Carbon Dioxide in Angiography to Reduce the Risk of Contrast-Induced Nephropathy

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- Bleeding
- Tumors
- Uterine artery

Carbon dioxide (CO\textsubscript{2}) is a nontoxic, invisible gas that is highly compressible, nonviscous, buoyant, and rapidly absorbed. It is 20 times more soluble than oxygen. CO\textsubscript{2} is not only rapidly dissolved in the blood but, when delivered intravenously, is eliminated by one pass through the lungs. Most importantly, CO\textsubscript{2}, as an intravascular imaging agent, lacks both allergic potential and renal toxicity. Moreover, its low viscosity (1/400 that of iodinated contrast) provides unique qualities useful in both angiographic diagnosis and intervention.

Currently, CO\textsubscript{2} has been used as an intravascular alternative to iodinated contrast material for over three decades. Although it is dissimilar to routine contrast and requires a unique delivery system, it has been routinely used successfully as an adjunct to liquid contrast in patients in renal failure and those allergic to contrast. It is not the quintessential contrast agent and often requires more meticulous manipulation to produce the desired images. In the past, fool-proof, safe delivery of CO\textsubscript{2} was very difficult. However, a converted fluid management plastic bag delivery system has now been used for the last 14 years, and is both faster and easier than injecting iodinated contrast. More importantly, the delivery system is almost completely fail-safe.\textsuperscript{1}

With the advent of MR angiography and CT angiography, the diagnostic use of CO\textsubscript{2} digital subtraction angiography (DSA) has declined significantly. Recently, however, there has been resurgence because of gadolinium-induced nephrogenic systemic fibrosis (NSF) in patients with advanced reduction in renal function.\textsuperscript{2} Therefore, if an angiographic examination is necessary in patients with renal impairment, the choices may potentiate either NSF from the gadolinium- or contrast-induced nephropathy from iodinated contrast. Alternatively, CO\textsubscript{2} DSA can be used safely in many of these cases. Additionally, intravascular CO\textsubscript{2} use has also increased because of the recent discoveries of more useful applications, as well as the increasing complexity of cases requiring greater contrast doses. CO\textsubscript{2} can be used in unlimited doses without jeopardizing the kidney.

UNIQUE PROPERTIES OF CO\textsubscript{2}

CO\textsubscript{2} is invisible, buoyant, compressible, and nonviscous. These unique properties can provide...
distinct advantages and disadvantages in angiographic procedures. As an endogenous gas, it is nonallergic, nonnephrotoxic, and its viscosity is 1/400 that of iodinated contrast and, therefore, can disseminate more readily than liquid contrast. Because it is a gas, CO₂ is invisible, and air contamination must be avoided. Moreover, even without contamination, administration of the gas into the cerebral vessels is an absolute contraindication.

As opposed to liquid contrast, CO₂ does not mix with blood. It is buoyant and will rise to the nonpendent portion of a large diameter vessel. Therefore, to assure accurate representation of a vascular structure the entirety of blood in the imaged vessel should be displaced. Incomplete displacement can lead to spurious imaging (i.e., smaller vessels or larger percentage stenoses).

Because CO₂ is compressible, steps must be taken to avoid excessive volumes and explosive delivery. If compressed, a 20-cc syringe can hold 200 ccs of CO₂. This exposes the patient to possible explosive and explosive delivery, which can lead to undesired reflux and rapid expansion of vessels, which could cause untoward symptoms, such as pain, nausea, and vomiting following CO₂ injection into the abdominal aorta, celiac, or superior mesenteric artery. Advantages and disadvantages of CO₂ are presented in Box 1.

WHY SHOULD I LEARN HOW TO USE CO₂?

Presently, with advances in delivery and imaging systems, CO₂ can be safely used in patients at risk for adverse reactions to iodine- or gadolinium-based contrast agents for most diagnostic and interventional procedures. In addition, CO₂ has definite advantages for many interventional procedures. The authors' 38-year experience in over 5,000 patients and review of the literature have shown that CO₂ is the only safe angiographic contrast for patients with a history of serious allergic reactions to iodinated contrast media and in patients with renal failure. Contrast-induced nephropathy (CIN) and NSF are serious complications that should be avoided. As discussed in detail elsewhere in this issue of The Clinics, these complications are associated with marked increase in morbidity and mortality of the affected patients.

LACK OF RENAL TOXICITY OF CO₂

Animal studies in canines showed that selective CO₂ injection in renal arteries had no significant effect on renal function or histology, with the exception of one dog that sustained a minimal degree of acute tubular necrosis. This animal endured multiple selective renal CO₂ injections while the dog's kidney was positioned above the injection catheter, resulting in trapped CO₂ and minimal ischemia. A more recent study in rats comparing renal cortical and medullary blood flow with CO₂ versus ioxaglate showed that the marked decrease in medullary flow with ioxaglate was absent with CO₂.

As far as the authors are aware, there are no reports in the published literature of CO₂ causing CIN. The authors' clinical experience in using CO₂ for angiography in patients with renal failure and renal transplant patients (over 100 patients) has been extremely encouraging, with no technical complications or important deterioration in renal function. In renal transplant patients, CO₂ angiography is more effective because of the anterior position of the transplanted kidney, which allows good filling of the renal arteries with CO₂, much better than in the native kidney, which has a posterior-oriented position.

The right renal artery always fills with aortic injections; however, the more posterior located left renal artery occasionally is difficult to image. Using the plastic bag system injecting smaller volumes (30 cc) of CO₂ with nonexplosive delivery

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**Box 1**

**Advantages and disadvantages of CO₂**

**Advantages**

- Nonallergic
- Nonnephrotoxic
- Low viscosity—easily delivered via microcatheter, between catheter and guidewire, flows readily into bleeding sites and from parenchymal injections into the venous system
- Can inject larger volumes via small catheter with reflux resulting in CO₂ filling of proximal vessels
- Cost

**Disadvantages**

- Invisible, allowing potential for undetected contamination
- Requires a unique delivery system
- Gas is compressible
- Contraindicated in the cerebral and coronary circulation and thoracic aorta
- Bowel gas and motion can reduce or eliminate image quality
- Obtaining quality diagnostic images may be more labor intense
and an end-hole catheter, the left renal artery is much more frequently seen (Fig. 1). If, after one or two abdominal injections, the left renal artery is not seen, the authors either selectively catheterize this artery or elevate the left side of the patient. If these maneuvers are not successful, placing the patient in the right lateral decubitus position always results in filling the left renal artery with CO₂ if it is patent.

**IMPORTANT FEATURES OF CO₂**

**Low Viscosity**

The low viscosity of CO₂ increases its sensitivity in detecting acute hemorrhage, arteriovenous shunting, collateral vessels, and arteriovenous shunting in tumors. The low viscosity also allows easy administration of CO₂ into microcatheters and permits injection between the catheter and guidewire, eliminating the need to remove the guidewire from the target organ after intervention. This makes CO₂ an ideal contrast agent for intervention procedures, such as angioplasty and stent placement and verifying the exact position of the needle or catheter before a larger catheter or device is placed in a potentially dangerous location. With wedged hepatic and splenic arterial injection and injection into the hepatic parenchyma and splenic pulp, the low viscosity facilitates visualization of the portal veins without causing histologic damage.

**Reflux**

The gaseous property of CO₂ results in central reflux from the point of administration. This permits central assessment of the feeding vessels without the need for catheter withdrawal to improve central visualization that might be required with iodinated contrast agents. This is exemplified by the placement of renal stents and the need to identify the appropriate position of the ostium and stenosis. Using CO₂ injection through the sheath with the stent-mounted balloon catheter in place, and between the balloon catheter and guidewire, the location of the more central stenosis can be assessed and the stent positioned with precision.

**POTENTIAL COMPLICATIONS OF CO₂**

**Excessive Volumes**

Injecting excessive volumes of CO₂ is probably one of the most serious potential complications and might lead to drop in blood pressure, bradycardia, and elevation of the ST segments in EKG. The authors experienced this complication only once with one patient after inadvertently injecting over 3,000 cc of CO₂ during a transjugular intrahepatic portosystemic shunt (TIPS) procedure. The patient was placed in the left lateral decubitus position with immediate normalization of vital signs and EKG. With the right side elevated, the buoyant gas shifted to the higher right atrium and the blood flowed under the gas to perfuse the pulmonary artery. The patient’s survival can be attributed to the extreme solubility of CO₂. In another patient, after injection over 2,000 cc of CO₂ into an abdominal aortic aneurysm (AAA), the patient developed severe diarrhea, with follow-up endoscopy demonstrating colonic ischemia. The trapped CO₂ prevented flow into the inferior mesenteric artery (IMA) for over 1 hour and the gas, which does not mix with blood, produced a barrier preventing normal collateral blood flow. Fortunately, the colon was found to be normal 2 weeks later during the AAA surgery.

More recently, the authors have performed an extensive venous study in 20 swine, injecting the equivalent of 50 cc to 600 cc of CO₂ in man. There were no untoward events and little or no changes in blood gases, pH, or pulmonary or arterial blood pressure when the equivalent of 100 cc was injected. However, when an amount comparable to 600 cc was injected, there was one death. It was noted that as the volume of CO₂ was increased, the pulmonary pressure increased incrementally. Although the authors have not experienced any cerebral complications,
theoretically, if the pulmonary pressure increases
markedly, a potentially patent foramen ovale may
open and the CO₂ could flow into the left atrium
and subsequently into the aortic arch.

To prevent any possibility of injecting excessive
volumes of CO₂, the patient should never be con-
nected directly to the CO₂ cylinder. The cylinder
typically contains over 3 million cc of compressed
gas at very high pressure. If a stopcock is turned in
the wrong direction, the cylinder can unload
directly into the vascular system. Even a syringe
connected directly to a cylinder can contain an
excessive volume. Because of Boyle’s law, the
volume of CO₂ decreases with increased pressure.
If the cylinder’s CO₂ regulator is set at a high psi,
a hand syringe will be filled with a higher volume
of CO₂. If a finite-volume plastic bag delivery
system is used, there is no possibility of injecting
excessive or inaccurate volumes. When the CO₂
source (plastic bag) is at atmospheric pressure
(flaccid plastic bag), whatever volume is aspirated
from the source will be the exact volume in the
syringe.

AIR CONTAMINATION

An uncompromised closed-delivery system is
crucially important to avoid air contamination.

Cho and colleagues have shown that if the stop-
cock of a syringe remains open, the extremely
diffusible CO₂ in the syringe is quickly replaced
with room air, regardless of the syringe’s position.
The differential in partial pressure between CO₂ in
the syringe and in the room air causes room air to
diffuse into the syringe with the open stopcock at
a rate of 0.2 cc per second, with air replacing the
majority of the CO₂ within 20 minutes. Thus, it is
very important to use a leak-proof closed system
to prevent potential lethal air complications.

Indications of CO₂ Angiography

CO₂ is used primarily for angiography, with the
exception of the cerebral or coronary circulations
in patients with iodinated contrast allergy and renal
failure. It permits multiple, safe injections for renal
transplant evaluation and intervention. CO₂ is also
very beneficial in complex interventional proce-
dures, where it can be used alone or in combina-
tion with iodinated contrast to minimize the risk
of renal complications and volume-overload prob-
lems in patients with congestive heart failure.
Because of the rapid dissolution and one-pass
elimination by the lungs, there is no maximum
CO₂ dose when less than 100 cc is injected every
2 minutes. In addition, using the closed plastic bag
delivery system, CO₂ can be very expeditiously in-
jected as a contrast agent in any luminal structure,
such as the biliary tree, urinary tract, abscess
 cavity, and fistula.

The very low-viscosity of CO₂ can occasionally
provide additional information, otherwise not
obtainable with iodinated contrast. In addition to
the previously mentioned advantages of the low
viscosity of CO₂, the authors have noted that
when CO₂ was used during embolization the
tumors have appeared totally ablated with liquid
contrast but were only partially embolized, as
noted with subsequent CO₂ injections. Because
embolization procedures alone can exacerbate
renal failure and many are high risk, the authors
are routinely using the many unique properties
of CO₂ for most oncologic procedures. For TIPS
procedures (Fig. 2), evaluation of portal

![Diagram of portal vein targeting: 21-gauge needle advanced 1 cm through hepatic vein into parenchyma, injecting 30 cc of CO₂ forcefully. (B) Entire portal system filled, including extra hepatic portal vein.]

Fig. 2. CO₂ prechymal hepatic injection with fine needle for TIPS. (A)
hypertension and occlusion, and portal vein embolization, the low-viscosity also permits filling of the portal system much more reliably than iodinated contrast, either by wedged hepatic vein injections, direct injections into the parenchyma of the liver, or via a fine-needle in the splenic pulp and injection into peripheral hepatic arteries. CO₂ passes very easily through the sinusoids into the portal system against the direction of blood flow. CO₂ is also ideal for the filling of central veins from distal injection site (25 gauge needle in hand vein) and frequently, in patients with venous thrombosis, it is the only contrast that will opacify the more central system, permitting accurate assessment and successful intervention (Fig. 3).

It can be used effectively for inferior vena cava (IVC) filter placement, even at the bedside. There is a recent report of CO₂ use for intraosseous venography in percutaneous vertebroplasty. Recently, CO₂ has been used in high-risk endovascular aneurysm repair procedures to reduce CIN and has been effective in demonstrating endoleaks. This was underscored in a case where a covered stent was placed to repair a lacerated superficial femoral artery (Fig. 4). The leak was detected only after CO₂ was employed.

ABSOLUTE CONTRAINDICATIONS

Studies of CO₂ carotid injections in rats, dogs, and rabbits have suggested that CO₂ could be neurotoxic. Because of possible neurotoxicity and cardiac ischemia, the cerebral and coronary arterial circulation should never be exposed to CO₂. The authors never inject CO₂ in the prone position because the buoyancy will fill spinal arteries and may cause spinal cord ischemia. Never administer CO₂ with the patient's head in an elevated position because the buoyant CO₂ can flow countercurrent and cause possible reflux into the cerebral circulation. Because of the possibility of central reflux into the cerebral circulation, CO₂ should not be used to evaluate the arterial

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Fig. 3. Right axillosubclavian vein thrombosis in a 31-year-old man with right arm swelling and recent pulmonary embolism. (A) Right arm venogram with iodinated contrast shows no filling of the brachial or axillary veins secondary to thrombosis. (B) Only a few isolated veins are filled in the shoulder and axilla. (C) CO₂ venogram again shows occlusion of the axillary and subscapular veins with acute thrombus in cephalic vein (shorter arrow). There is excellent filling of the right and left innominate veins (long arrows) and the superior vena cava (SVC) secondary to the low viscosity of CO₂, which guided a successful catheter-directed fibrinolysis.
Fig. 4. Endoleak seen only with CO₂ in a patient with a lacerated femoral artery. (A) Injection of 10 cc of CO₂ as the covered stent catheter was positioned at the bleeding site of a superficial femoral artery laceration with shunting into the femoral vein (longer arrow). After the stent was deployed, hemorrhage stopped. Note the irregular wall along the deep femoral artery (shorter arrow) representing stationary arterial wave. (B) One day after stent placement, the patient clinically was massively bleeding; however, injection of 20 cc of iodinated contrast showed no evidence of extravasation. (C) Injection of 10 cc of CO₂ immediately after the iodinated injection showed type one endoleak (arrow), which was treated successfully by over-dilating the stent graft.

limb of dialysis fistula. It can, however, be used cautiously for evaluating the venous limb.

RELATIVE CONTRAINDICATIONS

The authors do not use CO₂ in conjunction with nitrous oxide anesthesia during CO₂ studies, because in animals it has been found that partial pressure differentials of the nitrous oxide saturated in the soft tissues will diffuse into the CO₂ bubble, increasing its volume by approximately six times. The CO₂ bubble may increase from 100 cc of injected CO₂ to 600 cc, which in the venous system may cause significant problems (vapor lock of the pulmonary artery). If only small volumes of CO₂ are required, nitrous oxide could be used safely if there is no alternative contrast available.

The authors have used CO₂ in hundreds of patients with pulmonary compromise without complications; however, the volumes are reduced and a greater delay between injections allows more time for the CO₂ to be absorbed.

In patients who present with intestinal ischemia or an AAA, the authors reduce the number of injections and volumes and allow more time between injections, permitting absorption of the CO₂. If the gas remains trapped in the aneurysm, the patient’s position is changed to free the gas.

CO₂ DELIVERY

The delivery of CO₂ has evolved over the past 38 years. It has included many different manual delivery systems, with or without manifolds, as well as more than five dedicated automated controlled systems. Many of these were not user friendly and never approved by the Food and Drug Administration. Previously, during bench testing of these devices, the authors discovered multiple potential complications but experienced a few clinical complications, which were short-lived.

After more than 20 years of experimenting with many different systems, the authors introduced a plastic bag system, as well as a technique of delivery extrapolated from their experience with computer-controlled injectors. The plastic bag system has proven to be very user friendly and actually much faster and easier than liquid angiographic injectors or hand delivery systems. If assembled correctly, its only disadvantage is the ease of making rapid injections in regions where ischemia could occur if injections are made more frequently, without time for the CO₂ to reabsorb.

Because the plastic bag, which only contains 1,500 cc at atmospheric pressure (if it is not disturbed), there is no possibility of inadvertently injecting excessive volumes and virtually no probability of air contamination if one uses the system properly. The authors have used this system for over 12 years without complications. In the last 8 years, improvements have been instituted that further reduce the probability of air contamination (Fig. 5).²

The authors feel that it is extremely important to employ a disposable aluminum cylinder containing United States Pharmacopeia (USP) grade
tube permits the operator to stand behind a protective radiation barrier during the injections. The distal high-pressure three-way stopcock, which is connected to the angiographic catheter, is used to remove air from the stopcock by back-bleeding the angiographic catheter and then closing the stopcock to the patient and flushing the stopcock with CO₂ three times, resulting in a pure CO₂-blood interface. After a forceful injection of 5 cc of CO₂ is made to clear the blood from the catheter, the system is ready for multiple nonexplosive CO₂ injections and imaging. The high-pressure three-way stopcock can also be used to administer drugs or inject iodinated contrast, either by hand or angiographic injector.

It can also be used to discharge excess CO₂ from the delivery syringe, maintaining a closed system without chance of air contamination at all times. The distal three-way stopcock is never used for CO₂ delivery because if the port closest to the plastic bag is open, air will be aspirated as the syringe is filled. This is the only way air can be inadvertently injected.

The system can also be used for interventional procedures if a specialized side-arm O-ring fitting is attached. This permits injection of the low-viscosity CO₂ between the guidewire and the catheter, or guidewire and any size needle. Injection of relatively large amounts of CO₂ between the guidewire and catheter permits accurate visualization of vascular anatomy before, during, and after interventional procedures (balloon dilation, stent placement, or placement of larger potentially dangerous catheters, and so forth). A large syringe and considerable force is required to purge the liquid from the small space between the catheter and the guidewire or needle. There is a prolonged delay of many seconds; however, when the liquid is cleared, the syringe’s plunger moves forward easily and subsequent injections can be made rapidly with little effort.

Hospital stores can provide a CO₂ cylinder that is filled with pure USP grade gas; however, frequently the tanks are cast iron and may contain rust and other contaminants. Again, the authors strongly suggest obtaining a disposable cylinder, with gas-type fittings, that has been individually tested for purity. When a new cylinder is delivered, 15 cc to 20 cc of CO₂ should be injected into the venous system imaging the pulmonary artery, to be absolutely sure that there is no air contamination. The CO₂ will trap in the anterior-located main pulmonary artery and will absorb within 15 to 20 seconds. It is easily seen with routine fluoroscopy; however, the pulmonary artery can be more accurately visualized with DSA (Fig. 6). If it remains longer, there is a possibility of air contamination.
Fig. 6. Method to detect possible air contamination of CO₂. (A) For TIPS procedure or any venous study when multiple injections are anticipated, a hepatic vein or any vein is injected imaging the pulmonary artery. Initially CO₂ traps in most anterior main pulmonary artery (arrow). (B) After 15 to 20 seconds, the majority of CO₂ will dissolve because of extreme solubility of CO₂ in blood (arrowhead). If CO₂ remains longer than 20 seconds, one should suspect air contamination.

A closed system without any possibility of valves connecting to the exterior is absolutely necessary to prevent air contamination. With the present plastic bag system, it is extremely important to connect the bag to the delivery system properly. A 30 cc to 60 cc Luer-lock delivery syringe is connected to the end where the O-ring gas fitting is attached. A label stating delivery port is attached. After the plastic bag is filled, the delivery syringe is also flushed three times. Do not add stopcocks and never connect the delivery system to the CO₂ cylinder. There is never a need to refill the plastic bag (1,500 cc is always more than enough).

To be sure there are no leaks in the delivery connections, the one-way bag’s stopcock is closed and the delivery syringe is forcefully aspirated. If there is a leak in the tubing or the fittings, the syringe will fill with room air. If the system is sealed, the operator is able to only retract the syringe’s plunger a short distance.

During the last 12 years the authors have not flushed the catheter with saline because CO₂ plus water produces carbonic acid and discomfort. The catheter is flushed every 2 to 5 minutes with CO₂.

General principles for CO₂ delivery are as follows:

Be absolutely sure that you are using a pure source of CO₂ USP (99.9%). CO₂ may be used to fill the cylinder; however, the cylinder itself may be contaminated with rust, bacteria, methane or some other contaminant. It is recommended to use a disposable cylinder individually tested for purity.

Use a delivery system where there is no possibility of injecting excessive volumes of CO₂. The flaccid plastic bag prevents inaccurate and inadvertent injections of excessive volumes.

Use a closed system to prevent air contamination. The CO₂ cylinder, which contains over 3,000,000 cc, should never be connected to the closed system. Always maintain the closed integrity of the system. Never use additional stopcocks. When using the plastic bag delivery system, be sure that all ports are closed and that the delivery syringe is attached adjacent to the gas-fitting port for the plastic bag.

Prevent explosive delivery. Purging liquid (blood or saline) from the angiographic catheter prior to CO₂ delivery results in a more consistent delivery, with less discomfort and less breakup into small bubbles.

Initially inject small volumes of CO₂ (30 cc for aortography and 5 cc to 10 cc for most selective injections) and increase or decrease the injection rate and volume.
Carbon Dioxide in Angiography to Reduce the Risk of CIN

depending upon the vascular bed that is being imaged.

Wait 2 minutes between injections, depending upon the volume injected and ischemic tolerance of the vascular bed. In high-risk areas, such as abdominal aneurysms, intestinal ischemia, or severe pulmonary compromise, the authors suggest waiting approximately 5 minutes between injections.

In poor flow conditions, elevate the area of interest (legs 10° to 15°, renal arteries 30° to 45°), and if the renal arteries cannot be filled, use the cross-table decubitus position. Alternatively, placing the catheter’s tip close to the area of interest will also improve filling.

Injecting vasodilators (nitroglycerin 100 mcg to 250 mcg intra-arterially into the vascular bed prior to CO₂ delivery improves filling considerably.

Any type radio-opaque-tipped catheter can be used; however, a single end-hole catheter causes less breakup into small bubbles.

DSA imaging: Use a 1,024 × 1,024 high-resolution system with a high-framing rate (4-6 frames per second). Most equipment manufacturers provide a software package that increases photon flux to improve visualization of this low-negative contrast agent, and a stacking program, which integrates multiple frames to produce a single diagnostic composite image.

If the operator has not used the delivery system previously, the following recommendations are suggested:

Assemble the bag and delivery system and practice injecting the CO₂ via a catheter into a container filled with water. Inject both with the angiographic catheter and, for interventional procedures between the guidewire and the catheter, between the needle and a guidewire using a specialized side-arm O-ring fitting.

The integrity of the connection to the bag should be tested frequently by closing the stopcock to the plastic bag and forcefully aspirating.

After one feels comfortable with the system’s setup and the delivery technique, the DSA imaging should be tested with the injection of 20 cc of CO₂ into an iliac or a peripheral vein. If the images demonstrate poor contrast (gray), the angiographic equipment applications person should be contacted to change the acquisition parameters. Do not perform your first procedure when iodinated contrast cannot be used.

Furthermore, to ensure the purity of every new CO₂ cylinder, the authors suggest making a venous injection (SVC, IVC, right atrium, or even a peripheral vein) and imaging the pulmonary artery to see if the trapped CO₂ disappears from the pulmonary artery within 15 to 20 seconds. If it remains longer, air contamination is a possibility. Injection of 20 cc of room air is not lethal; however, multiple large volume injections may be disastrous.

Current procedural parameters are as follows:

Runoff (pelvis and lower extremity)

a. Initially, obtain both leg runoffs with the catheter in the distal aorta.

b. Inject 20 cc to 40 cc in 1 second.

c. Elevate the feet 10° to 15° for optimal filling and obtain images of pelvis, thigh, knee, lower legs, and feet.

d. If the IMA is filled and the patient experiences pain, urge to defecate, or has symptoms of intestinal ischemia, the injections should be aborted or the injections should be made more distally in either femoral artery, where the IMA will not be filled.

e. If there is no stacking program, a longer injection (approximate 60 cc over 2 to 3 seconds) is necessary.

Single leg runoff with selective common iliac or more distal femoral arterial injections produce better filling and are unlikely to cause intestinal ischemia. This is the authors’ presently preferred method.

a. Perform a selective (antegrade preferable) injection of the common femoral or more distal arteries. Positioning can be either “over-the-hill” or antegrade placement of a 4 French catheter in the contralateral extremity. If distal filling is suboptimal, a microcatheter can be passed through the antegrade catheter and advanced as distally as possible (Fig. 7). For ipsilateral vessels, retract the catheter to the distal external iliac artery.

b. With stacking, inject 20 cc in 2 seconds. If filling remains poor, inject 20 cc to 40 cc over 3 to 4 seconds.

c. Without stacking, begin with 20 cc to 40 cc over 3 to 4 seconds.

d. Intra-arterial nitroglycerine, 100 Fg to 150 Fg prior to injection.
Fig. 7. Coaxial catheterization for preoperative lower extremity arteriogram in a 48-year-old man with ameloblastoma of the mandible. (A) Normal CO₂ pelvic arteriogram using an end-hole catheter (shepherd's hook catheter). (B) Right superficial femoral arteriogram was performed with the shepherd's hook catheter positioned in the proximal superficial femoral artery. (C) The 3-French microwire catheter was passed coaxially for the popliteal arteriogram. The popliteal artery is normal. (D) The popliteal artery and its trifurcation branches are normal. Both tibial and peroneal arteries are patent. The volume of CO₂ injected, ranged from 20 cc to 30 cc every 2 seconds.

Fig. 8. CO₂-guided anterior tibial angioplasty via the contralateral approach. (A) A 10-cc CO₂ injection via a 300-cm coronary angioplasty catheter demonstrates a 99% stenosis of the mid-anterior tibial artery and 50% stenosis of its lower one-third. (B) With a specialized side-arm O-ring fitting multiple CO₂ injections were made with the 0.018-inch guidewire positioned distal to the lesions. Postangioplasty imaging shows only very minimal residual stenosis (arrows). (C) Good filling of the foot and of dorsalis pedis artery and other unnamed collaterals, again injecting between the guidewire and the balloon catheter. No vasodilators or stacking was required. If iodinated contrast were used, very large amounts of contrast for each injection would have been required via a large guiding catheter at the aortic bifurcation.
Fig. 9. Bilateral renal stent placement. (A) Selective iodinated contrast injection of the right renal artery shows a tight stenosis without any filling of the distal renal arteries. (B) A similar injection of 20 cc of CO₂ shows the tight stenosis plus more distal filling of the right renal artery and a 50% stenosis of the origin of the left renal artery. (C) Injection between the stent catheter and the Rosen wire with reflux into the aorta demonstrates that the stent has advanced too distally (arrow). (D) Injection between the Rosen wire and the stent catheter demonstrating that the stent has been advanced several millimeters too distally into the left renal artery (arrow). (E) Final CO₂ injection between the guiding catheter and the Rosen wire showing excellent position and patency of both stents.

Aortogram

a. Twenty years ago, the authors injected 200 cc in 2 seconds with a computer-controlled injector, with occasional nausea, abdominal discomfort, urge to defecate, and more nausea when glucagon was used.

b. During the last 14 years, with the nonexplosive plastic bag system the authors have reduced the volume to 30 cc in half a second with less nausea, and if bowel gas obscures the image glucagon may be used.

c. The left renal artery 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 cc–20 cc CO₂ in 1 second) can be performed. Do not inject with patient in the prone position because the lumbar arteries will always fill with potential unknown neurotoxic effects.
d. Selective injections of the visceral arteries commonly require 5 cc to 30 cc in 1 to 2 seconds.

Venous: always image the pulmonary artery after the first injection to rule out air contamination (persistent gas). Normally, CO₂ should disappear after 10 to 20 seconds.

a. SVC and IVC: 20 cc to 50 cc in 1 to 2 seconds.

b. Subclavian: 20 cc to 40 cc in 1 to 2 seconds.

c. Peripheral veins: 15 cc to 25 cc, 4 to 8 seconds, usually with 22-gauge Angiocatheter. Rapid injection precipitates pain.

Interventional procedures:

a. Using a specialized side-arm O-ring fitting, CO₂ can be injected between the guidewire and needle or catheter.

b. Use a 20 cc to 50 cc Luer-locked syringe. With a smaller syringe, CO₂ will simply compress without injecting.

c. Wait 5 to 10 seconds for CO₂ to exit the catheter. CO₂ will compress as it purges fluid from the catheter.

d. After purging, subsequent injections require less pressure and delay.

For angioplasty, stent placement, and fibrolysis (renal, superior mesenteric artery, iliac) over the celiac bifurcation with distal Intervention (Fig. 8), CO₂ can be injected between the guidewire and the stent catheter to verify its exact position before the stent is deployed. For renal stent placement, the extreme buoyancy of the gas always results in reflux into the aorta, which visualizes the exact positions of the renal artery ostium (Fig. 9).

TIPS: Using any needle, inject 30 cc of CO₂ into the hepatic parenchyma for visualization of the portal vein throughout the various steps of the procedure. With the guidewire in place, CO₂ can be injected between the needle and the guidewire to verify the needle entry site and determine stent positioning.

REFERENCES


