

## Case Report

# Hyperbaric oxygen therapy in the treatment of carbon dioxide gas embolism.

R. GORJI<sup>1</sup>, E. M. CAMPORESI<sup>2</sup>

<sup>1</sup>Associate Professor, Department of Anesthesiology and Neurosurgery, SUNY Upstate Medical University Hyperbaric Center, Syracuse, New York 13210 [Gorji@Excite.com](mailto:Gorji@Excite.com); <sup>2</sup>Professor and Chairman, Department of Anesthesiology, Professor of Physiology, SUNY Upstate Medical University Hyperbaric Center, Syracuse, New York 13210, [campores@upstate.edu](mailto:campores@upstate.edu)

## INTRODUCTION

Patients with end stage renal disease requiring hemodialysis pose multiple clinical problems, among them provision of a trouble free permanent venous access. The atriovenous shunt, made of polytetrafluoroethylene (PTFE) is the most popular choice for such patients. When assessing the functionality of these grafts, a fistulogram is often a necessary prerequisite for any potential access revision. Iodinated contrast agents are associated with nephrotoxicity, which in patients with borderline renal function is problematic (1). Newer contrast agents are not totally devoid of undesirable nephrotoxicity (2). Often these patients acquire contrast dye allergies and offer additional therapeutic challenges.

Gaseous carbon dioxide (CO<sub>2</sub>) is an alternative in patients with contrast allergies who need a fistulogram. The work of Hawkins on carbon dioxide as a contrast agent has been instrumental in gaining acceptance in the radiology community (3, 4). Intravascular venous injection of CO<sub>2</sub> is usually well tolerated due to the high solubility of CO<sub>2</sub> in blood. Carbon dioxide is inexpensive, non-allergenic, and is devoid of known nephrotoxicity. However this procedure for radiographic visualization of fistulogram is not devoid of problems. Arterial gas embolism is an exceedingly rare complication of CO<sub>2</sub> injection in such patients. We review a case of a patient who suffered a possible retrograde arterial gas embolism following injection of CO<sub>2</sub> during a fistulogram.

### Case Report

The patient was a 79-year-old female with a history of end stage renal disease (ESRD) and contrast-dye allergy. The patient had a past medical history significant for coronary artery disease, a non-Q wave myocardial infarction, hypertension and hyperlipidemia. In addition the patient had a history of subclavian vein stenosis. She presented to a community hospital for evaluation of a malfunctioning left forearm arteriovenous fistula. A fistulogram using CO<sub>2</sub>

arteriography (fistulogram) was performed under fluoroscopic guidance by accessing the left forearm fistula using a 19-gauge needle. Imaging was performed through the loop graft to the superior vena cava. Immediately after injection of 20 cc into the fistula, the patient complained of an intense headache. While the headache resolved in a few minutes, she developed progressive aphasia, right upper extremity weakness, visual disturbances and hypertension (B/P 240/140). She became poorly responsive to commands. An immediate CT scan was performed which showed diffuse cerebral atrophy with no evidence of hemorrhage or edema. The procedure was halted and patient transferred to the emergency room. After telephone consultation, she was transferred to our institution for recompression treatment. On presentation to us, the patient was awake but incoherent and did not follow commands. Furthermore, the neurological exam revealed a left facial droop, flaccid right upper extremity, diminished lower extremity reflexes and a right lower extremity that responded only by withdrawing to pain. The patient's vital signs were remarkable only for hypertension. ECG showed a right bundle branch block. Follow up CT scan (~3 hours later) showed new areas of hypodensity. Because the suspicion of embolism was high, the patient received emergent hyperbaric oxygen (HBO<sub>2</sub>) at 3.0 ATA for 90 minutes beginning four hours after the fistulogram. Her mental status improved rapidly after 15 minutes at 3 ATA: she began moving all extremities, voiced concern, recognized her son through the chamber walls and conversed rationally with the treating team. The patient tolerated the hyperbaric treatment well and after treatment continued to improve clinically. A subsequent electroencephalogram showed a profoundly abnormal tracing with slowing and burst suppression suggestive of a significant insult to the brain. An MRI, third day post-incident, revealed infarctions in the frontal, parietal and occipital regions bilaterally. Upon discharge from the hospital her neurological status was back to her baseline.

## **DISCUSSION**

### **Carbon dioxide as a contrast agent**

The use of CO<sub>2</sub> gas as a contrast agent was first described by Dotter and Judkins (5). CO<sub>2</sub> is nontoxic and non-allergenic, rapidly absorbed by blood, and then excreted by the lungs. Because of the lack of hyperosmolality and nephrotoxicity, CO<sub>2</sub> is useful in patients with end stage renal disease and those where preservation of renal function is paramount. The mixture of CO<sub>2</sub> and blood results in an increase in radiographic density. The viscosity of CO<sub>2</sub> is 1/400th that of iodinated agents, thus it can be used to visualize stenotic vessels. This depends on several factors including blood volume and flow, rate and volume of contrast injected, and the degree of dilution with the blood. Once CO<sub>2</sub> is injected it immediately starts to dissolve in blood because of its high solubility. Sometimes the radiologist has to inject large volumes of CO<sub>2</sub> in order to visualize the structure of interest because not enough CO<sub>2</sub> will otherwise reach the area due to its blood solubility. Dissolved CO<sub>2</sub> is eliminated by the lungs in a single pass.

A simple method for carbon dioxide delivery involves hand injection with a 50 ml syringe along with a closed system reservoir bag. A purge syringe is used to rid the system of any air contamination. As CO<sub>2</sub> is denser than air, the syringe tip should point upwards so as to purge any air potential contamination. Standard injectors may also be used for CO<sub>2</sub> delivery. Limitations here related to air contamination. Dedicated systems for CO<sub>2</sub> injections are not available in the United States.

CO<sub>2</sub> is delivered in the form of compressed gas. Administration to the patient can pose a problem because a bolus injection can result in excess administration. Hand injection is the

simplest form of administration however this can result in an unpredictable bolus amount. The volume and rate of injection varies with the structure being studied. Ehrman and colleagues have described CO<sub>2</sub> embolization (6). Several of the patients in their study had seizures after injection of CO<sub>2</sub> into arterial anastomoses. Seizures were accompanied by respiratory arrest and loss of consciousness. The authors note that CO<sub>2</sub> injections may be safer for venous injection than arterial injections. Voochies describes a patient with air embolism (confirmed with high-resolution CT scan) during cerebral angiography (7). Cerebral CO<sub>2</sub> embolism during laparoscopic cholecystectomy is also reported in the literature (8). Other deleterious effects of CO<sub>2</sub> have also been described (9). With the use of dedicated CO<sub>2</sub> injectors, many of the problems unique to gas delivery system have been solved (10). More recent advances in CO<sub>2</sub> delivery systems and its extension to new vascular interventional procedures have greatly expanded the usefulness of CO<sub>2</sub> angiography in both diagnostic and interventional vascular radiology.

### **Cerebral arterial gas embolism**

Cerebral arterial gas embolism has been well documented in the literature: gas embolism can occur with air but also with other medical gases such as nitrous oxide, and nitrogen (11, 12). Iatrogenic causes of arterial gas embolism include mishaps in renal dialysis and during operations requiring extracorporeal bypass (13, 14).

The pathophysiology of arterial gas embolism is one of deteriorating end organ function. Embolization of small amounts of air into coronary arteries leads to ischemia, infarction, dysrhythmias, and heart failure (15). Cerebral gas embolization reduces perfusion pressure and causes an inflammatory-thrombotic response (16). In addition to acute hypoperfusion and ischemia from mechanical obstruction of arterioles as a cause of pathology, it has been shown that bubble contact affects venous (17) and arterial (18, 19) endothelium without vascular occlusion, resulting in activation of leukocytes and coagulation, which interfere with normal blood rheology, e.g. causing low cerebral blood flow.

The neurological signs and symptoms of cerebral gas embolism can be non-specific and include loss of consciousness, seizures, coma, hemiparesis, and other focal deficits (20). Other symptoms include asymmetrical pupils, hemianopsia, and impairment of control of circulation and respiration. In patients undergoing operations, delayed recovery from general anesthesia should arouse suspicion when the procedure carried a high risk of gas embolism. Failure to recognize gas embolism promptly as a cause of neurological symptoms may result in poor outcome despite therapy.

The most important clue to the diagnosis is the history, especially the temporal relationship of symptom onset to a high risk clinical scenario. CT scan is not a valuable diagnostic tool in early diagnosis, as air and CO<sub>2</sub> are absorbed rapidly. Procedures with a potential for air embolism (vein and artery) are given in Table 1.

### **Treatment**

Treatment of arterial gas embolism should be instituted as soon as possible in order to protect against organ ischemia and infarction. Removal of the air source, administration of 100% oxygen (21) and the use of HBO<sub>2</sub> to reduce the volume of the bubble are steps to be taken. Mechanical ventilation with FIO<sub>2</sub> of 1.0 has been shown to aid in removal rate of air from cerebral arteries (22). HBO<sub>2</sub> therapy also serves as a mechanism to compress and reduce the size of the bubble. Both normobaric and hyperbaric oxygen create a diffusion gradient for the egress of inert gas from the bubble into the circulation. Patient position is important (probably only to

maintain blood pressure and CPP; buoyancy effects are probably minimal. Avoiding a head-down position helps avoid cerebral edema. A supine position is probably best as the embolic bubbles do not have sufficient force and buoyancy to counteract blood flow and thus cannot enter the cerebral circulation (23).

**Table 1:** Situations with high probability of gas embolism

Sitting craniotomies
Hip replacement
Caesarian section
Cardiac surgery in conjunction with cardiopulmonary bypass
Rapid ascent or breath hold ascent from a scuba dive
Aspiration of venous air through an open central venous catheter

HBO<sub>2</sub> therapy is the treatment of choice in cases of arterial gas embolism. When a patient breathes 100% oxygen at higher atmospheric pressures (commonly 2-3 ATA), an arterial partial pressure of 2000 mm Hg is commonly achieved. The effect of increased pressure is two fold: mechanical compression of the gas emboli as well as creation of a diffusion gradient for gas emboli. The hyperoxic circulation serves to increase the oxygen delivery to tissues as well as offset some of the deleterious effects of an embolic insult (24). HBO<sub>2</sub> may also reduce blood brain barrier permeability (25, 26) and thus reduce cerebral edema. In addition, diminished adherence of white blood cells to air damaged endothelium has been demonstrated (27).

Immediate recompression in a gas embolism patient offers the best outcome (28), but delayed treatment may be efficacious (29). Treatment should not be based upon the ability to confirm the presence of gas using imaging techniques. CT and MRI are only useful to exclude other pathologies, if there is reason to suspect them (30).

In the current case, the patient’s immediate decompensation while a fistulogram was being performed pointed to the diagnosis of air embolism. While CO<sub>2</sub> was being injected, it is likely that the system was not “air tight” and air contamination occurred leading to air embolism and the clinical presentation. Another consideration is the presence of an unappreciated patent foramen ovale, which could have led our patient to suffer a paradoxical air embolism. We offer this case to alert clinicians to the possibility of air embolism during CO<sub>2</sub> arteriography.

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