

CO₂ DSA - A Quick Reference Guide

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The use of CO₂ as an imaging agent dates back to 1914 when it was originally used for the visualization of the abdominal viscera (1). It was subsequently utilized safely in the evaluation of the retroperitoneum and hepatic veins, as well as in the diagnosis of pericardial effusion (2, 3, 4). In the 1970's, the intraarterial use of CO₂ was pioneered by Hawkins (5), but the resolution was poor. With the development of digital subtraction angiography, stacking software, tilting tables and reliable delivery systems, it became viable as an angiographic imaging agent.

Unique Properties of CO₂

CO₂ is a nontoxic, invisible gas that is highly compressible, non viscous and buoyant. Most importantly, CO₂, as an intravascular imaging agent, lacks both allergic potential and renal toxicity. It is 20 times more soluble than O₂ and is rapidly dissolved in the blood.

Unlike iodinated contrast, CO₂ does not mix with blood but must displace it to render an image. In addition, the buoyancy of CO₂ causes it to rise to the anterior, nondependent portion of the vessel. Therefore in larger vessels (aorta and iliac arteries), if an insufficient volume is injected, there will be incomplete displacement of blood resulting in diminished contrast and potentially, a spurious image. As a result, normal vessels may appear smaller than their true caliber. To overcome this phenomenon, either a larger amount of CO₂ must be administered or, using the buoyancy principle, the area of interest should be placed in the nondependent position.

Indications:

CO₂ can be injected as a contrast agent in any luminal structure (arterial, venous, biliary tree, urinary tract, abscess cavity, or fistula). We previously used CO₂ primarily in patients with iodinated **contrast allergy** and **renal failure**. However, its gaseous characteristics can occasionally provide additional information otherwise unattainable and it is now used in multiple scenarios. Its very low viscosity permits detection of **arterial bleeding**, visualization of the portal system by hepatic parenchymal injection for **TIPS** procedures, visualization of **small collaterals** in ischemic disease and **AV shunting** in tumors. The lack of viscosity also allows delivery via very small catheters and injections between the guidewire and the needle or catheter, making it ideal for **interventional procedures** such as angioplasty and stent placement. This obviates additional steps or the need to remove the guidewire. Furthermore, there is no maximum CO₂ dose if less than 100 cc are injected every 2-4 min. since we believe CO₂ dissolves rapidly and is eliminated by the lungs in a single pass. This is of great benefit in complex interventional procedures where CO₂ can be used in **combination with iodinated contrast** to minimize the risk of renal compromise.

Contraindications:

Our studies with rats (6) suggest that the safety of cerebral CO₂ is questionable. Since that experiment, conflicting studies have been performed that suggest CNS CO₂ may or may not be neurotoxic. It may be, in fact, that the toxic effects seen with CNS CO₂ are not due to the CO₂ itself but are perhaps secondary to air contamination or explosive delivery. Since we are unsure at this time, we **avoid any arterial injections above the diaphragm** and never administer CO₂ with the patient's head in an elevated position.

CO₂ DSA has not been a problem in patients with chronic obstructive airway disease (COPD). However, in these patients, as a precaution, we do attempt to reduce the volume and allow more time between each injection. A recent evaluation by our laboratory using swine included the direct IVC administration of CO₂ at different volumes. This resulted in no significant change in PO₂, pulmonary artery, central venous or systemic arterial pressure at an injection of 1.6 ml/kg. This is well above the individual dose required for diagnostic purposes.

Potential Complications and Precautions:

Because CO₂ is invisible, it is subject to contamination without detection. Our initial studies revealed water, rust and particulate matter within reusable CO₂ cylinders. Therefore, a pure medical-grade source and disposable cylinder are mandatory. Furthermore, a closed delivery system is imperative to eliminate the additional possibility of room air contamination (air embolus). Because of diffusivity, an open syringe containing CO₂ can be replaced with less soluble room air in approximately 72 minutes. In addition, a system employing stopcocks can be easily contaminated either via the Venturi effect or by aspiration with inadvertently malpositioned stopcocks. In a closed system, one-way “check” valves and glued stopcocks can be utilized to reduce these possibilities.

Another rare, yet potential, complication is “trapping.” This occurs when an excessive volume of CO₂ is delivered or the blood-gas interface is reduced and interferes with normal dissolution. Because of buoyancy, it usually occurs in the nondependent portion of a vessel. As a result, a bolus of gas can cause a vapor lock which can restrict blood flow and potentially cause ischemia. Abdominal aortic aneurysms, pulmonary outflow tract, celiac, superior and inferior mesenteric arteries are most susceptible because of their nondependent location.

If trapping does occur, it can be reduced by positional maneuvers. For example, if trapping occurs in the pulmonary artery as a result of an inadvertent excessive, large venous injection, obstruction of blood flow and coronary ischemia can result. By placing the patient in the left lateral decubitus position, CO₂ migrates to the nondependent portion of both the pulmonary artery and the right atrium. This allows blood flow to be reestablished beneath the residual CO₂ in the right atrium. Similarly, trapping in an AAA can be reduced by rolling the patient, first to one decubitus position and then to the other. As a precaution for trapping, fluoroscopy of susceptible sites can be performed between CO₂ injections. If persistent gas is visualized, positional changes can be instituted. For venous injections, fluoroscopy of the pulmonary artery will demonstrate dissolution of a normal volume of the gas within 10-30 sec. If the gas remains longer, the possibility of room air contamination must be considered.

Injection of excessive volumes is the most dangerous potential complication. Excessive doses are first and foremost avoided by ensuring that the CO₂ cylinder is never connected directly to the catheter. A CO₂ cylinder usually contains 3,000,000 cc of pressurized gas and can flood the low resistance circulatory system if a stopcock is inadvertently malpositioned. Also, because it is compressible, a syringe loaded under pressure will have an indeterminate volume of CO₂ and potentially result in an excessive dose. It is suggested that a non compressed, known volume (usually 100 cc, or less, depending on the site of evaluation) be administered via a dedicated injector or closed plastic bag system. Purging the catheter of saline or blood with a small volume of CO₂ should be performed prior to injection to eliminate compressed CO₂ and explosive delivery. We have also found that the elimination of explosive delivery reduces the subjective discomfort of pain, nausea and the urge to defecate. Moreover, if using CO₂ to evaluate

permanent dialysis access, great care should be taken to avoid explosive delivery which may result in reflux into the cerebral circulation (7).

CO₂ should be used cautiously with nitrous oxide anesthesia. In theory, because of partial pressure differences, nitrous oxide may diffuse from the soft tissues into the CO₂ “gas bubble” resulting in an increase in volume of the bubble as well as dilution of the CO₂ (8). As a result, the gas bubble will be 5-6 times more occlusive than CO₂ alone.

Delivery

Currently, there are two safe delivery mechanisms: dedicated injectors and a closed plastic bag hand delivery system (9). Since a dedicated CO₂ injector is not currently available in the United States, the closed bag system can be utilized (Figure 1). It consists of a plastic bag reservoir, extension tubing, one-way check valves with glued fittings, delivery and purge syringes. Using a pure source, the bag is filled with CO₂ and flushed three times to purge any residual air. Following this, the bag should be left flaccid to avoid CO₂ compression and the potential for explosive delivery. Next the bag is connected to the delivery fitting with a one-way stopcock. Now the delivery system is similarly flushed to eliminate room air prior to injection. It is then connected to the angiographic catheter which is subsequently relieved of any residual blood or saline by forcefully injecting three cc of CO₂ via the purge syringe. A controlled, nonexplosive delivery of known volume can then be performed. The check valves primarily prevent reflux of blood into the catheter and permit rapid injections without stopcock manipulation. No additional connecting tubes or stopcocks should be added to the system. All ports should be occupied and syringes attached to prevent any possibility of air contamination.

General Delivery Principles

1. Use a closed system, i.e., the plastic bag or a dedicated CO₂ injector.
 - a. Never connect the catheter directly to the CO₂ cylinder. This avoids the potential inadvertent delivery of excessive and possibly lethal volumes.
 - b. Malpositioned stopcocks can result in room air contamination and air embolus.
2. Avoid explosive delivery. Purging fluid (blood or saline) from the angiographic catheter results in a more consistent delivery (known volume) with less discomfort.
3. Initially, inject small volumes of CO₂. Increase volume as required for specific anatomy.
4. Wait 2-3 min. between injections to allow any potentially trapped CO₂ to dissolve.
5. Elevate area of interest in poor flow conditions (feet, 10-15°; renal artery, 30-45°).
6. Vasodilators (nitroglycerin 100-150 ug IA) can be used to improve filling.
7. Delivery catheter
 - a. Use radiopaque-tipped catheter (allows visualization without contrast).
 - b. At least one sidehole is recommended for safety (eliminates potential for dissection in diseased artery).
 - c. Any flush catheter is acceptable.
8. DSA imaging
 - a. Three-to-four frames/sec. using a 60 ms pulse width with adequate penetration.
 - b. When the CO₂ bolus is “broken up” (fragmented), use image stacking, if available. If not available, increase CO₂ volume.
 - c. If imaging is consistently poor, consult an equipment applications specialist to optimize acquisition.

Specific Procedure

1. Runoff

- a. Initially, obtain both leg runoffs with the catheter in the distal aorta. Perform aortogram after the runoff.
- b. Inject 20-40 cc in ½ second.
- c. Elevate the feet 10-15° for optimal filling and obtain images of pelvis, thigh, knee, lower legs and feet.
- d. If there is no stacking program, a longer injection (~ 60 cc over 2-3 sec.) is necessary.
- e. Problem - poor filling of the lower leg and feet.
 - Perform a selective (antegrade is preferable) injection of the common femoral or more distal arteries. Positioning can be either “over the hill” or antegrade placement of a 3-F catheter in the contralateral extremity, if necessary. For ipsilateral vessels, retract the catheter to the distal external iliac.
 - With stacking, inject 20 cc in two sec. If filling remains poor, inject 20-40 cc over 3-4 sec.
 - Without stacking, begin with 20-40 cc over 3-4 sec.
 - Intraarterial nitroglycerine, 100-150 ug prior to injection.
 - When large volumes are required, discomfort may occur, precipitating patient motion and distorting images. We have found the use of intraarterial lidocaine helpful in those rare occasions.

3. Aortogram

- a. Usually performed after the runoff. We believe this allows the patient to become acclimated to CO₂ and, as a result, less discomfort and nausea are experienced with larger aortic injections.
- b. Attempt to obtain the aortogram **without glucagon**. Our experience is that CO₂ and glucagon may cause nausea.
- c. High-flow rates are necessary (60 cc in ½ sec.).
- d. The left renal is more difficult to image and may be better visualized by elevating that side. If necessary, a selective injection with a shepherd hook catheter (10-30 cc CO₂ in ½-1 second) can be performed. The renal artery ostium is usually apparent secondary to CO₂ reflux.
- e. Selective injections of the visceral arteries commonly require 10-30 cc in ½-2 seconds.

4. Venous - **always image the pulmonary artery after the first injection** to rule out air contamination (persistent gas). Normally, CO₂ should disappear after 10-30 sec.

- a. SVC and IVC - 20-60 cc in ½-2 sec.
- b. Subclavian - 20-40 cc in 1-2 sec.
- c. Peripheral veins - 20-40 cc, 4-8 sec.

5. Interventional Procedures

- a. Using a Touhey-Borst fitting, CO₂ can be injected between the guidewire and needle or catheter. Wires without coil wrap are better (glidewire, .018 torque wire).

- b. Use a 20-40 cc Luer-locked syringe. With a smaller syringe, CO₂ will simply compress without injecting.
- c. Wait 20-30 sec. for CO₂ to exit the catheter. CO₂ will compress, purge fluid from the catheter and inject.
- d. After purging, subsequent injections require less pressure and delay.

6. TIPS

- a. Hepatic venogram with CO₂ to determine anatomy.
- b. Using any needle, inject 20 cc of CO₂ into the hepatic parenchyma for visualization of the portal vein.
- c. With the guidewire in place, CO₂ can be used to verify the needle entry site into the portal vein and determine both balloon and stent positioning.
- d. Post procedure portogram can be performed with CO₂.

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Index Terms:

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