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◆CASE REPORT

# Endoleak Visualized With Carbon Dioxide Angiography During Endovascular Aneurysm Repair Using the Endurant Stent-Graft

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***Purpose:*** To make interventionists aware of the potential for type IV endoleak on completion carbon dioxide ($CO_2$) angiography during endovascular aneurysm repair (EVAR) using the Endurant stent-graft.

***Case Report:*** A 74-year-old man with chronic kidney disease underwent EVAR with an Endurant stent-graft using $CO_2$ angiography to guide graft placement. Completion $CO_2$ angiography demonstrated immediate accumulation of $CO_2$ in the aneurysm sac suggestive of an endoleak, but confirmatory angiography with conventional iodinated contrast showed no evidence of an endoleak. We speculate that this is a type IV endoleak, and graft porosity may be responsible.

***Conclusion:*** Interventionists should be alerted to the possibility of visualizing these endoleaks through Endurant stent-grafts under $CO_2$ angiography. Further work should be done to elucidate the exact mechanism of the endoleak.

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***Key words:*** endovascular aneurysm repair, stent-graft, endoleak, type IV endoleak, $CO_2$ angiography

One of the recognized complications following endovascular aneurysm repair (EVAR) is progressive deterioration of renal function over time.[1,2] Patients with pre-existing renal impairment who undergo EVAR are at increased risk for developing postoperative deterioration of renal function and death.[3,4] There are several causes of renal dysfunction following EVAR, including atheroembolism, contrast-induced nephrotoxicity (CIN), suprarenal fixation, and graft malpositioning.[2] One strategy to mitigate the risk of CIN following EVAR is to use non-iodinated contrast material such as carbon dioxide ($CO_2$). Several authors have reported their experience with $CO_2$ during EVAR and have shown it to be safe and effective.[5–8] Interestingly, all of these authors reported endoleaks demonstrated during completion $CO_2$ angiography in their series, with two reports suggesting that $CO_2$ angiography is more sensitive than conventional angiography for the detection of endoleaks.[5,6] We report a case of an endoleak seen on completion $CO_2$ angiography during implantation of an Endurant stent-graft, and we postulate a mechanism for this endoleak that requires further study.

## CASE REPORT

A 74-year-old man with stage IV chronic kidney disease presented with acute on

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chronic renal failure [serum creatinine (SCr) 4.6 md/dL and estimated glomerular filtration rate (eGFR) of 12.6 mL/min/1.73 $m^2$] characterized by decompensated congestive heart failure and dyspnea with oliguria. Non-contrast computed tomography (CT) of the abdomen and pelvis demonstrated an incidental asymptomatic 7.9-cm infrarenal abdominal aortic aneurysm (AAA). The patient was a candidate for EVAR, but the procedure was delayed for preoperative hemodialysis to optimize the volume and electrolyte status.

The EVAR procedure was performed using intravascular ultrasound (IVUS) and $CO_2$ angiography to avoid nephrotoxic iodinated contrast. The right kidney was atrophic on the preoperative CT scan, so attention was given to preserving the left renal artery, which was marked with IVUS, along with the bilateral hypogastric arteries. The anatomy was confirmed using $CO_2$ angiography with planned selective catheterization of the left renal artery prior to graft deployment (Fig. 1A).

With the patient under systemic anticoagulation with weight based heparin dosing (100 U/kg) to achieve an activated clotting time of $>$250 seconds, a bifurcated Endurant stent-graft (Medtronic CardioVascular, Santa Rosa, CA, USA) was successfully implanted through percutaneous access in both common femoral arteries, using $CO_2$ throughout the case to guide graft placement. Completion $CO_2$ angiography with 50 mL of compressed gas was performed after treating the seal zones and overlap zones with a Coda balloon in standard fashion. Immediately after $CO_2$ injection, the aneurysm sac was promptly seen to fill with $CO_2$ and continued to fill more intensely as the digital subtraction images were acquired (Fig. 1B,C). This immediate visualization of $CO_2$ in the aneurysm sac was uncharacteristic of a type II endoleak, and given the long 3-cm proximal neck and the favorable iliac landing zones, a type I endoleak on either end seemed rather unlikely. However, feeling compelled to rule out a type I or III endoleak in this patient with a large aneurysm, the decision was made, despite the renal failure, to perform a completion angiogram with iodinated contrast.

While still under anticoagulation and without any repeat balloon dilation of the overlap zones, 20 mL of half strength Visipaque (320 mg I/mL, GE Healthcare Canada Inc, Mississauga, ON, Canada) was injected for the final angiogram, which demonstrated no evidence of an endoleak (Fig. 1D). Review of the timing of the images acquired during the procedure revealed that only 3 minutes had elapsed between the $CO_2$ angiogram and the conventional angiogram. With no endoleak noted on the conventional angiogram, the heparin was reversed, and the femoral access sites were closed.

The patient had an uneventful postoperative course and was discharged to home on postoperative day 1 with plans to continue outpatient hemodialysis with regular monitoring of his renal function. At the 1-month follow-up appointment, the patient was recovering well from the aneurysm repair but had demonstrated no signs of renal recovery and was still requiring regular hemodialysis. Non-contrast CT demonstrated a stable position of the bifurcated stent-graft with a small residual pocket of trapped gas anteriorly inside the thrombus of the sac (Fig. 2A). Aortic duplex demonstrated patent graft limbs and no evidence of an endoleak at that time (Fig. 2B). At 13 months, a contrast-enhanced CT angiogram demonstrated stable position of the endograft, resolution of the gas pocket in the sac, no evidence of endoleak, and a decrease in sac size from 7.9 to 6.2 cm (Fig. 2C).

## DISCUSSION

In 1982, Hawkins[9] first described the use of $CO_2$ as an alternative to iodinated contrast material in a series of 17 patients undergoing diagnostic arteriography. Since then, $CO_2$ has become well established not only in diagnostic angiography but also in therapeutic techniques.[10] Because of the risk of renal dysfunction associated with EVAR, several authors have used $CO_2$ during these procedures and have shown it to be safe and effective,[5–8] even for cases of ruptured AAA.[11] As endovascular specialists continue to implement efforts to reduce nephrotoxicity in their patients, $CO_2$ angiography may play a larger role in the management of patients with chronic kidney disease in the future.

The recognized benefits of $CO_2$ as a contrast material include its ease of use, low cost, lack

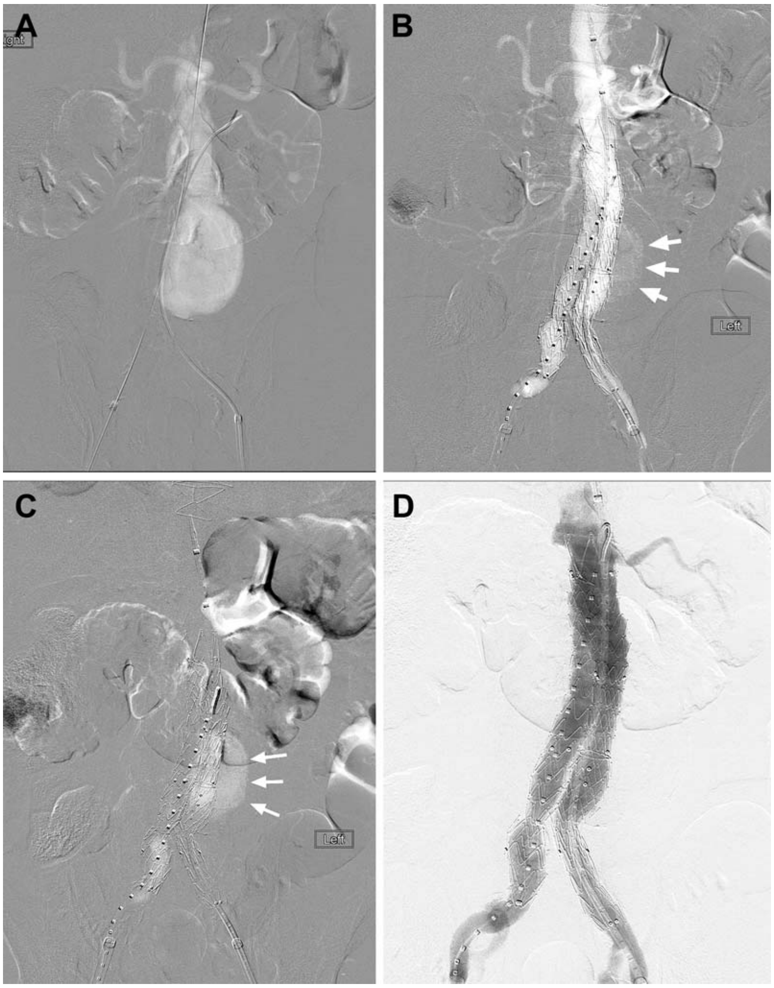


**Figure 1** ◆ (**A**) Initial $CO_2$ angiogram via a selective catheter in the left renal artery to mark the position of the artery prior to graft deployment. Note the preferential filling of non-dependent celiac and superior mesenteric arteries. Completion $CO_2$ angiograms demonstrating (**B**) early accumulation of $CO_2$ in the aneurysm sac (white arrows) immediately after injection and (**C**) progressive accumulation of gas in the sac (white arrows), which persisted after the remainder of the $CO_2$ washed out. (**D**) Final completion angiogram using iodinated contrast demonstrating no evidence of an endoleak. The left renal artery and both hypogastric arteries are patent. The right renal artery is chronically occluded.

of renal toxicity and allergic reaction, low viscosity facilitating injection through smaller caliber catheters, and overall safety when introduced into the arterial system below the diaphragm. The use of $CO_2$ is not recommended above the diaphragm where it could theoretically disrupt the blood-brain barrier. Also, any gas introduced into the arterial system can theoretically create a "vapor lock" in small vessels, causing end organ ischemia, which in the cerebral circulation could lead to anoxic injury.

The compressible gas is rapidly dissolved inside the arterial system and eliminated in the lungs during normal respiration. Because the gas is far more buoyant than blood, it rapidly displaces flowing blood within the vascular tree, tending to preferentially fill vessels that are situated in a non-dependent position, such as the celiac artery and superior mesenteric artery (SMA) in a supine patient (Fig. 1A). Some patients report the feeling of nausea immediately after injection in the abdominal aorta. Caution should be

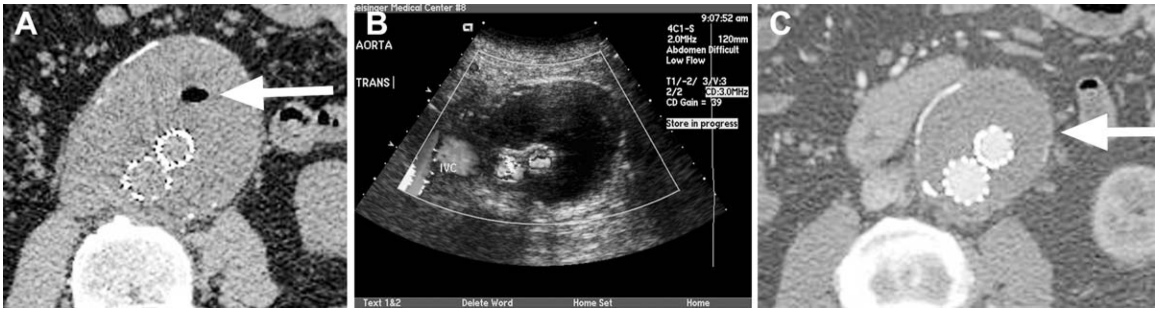


**Figure 2** ◆ (**A**) Non-contrast CT scan 1 month after surgery demonstrating a small residual collection of trapped gas anteriorly within the thrombus of the sac (arrow). (**B**) Duplex scan at 1 month after surgery demonstrating a patent aortic stent-graft without flow in the sac. (**C**) Contrast-enhanced CT scan at 13 months demonstrating patent graft limbs, no evidence of endoleak, resolution of the anterior gas pocket, and a significant decrease in sac size (arrow).

used when attempting to visualize arteries in a dependent position (such as the renal arteries and lumbar arteries) because the $CO_2$ may not fill these vessels well.

The previous reports of $CO_2$ angiography during EVAR all describe endoleaks in some of the patients following final graft deployment.[5–8] Two of the reports described exclusive use of the Cook Zenith device,[6,7] while the other studies employed multiple devices[5,8] (Guidant Ancure, Gore Excluder, Medtronic AneuRx, and Lombard Aorfix) without reporting the incidence of endoleak based on device type. None of these reports described experience with the Endurant stent-graft, which was used in our patient. Due to the low viscosity of $CO_2$, it could be postulated that the gas would track more easily between the graft material and the aortic wall (type I endoleak) or between graft components (type III endoleak). Indeed, Chao et al.[5] observed that the $CO_2$ seems to be more sensitive in detecting endoleaks, but they do not offer a hypothesis as to the exact mechanism to explain the phenomenon.

Close scrutiny of the serial acquisition images from the digital subtraction $CO_2$ angiogram in our patient makes it seem as though the $CO_2$ passed through the graft fabric almost immediately after injection, causing a type IV endoleak that would not otherwise be detected with conventional angiography. This may be due to the low-viscosity $CO_2$ being able to permeate the graft fabric. It is unlikely that a type II endoleak would show up with $CO_2$ angiography because the $CO_2$ would preferentially fill nondependent arterial branches and not the dependently situated lumbar arteries, unless the $CO_2$ rapidly coursed through the SMA branches and filled the inferior mesenteric artery retrograde into the sac, which was not visualized on the angiogram. In our patient, the long proximal and distal landing zones would make a type I endoleak less likely, though not impossible. Because only 3 minutes had transpired between the final $CO_2$ angiogram and the confirmatory conventional angiogram, it is unlikely that the $CO_2$ angiogram was demonstrating a type I or III endoleak that spontaneously sealed within the intervening 3-minute time frame, thus a type IV endoleak directly through the graft material seemed most plausible. Lastly, the possibility of a type V endoleak needs to be considered, but type V endoleaks usually present in delayed fashion with an increase in sac size over time without another documented type of endoleak. We would not expect a type V endoleak to manifest intraoperatively; furthermore, the 13-month CT scan showed an appreciable decrease in sac size that would rule this out in our patient.

The graft material on the Endurant device is a high density woven polyester fabric made from a multifilament yarn. The same multifilament yarn is also used to secure the graft fabric to the stent components without the use of additional suture material. The porosity of this fabric is reported to be roughly 150 mL/cm$^2$/min (direct correspondence with manufacturer). Whether or not this level of porosity would allow direct permeation by $CO_2$ is unknown, as no benchtop data are available regarding porosity testing using $CO_2$ with this device (direct correspondence with manufacturer). Since there was no endoleak of any type seen on the conventional angiogram only 3 minutes after the $CO_2$ angiogram, the final explanation for the $CO_2$ endoleak remains unresolved. We postulate that graft porosity coupled with the unique physical properties of $CO_2$ described above may account for this apparently unique type IV endoleak that is seen only with the low-viscosity $CO_2$. Obviously, this hypothesis needs further study to determine its merit.

## Conclusion

To our knowledge, there are no prior reports of an endoleak using $CO_2$ during EVAR with the Endurant stent-graft. We are hopeful that further work can be done in this area to elucidate the exact mechanism of the endoleak. Investigating this endoleak caused us to use a small volume of iodinated contrast to confirm the findings, which could only have had a detrimental effect on the patient's renal recovery. Our hope is that as $CO_2$ use becomes more widely employed in EVAR, we can learn how to interpret $CO_2$-related endoleaks and make appropriate clinical decisions that avoid potentially harmful nephrotoxic contrast agents in patients with preexisting renal dysfunction.

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