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Original Article

Endovascular aortic repair via carbon-dioxide imaging in renal insufficiency?

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Abstract

Aim: In our study, we aimed not only if CO_2 is a safe and effective vascular roadmap for EVAR procedure instead of ICM but if it is a feasible opportunity for patients with hostile neck anatomy as well.
Material and Methods: From January 2019 to July 2022, 42 patients with renal insufficiency had elective EVAR procedures for infrarenal abdominal aortic aneurysm in our Cardiovascular Surgery Clinic with CO_2-guided DSA.
Results: There were no conversions to open surgery or no need for ICM for the CO_2-guided DSA. Technical success for CO_2 guidance EVAR was 100% with the second shot. There was no decline in GFR values, only one patient showed transient manifestations of CIN without need for hemodialysis.
Conclusion: CO_2 DSA is a safe and effective technique that can guide not only the standard but endovascular procedures with a hostile neck for renal insufficiency below the diaphragm allowing virtually unlimited images. With modern automated closed systems, CO_2-specific complications will be negligible if the operator has experience with the limitations and contraindications of the technique.

Keywords: EVAR, Carbon dioxide angiography, renal insufficiency, hostile neck anatomy

INTRODUCTION

Endovascular aneurysm repair (EVAR) is a less invasive, less mortal treatment option for aortic aneurysms when compared to open surgical repair and today is the treatment of choice for almost all anatomically suitable cases [1]. Iodine contrast medium is the gold standard in endovascular procedures, however, nephrotoxicity and hyperallergic reactions limit its use. Among the EVAR patients, 7-12% have potential nephrotoxicity risk [2]. Acute renal injury incidence was reported as 2-16% [3-7] after contrast-enhanced computerized tomography and peripheral angiography.

Increasing use of ICM in diagnostic and interventional procedures

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causes an increase in renal function impairment called Contrast-induced nephropathy (CIN). CIN has been defined as an increase of 25% or more or an absolute increase of 0.5 mg/dl or more in serum creatinine (sCr) from baseline value at 48-72 hours following exposure to contrast media. A more reliable indicator is the estimated glomerular filtration rate (eGFR) [8-13]. Hydration protocols, various oral medications, and cessation of certain medications are thought to be renal protective [14-17]. CO_2 was initially described as a contrast media in the 1970s by Hawkins who inadvertently injected air into a celiac artery [18]. CO_2 is a naturally occurring neutral, colorless, odorless gas with rapid complete intravascular clearance by the lungs at the first pass. CO_2 is highly buoyant opacifying the anterior portion of the target vessel. Since CO_2 is a negative contrast agent imaged using the DSA technique, bowel gas, peristalsis, and other motion degrade imaging quality.

In our study, we retrospectively revealed our patients who had compensated renal failure (eGFR <60 ml/min/1.73m^2) and had elective EVAR procedures for infrarenal abdominal aortic aneurysm since January 2019. We wanted to share our experience with CO_2 angiography, the feasibility, and important issues of this procedure in standard or hostile neck anatomy.

MATERIAL AND METHODS

After ethics committee approval (03.02.2021 No: E1-21-1485), from January 2019 to July 2022, 42 patients who had elective EVAR procedures for infrarenal abdominal aortic aneurysm in our Cardiovascular Surgery Clinic with CO_2-guided DSA were researched retrospectively. This was 11.35% of our elective EVAR patients suffering from renal insufficiency who had infrarenal abdominal aortic aneurysms and were treated endovascularly in elective manners, during that period. Urgent patients and chronic hemodialysis patients were excluded from the study. All patients were male except three and the average age of the patients was 74.1±5.03 years (66-84 years). The preoperative patient profile is given in Table 1. Twelve patients were not suitable for instructions for use (IFU) because of hostile neck anatomy where two patients with over 60 degrees of angulation, one short and wide neck (8 mm and 36mm infrarenal abdominal aortic neck diameter) and others having necks shorter than 15mm. For all patients, Lifetech Ankura™ AAA Stent Graft (Lifetech, Shenzen, China) was used which has ePTFE material with nitinol endoskeleton.

The standard evaluation and preparation used for catheter-based angiography with a contrast medium are also used for CO_2 angiography. All procedures were performed with the same cardiovascular surgical team. There are multiple options for CO_2 delivery from its source, however, we used Angiodroid (SRL San Lorenzo di Savena, Italy) automated CO_2 injection system for delivery.

Table 1. Patient preoperative characteristics

	n (%)
Diabetes Mellitus	11 (26.2%)
Hypertension	28 (66.6%)
Coronary artery disease	21(50%)
Chronic obstructive pulmonary disease	10 (23.8%)
Peripheral arterial disease	8 (19%)
Congestive heart failure	8 (19%)
Serum Creatinine (mg/dl)	1.9 ± 0.5
Glomerular Filtration Rate	40.7 ± 12.3
Instructions for use compatibility	12 (28.6%)

The primary endpoints of the study were the pre-postprocedural estimated Glomerular filtration rate (GFR), serum creatinine levels at the postoperative 1, 2, 3 days, absence of type I or III endoleak at the completion angiography, and the periprocedural morbidity and mortality. Secondary endpoints were the follow-up controls and renal functions in the first postoperative month. Any type of endoleak or migration and renal function parameters were studied.

Definitions CIN was defined as impairment of kidney function, measured as either a 25% increase in sCr from baseline or a 0.5 mg/dL increase in absolute sCr value within 48 hours after intravenous contrast administration. Early mortality was defined as 30-day and/or in-hospital mortality.

Anesthesia Type and Technique

General anesthesia was used for all patients. In this way, there was no patient movement and pain achievement was sufficient. As degradation of images by motion artifact was possible, we preferred general anesthesia to provide better images and motion-less of the patient, especially during the learning curve period. Nitrous oxide anesthesia also should be avoided with CO_2 as nitrous oxide can diffuse into the CO_2 bubble increasing the volume and gas entrapment as vapor lock. All images were taken in apnea status. In the perioperative period, we preferred volumetric and normotensive status, we closely monitored the urine output. Instead of inhalant anesthetic agents, we preferred totally intravenous anesthesia (TIVA) with short-acting low nephrotoxic propofol and remifentanil infusions. Preoperatively we administered NAC infusions and hydration (500-1000cc positive balance) according to the nephrologist's consult [14-17].

Carbon-Dioxide Delivery Systems

There are multiple options for CO_2 delivery from its source, including the hand injection purged syringe method, plastic bag system, automated CO_2 injectors, and portable closed system platforms. We used Angiodroid (SRL San Lorenzo di Savena, Italy) automated CO_2 injection system, which was one of the newest generations, offering computerized operation and a highly controlled delivery.

After standard preparation of the patient with heparin administration and bilateral femoral surgical exposure, deployment of the endograft was guided with carbon dioxide given by the "Angiodroid" automated CO_2 machine. The connecting tube for carbon dioxide has a one-sided valve on the pigtail side and opens on the other side which plugs into the Angiodroid machine with a medical CO_2 tube attached inside. At first, sufflation of CO_2 was performed and the valve automatically closes. So, in this manner, there is only CO_2 in the tube with no air contamination. Both Volume and Pressure depend on the injection site and the body district of interest. According to the patients' aneurysm size, 80-100 ml of CO_2 at 400-500 psi pressure was given. Completion angiography was performed on all patients with CO_2-guided DSA. For the first injection, these settings were performed. For every consecutive image, CO_2 delivery had a waiting period to avoid gas entrapment. This waiting period was of great concern for better image quality and the elimination of CO_2 from the aneurysm sac and always obeyed.

Statistical analysis

The variables were investigated using visual (histograms, probability plots) and analytical methods (Kolmogorov–Smirnov/Shapiro–Wilk test) to determine the normality of their distribution. Normally distributed continuous variables were expressed as mean ± standard deviation (SD), or median values with an interquartile range if not normally distributed. Categorical variables were expressed as numbers and percentages. Demographic characteristics, perioperative variables, and calculated values were compared using the independent Samples t-test or the Mann-Whitney U-test for continuous variables, and the Chi-Square test or Fisher's Exact Test for categorical variables. A general linear model was used to determine the course of GFR levels over time. A p-value of <0.05 was statistically significant, and all other statistical analyses were performed using the SPSS for Windows version 15.0 statistical software program (SPSS Inc., Chicago, IL, USA).

RESULTS

There was no conversion to open surgery or no need for ICM for the CO_2-guided DSA. Technical success for CO_2 guidance EVAR was 100% with the second shot. We did not necessitate a second shot in 75% of the patients. Figure 1 demonstrates the renal target vessels clearly with CO_2 DSA. The rate of diluted contrast media usage (needed for accuracy) of endoleaks was 11.9% (5/42 patients). When compared to unpublished data with ICM, duration of surgery, and fluoroscopy time were similar. The perioperative and postoperative follow-up data are given in Table 2. No preoperative diet or patient position was given for a better image. There was no early morbidity or mortality except for one incisional infection. There was no decline in GFR values, only one patient showed transient manifestations of CIN without need for hemodialysis. All patients were discharged on the third day after the serum creatinine levels were controlled. IFU noncompatible patients with hostile neck anatomy were also successfully treated with CO_2-guided EVAR. The average fluoroscopy time was 10.4±3.6 minutes (6-18 minutes), slightly longer than the standard EVAR procedures (9.2±3.9 minutes). All patients were guided with sole carbon dioxide DSA.

Figure 1. *CO_2 DSA*

One patient had type 1b, two patients had type 2, and one patient had type 3 endoleak. Both type 1b and 3 endoleaks were ballooned, only two type 2 endoleak were left to follow up. Figure 2A and 2B show the endoleak before and after ballooning. The follow-up protocol was built up as mainly colored doppler ultrasound for the first, sixth month, and annually thereafter [19]. Sac enlargement and endoleak were closely followed up with two doppler operators. Follow up period was 17.2 ± 6.5 months on average. In the follow-up period, there were two cardiac mortalities at the 11th and 14th months. There was no aneurysm-related renal morbidity or mortality.

For all patients, serum creatinine levels were controlled on the 24th.,48th., and 72nd. hours. Also, in the follow-up, in the first and sixth months patients were under control with the blood samples, routinely, and colored abdominal aortic doppler ultrasound. In this limited patient cohort, there were no endoleaks detected or sac enlargement therefore computerized tomographic angiography was not necessitated. There was no significant difference in pre-postoperative creatinine values (Table 2). There was no decline in GFR values, only one patient showed transient manifestations of CIN without need for hemodialysis.

All patients were routinely hydrated and consulted with the nephrologists preoperatively. For the early period, reductions in the renal dysfunction parameters were thought to be due to the medical protocols and infusions given by nephrologists.

Table 2. Serum creatinine and e-GFR levels showed no improvement in renal impairment

	Serum creatinine level (mg/dl)	Estimated GFR
Preoperative	1.85 ± 0.55 (1.4- 3.4)	40.71 ± 12.33 (20- 59)
Postoperative 48th hour	1.76 ± 0.54 (1.1- 3.0)	41.64 ± 13.95 (20- 61)
Postoperative 72nd hour	1.67 ± 0.56 (1.2- 3.3)	44.57 ± 12.83 (22- 62)
Postoperative first month	1.72 ± 0.63 (1.4- 3.5)	43.29 ± 13.04 (24- 60)

GFR: Glomerular Filtration Rate

Figure 2 A-B. *Endoleak before and after*

DISCUSSION

Diagnostic or interventional ICM has the potential risk of acute renal deterioration, where perioperative renal insufficiency is related to higher morbidity, mortality, a longer length of stay in the hospital, the way, increased costs. Alternative routes to reduce the risk of contrast-associated complications, the best solution seems to be CO_2-guided DSA for today. The lack of increased serum creatinine and decreased GFR levels during the first 72 hours and in the first-month follow-up in our study, suggests CO_2 is a suitable method for EVAR patients with renal dysfunction. 100% technical success and satisfactory results with hostile neck anatomy confirm the safety and efficacy of CO_2-guided EVAR. Figure 3A and 3B shows the preoperative and postoperative images of hostile neck patient. Currently, CO_2 has been used as an intravascular alternative to ICM for over three decades. Since the first administration of CO_2 as a contrast agent by Hawkins, concerns about the basic principles and limitations are well studied [20-26]. We did not perform any medical preprocedural preparations for the patients or the position of the table for obtaining better images. Images in our EVAR patients in 2 shots were sufficient for successful deployment. Having no side effects, CO_2 delivery of 80-100 ml was administered consecutively if needed only with 60 seconds of waiting interval. This waiting period is obligatory for the elimination of the gas without any trapment and the quality of the next image. The quality of the first aortogram varies, as the pigtail may not be positioned properly. Almost always after placing the pigtail in the right position just below the renal arteries and maintaining the blood pressure, the image for deployment was achieved at the first or the second shot. A completion angiogram should be taken with the pigtail inside the endograft. Our study showed performing the reflux technique with the placement of the pigtail catheter below the renal arteries and confirmation with preoperative planning and measurements will be satisfactory for successful deployment.

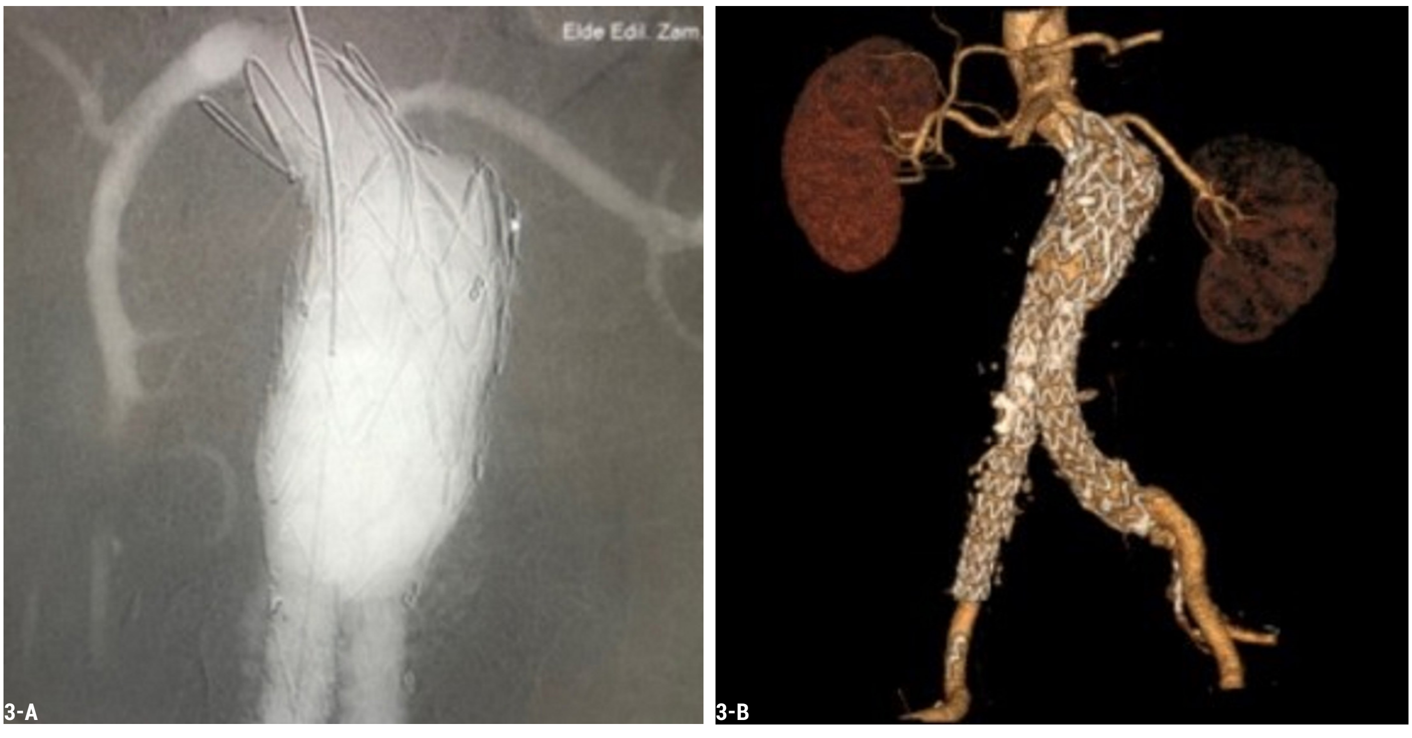

Figure 3 A-B. *Hostile neck patient*

CO_2-specific potential complications almost always occur because of excessive volumes of CO_2 administered in a short time and possible air contamination. Trapment of CO_2 preventing blood flow and producing a barrier is the main event. The incidence of adverse effects varies considerably due to operator experience and delivery techniques from rare to as high as 17% [27-29]. The overall complication rate appears to diminish after the adoption of closed automated CO_2 delivery systems. Rundback et al reported 7,3% minor and 1,1% major complications with CO_2 in their review before 2000 [30]. We had no CO_2-related complications, there was no decline in GFR values, and only one patient showed transient manifestations of

CIN without the need for hemodialysis.

Injection of CO_2 into the abdominal aorta may cause epigastric pain, and nausea that may usually last a few minutes, due to transient CO_2 entrapment in the mesenteric arteries. Because of the rapid dissolution and one-pass elimination by the lungs, there is no maximum CO_2 dose when less than 100 cc is injected every 60 seconds. CO_2 is used primarily for angiography except for cerebral or coronary circulations in patients with ICM allergy and renal failure. Because of the buoyancy of CO_2, it should not be given in a prone position which may cause spinal cord ischemia by filling the spinal arteries. General anesthesia is not obligatory however provides luxury for both patient and the medical team.

We did not find any difference between the scopy period and the procedure duration of CO_2 and ICM guidance EVAR. Waiting intervals between the CO_2 shots were negligible and were disregarded. In our patient cohort, CO_2 DSA during EVAR was efficient for renal artery targeting, iliac bifurcation, and detection of endoleaks after angiography. However, for patient safety, we checked completion angiograms for 4 patients and renal targeting in one obese patient with diluted ICM almost all at the learning curve period. During the follow-up period and the first 48-72 hours after the procedure serum creatinine levels and estimated GFR were stable. The higher GFR is thought to be due to hydration protocols and renal protection [Table 2]. Barbieri et al reported the ratio of contrast volume to creatinine clearance (V/CrCl) is used as an independent predictor of CIN following angiography in patients with or without impaired renal functions [31]. 50% dilution of the ICM is our clinical principle for every endovascular case.

In our country, CO_2 DSA found a place for peripheral vascular interventions mostly, maybe that is because the potential complications seem to be avoided while using CO_2 for the infra-inguinal part of the body. However, many reports claimed the safety and efficacy of the CO_2-guided EVAR procedures with negligible complications [20-22]. Cardiovascular or endovascular surgeons have traditionally been trained with the use of ICM for interventional procedures and very few are familiar with alternative contrast agents. This may be the most acceptable reason for anecdotal use of CO_2 DSA considering the larger number of endovascular patients annually.

Endoleak detection with CO_2 seems to be superior with the low viscosity and buoyancy of the CO_2 [32-34]. The buoyancy and low viscosity of CO_2 allow it to demonstrate even low flow endoleaks which results in nonvisibility in conventional angiography. Therefore, this may be a key issue for the endotension entity, recommending the idea of missed detection of a minor endoleak that may be captured by CO_2-guided DSA. For surveillance, colored doppler ultrasound was our primary tool, giving a high correlation with CTA for type I and III endoleaks and a very high correlation for sac diameter measurement.

The graft we used was Lifetech Ankura endograft made of ePTFE graft material. Garvin et al reported the possibility of visualizing endoleak through Dacron endograft under CO_2 angiography where endograft porosity was thought to be responsible [35].

With a limited number of patients resulted in no operative mortality, no conversion to open surgery, or reintervention in the follow-up. Our results are comparable with EVAR patients under optimal conditions with ICM usage. It is important to note that our experience includes the learning curve period and will improve with more experience. As this study was only about the feasibility of CO_2 guidance, there was no matched standard ICM-guided EVAR group, and the possible protective effect was not studied.

Conclusion

With modern automated closed systems, if there is experience with the limitations and contraindications of this technique, CO_2 DSA is a safe and effective way to guide endovascular procedures for renal insufficiency. For complex procedures, the amount of ICM use may be reduced.

Ethics Committee Approval: The study protocol was approved by the Ankara City Hospital Ethics Committee (03.02.2021 No: E1-21-1485). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: All authors contributed equally to the article.

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