the origin of the hypogastric artery (arrow). B, After deployment of the iliac graft, repeat CO_2 DSA confirmed the position of the iliac limb (arrow) seen above the hypogastric artery.

additional transluminal procedures done in six patients were also completed exclusively under CO_2 angiographic guidance. The mean number of angiographic runs per case was 10 (range: 3 to 20). The average volume of CO_2 injection used per case (including additional procedures) was 363 milliliters (range: 120 to 670 milliliters). An additional final completion angiogram with 30-milliliters of iodinated contrast of volume injection was done in 13 patients (mean volume injection 44 milliliters per patient). Mean fluoroscopy time was 23 minutes (range: 16 to 29 minutes). Mean procedure time, including additional procedures, was 175 minutes (range: 127 to 264 minutes).

Two type II endoleaks (one from a lumbar artery and one from the inferior mesenteric artery [IMA]) were identified with CO_2 angiography (no type I, III, or IV endoleaks were seen). One of them was confirmed intraoperatively with completion iodinated contrast angiogram; however neither leak was seen on follow-up CT-scan at 1 month (Fig 6). Completion angiography with iodinated contrast done in 13 cases revealed findings not seen with CO_2 angiography in only one patient, in whom an IMA endoleak was identified and confirmed with CT-scan at one month. However, the additional completion angiogram performed with iodinated contrast did not change the final decision on the procedure in any case. Follow-up CT-scan and abdominal ultrasonography at one month confirmed adequate anatomical placement of the endograft in all cases

without any additional endoleaks, and noted a reduced mean aneurysm diameter of 55 millimeters, with a decrease in diameter noted in 13 of 18 patients (no change in 5 patients and a decrease ranging from 1 to 7 mm in diameter in 13).

There were no deaths, and there was one complication; an extraperitoneal hematoma which did not require intervention. This occurred in a patient who also underwent hypogastric artery embolization, and was probably related to a distal vessel perforation during selective catheterization of the gluteal vessels. The patient was discharged on postoperative day 2. There were no instances of bowel or lower extremity ischemia. All patients, except one with pre-existing dialysis dependent renal failure, were discharged within 2 days of the procedure.

Mean postoperative creatinine level measured at the time of discharge from the hospital was 1.05 mg/100 mls, compared with 1.16 mg/100 milliliters preoperatively. No patient sustained an increase in creatinine level >0.5 mg/dL or greater than 25%. The creatinine level increased postoperatively, although transiently, in only one patient who also had iodinated media angiography (creatinine 1.4 to 1.7 mg/100 mls). No patient went into renal failure.

DISCUSSION

Deterioration in renal function remains a significant concern following EVAR. In patients with pre-existing

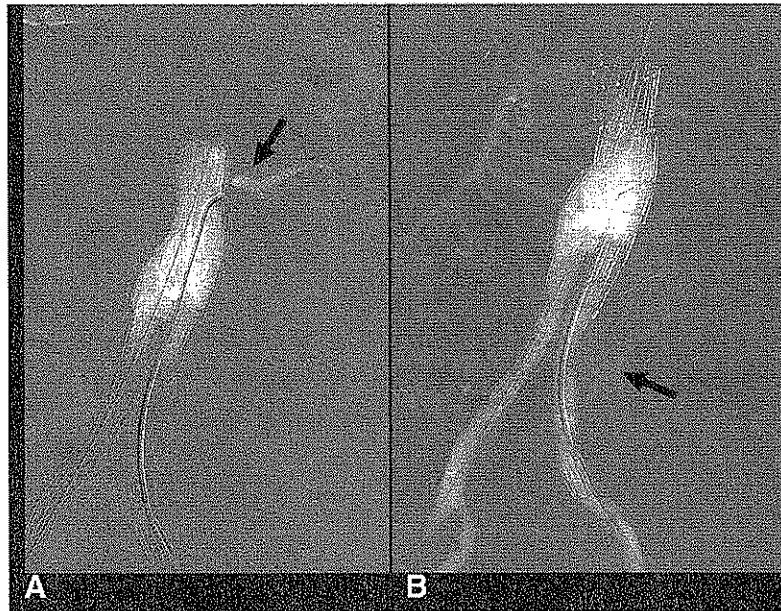


Fig 5. Completion CO₂ digital subtraction angiographic (DSA). After expansion of the molding balloon with dilute contrast along the aortic graft, a 5F cobra catheter is advanced from the left femoral sheath to the proximal end of the graft. **A**, DSA with the injection of 30-cc of CO₂ confirmed the position of the main graft and patency of the renal artery (arrow). There is no endoleak from the proximal fixation site. **B**, After placing the catheter within the main body, repeat CO₂ DSA is obtained. The graft and both iliac limbs are visualized. The middle colic artery of the superior mesenteric artery provides the primary collateral pathway to the excluded inferior mesenteric artery (arrow). There are no endoleaks or kinks. The renal and bilateral hypogastric arteries are filled by this injection.

renal insufficiency or major allergy to iodinated contrast agents, avoidance of these contrast agents is advisable if not mandatory. Carbon dioxide is an inexpensive, readily available gas with no known renal toxicity and which does not elicit allergic response. Furthermore, CO₂ is the only proven safe contrast agent in patients with hypersensitivity to iodinated contrast material, which eliminates the need for pre-procedure steroid preparation.

During our previous experience with catheter delivered CO₂ angiography for EVAR, we observed that CO₂ could also be injected intravascularly through the delivery systems of aortic endografts. Based on this finding, we realized that the angiography during endograft deployment could be done injecting CO₂ through the side-port of the endograft delivery system and femoral access sheaths, without the need of additional angiographic catheter placement. This technique obviates the need for placement of a separate angiographic catheter and avoids any catheter exchanges and replacements that may be required throughout endograft deployment, a potential advantage over conventional catheter angiography. It is difficult to quantitate how the procedure is expedited by avoiding the use of angiographic catheters, but it is certain that a number of catheter placements and over the wire exchanges are eliminated with this technique.

There is a significant experience in the interventional radiology literature using CO₂ for peripheral angiography,

venography and peripheral intervention. However, there is very little experience with the use of CO₂ for angiography during EVAR, perhaps due to the fact that few surgeons are proficient with CO₂ angiography.

A thorough understanding of the physical properties of CO₂ and peculiar features of its angiographic technique is essential in the safe and effective performance of CO₂ angiography. Carbon dioxide is a highly soluble, buoyant, low viscosity and compressible gas. In addition CO₂ is a colorless and odorless gas that is indistinguishable from air. For this reason, inadvertent air contamination may occur during CO₂ delivery and must be prevented because it may produce ischemic complications when air is intravascularly injected. Air contamination may occur when CO₂ containing tubes are in communication with room air through open tubes or stopcocks, as air will gradually mix with the CO₂ over a period of minutes. For this reason, we use a commercially available CO₂ bag and delivery system that incorporates a number of one-way valves that prevent entrance of air into the gas reservoir and connection tubing. In addition, to eliminate air contamination we prime the tubing and the endograft delivery sheath with CO₂ outside the body, just before it is introduced in the vascular lumen. Priming the delivery sheath with CO₂ avoids the explosive delivery of CO₂ that occurs when the gas is compressed into a lumen filled with fluid. The smooth, non-explosive



Fig 6. Sac perfusion after endograft placement. Intraprocedural digital subtraction angiography was performed in the left anterior oblique projection with the injection of 30-cc of carbon dioxide (CO₂) into the main body. The main body and left iliac limb are filled with CO₂. The aneurysm sac (arrow) is filled partially through left internal iliac-inferior mesenteric collateral channels. A CT scan one month after endograft placement showed no endoleak.

gas delivery provides higher quality images and control of the gas injection process.

Carbon dioxide, when injected intravascularly, produces excellent opacification of the lumen, comparable to that obtained with iodinated contrast. When CO₂ is delivered under pressure into the vascular system, it forms a gas bubble that displaces blood initially, rapidly dissolves in the blood, and is transported to the lungs where the gas is exhaled. For this reason, large volumes of CO₂ can be injected intravascularly in multiple injections throughout the procedure. However, ischemic colitis may occur in patients with aortic aneurysms after receiving diagnostic angiography with large volumes of CO₂ (1000 to 2000 milliliters) in 30-minute periods.⁶ Because CO₂ is highly buoyant, trapping of the gas may occur in the dome of an aneurysm sac. Once the gas is trapped, CO₂ is gradually replaced by nitrogen. Theoretically, the gas bubble may prevent blood flow into the inferior mesenteric artery, or poorly soluble nitrogen may flow into the inferior mesenteric artery and result in colonic ischemia. For this reason, if persistent large gas bubbles are seen in the aneurysm they

can be easily removed by tilting the table right and left. However, this concern applies little to EVAR, since the procedure intends to occlude flow into the inferior mesenteric artery anyway.

In our experience the volume of CO₂ injection required for EVAR procedures averaged 363 milliliters, a fraction of the volume reported to produce transient bowel ischemia. Furthermore, none of our patients developed abdominal pain or signs consistent with bowel ischemia.

A major theoretical risk of CO₂ administration is the risk of stroke or spinal cord ischemia when injected above the diaphragm. For this reason, we do not advocate the use of CO₂ for thoracic arterial imaging. On the other hand, accidental injection of air bubbles into the brain or spinal cord is theoretically far more dangerous than injection of CO₂ bubbles.

It is important to note that CO₂ when injected forms a buoyant gas bubble that under pressure displaces the fluid column and locates in the non-dependent areas of catheters and blood vessels. For this reason, dependently located branches of the aorta may not be well visualized with CO₂. In our experience, the renal arteries opacified well with the injection of CO₂ through the introducer sheath in the supine position in most cases, and table tilting was only required in one patient. For the same reason, endoleaks from dependent branches of the aneurysm may not be detected. However, CO₂ identified an endoleak that was not seen with iodinated contrast, and we only found an additional IMA endoleak with iodinated contrast angiography, which could have been identified by CO₂ if additional runs would have been done. More importantly, completion angiography with iodinated contrast did not alter the procedure in any case. Since CO₂ advances faster than iodinated contrast in the vascular tree, it is theoretically plausible that CO₂ may be more sensitive in demonstrating endoleaks. Our initial experience does not suggest that significant endoleaks are missed with CO₂ angiography. However, additional oblique projection completion arteriograms may increase the detection of subtle, albeit clinically insignificant, endoleaks.

The presence of anterior neck angulation may potentially pose a problem in imaging branches at this level. However, we have not found this problem in our experience.

An additional potential advantage of the physical properties of CO₂ when intravascularly injected is that it readily displaces the blood mass contained in a stagnant vascular segment, such as the aorta with proximal balloon occlusion, perhaps making CO₂ angiography best suited for endovascular repair of ruptured aortic aneurysms, a clinical situation with a high risk for renal failure.⁷

The follow-up CT scans of our patients demonstrated that all endografts were properly deployed in their intended positions, and did not reveal any findings to suggest that CO₂ imaging missed any essential information that could have altered the procedures.

Postoperatively, only one of our patients experienced a transient increase in creatinine levels (<25%), and that

occurred in a patient who also received a single injection of iodinated contrast media. It is important to remember that the association of CO₂ arteriography with small amounts of iodinated contrast still carries the risk of renal toxicity and, therefore, should be avoided in patients with pre-existing renal insufficiency.⁸ For this reason, we now feel that the entire EVAR procedure can and should be done under CO₂ DSA guidance without the use of any intra-operative iodinated contrast material, as it was done in five of these patients during the final part of this experience as we became more comfortable with the technique, and is currently our practice. In addition, to decrease contrast nephropathy, we rely on ultrasound scans for endoleak detection in patients with elevated creatinine, and use un-enhanced CT-scans for accurate measurement of sac diameter. Further sophistication in ultrasound imaging may eventually obviate the need for enhanced CT-scanning during follow-up.

The elimination of iodinated contrast and angiographic catheters from the procedure may produce significant savings in institutions where large numbers of EVAR cases are done on a yearly basis. Intravascular ultrasound is another useful imaging alternative for endovascular aneurysm repair which may also eliminate the need for the use of contrast angiography.⁹

CONCLUSION

In summary, our preliminary experience with this technique is quite encouraging. It shows that CO₂ digital subtraction angiography injected through the side port of the endograft delivery sheath is a safe and reliable method of localizing the renal and hypogastric arteries for precise deployment of aortic endografts. In addition, this angiographic technique appears to provide sufficient information for the safe completion of EVAR procedures without the aid of iodinated contrast injection. It is foreseeable that commercially available endografts may incorporate a miniscule port to allow CO₂ angiography throughout the procedure.

AUTHOR CONTRIBUTIONS

Conception and design: EC
 Analysis and interpretation: EC, KC
 Data collection: EC, LK
 Writing the article: EC, KC
 Critical revision of the article: EC, KC, LK
 Final approval of the article: EC, KC
 Statistical analysis: Not applicable
 Obtained funding: EC
 Overall responsibility: EC

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