Clinical Research

Endovascular Repair of Ruptured Aortic Aneurysms Using Carbon Dioxide Contrast Angiography

Brian S. Knipp, Guillermo A. Escobar, Sean English, Gilbert R. Upchurch Jr, and Enrique Criado, Ann Arbor, Michigan

Background: Endovascular aneurysm repair (EVAR) has become a common approach to the management of ruptured abdominal aortic aneurysms (rAAA). The use of iodinated contrast during EVAR for rAAA has several disadvantages, including contrast nephropathy, potential allergic response, and the need for high-pressure injection. We evaluated the use of carbon dioxide (CO_2) as the primary contrast agent for endovascular repair of ruptured aortic aneurysms.
Methods: Between December 2007 and July 2009, we retrospectively reviewed our experience with patients undergoing endovascular repair of rAAA, with CO_2as the principal contrast agent, and compared them with patients who underwent EVAR using iodinated contrast.
Results: Four patients underwent endovascular repair of rAAA with CO_2 angiography (group 1) and seven with iodinated contrast (group 2). The mean age of the patients was not different between groups ($p = 0.353$). Patients in group 1 received a mean of 443 ± 99 mL of CO_2 and 4.3 ± 8.5 mL of iodinated contrast. Patients in group 2 received 110.2 ± 37.6 mL of iodinated contrast ($p < 0.001$). Overall mortality was not different between group 1 (0.0%) and group 2 (28.6%, $p = 0.491$). In patients who survived to discharge, the change in creatinine between admission and discharge was greater in group 2 although not statistically significant (0.25 ± 0.19 mg/dL for group 1 vs. 0.58 ± 0.25 mg/dL for group 2, $p = 0.066$). There was no significant difference in length of stay between group 1 (intensive care unit, 1.00 ± 0.82 days; hospital, 4.25 ± 0.96 days) and group 2 (intensive care unit, 3.60 ± 3.44 days; hospital, 9.00 ± 6.60 days).
Conclusions: Endovascular repair of rAAA using CO_2 as a contrast agent is technically feasible and safe. The potential benefits of CO_2 angiography support the continued use of CO_2 in cases of ruptured aneurysms. Further studies are necessary to determine whether CO_2 improves survival and limits the progression of renal dysfunction after endovascular repair of rAAA.

INTRODUCTION

Ruptured abdominal aortic aneurysms (rAAA) have historically been associated with high pre-hospital and in-hospital mortality.[1] Even in centers of excellence, it was found that the mortality rate ranged between 25 and 50% after an open repair of rAAA.[2-5]; considering this minimal improvement in the last several decades, there is a growing trend toward endovascular aneurysm repair (EVAR) in patients with rAAA and favorable anatomy.

The rate of risk of death in patients undergoing elective aortic aneurysm repair who require postoperative renal replacement therapy is 66% compared with 3-7% in those who do not, and increases to 71% in rAAA.[6,7] A major concern for performing EVAR in patients with rAAA is the need for use of iodinated contrast agents (ICA), particularly when patients undergo enhanced computed tomography

Section of Vascular Surgery, Department of Surgery, University of Michigan School of Medicine, Ann Arbor, MI.

Correspondence to: Enrique Criado, MD, 1500 East Medical Center Drive, SPC 5867, CVC 5463, Ann Arbor, MI 48109-5867, USA, E-mail: ecriado@umich.edu

Ann Vasc Surg 2010; 24: 845-850
DOI: 10.1016/j.avsg.2010.05.013

angiogram (CTA) to establish the diagnosis. In the setting of acute hypotension, the use of ICA in combination with baseline renal dysfunction can precipitate or worsen renal failure. Although there appears to be an improved survival after EVAR for rAAA,[3] the risk of renal dysfunction in this acute setting remains significant. We have demonstrated the feasibility of EVAR using carbon dioxide (CO_2) as the main contrast agent in elective cases to minimize contrast exposure and cost, and have since adopted it into our clinical practice.[8]

Our current management of rAAA includes a rapid assessment of suitability for EVAR with CTA (with or without contrast) followed by EVAR with CO_2, with ICA used selectively. We present our experience with four patients undergoing repair of ruptured aneurysms, using endovascular techniques with CO_2 as the primary or sole contrast agent, and also compare the outcomes with contemporaneous controls undergoing EVAR with iodinated contrast.

METHODS

Patient Cohort

We retrospectively reviewed the charts of all patients undergoing rAAA at the University of Michigan between December 2007 and July 2009. We excluded patients with preexisting renal failure on dialysis or patients undergoing open repair. The patients were divided into those receiving CO_2 as their primary contrast agent during EVAR (group 1) or those undergoing EVAR with iodinated contrast (group 2).

Technique of CO_2 Repair

Patients are placed supine on the operating table under general endotracheal anesthesia. Bilateral femoral artery exposures are performed and 9-French sheaths and Lunderquist Extra Stiff Guidewires (Cook Medical Inc, Bloomington, IN) are placed in the standard manner. The CO_2 delivery system, a 1500 cm^3 plastic bag 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 connected to 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, is connected to the hemostatic valve of the main body delivery system of the endograft. The endograft placement procedure is then completed in the standard manner, with the exception that angiograms are performed through the sideports of the delivery sheaths or through a 5F endhole or angiographic catheter using 40 mL of CO_2 bolus. Tilting of the table is occasionally necessary to permit the buoyant CO_2 to enter posteriorly oriented renal arteries. The hypogastric arteries are localized through retrograde injections of CO_2 from the femoral sheaths or through the sideport of the limb component delivery sheath. After the modular components of the endograft are in place and shaped with a compliant balloon, a completion CO_2 angiogram is performed through an endhole catheter, and the procedure is completed in a standard manner.

Statistical Analysis

Statistical analysis was performed using GraphPad Prism software (GraphPad Prism version 5.0b for Macintosh, GraphPad Software, San Diego, CA). Continuous variables were compared using Student's *t*-test and categorical variables were compared using the Chi-squared analysis.

RESULTS

Case 1

A 75-year old man presented with a 3-day history of progressive back pain. On physical examination, he was alert with stable vital signs. His preoperative creatinine was 1.2 mg/dL. Computed tomography (CT) demonstrated an infrarenal 11-cm rAAA (Fig. 1). The patient underwent EVAR with a bifurcated endograft using 380 mL of CO_2 and no ICA. Estimated blood loss was 300 mL; however, he received no blood products. His maximum creatinine was 1.4 mg/dL immediately postoperatively, which decreased to 0.8 mg/dL at the time of discharge. On postoperative day 2, CTA was performed with 125 mL of iodinated contrast which demonstrated no endoleak. He was discharged home on postoperative day 5. One month postprocedure, CTA demonstrated a patent graft with no endoleak and unchanged renal function.

Case 2

A 70-year old man presented with an infrarenal 7-cm rAAA. On physical examination, he was alert with stable vital signs. His preoperative creatinine was 0.9 mg/dL. He was treated with a bifurcated endograft EVAR using 360 mL of CO_2 and no ICA. Estimated blood loss was 125 mL; he received three units of blood and 500 cm^3 of colloid during the operation. His maximum creatinine was 0.9 mg/dL

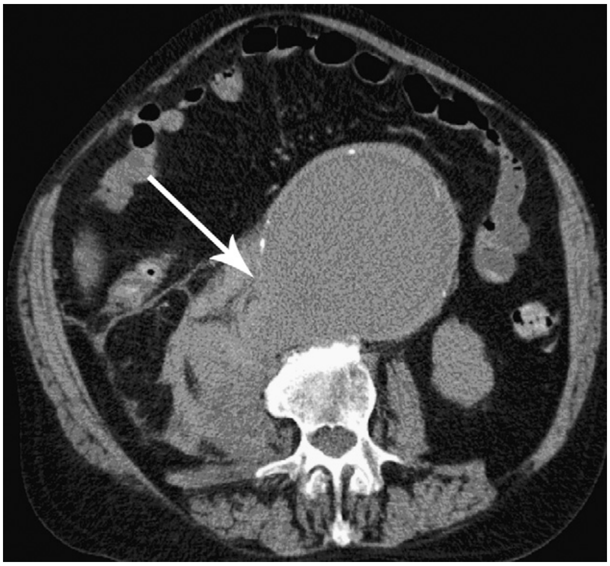

Fig. 1. Noncontrast computed tomography of the abdomen demonstrating a ruptured abdominal aortic aneurysm with right-sided, retroperitoneal extravasation.

immediately postoperatively and decreased to 0.7 mg/dL at discharge. CTA on postoperative day 1 was performed with 125 mL of iodinated contrast which demonstrated no endoleak. His intensive care unit (ICU) stay was 1 day, and his hospital length of stay was 5 days. At 7.3 months postoperatively, he remains well without endoleak and unchanged renal function.

Case 3

A 67-year old man presented with an rAAA because of a type Ia endoleak. The patient had a history of an EVAR 3 years before his presentation. On physical examination, he was alert with stable vital signs. His preoperative creatinine was 0.7 mg/dL. He underwent conversion of the migrated AneuRx graft (Medtronic, Inc., Minneapolis, MN) to an aorto-uniiliac stent graft down the left external iliac artery, embolization of the left hypogastric artery, placement of an iliac occluder in the right iliac limb of the bifurcated graft, and left to right femorofemoral bypass (Fig. 2). We used 580 mL of CO_2 and 17 mL iodinated contrast (to identify the internal iliac artery origin). Estimated blood loss was 500 mL; the patient received two units of blood during the operation. His maximum creatinine was 0.8 mg/dL, which decreased to 0.7 mg/dL at discharge. CTA on postoperative day 2 was performed with 120 mL of iodinated contrast which showed no endoleak. His ICU stay was 1 day, and his hospital length of stay was 3 days. At 8 months postoperatively, he required angioplasty and placement of a self-expanding stent

Fig. 2. Surveillance computed tomography angiogram demonstrating a patent aorto-uniiliac endograft conversion and femoral-femoral bypass placed for a ruptured abdominal aortic aneurysm secondary to a type Ia endoleak.

in the distal left external iliac artery stent graft because of stenosis and decreasing ankle-brachial indices. His renal function remains unchanged.

Case 4

A 59-year old man presented with left groin and back pain and a syncopal episode. On examination, he was found to be alert and stable, with a preoperative creatinine of 1.3 mg/dL. CTA demonstrated an 8-cm infrarenal rAAA. After the patient returned from CTA, he became hypotensive and required two units of blood. He underwent EVAR with a bifurcated endograft using 450 mL of CO_2 and no ICA. Estimated blood loss was 200 mL; however, he did not receive blood products or colloid. His maximum creatinine was 1.7 mg/dL, which decreased to 0.9 mg/dL at discharge. CTA on postoperative day 3 was performed with 110 mL of iodinated contrast and demonstrated no endoleak. His ICU of stay was 2 days, and his hospital length of stay was 4 days. At 1.2 months postoperatively, CTA demonstrated patent flow through his grafts without evidence of endoleak and unchanged renal function.

Table I. Comparison of patient groups

	Group 1 ($n = 4$)	Group 2 ($n = 7$)	p value
Age, mean ± SD	68.0 ± 6.68	72.7 ± 8.14	0.353
Male gender, n (%)	5 (100)	7 (100)	1.000
Mortality, n (%)	0 (0)	2 (28.6)	0.491
Creatinine clearance on admission (mL/min)	83.0 ± 27.9	47.1 ± 13.1	0.016
Change in creatinine between admission and discharge (mg/dL)	0.25 ± 0.19	0.58 ± 0.25	0.066
Operative time (min)	191.25 ± 36.29	251.14 ± 83.83	0.212
LOS (ICU), mean ± SD	1.00 ± 0.82	3.60 ± 3.44	0.187
LOS (Hospital), mean ± SD	4.25 ± 0.96	9.00 ± 6.60	0.202

There were no significant differences in the study groups other than a longer overall length of stay the patients undergoing open repair (group 3). Group 1: Ruptured abdominal aortic aneurysms (rAAA) treated with endovascular technique (EVAR) with carbon dioxide contrast. Group 2: rAAA treated with EVAR with iodinated contrast.

During the 18-month period under study, four patients underwent EVAR for rAAA with CO_2 angiography (group 1) and seven with iodinated contrast (group 2). In group 1, all patients underwent preoperative CT scans. Two were performed without contrast, and two with contrast at outside hospitals (volumes not available for our review). In group 2, one patient was diagnosed by ultrasound, and CT scans were performed in the remaining patients (again, the contrast volumes were unavailable). All endografts placed had suprarenal fixation stents. The mean age of patients in group 1 was 68.0 ± 6.68 as compared with 72.7 ± 8.14 in group 2 ($p =$ 0.353). Preoperative creatinine clearance in group 1 was 83.0 ± 27.9 mL/min compared with 47.1 ± 13.1 mL/min in group 2 ($p = 0.016$). Patients in group 1 received 443 ± 99 mL CO_2 those in group 2 received 33 ± 60 mL ($p < 0.001$). Interoperative iodinated contrast volumes were 4.3 ± 8.5 mL in group 1 (only one patient received iodinated contrast) and 110.2 ± 37.6 mL in group 2 ($p <$ 0.001). The overall mortality in group 1 was 0% and in group 2 it was 28.6% ($p = 0.491$; Table I). In patients who survived to discharge, the change in creatinine between the period of admission and discharge was greater in group 2 as compared with group 1, although this did not reach statistical significance (0.25 ± 0.19 mg/dL in group 1 vs. 0.58 ± 0.25 mg/dL in group 2, $p = 0.066$). All patients surviving their procedure underwent CT angiography before discharge to rule out an endoleak. The total volume of iodinated contrast administered during the hospitalization was lower in group 1 (124 ± 11 mL) compared with group 2 (213 ± 99 mL), although this difference was not significant ($p = 0.116$). Length of stay was not statistically different for ICU (1.00 ± 0.82 days for group 1 vs. 3.60 ± 3.44 days for group 2, $p = 0.187$) or overall hospitalization (4.25 ± 0.96 days for group 1 vs. 9.00 ± 6.60 days for group 2, $p = 0.202$). Mean operative time in group 1 was 191.25 ± 36.29 minutes, as compared with 251.14 ± 83.83 minutes in group 2 ($p = 0.212$).

There were no cases of postoperative pancreatitis and gas embolization in either group. In group 1, there was one case of atrial fibrillation, one iliac limb stenosis requiring repeat angioplasty and stenting, and one late occlusion of the common femoral artery requiring endarterectomy. In group 2, there were two deaths, one non-ST elevation myocardial infarction, two cases of abdominal compartment syndrome requiring decompressive laparotomy, one case of colonic ischemia requiring colectomy, two type II endoleaks, one acute pulmonary embolism, two seromas, and one case of transient hyperbilirubinemia.

DISCUSSION

We present a small series of four patients who underwent successful EVAR for rAAA using primarily or solely CO_2 as a contrast medium. These patients were compared with those undergoing EVAR with iodinated contrast as the primary contrast agent. There were two in-hospital deaths, both of which occurred in patients who had undergone EVAR with iodinated contrast. There was no statistical difference in the mortality rate between groups. In the CO_2 group, worsening renal function did not develop in any patient[9] and all were discharged with normal creatinine values. Although there were no statistically significant differences, one of the five patients in the iodinated contrast group who survived to discharge had an elevated creatinine at discharge. One patient who underwent EVAR with iodinated contrast, subsequently suffered permanent renal failure as a complication of a thoracic endograft placed emergently for an expanding type IV thoracoabdominal aneurysm which covered the renal ostia. A planned renal debranching procedure was not performed given the patient's poor clinical condition. Hence, the renal failure in this case was not related to the initial EVAR procedure. All other patients maintained normal renal function during follow-up.

Patients presenting with acute rupture of abdominal aortic aneurysms have a high mortality and morbidity. Postoperative mortality rates range from 26 to 45% for open repair of ruptured aortic aneurysms.[2-5] The mortality is secondary to multiple organ system failure in many patients, and renal failure is a major contributor to it.[10]

Endovascular repair has the advantage of limiting the physiologic insult to the patient. Given the lack of substantial improvement in the outcomes for ruptured aortic aneurysms, there has been a shift in management toward endovascular treatment. A recent survey of Medicare patients undergoing treatment for rAAA through either open repair or EVAR demonstrated a decreased mortality rate for EVAR after propensity matching for the cohort.[3] Over the past decade, several studies demonstrated decreased mortality with EVAR for the treatment of rAAA, ranging from 18 to 40%,[11-13] albeit with significant heterogeneity in the studies and potential for bias.

Renal failure after EVAR for rAAA ranges from 5 to 23%,[11,12,14] which appears to be lower than renal failure after open surgical repair, which occurs in 16-35% of cases.[11,14-16] Deterioration in renal function has been documented after the endovascular repair of abdominal aortic aneurysms, and is a significant independent predictor of postoperative mortality.[5] Although the pathophysiology of this dysfunction is not entirely clear, the use of iodinated contrast is a likely contributor.[17] The use of CO_2 as an angiographic contrast agent was first reported by Moore and Braselton in 1940 during pulmonary venography.[18] Since then, CO_2 has been used rather extensively for arteriography but very sporadically for EVAR. A randomized trial comparing CO_2 with ICA as contrast agents for renal angiography demonstrated a significant reduction in renal dysfunction when CO_2 was used.[19] In our report of the use of CO_2 contrast for elective EVAR, we found stable or improved renal function at discharge in all patients who were not on hemodialysis preoperatively.[8] CO_2 has several other properties making it advantageous for treatment of ruptured aneurysms. In addition to its well-known lack of renal toxicity, CO_2 lacks allergic response, is easy to handle, and is inexpensive It can be injected directly through the graft's delivery system, which decreases the required number of catheter and sheath exchanges, and may thus be helpful in unstable patients allowing for faster exclusion of the ruptured aneurysm and less time in the operating room. In patients with rAAA who require proximal aortic occlusion, imaging of the renal arteries may be difficult with conventional ICA injection, because the static blood column is not completely displaced by iodinated contrast. However, the buoyant property of CO_2 allows it to displace blood, which improves visualization of the branches in most cases.[20] In some patients, the renal or hypogastric arteries may be difficult to visualize, and may require placement of an endhole catheter close to the suspected arterial origins (Figs. 3, 4), with lateral table tilting, or occasionally use of small amounts of iodinated contrast.

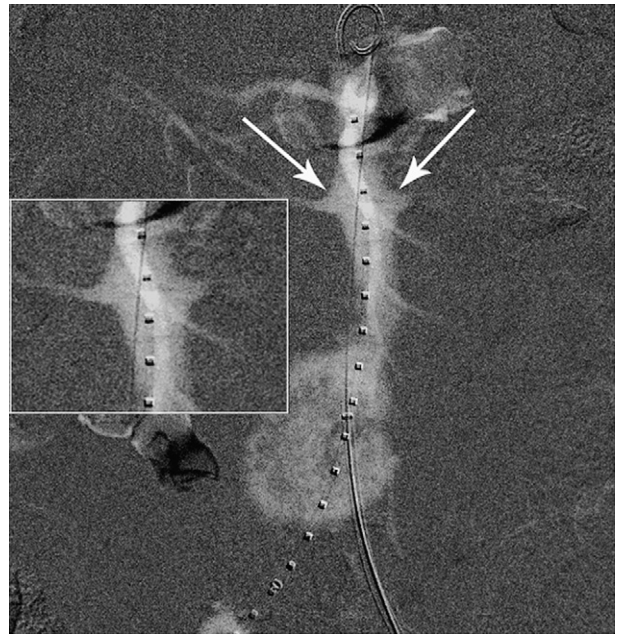

Fig. 3. CO_2 angiogram demonstrating renal artery origins (*arrows*) and mesenteric vessels in a ruptured abdominal aortic aneurysm. Close-up view of the renal artery origins (Inset).

Another advantage of CO_2 is that there is no need for a power injector, which makes the technique accessible to practitioners in facilities lacking the additional personnel to control the injector in emergency cases.

Although our experience using CO_2 for EVAR in patients with rAAA is encouraging, the cohorts in this study are very small and therefore do not allow us to draw conclusions aside from safety and technical feasibility. The rate of renal dysfunction in this study was very low in all groups, and therefore our ability to detect improvements in renal function is limited. The baseline estimated glomerular filtration rate was significantly lower in group 2 than in group 1, lending heterogeneity to our patient population and possibly affecting outcomes. Another limitation of this study is that, although all patients

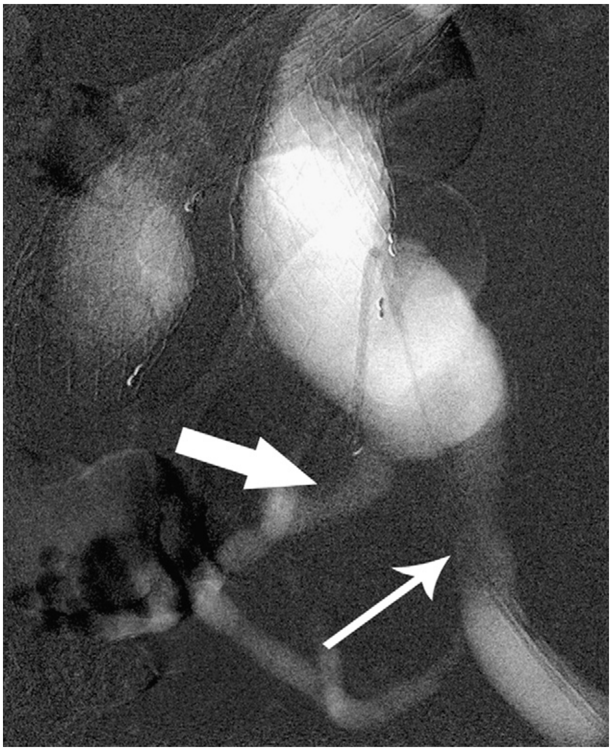

Fig. 4. CO_2 angiogram of a left iliac artery in a patient with a ruptured abdominal aortic aneurysm because of a type Ia endoleak. Identified are the internal iliac artery (*wide arrow*) and the external iliac artery (*thin arrow*).

underwent preoperative CT scans, most were obtained from outside institutions and the contrast volumes administered were not available for our review. We are, however, encouraged by the trends we see in this small series and plan to continue accruing cases to determine whether the use of CO_2 angiography will shorten operative times significantly, decrease risk of renal dysfunction, and lead to improved survival outcomes.

In summary, our experience suggests that endovascular repair of rAAA using CO_2 as the angiographic contrast agent is feasible and safe. CO_2-guided EVAR appears best suited for rAAA. Its potential for a reduction in renal dysfunction and mortality warrants further investigation.

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