Technical Tips for Using CO2 as a Contrast Agent to Image Patent Tibial and Foot Arteries Better and Safely

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Introduction

• Use of CO\textsubscript{2} goes back to the 1920s when used to visualize retroperitoneal structures

• Incorporated into Digital Subtraction Angiography after 1980s

• CO\textsubscript{2} displaces the blood producing negative contrast for digital subtraction imaging

Indications

• Renal insufficiency
  – avoid Contrast Induced Nephropathy

• Allergy to contrast media

• Applications where CO\textsubscript{2} out-performs conventional contrast media
  – improved demonstration of collateral pathways
  – enhanced vascular filling during central venography

Properties of CO\textsubscript{2} as an Imaging Adjunct

• Colorless, odorless gas occurs naturally in atmosphere and human body

• Safe as alternative contrast agent

• CO\textsubscript{2} bolus displaces equal volume of blood

• Important physical properties
  – High solubility
    • 20 x greater water solubility than O\textsubscript{2}
    • No dose limit
  – Low viscosity
    • Can be administered at high rate, Better visualization of distally reconstituted arteries and veins due to better filling of collaterals
  – Buoyancy
    • Preferential visualization of nondependent section of the vascular tree

• Compressibility: Explosive delivery/vessel distention causing embolization

CO\textsubscript{2} Characteristics & Implications

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>What advantage this confers as contrast agent?</th>
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<tbody>
<tr>
<td>High plasma solubility</td>
<td>• 20 x greater water solubility than O\textsubscript{2}</td>
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<td>• Rapid enzymatic clearance of dissolved CO\textsubscript{2}</td>
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<td>• First-pass lung clearance: 60 mL intra-arterial bolus completely dissolves in 30-60 seconds</td>
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<td>• No limit to amount that can be given</td>
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<td>High buoyancy</td>
<td>• Preferential visualization of nondependent section of the vascular tree</td>
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<td>• Potential for trapping/vapor lock</td>
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<td>Liquid displacement properties</td>
<td>• Lack of bolus fragmentation, allowing the CO\textsubscript{2} bolus to be maintained well past the injection point</td>
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<td>• CO\textsubscript{2} bolus displaces an equal volume of blood</td>
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CO₂ Characteristics & Implications

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<tr>
<td>Low viscosity</td>
<td>• Can be administered at high rate (through microcatheters or interventional sheath)</td>
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<td>• Better visualization of distally reconstituted arteries and veins due to better filling of collaterals</td>
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<td>Lower attenuation than tissue</td>
<td>• CO₂ is a negative contrast agent</td>
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<td>• Implications on the radiographic imaging technique parameters (kV, mA).</td>
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<td>• Use of digital subtraction with stacking to produce diagnostic quality angiograms</td>
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<td>• Higher susceptibility to motion and bowel peristalsis artifact</td>
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<td>Compressibility</td>
<td>• Explosive delivery/vessel distention</td>
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<td>• Aneurysm/plaque debris embolization</td>
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Contraindications of CO₂ as Contrast Agent

• Absolute
  – Above the diaphragm
  • Thoracic angiography - potential neurotoxicity
  • Coronary angiography - causing myocardial ischemia
  – During AV fistula work - prevent reflux of gas into brachial or subclavian arteries
  – Abdominal aorta in prone position or with patient’s head in elevated position
  • gas may fill spinal or lumbar arteries and cause spinal cord ischemia
• Relative
  – presence of pulmonary hypertension or COPD
  – in patients with patent foramen oval (PFO) or atrial septal defect (ASD)

CO₂ Storage and Delivery System

• Hand-injection approach
  – medical grade CO₂ cylinder/laparoscopic insufflators with an inline bacterial filter, three-way stopcock connectors, and one-way check flow connectors
  • Advantages - optimal timing, injection control, ability to arrest injection at any time, wide availability, low cost
  • Disadvantages - high radiation exposure and the open nature of the CO₂ delivery system, with the potential for air contamination
• CO₂ Bag Reservoir Delivery System
  • 1.5 L flaccid bag attached to a three port check valve, multiple three-way ports and one-way check flow valves
  • A particulate filter (0.2 mm), and a bleed-back/contrast injection port near the catheter hub.
  – bag is filled with CO₂ and emptied three times to purge any air contamination

Gas Storage and Delivery System

• CO₂MMANDER/ AngiAssist Portable system
  – portable CO₂ delivery system used in conjunction with the AngiAssist, a disposable delivery apparatus
  • key components
    • three-way fit connector (K-Connector),
    • series of one-way safety valves
    • multiuse CO₂ cartridge,
    • pre-attached 60 mL reservoir syringe
    • 30 mL injection syringe (Fig 3).
  • Advantages
    • disposable miniature CO₂ source allowing numerous uses, avoidance of direct connection between the CO₂
• CO₂ Storage and Delivery System
  • CO₂ Angioset
    – dedicated, well-marked medical grade CO₂ canister, a pressure-relief valve ensuring that any excessive pressure rise is purged, a sterile filter, three-way stopcock, and a dedicated 100-mL syringe allowing the delivered volume to be adjusted in 20-mL increments
  • Automated injectors
    – automated injection of CO₂
    – Advantages
      • precise control of injection timing, pressure, and volume,
      • reducing radiation exposure to the operator
      • Angiodroid Injector; INSPECT 3005R
**CO₂ Angiography Technique**

- Any size and shape of distal catheter bend
- End-hole catheter can be used for CO₂ angiography of the aorta or vena cava. Multi-hole catheter not needed
- Prevent explosive gas delivery and air contamination.
  - Use the plastic bag system, CO₂mmander with AngiAssist or the hand-held syringe method
  - Close the stopcock of the CO₂-filled hand-held syringe until injection
  - Purge the catheter with 5 ml of CO₂ immediately prior to CO₂ injection
- Never connect the catheter directly to the CO₂ cylinder

**CO₂ Angiography Tips/ Tricks for Tibial Artery Imaging**

- Perform selective injection
- Increase CO₂ volumes to improve imaging quality
- Separate CO₂ injections by 2-3 min
- Elevate the area of interest (15 degrees for the lower extremity imaging and 45 degree for renal imaging)
- Inject 100 ug of NTG intra-arterially prior to lower extremity CO₂ arteriogram

**Tibial and foot angio**

- CO₂ NTG + elevation vs DSA

**Adverse Events**

- Air contamination
  - Breeched technique or equipment failure can go unrecognized
  - Ischemic manifestations of air embolism depend on the vascular bed and are quite variable in severity
  - Neurotoxicity
  - Abdominal aortic or cardiopulmonary air-lock can lead to bowel ischemia or cardiovascular collapse
    - Aortic Vapor Lock: result of exchange and equilibration of non-soluble blood gases (mainly nitrogen gas [N₂] and O₂) with the trapped CO₂ pocket
    - resulting non-dissolvable gas pocket can cause a mechanical obstructive effect
Conclusions
• CO₂ can be used safely as a contrast agent
  – Useful in patients with renal insufficiency and contrast allergy
  – For arterial and venous beds except thoracic aorta, coronary artery, and cerebral circulation
• An understanding of CO₂ properties and development of facile use is essential
  – Complementary angiographic technique
  – Can allow broader application in appropriate vascular beds – including tibial vessels
  – Must prevent air contamination during use
• Good addition to the toolbox of the vascular surgeon