Reprints: Volume 1, No. 1, 1996, p. 20–23.

Carbon dioxide angiography

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Abstract. Carbon dioxide angiography (CDA) has been used at The Royal Melbourne Hospital For over two years for angiography below the level of the diaphragm. The use of a specialised injector system with predictable and non-explosive delivery of gaseous carbon dioxide and the use of digital subtraction techniques provides vessel opacification comparable to that achieved with iodinated contrast. The gas dissolves rapidly in blood and is eliminated by the lungs. It does not affect renal function. CDA is primarily indicated in the diagnosis of vascular disease in the patient with impaired renal function or contra-indication to iodinated contrast.

Key words: Carbon dioxide angiography (CDA), Radiographic contrast media, Renal failure

Introduction

During the last two decades advances in surgical and percutaneous interventional radiology techniques have demanded more sophisticated imaging. Interventional radiological techniques may require very large amounts of contrast which can limit the extent of the procedure and add to the patient's risk. Even with the new and expensive non-ionic iodinated contrast media, contrast induced nephropathy is a significant problem which may develop in any patient even without the risk factors of diabetes and renal insufficiency [1,2].

Carbon dioxide (CO_2) gas is eliminated from the blood by the lungs in a single pass and blood has an efficient means of carbon dioxide transport thus it offers an alternative to iodinated contrast for angiography. Carbon dioxide was first used by radiologists in the 1920's to visualise the retroperitoneum, and in the 1950's it was injected intravenously for detection of pericardial effusion [3,4] but because of its low density it required large volumes to be visible on unsubtracted images. Hand injection of small volumes of carbon dioxide is possible. However, due to the compressibility of the gas, it is possible for the plunger of the syringe to move forward easily until the pressure of resistance from blood in the tip of the catheter is overcome, and the gas explodes from the syringe. A further problem is ensuring that the gas in a hand filled syringe is free of air. Until recently we have lacked a safe method of delivery of the carbon dioxide which overcomes the problem of explosive delivery of the gas and effective dose control.

This report details our experience with a specialised carbon dioxide injector for angiography (CO_2-Ject®, Angiodynamics Corporation) and the effects of CDA on patients with renal insufficiency who required angiography.

Methods

From among the patients, referred for angiography, only those with a history of allergy to non-ionic contrast media and with renal insufficiency were selected to have carbon dioxide angiography. A total of 28 patients with renal insufficiency had serum creatinine measured before the CDA, 24 hours and 1 week after the injection of carbon dioxide. No other contrast agent was used for the angiogram.

Three patients who had prior documented severe adverse effects as a result of non-ionic contrast media were examined with carbon dioxide as the only contrast medium. A further 102 studies were performed by using a combination of carbon dioxide and non-ionic iodinated contrast media.

Film quality was assessed using a five point scale given below.

0. Absolutely inadequate
1. Almost inadequate
2. Diagnostic-quality less than iodinated contrast
3. Diagnostic-equivalent to iodinated contrast
4. Excellent quality or special advantage.

Films showing special advantage were those in which the carbon dioxide by virtue of its low viscosity identified low rate bleeding, portal vein filling or other features not seen on the comparable iodinate contrast images. A total of 51 patients had duplicate films run obtained with both types of contrast on the same day which could be exactly compared. All carbon dioxide angiogram were graded for quality even if no equivalent iodinated contrast examination was performed.

For venous carbon dioxide injections, hand injections were made using a three-way stopcock and a 10 ml and a

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25 ml syringe. The smaller syringe was used to clear the catheter of blood just before the larger syringe was injected to remove resistance at the catheter tip. Carbon dioxide was supplied from a disposable cylinder using a micropore filter. Recently, a low pressure carbon dioxide delivered system for hand injections had become available which removes the possiblility of air contamination [5].

For arterial injections, a specialised rate controlled carbon dioxide injector was used (CO_2-Ject®, Angiodynamics Corporation). This injector provides computer controlled non-explosive and reproducible delivery of carbon dioxide at rates from 1 to 200 cc per second and to a total volume of 2000 cc. The usual injection parameters are shown in Table 1 but the actual amount used depended on the size of the artery being examined.

Table 1. Representative carbon dioxide gas injection parameters at 1 atmosphere pressure and room temperature (After Hawkins)

Region	Rate (cc/sec)	Volume (cc)
Abdominal Aorta	100–150	50–100
Iliac or Pelvic Artery	40–80	40–60
Lower Limb (selective)	10–20	20–40
Dialysis Fistula	10–20	20–40
Arm Venogram	10–20	20–40
Vena Cava Gram	50–100	40–50
Selective Renal Artery	10–20	10–20
Mesenteric Artery	10–20	20–40
Direct Portography	50–100	40–50

The production model of the injector, which arrived near the end of this study, also provided an integrated iodinated contrast injector (Angomat® 6000) and full patient monitoring with a video display of E.C.G., invasive blood pressure waveforms, pulse, oxygen saturation, respiration and non-invasive automatic peripheral blood pressure.

For abdominal examinations intravenous Hyoscine-N-butylbromide 20 mg (Buscopan, Boehringer Ingelheim) or Glucagon 1 unit (Lilly) was injected just prior to the carbon dioxide. A one second delay between film and contrast injection was used and films made at 5.1 images per second for 3 seconds and 2 per second for 5 seconds. Filming was stopped when the gas disappeared. For iodinated contrast, the maximum film rate was 3.2 images per second but other parameters remained the same. Exposure setting were identical for both types of contrast. For carbon dioxide injections the target area was elevated until the injection was complete. In the case of the lower limbs an elevating table was placed under the legs.

After each injection the patient was rotated or the legs lowered to ensure that no carbon dioxide was trapped in tortuous vessels.

Results

Almost all the patients experienced a sensation of heat or tingling with each injection. Since no patient received any sedation prior to the injection the patient responses varied widely. Two patients developed a severe but brief pain in the abdomen which eased after 2 minutes. In one of the patients this caused such movement that the examination was totally inadequate. After the first injection, patient response was much less and as a result we routinely employed a "test" injection of a small amount of carbon dioxide to reassure the patient before films were obtained.

Renal CDA was not associated with any change in serum creatinine or worsening of renal function in the 28 persons who did not receive iodinated contrast. No reaction was observed in the patients who had prior iodinated contrast reactions (Fig. 1).

Film quality of CDA was judged to be excellent in eleven patients and in 22 patients (78%) the film quality was judged to be diagnostic or better (Fig. 2). One of the iodinated

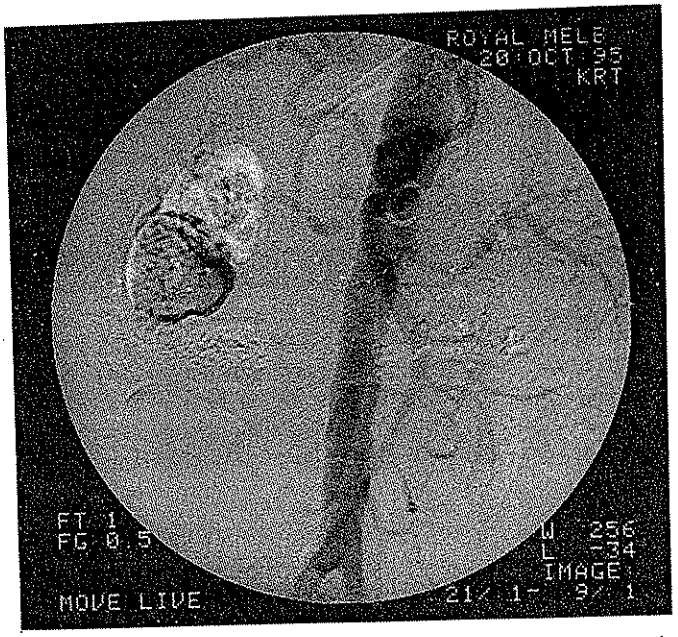

Fig. 1. Aortorenal CDA. Oblique view of the renal areas. The left renal artery is normal. The stenosis in the proximal right renal artery is well seen. Injection parameters 50 cc carbon dioxide at 100 cc per second

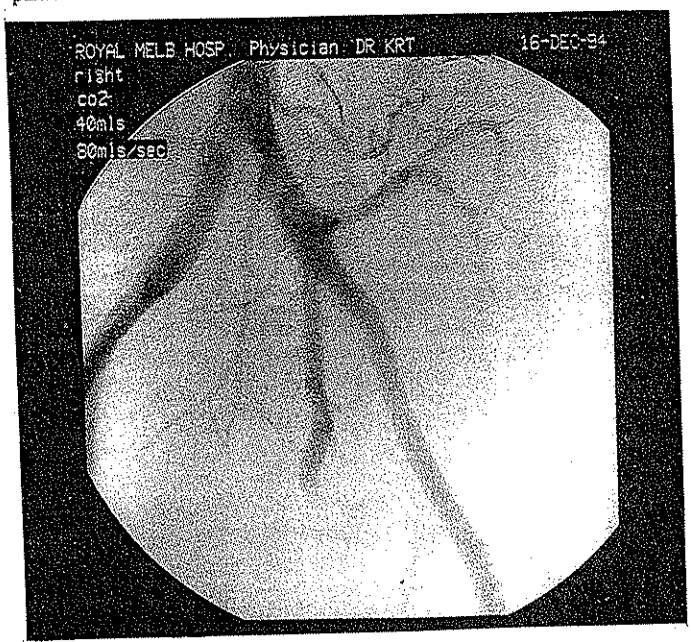

Fig. 2. Renal transplant CDA. Multiple oblique views were obtained with carbon dioxide until the exact projection to show the proximal anastomosis was found. This film shows no stenosis. The CDA does not normally show the renal vein or nephrogram. Injection parameters 40 cc carbon dioxide at 80 cc per second

contrast examinations was judged inadequate due to patient motion and large amount of bowel gas.

Discussion

Carbon dioxide has been used safely for over two years in our hospital and others [6,7] have reported similar results in over 1000 patient examinations. Comparison studies in lower limb CDA [8] showed that in over 90 per cent of patients there was equivalent image quality and therapeutic plan agreement between iodinated contrast DSA and CDA.

Unlike water soluble contrast agents carbon dioxide "floats" on the blood until it is absorbed. The gas bubble displaces the blood from the vessel transiently and if under-filled only the upper portion of the blood vessel will be imaged (Fig. 3). Once the vessel is completely filled, further injection of carbon dioxide does not improve image quality [9]. In the lower limb the use of selective injections and vasodilators improves distal filling with carbon dioxide (Fig. 4).

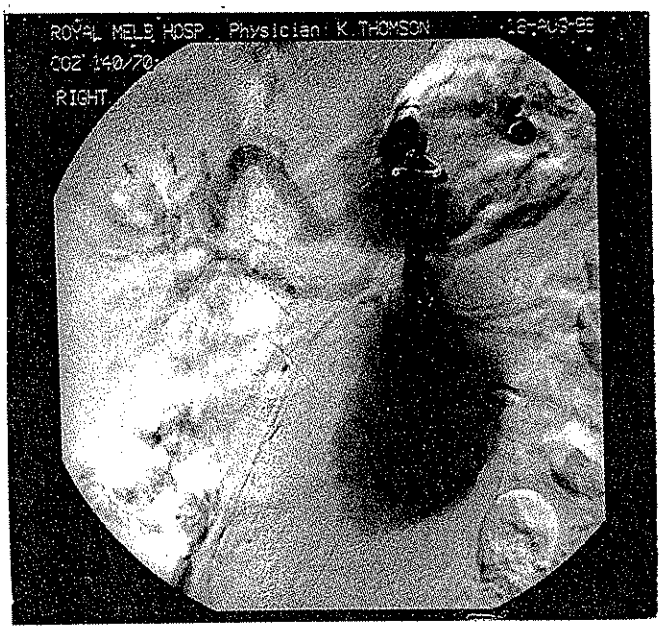

Fig. 3. Renal CDA in a patient with a large abdominal aortic aneurysm. Note that the carbon dioxide has accumulated in the aneurysm which extends above and below the renal arteries. Filling of aneurysms is usually more complete with carbon dioxide than with iodinated contrast but it must be removed to avoid inferior mesenteric artery ischaemia. This can be done by aspiration through the catheter and repositioning the patient. Both the renal arteries are well seen. Injection parameters 70 cc carbon dioxide at 140 cc per second

Because of the high solubility of carbon dioxide in blood (20 times higher than oxygen) it is absorbed rapidly to result in transient, if any, ischaemia. In animal experiments, Hawkins [10] showed the selective injections of carbon dioxide in an elevated kidney could result in gas trapping for up to two minutes. However, scanning electron microscopy showed no abnormality in the endothelium and in live animals renal function returned to normal within 24 hours. However, due to the potential for carbon dioxide gas trapping in tortuous arterial segments, we recommend repositioning the imaged structure to prevent gas lodgement after the injection of carbon dioxide. Clearance of the absorbed carbon

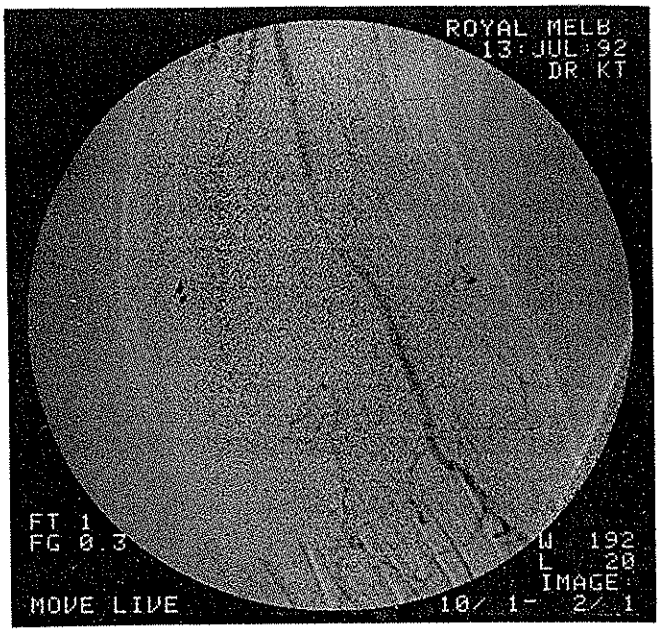

Fig. 4. CDA of the foot showing the dorsalis pedis artery. The injection was made at the level of the external iliac artery. Injection parameters 40 cc carbon dioxide at 15 cc per second with intra-arterial nitroglycerin 300 µgms

dioxide is performed in the lungs on a single pass and the dose of carbon dioxide is therefore, almost unlimited if the dose per injection is less than 200 cc and time is given between injections. The injector has a dose limit of 2000 cc at which time a power off reset is required.

A major advantage of carbon dioxide is that the gas has a very low viscosity and can be injected easily through 3 French catheters, around a wireguide or through needles. In situations where there is low rate bleeding or abnormal vessels, the gas will show the abnormality more readily than iodinated contrast. Injections of carbon dioxide directly into the liver or spleen will fill the portal vein without leaving a contrast stain to obscure later manipulation (Fig. 5, 6). Injection of carbon

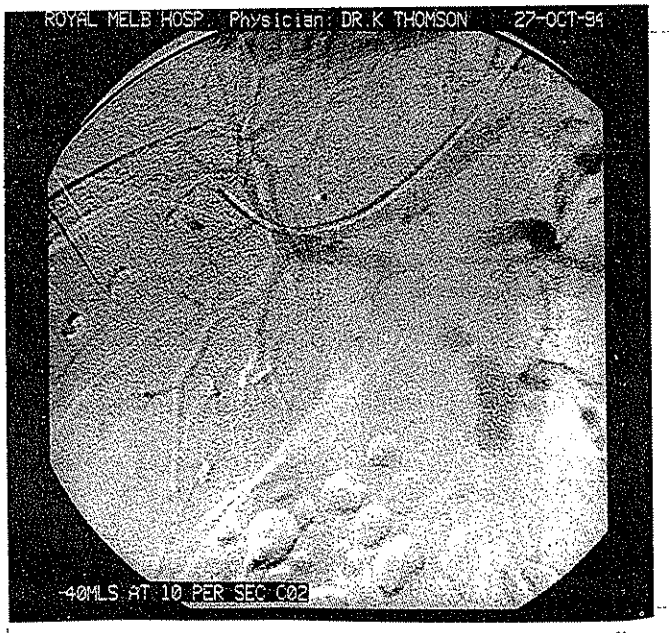

Fig. 5. CDA through a catheter wedged in the hepatic vein. There is excellent filling of the portal vein. Injection parameters 30 cc carbon dioxide at 50 cc per second

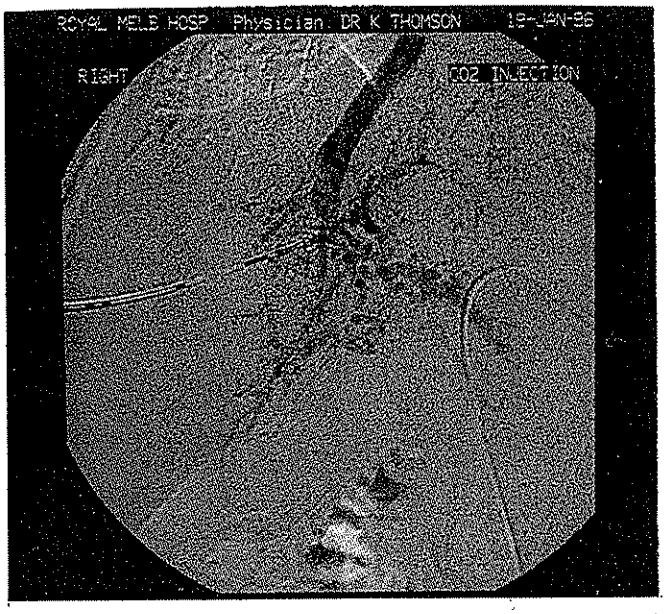

Fig. 6. Direct portography with carbon dioxide. Hand injection of 25 cc of carbon dioxide through a 22 g Chiba needle. The portal vein has partially thrombosed and only a portion of it is visible. The hepatic vein is well filled

dioxide around a wire guide allows check angiography after angioplasty or thrombolysis without the need for long and large calibre guide catheters. Another potential area for use of CDA is in the evaluation of leaks after placement of stent-grafts for aortic aneurysms.

In long and involved interventional radiology procedures the use of CDA as well as conventional DSA reduces the iodinated contrast burden on the patient with less chance of fluid overload and renal damage. For example we have been able to place a renal artery stent with CDA control and less than 20 ml of iodinated contrast.

Carbon dioxide angiography with the new injector has improved the safety and efficacy of our angiograms below the diaphragm. As a direct result of this study the primary choice of contrast for renal angiography at The Royal Melbourne Hospital is now carbon dioxide.

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