Carbon Dioxide Digital Subtraction Angiography: Everything You Need to Know and More

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Abstract

In 1971, during a routine celiac axis injection, 70 cc of room air was inadvertently injected into a patient instead of iodinated contrast. Fortunately, there were no ill effects, and despite the use of cut film at the time, Dr. Hawkins visualized the celiac axis and its branches as a negative image. Because of this incident, in combination with his previous knowledge of carbon dioxide (CO2) in venous imaging, he began to study the intra-arterial use of CO2 in animals. After the safe and successful use in animals, he applied the same principles to humans. As technology continued to improve, CO2 evolved into a viable vascular imaging agent. Although used initially for renal failure and iodinated contrast allergy, the many unique properties of CO2 yielded multiple advantages, which are now used in a multitude of scenarios alone or in combination with traditional contrast. Despite somewhat awkward delivery devices in the past, it has now been used with great success in both adults and children for more than 3 decades with only limited reportable complications. Its safe use in children has been described, and when performed in this age group, the same principles apply as for adults. This article describes the history and technique of CO2 angiography for vascular procedures.

Keywords:
Carbon dioxide
Contrast allergy
Nephrotoxicity

History

It was not long after the discovery of X-rays by Conrad Roentgen in 1895 that gas was first used as an imaging agent. In 1914, room air was used with radiographs in an attempt to visualize intra-abdominal contents (Rotenberg, 1914). Less than a decade later, room air, oxygen, and carbon dioxide (CO2) were insufflated in the retroperitoneum to evaluate for masses (Carelli & Sorddelli, 1921; Rosenstein, 1921). Because of the problem of air emboli, room air and oxygen, less soluble than CO2, were eventually replaced with CO2.

In the 1950s and 1960s, CO2 was used as a venous contrast agent to evaluate for pericardial effusion (Bendib, Tourni, & Boudjella, 1977; Paul, Durant, Oppenheimer, & Stauffer, 1957; Phillips, Burch, & Helliger, 1961; Scatliff, Kummer, & Janzen, 1959). Bendib et al. (1977) performed 1,600 cases without complications, using a peripheral injection of 100 to 200 cc of CO2 to evaluate for pericardial effusion (Figure 1). In addition, in 1969, Hipona, Ferris, and Pick (1969) reported the safe use of CO2 for the evaluation of the inferior vena cava (IVC).

Subsequently, the biggest advancement in the use of CO2 as a contrast agent was the fortuitous epiphany by Hawkins (Figure 2). After numerous safety studies in animals, he applied these principles to adults and children (Caridi et al., 2003; Hawkins & Caridi, 1998; Kriss, Cottrill, & Gurley, 1997). As technology continued to improve, CO2 evolved into a viable vascular imaging agent. Although used initially for renal failure and iodinated contrast allergy, the many unique properties of CO2 yielded multiple advantages, which are now used in a multitude of scenarios alone or in combination with traditional contrast.
blood displaced by the CO₂ (Figure 3). Typically, smaller vessels, especially those 10 mm or smaller, demonstrate a better correlation with iodinated contrast (Figure 4) (Ehrman, Taber, Gaylord, Brown, & Hage, 1994; McLennan et al., 2001; Moresco et al., 2000).

Buoyancy must also be considered when using CO₂. Typically, a gas will rise to the nondependent surface of the vessel. If all the blood is not displaced from the vessel, it will readily demonstrate the anterior structures but potentially generate a spuriously smaller image of the larger feeding vessel. It is imperative to displace as much blood as possible to generate a comparable image.

In addition to its buoyancy, when CO₂ is administered into the vessel via a catheter, it has the potential to fragment into random bubbles depending on how it is delivered. In an attempt to avoid this, the catheter should be purged before definitive delivery, and a continuous and controlled delivery of the volume of choice should be given. Dr. Cho studied the best catheter to administer a uniform and organized bolus of gas to minimize the bubbling effect. He found that an end-hole catheter yielded the best results (Figure 5) (Cho, 2007).

Again with respect to buoyancy, there is one instance in which it can be a significant detriment. When a blood gas interface is not present in an anterior structure such as an abdominal aortic aneurysm, the CO₂ may sit without dissolving and trap in that position (Figure 6). Trapping could potentially lead to ischemia manifested by pain. The reported incidence of this occurrence is negligible.

The incidence of gas trapping most commonly arises if a typical large tank (usually 3 million cc) of CO₂ under pressure is misconnected to the delivery catheter allowing unfiltered flow of gas into the vessel. It is best to wait at least 30 to 60 s between injections to allow for CO₂ to be dissolved.

As with any interventional procedure, patients undergo routine procedural monitoring. As a safety measure, Cho (2007) recommends monitoring blood pressure 1, 2, and 3 min after the first CO₂ injection.

Besides buoyancy, another important divergent property of CO₂ when compared with liquid agents is its compressibility. Because CO₂ is a gas it is extremely compressible under pressure. A 20 cc syringe can hold a volume of 200 cc if compressed sufficiently. Therefore, the delivery system should be purged to atmospheric pressure to eliminate the compression and avoid administering a larger dose than the amount indicated on the syringe.

In addition, we have found that when a compressed dose is delivered, it can be explosive causing pain and degrade acquired images. Compression can also cause CO₂ to reflux into inappropriate vessels, potentially resulting in complication. This is especially true of the cerebral vessels in which CO₂ should be avoided. Finally, to completely avoid explosive delivery, the delivery catheter should be purged of saline or blood before the definitive dose and not be under pressure.

Whatever system is being used should be purged to the atmosphere for equilibrium. After this, the delivery syringe plunger should be gently advanced to purge the diagnostic catheter of saline or blood. Subsequently, the CO₂ can be delivered in a controlled and nonexplosive manner. Note that unlike a liquid contrast syringe, in which a smaller syringe generates more pressure, a larger syringe (usually 20 to 35 cc) should be used with CO₂. If not, the gas may

### Table 1

<table>
<thead>
<tr>
<th>Properties</th>
<th>CO₂</th>
<th>O₂</th>
<th>N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight</td>
<td>42</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td>Solubility</td>
<td>0.87</td>
<td>0.03</td>
<td>0.016</td>
</tr>
</tbody>
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CO₂ — Carbon dioxide; O₂ — oxygen; N₂ — nitrogen.
simply compress in the syringe without delivery, especially if the catheter is not purged.

Invisibility is the most significant property of CO2 and the one that causes the most concern and discourages competent operators from using it. Because it is invisible, contamination with more occlusive room air is a major concern of many operators. Knowledge of the sources of contamination and how to avoid them is imperative but relatively simple. It is essential, therefore, that disposable sources of at least medical grade CO2 be used (Table 2).

Contamination may also result when a syringe of CO2 is left open to room air. This can be avoided with the use of a closed delivery system that is not open to room air. Delivery systems, especially those that use a bag reservoir, should be purged three times to rid the system of residual room air. Finally, delivery system connections should be secured, either with glue or luer lock. Loose connections can lead to the aspiration of room air. Some individuals also hypothesize that stopcocks are not impervious to gas introduction with aspiration. Therefore, stopcocks and aspiration should be kept to a minimum.

Contraindications, caveats, and disadvantages

When using gas as an imaging agent, the biggest concern is the possibility of embolic occlusion and secondary ischemia. The rapid solubility of CO2 allows for intravascular use, but the coronary, thoracic aortic, and cerebral vessels are less forgiving, and delivery into these vessels should be avoided. In addition, because of the tendency of CO2 to reflux, it is prudent to avoid intra-arterial injections above the diaphragm. To reduce the possibility of central cerebral reflux, the patient can be placed in the Trendelenburg position.

Other clinical scenarios that predispose a patient to untoward embolization include right-to-left shunts and the combination of pulmonary arterial hypertension and a patent foramen ovale. An additional rare contraindication is the use of nitrous oxide general anesthesia when using intravenous CO2.

A recurrent concern for novice operators is the use of CO2 in patients with chronic obstructive pulmonary disorder (COPD). As a precautionary measure in COPD patients, it is suggested to allow more time between injections. Instead of the recommended 30 to 60 s between injections in most routine patients, those with COPD should be increased to 2 min to allow for definitive dissolution.

It is important to remember the potential increase in radiation exposure to the operator and the patient when using CO2 DSA. It is recommended that the frame rate for acquiring CO2 images approximate 6/s or more.

In addition to the aforementioned contraindications, there are a few minor disadvantages that exist when changing from a fluid-based vascular contrast to CO2. The primary disadvantage is learning how to use a gas-based delivery system as opposed to

Figure 3. Comparison of carbon dioxide and contrast, respectively. Less than 10 mm vessels yield comparable images. This is a good quality CO2 image given adequate amounts of blood were displaced.

Figure 4. Anterior vessels are well demonstrated by carbon dioxide digital subtraction angiography. (A) Superior mesenteric artery celiac, (B) reimplanted renal arteries, and (C) transplant renal arteries.
iodinated contrast. CO2 is invisible, colorless, odorless, and cannot be seen or felt; therefore, the comfort level for use is much less than iodinated contrast. The operator must learn and feel confident in the type of delivery system. In addition, CO2 vascular imaging is typically not as dense, and patient motion can seriously affect the final product.

**Advantages**

*Nonallergic Quality of CO2*

Because CO2 is disseminated throughout the body’s soft tissues, it is nonallergenic. This advantage is extremely beneficial when an operator is confronted with an emergent intravascular procedure in a patient with a severe allergy to iodinated contrast. Currently, most operators use low osmolar nonionic contrast, which has an incidence of allergic reaction of 0.7% to 3% and severe anaphylaxis of 0.02% to 0.04% (Caro, Trindade, & McGregor, 1991; Lieberman & Seigle, 1999; Trcka et al., 2008).

*Non-nephrotoxic Quality of CO2*


Early animal studies by Hawkins (1982) and others showed that CO2 as an intravascular contrast agent did not affect the renal function. Hawkins later went on to demonstrate this in

**Figure 5. End hole vs multiside hole catheters.** CO2 delivery via end hole catheters (column A) demonstrates a more uniform column of CO2 than those catheters with multiple side holes (columns B and C).

**Figure 6.** (A) Cross table lateral showing carbon dioxide (CO2) pooling anteriorly in abdominal aortic aneurysm (AAA). (B) Delayed image demonstrating persistent CO2 anteriorly in an AAA.
humans as well. Comparing iodinated contrast, gadolinium, and CO₂ in renal-insufficient patients, CO₂ was the only agent not demonstrating an elevation in creatinine (Spinosa et al., 1998, 2000). It should be the first-line imaging agent in patients with renal insufficiency requiring vascular evaluation or intervention. Even if there are limitations to the CO₂ imaging, it can be used in conjunction with limited diluted doses of iodinated contrast.

**Low Viscosity**

The viscosity of CO₂ is 1/400 that of iodinated contrast, permitting its delivery through smaller and less invasive catheters and needles. This is advantageous when using microcatheters in which sufficient volumes of thicker contrast may be difficult to deliver. CO₂ can easily be administered in significant doses and has the advantage of central reflux resulting in opacification of the entire vascular structure (Figure 7).

Likewise, CO₂ can be injected through (ultrafine) needles as small as 27 gauge. These needles are much less invasive and have been used successfully with CO₂ in the liver and spleen as well as peripheral venography (Figure 8).

Because of its low viscosity, CO₂ can be injected through a catheter with the wire in place using a Y-adapter (Figure 9). This is advantageous when performing invasive procedures and at times when it is preferable to maintain wire access.

**Other**

Finally, one of the biggest advantages of CO₂ is its cost. The typical cost for CO₂ is 3 cents per 100 cc, which is exponentially cheaper than iodinated contrast.

**Indications: alone or as an adjunct to iodinated contrast allergy**

Iodinated contrast allergy is explained previously. Emergent patients or those who for a variety of reasons did not receive prednisone preparation can use CO₂ DSA if necessary.

**Contrast-induced Nephropathy**

There are many clinical scenarios that predispose a patient to CIN. These include myeloma, diabetes, acute cardiac abnormalities, hypotension, nephrotoxic drugs, and underlying renal disease. In these patients, the incidence of CIN is increased but can be lessened with the use of CO₂ DSA. Most commonly, the incidence of CIN is related to the volume of iodinated contrast, the route of administration (intra-arterial carries higher risk than intravenous), and pre-existing renal insufficiency (Kooiman et al., 2012; Moresco et al., 1998; Murakami et al., 2012; Seeger, Self, Harward, Flynn, & Hawkins, 1993).

When performing procedures requiring significant volumes of contrast, CO₂ can be used alone or as an adjunct to decrease this possibility. It should be the preferred contrast in evaluation and intervention of the renal artery in renal transplants and renal arterial reimplantation cases (See Figure 11).

**Hemorrhage**

CO₂ is extremely beneficial in the demonstration of acute arterial and venous hemorrhage (Figures 10 and 12) and is 2.5 times more sensitive than the thicker contrast (Hashimoto, Hashimoto, & Soto, 1997; Hawkins, Cardi, LeVeen, Klioze, & Mladinich, 2000; Hawkins, Cardi, Wiechman, & Kerns, 1997; Krajina et al., 2004; Sandhu, Buckenham, & Belli, 1999). Regardless of the etiology, whether iatrogenic, traumatic, or gastrointestinal bleed, delineating the origin of bleeding and treating it precipitously can lead to significantly less morbidity and mortality. Hawkins reported that the use of CO₂ DSA has approximately 2.5 times the sensitivity for defining the acute hemorrhage when compared with iodinated contrast (Hawkins et al., 1997).

**Peripheral Arterial Occlusive Disease**

The incidence of peripheral arterial occlusive disease (PAD), chronic limb ischemia, and endovascular repair is increasing. CO₂...
DSA is vital and extremely useful in this clinical scenario, but it is currently underused. Successful correlation of CO₂ and iodinated contrast in PAD was demonstrated by Seeger's group in the mid 1990s (Seeger et al., 1993). They demonstrated a 92% correlation with an increase to 100% when a small amount of iodinated contrast was administered (Figure 13).

A large number of patients with PAD/chronic limb ischemia commonly have concomitant renal artery disease and other predisposition to renal insufficiency. Considering these facts and the susceptibility of this group to CIN, it would seem intuitive to use CO₂ as a contrast agent whenever possible.

**Endovascular Abdominal Aneurysm Repair**

One current use of CO₂ DSA has been in the placement and evaluation of abdominal aortic endografts. This use has been proliferating among numerous operators for a variety of reasons, including decrease of iodinated contrast load, more sensitive evaluation of endoleaks, safety, and cost (Beese et al., 2000; Caro et al., 1991; Hawkins et al., 1994; Walsh et al., 2008). The typical EVAR patient is usually older than 70 years. This group of individuals has approximately a 30% incidence of abnormally low glomerular filtration rate that may not be reflected by serum creatinine levels alone. They also tend to have comorbid conditions that predispose them to renal insult. The incidence of renal insufficiency in patients undergoing EVAR approximates 7% to 25% with acute renal failure occurring in 2% to 16%, resulting in an associated mortality of 30% to 50%. CO₂ can be used as the exclusive contrast agent or in addition to smaller volumes of iodinated contrast, allowing accurate and complete endovascular repair without inducing renal compromise. In addition, because of its low viscosity, it has also been noted by several of the aforementioned authors that CO₂ is more sensitive for detecting endoleaks.

**Interventional oncology**

Interventional oncology is a recent catchall phrase for a specialty that includes a multitude of minimally invasive procedures in the treatment of a variety of tumors. One aspect of this specialty is

Figure 8. (A) Large patient with poor opacification of central structures using iodinated contrast. (B) Carbon dioxide that can be delivered via 25-gauge peripheral needle, does not mix with blood, and readily demonstrates central structures.

Figure 9. (A) Arteriovenous fistula (AVF) from previous common femoral artery approach. Nonselective injection demonstrates an early draining vein. (B) Magnified view with a more selective injection. (C) After stent placement demonstrating resolution of the AVF, all with carbon dioxide.
catheter directed and requires angiography/venography and embolization. The contrast load for these patients is often high.

Transarterial Chemoembolization, Drug-eluting Beads, and Yttrium-90

There are procedures that use angiographically directed therapy predominantly for liver tumors. Transarterial chemoembolization, drug-eluting beads, and yttrium-90 therapy are used with liver tumor patients, who tend to be older and usually have other comorbidities, such as renal insufficiency, diabetes, and hypertension. Patients with primary hepatic tumors also have significant underlying liver disease and are at risk for hepatorenal compromise. Approximately 75% of patients with cirrhosis will have renal insufficiency at some time during the course of their disease.

Commonly, a large volume of contrast is required for interrogation of the vasculature, treatment, and follow-up examination. These risks can be exacerbated by postembolization syndrome followed by decreased oral intake or very rarely nontarget embolization and tumor lysis syndrome. All these factors, especially the high volume of contrast, place the patient at risk for CIN. Probably, the most significant scenario is that some of these patients may be

![Figure 10.](image1.png)

(A) Posthepatic trauma, no evidence of acute hemorrhage with liquid contrast. (B) Gross carbon dioxide extravasation demonstrating site of bleeding for embolization.

![Figure 11.](image2.png)

Renal transplant carbon dioxide (CO₂) digital subtraction angiography demonstrating ostial stenosis treated with a stent. All performed with CO₂ without insulting the transplant kidney.
denied life-prolonging therapy because of their elevated creatinine and risk for CIN (Figure 14).

Another procedure, uterine fibroid embolization, is usually performed in young and healthy individuals. Less invasive transarterial therapy can be precluded if there is an elevation of the serum creatinine. In fact, renal insufficiency is listed as one of the relative contraindications (Stokes et al., 2010) and has been described (Rastogi, Wu, Shlansky-Goldberg, & Stavropoulos, 2004).

Figure 12. Renal angiogram after robotic surgery for renal cell carcinoma and potential postoperative bleeding. (A) Traditional contrast not only does make the diagnosis but also jeopardizes a compromised kidney. (B and C) Arrows indicate source of bleeding using carbon dioxide digital subtraction angiography.

Figure 13. Advanced arterial disease can be demonstrated using refined imaging techniques.
As with transarterial chemoembolization procedures, they may also be subjected to high volumes of iodinated contrast and develop postembolization syndrome (Figure 15).

Similarly, some patients with renal cell carcinoma require embolization of the primary tumor or the hypervascular metastasis. Obviously, many of these patients are susceptible to CIN.

In each of the clinical scenarios delineated previously, CO₂ can usually be used as the predominant contrast agent with the addition of a small or limited amount of dilute iodinated contrast.

**Venous evaluation and treatment**

As noted, CO₂ was used safely in the venous system early in the 1960s. Since the discovery and refinement of DSA, the myriad uses for CO₂ as a venous vascular contrast agent have proliferated. The gaseous properties noted previously make it an ideal venous contrast agent.

In the extremities, the low viscosity of CO₂ permits delivery of sufficient volumes through smaller 25-gauge needles. This is less invasive and less painful to the patient. Because CO₂ does not mix with blood, it is not diluted, and a peripheral hand injection will yield good opacification centrally. This is unlike contrast.

**Figure 14.** (A) Patient had previous transarterial chemoembolization and needs repeat delivery in a right hepatic artery branch. Iodinated contrast injected goes peripherally, and tumor is not seen. (B) Carbon dioxide digital subtraction angiography demonstrates central reflux and filling of the culprit vessel so inadvertent embolization is avoided and the catheter can be redirected for appropriate treatment.

**Figure 15.** Carbon dioxide digital subtraction angiography of pelvis demonstrating hypertrophied uterine arteries and tumor vascularity in the uterine fibroid.

**Figure 16.** Right upper extremity venogram demonstrating central venous occlusion and patency of collaterals and right internal jugular vein. This can be used to plan access in patients with limited veins.
In the presence of venous occlusion, the properties of low viscosity and reflux will often demonstrate collateral cervical and thoracic veins bilaterally (Figure 16). This is critical in patients with renal insufficiency and chronic venous occlusive disease. Because of CIN and nephrogenic systemic fibrosis, respectively, venous computed tomography and magnetic resonance cannot be used for a road map before venous access procedures. This can be circumvented nicely with CO2 extremity venography. It can help determine venous patency and potential access sites. CO2 venography can also be used in patients with iodinated contrast allergy.

CO2 DSA can be extremely useful in the examination of dialysis fistulas or interposition grafts (Figure 17). It is excellent at demonstrating the veins and central circulation.

Another good use is in IVC evaluation, especially for filter placement. Many times, these are emergent and patients may have allergy, have elevated creatinine, or do not need the additional volume of iodinated contrast boluses. CO2 has been shown to be a very effective imaging agent for the evaluation of the IVC (Figure 18) (Boyd-Kranis, Sullivan, Eschelman, Bonn, & Gardiner, 1999; Holtzman et al., 2003; Pessanha de Rezende et al., 2011; Sing, Stackhouse, Jacobs, & Heniford, 2001).

CO2 renal venography can also be performed in other procedures (adrenal vein sampling and balloon-occluded retrograde transvenous obliteration of varices) where evaluation of veins is essential.

A common venous use of CO2 involves a variety of clinical scenarios in the liver and spleen. It has been shown by Culp and Hawkins that, as opposed to iodinated contrast, CO2 does not have any negative effect on the splenocytes or hepatocytes when injected directly into the respective parenchyma (Culp, Mladinich, & Hawkins, 1999). Hawkins showed that an injection of as little as 12 cc/s had a negative effect as compared with CO2 at 200 cc/s.

One of the more unusual but effective uses of CO2 is in patients with abnormalities of the splenoportal system (Figure 19) (Burke, Weeks, Mauro, & Jaques, 2004; Caridi et al., 2003; Cho & Cho, 2003; Teng et al., 2006). The low viscosity of CO2 will cause opacification the small caliber splenoportal system, identifying the anatomy without significant bleeding (Burke et al., 2004; Caridi et al., 2003; Cho & Cho, 2003; Teng et al., 2006).

More commonly, it has become routine for many operators to use CO2 in transjugular intrahepatic portosystemic shunt (TIPS) procedures (Figure 20). The incidence of renal compromise after TIPS approximates 2% to 3%. The entire procedure, including hepatic and portal venography as well as tract measurement, portal localization, and post-TIPS placement, can be performed with CO2, reducing the possibility of CIN (Hawkins & Caridi, 1998). Where CO2 is most helpful in TIPS is in the localization of the portal vein. The low viscosity permits excellent visualization of the portal vein in greater than 80% of cases and visualizes more of the system than iodinated contrast without most of the consequences. However, because of a few complications of capsular rupture with catheter-
wedged CO₂ injections, balloon occlusion of the hepatic vein with venous CO₂ injections became the preferred method of choice (Figure 21) (Rees, Niblett, Lee, Diamond, & Crippin, 1994; Semba, Saperstein, Nyman, & Dake, 1996; Taylor, Smith, Watkins, Kohne, & Suh, 1999; Theuerkauf et al., 2001). Complications are fewer with the advantage of better portal visualization.

Visualizing the portal vein has also become more important with the rise in interventional oncology. Transhepatic portal vein access is necessary for certain procedures. More specifically, it is critical in performing selective portal vein embolization to generate hepatic parenchymal hypertrophy of the remaining future liver remnant when extended hepatectomy is necessary.

Finally, there have been additional reports of limited numbers of patients using CO₂ for atypical procedures. One of these is in pain management. CO₂ has been used instead of iodinated contrast before neurolysis when the patient is highly allergic (Hirata, Higa, Shono, Hirota, & Shinokuma, 2003). Another newer area of use requiring additional investigation is for intraosseous venography in percutaneous vertebroplasty (Tanigawa, Komemushi, Kariya, Kojima, & Sawada, 2005). CO₂ can also be used in angioscopy (Silverman, Mladinich, Hawkins, Abela, & Seeger, 1989). It persists longer than saline, giving a clearer view of the vessel. Similarly, it can be used percutaneously to separate organs before and during ablative procedures.

**CO₂ delivery**

Since the advent of intravascular CO₂ delivery, there has been a number of innovative methods of delivery developed (Alexander, 2011; Cherian et al., 2009; Cronin, Patel, Kessel, Robertson, & McPherson, 2005; Hawkins, Caridi, & Kerns, 1995; Mendes, Wolosker, & Krutman, 2013). CO₂ delivery begins with a source. As stated previously, a medical-grade CO₂ should be used, and because of potential impurities over time, the source should also be disposable. Next, there must be a mechanism to deliver the CO₂ from the source. One must be aware that many of the commercial canisters contain 3 million cc of pressurized gas.

To avoid the inadvertent overload of pressurized gas and the cumbersome presence of a large canister, we introduced the use of a flaccid reservoir bag with a series of one-way valves (Figures 22). This method used a converted fluid management system by Angiodynamics called the Angioflush III system (Angiodynamics, Inc., Queensbury, NY). A similar system by Merit Medical is also used successfully (Figure 23). The theory behind these systems was that they would be a nonpressurized flaccid reservoir of CO₂ that would avoid explosive delivery and excessive volumes.

The one-way glued valves are intended to eliminate stopcocks, prevent room air contamination, and eliminate the necessity to remove the delivery syringe. The inherent problem in each apparatus is that the systems required assembly. Regardless of the training and simplicity, incorrect assembly can result in air embolus. In addition, the bag must be filled and purged three times to remove residual room air. This step is somewhat cumbersome and time consuming, especially when the decision to use CO₂ occurs spontaneously during the procedure. Other similar systems do exist.

For years, we have reported that the patient should never be connected directly to the cylinder. This has been modified recently because of the development of a K valve stopcock that precludes the possibility of CO₂ passing directly from the canister to the patient (Figure 24). The next generation of delivery systems uses a compact regulator that uses a small 10,000 cc canister of pharmaceutical-grade CO₂ (Figure 25). The smaller system can be placed in a sterile sleeve or left beneath the sterile drape. It is connected to a series of two tubes with one-way valves, as well as...
a K valve and a reservoir and delivery syringe. The K valve prevents direct communication with the patient. CO₂ is introduced into the reservoir syringe. From the reservoir, the gas should be pushed, not aspirated, to the delivery syringe to avoid the unlikely possibility of air contamination through the K valve. Equilibrium with the atmosphere can be achieved with a three-way stopcock. The system does not require assembly and is extremely user friendly. Setup for use takes approximately 1 min.

Another recently developed type of delivery is the Angiodroid CO₂ injector (Angiodroid, Angiodynamics, Inc., Queensbury, NY), which uses digital versus hand injection.

Finally, some operators filter the CO₂ before it enters the vasculature. CO₂ can be delivered and has been delivered without filtration for arteriography and venography, as the gas is not injected as an arterial contrast agent above the diaphragm. However, the use of a filter (0.2 μm pore size) can effectively remove particulate contamination and bacteria (0.5 to 5.0 μm).

**Conclusion**

CO₂ is not the quintessential imaging agent, but it offers unique properties when used alone or in combination with iodinated contrast that can expand diagnostic and therapeutic options in a variety of clinical scenarios. Used appropriately, it is safe and can not only prevent CIN but also offer life-extending procedures to patients who would otherwise have been precluded because of their underlying renal status. It can also be used less invasively or when traditional contrast fails to make diagnoses and avoids more significant intervention. Current technology permits simple and safe administration with images comparable to liquid contrast. It is an inexpensive and versatile tool that should be added to every interventionist’s toolbox.
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Suggested Reading


