WHAT CAN WE DO WITH CO$_2$?

IMAGINATION!
DISCLOSURES

Consultant: AngioAdvancements LLC

Intravascular CO$_2$ is not FDA approved
Carbon Dioxide Digital Subtraction Angiography (CO₂ DSA): A Comprehensive User Guide for All Operators

James G. Caridi, MD, FSIR¹; Kyung J. Cho, MD²; Christian Fauria, MD, MSW, MPH¹; Navid Eghbalieh, MD¹
From the ¹Tulane University Medical Center, New Orleans, Louisiana and the ²University of Michigan Health System, Ann Arbor, Michigan.

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, 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. Following the safe, successful introduction of carbon dioxide angiography in animals, Hawkins demonstrated its feasibility in humans and histological proof of arterial and venous patency.
Welcome to the CO₂ Angiography Society
jimcaridi@gmail.com
NEED MONEY
FOR
BEER, DRUGS, HOOKER
(HEY, AT LEAST IM NOT
BULLSH!T IN YOU)
CO$_2$ UNIQUE PROPERTIES

- Invisible
- Buoyant
- Low viscosity
- Compressible
CO\(_2\) ADVANTAGES

• Non-allergic
• Non-nephrotoxic (unlimited volumes)
• Rapidly absorbed (20-30X O\(_2\))
• Low viscosity (1/400 iodinated contrast)
  – Easier to use with microcatheters
  – Can inject in-between catheter and wire
  – Better visualization of collaterals
  – Detection of bleeding, AVF
  – Portal vein visualization
• Central reflux
  – Ability to identify vessel/pathology central to catheter tip
• Cost (100cc = .03)
CO₂ DISADVANTAGES

- Requires unique delivery system
- Invisible – concern for undetected contamination
- Cerebral vessels should be avoided
- Bowel gas can interfere with abdominal images
- Potentially more labor intensive
CO$_2$ CONCERNS

- Contamination
- Excessive volumes
- Intracerebral exposure
- Compressive delivery
- COPD
- Pulmonary HTN
PREVENT CONTAMINATION

1. Use a disposable source of medical grade CO$_2$
2. Use a closed delivery system
3. Eliminate stopcocks
4. Glue connections
5. Flush system
Avoid excessive volumes
EXCESSIVE VOLUME

- One large bolus
- Multiple boluses given rapidly without time to resorb
THE HEMODYNAMIC AND VENTILATORY RESPONSES TO INTRACAVAL ADMINISTRATION OF ASCENDING DOSES OF GASEOUS CARBON DIOXIDE: EXPERIMENTAL STUDY IN 20 SWINE – Kyung Cho

- CO₂: 0.2 - 6.4 cc/kg
- Position in supine, LLD, RLD
- Monitoring:
  - HR, RR, BP,
  - PA, SaO₂, pCO₂
  - pO₂, pH, HCO₃⁻
  - ETCO₂ at 1, 3, 5, & 10 min post CO₂
- Histology of lungs
CONCLUSIONS

• Higher volumes showed various changes in recorded parameters

• \(\text{CO}_2\) in doses of 0.2-1.6 cc/kg (112 cc in 70Kg) caused no cardiopulmonary effects.

• Intravenous diagnostic \(\text{CO}_2\) DSA may increase PA pressure, \(\text{CO}_2\) should be used cautiously in patients with pulmonary hypertension.
CO₂ IS COMPRESSIBLE

- Inaccurate volumes
- Explosive delivery
PREVENT EXPLOSIVE DELIVERY

- Use a non-compressed closed system
- Purge to atmosphere
- Purge catheter before definitive injection
COPD

- CO$_2$ endogenous production 250 cc/min
- No problem unless in respiratory failure
- Precaution: decrease volume and increase interval between delivery
PULMONARY HTN

- Avoid high volume venous procedures
- Potential PFO
CONTRAINDICATIONS

• Supra-diaphragmatic arterial injections (intracranial CO$_2$)

• Known right to left shunts
INDICATIONS

• Iodinated contrast allergy
• Renal insufficiency
• High volume contrast procedures
• Detection of AVF/arterial bleeding
• Intervention: arterial and venous
NON-NEPHROTOXIC
CO$_2$ IS THE ONLY NON-NERPHOTOXIC CONTRAST AGENT!
CLASSIC CONTRAST INDUCED NEPHROPATHY (CIN) RISKS:

- Diabetic nephropathy
- Myeloma
- Intravascular volume depletion
- Large volume contrast
OTHER RISK FACTORS

- Hypotension (SBP < 80 mmHg)
- Heart Failure (NYHA III/IV)
- Use of intra-aortic balloon pump (IABP)
- Preexisting renal dysfunction SC > 1.5 mg/dl OR CrCL < 60 ml/mim
- Age ≥ 75 years
- Diabetes
- Hematocrit < 39% for men, or < 36% for women
- Dehydration
- Concomitant use of nephrotoxic drugs and/or renal perfusion reducing

Steven Dunn, Pharm.D, BCPS, University of Kentucky Chandler Medical Center (UK HealthCare)
HOSPITAL ACQUIRED CIN

Risk of death  \( \uparrow \) (34%) 6 x

Hospitalization  \( \uparrow \) 2 x

1 and 2 year mortality  \( \uparrow \) 2 x

Increase comorbid complications

McCullough P. Contrast Induced Acute Kidney Injury. J. Am.Coll. Cardiol 2008; 51:1419-1428
HOSPITAL ACQUIRED CIN

7500 Patients

In hospital mortality (22% vs 1.4%)

1 and 5 year mortality 4 x

Rihal et al.
CIN

- Patient population is aging
- Diabetes is increasing
- Vascular interventional procedures are increasing
- CLI & CTO 40% have renal insufficiency
- Creatinine clearance subnormal in > 80% of PAOD
- Serum Cr is inaccurate in 30% 40-49 yo and 90% > 70 yo
- 30% of Cr Clearance abnormal for > 70 yo
- CIN correlates with 30 day and 1 year mortality and is the strongest one year predictor of death
BOTTOM LINE!!!

REDUCE OR PREVENT CIN

LIMIT THE VOLUME OF CONTRAST
WHAT GOOD IS IT IF YOU HELP THEM WALK AND NOW THEY HAVE TO WALK TO DIALYSIS!!!!!
CO$_2$

- Eliminates CIN

- Permits procedures previously precluded in patients with renal insufficiency!!!
DELIVERY
Plastic Bag Delivery System for Hand Injection of Carbon Dioxide

Irvin F. Hawkins, Jr., James G. Caridi, Scott R. Kohn

Digital subtraction angiography with carbon dioxide as a contrast agent provides images useful in making a diagnosis and occasionally gives information not obtainable with use of iodinated contrast material. However, delivery of the gas is difficult because carbon dioxide is compressible and invisible (1, 2). Over the past 10 years, we have developed a reliable, user-friendly, computer-controlled injector, which is not yet approved by the Food and Drug Administration. We describe a hand-delivery system designed on the basis of principles learned from the development of the computer-controlled injector system.

Materials and Methods

The system has two main components (Fig. 1): a plastic bag (AngioShunt Bag Delivery System; Angiodynamics, Queensbury, N.Y.) that is used as a reservoir for the carbon dioxide and a closed fluid (or gas) delivery system (AngioShunt II, Angiodynamics) consisting of multiple check valves, stopcocks, and a connecting tube. The reservoir is a 1500-mL plastic bag with a 100-cm connecting tube. In order to remove residual air from the connecting tubing and the bag, a special remove-to-replace adaptor is connected to the one-way stopcock. After air is removed from the bag, the stopcock is...
WASTE BAG AND CONTRAST DELIVERY SET
CO₂ ANGIOGRAPHY TECHNIQUE
YOU THINK YOU KNOW CO$_2$?
CLINICAL APPLICATIONS

- Arterial diagnosis
- Arterial intervention
- Detection of bleeding and or fistulas
- Interventional oncology
- Venous diagnosis and intervention
- Dialysis
- Portal venography and intervention
- TIPS
CO$_2$ IS BOUYANT

Left Side Up
VASCULAR STRUCTURES LESS THAN 10 MM HAVE 1/1 CORRELATION WITH LIQUID CONTRAST
3 FRENCH CATHETER
CO₂ DSA - EFFICACY

• 128 CO₂ studies - 115 patients
  38 patients = high risk
  70 renal failure
  18 allergy

• Surgical correlation 92% CO₂ Alone
  100% with little contrast

TIPS FOR IMPROVING (RUNOFF) IMAGING

• Reduce motion
• Faster exposure (6 frames/sec)
• Elevate the extremity or area of interest
• Stacking software
• Endhole catheter
• Increase CO$_2$ volume
• (super) Selective injections
• Vasodilator (NTG 100 mcg)
ELEVATE THE AREA OF INTEREST
STACKING SOFTWARE
S/P 100 MCG NTG IA
BOWEL GAS?

GLUCAGON 1 mg IV
“THE PADDLE”
DISPLACE GAS WITH COMPRESSION
DELIVERY CATHETER
CO$_2$ DISPERSION PATTERNS FORM THE DIFFERENT CATHETERS

endhole

halo

pigtail
DETECTION OF BLEEDING

1. \( \text{CO}_2 \) - low viscosity
2. \( \text{CO}_2 \) exits the vessel and expands
3. Little or no capillary phase to obscure \( \text{CO}_2 \)
4. \( \text{CO}_2 \) is not diluted by blood

Hashimoto et al, Sem Interven Rad 1997; 14:163-173
Hawkins et al, Sem Interven Rad 1997; 14:175-180
CONTRAST  

$\text{CO}_2$
ARTERIAL INTERVENTION

• Reflux - can opacify the entire vessel including ostium for more precise stent placement

• Can inject between guide cath and catheter or wire and catheter to check placement without compromising position for PTA and stenting

• Microcatheter injections for easy opacification

• Can perform repeated injections without the fear of renal failure
Short communication

The use of carbon dioxide angiography for renal sympathetic denervation: a technical report

doi: 10.1093/ckj/sfx066
Original Article

Renal denervation using carbon dioxide renal angiography in patients with uncontrolled hypertension and moderate to severe chronic kidney disease

Mohammed Awais Hameed\(^1,2\), Jonathan S. Freedman\(^2\), Richard Watkin\(^2\), Arul Ganeshan\(^2\) and Indranil Dasgupta\(^2,3\)

\(^1\)Institute of Applied Health Research, University of Birmingham, Birmingham, UK, \(^2\)Heart of England NHS Foundation Trust, Birmingham, UK and \(^3\)Aston Medical School, Aston University, Birmingham, UK
CO$_2$ IN CLI AND CTO

0.014” CORONARY TURNPIKE LP MICROCATHERETER
CO\textsubscript{2} IN CLI AND CTO

- Single center, Prospective.
- 36 patients with DM, CLI (Rutherford V, VI) & CKD > 3.
- PVA and PVI guided by ACDA. No image degradation.
- TcPO2 improved from 11.8 to 58.4 mmHg (P<0.0001).
- Clinical improvement in 100% of patients.
- No changes were seen in CrCl & no CO\textsubscript{2} complications.
- ACDA is safe and efficient to guide PVI in pts with DM, CLI and CKD > 3.

*Journal Endovascular Therapy 2016; 23(1):40-48.*

Thanks to L.M. Palena, Policlinico Albano Terme, Italy
CO₂ IN CLI AND CTO

- Size of vessels is ideal
- Little soft tissue interference
- CO₂ can be used to roadmap and game plan and if necessary filled in with dilute contrast
- Small catheters (< 2 Fr) can be used with ease because of low viscosity
- Reflux allows opacification of central and peripheral structures with one injection
EVAR FACTS

• Predisposition for renal dysfunction > open

• Renal impairment independent predictor of mortality

• Occurs in pts with & without renal insufficiency

• ARF = 7 – 25% with & 2.5% without

• Associated mortality is 30 – 50%

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<td>Catheter-less angiography for endovascular aortic aneurysm repair: a new application of carbon dioxide as a contrast agent.</td>
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<td>A prospective study of carbon dioxide digital subtraction versus standard contrast arteriography in the detection of endoleaks in endovascular abdominal aortic aneurysm repairs.</td>
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<td>Huang SG et al</td>
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<td>Ann Vasc Surg</td>
<td><strong>Carbon Dioxide</strong> as Contrast Medium to Guide Endovascular Aortic Aneurysm Repair.</td>
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<td>2017</td>
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PRE-OP EVAR

- No fruit and vegetables 4 days prior to EVAR
- Simeticarbon intake the day before and the same morning of the EVAR
- Use of angiobelt or paddle to move possible bowel gas and reduce peristalsis
- Glucagon 1 mg IV
INTERVENTIONAL ONCOLOGY

- Comorbid conditions predisposing to CIN
  - Renal insufficiency, Diabetes, Hepatic insufficiency

- Peri-procedural medications can predispose to renal failure
  - NSAIDS

- Post embolization syndrome can deplete intravascular volume

- Many embolization procedures require high volume contrast

- Tumor lysis syndrome can induce renal failure

- Rare - non-target embolization of kidneys
WEDGED HEPATIC VENOGRAM WITH CO2
VENOUS DX & TREATMENT

• Slow gentle injection of 15-30 cc
• \( \text{CO}_2 \) is not diluted by blood and can opacify central veins more readily from a peripheral approach
• Venous PTA and stent placement
• IVC filter placement
• Ultra fine needle splenoportography
• Portal vein access
CO$_2$ BILATERAL UPPER EXTREMITY VENOGRAM FROM HAND ACCESS
Upper-Extremity Venography: CO₂ versus Iodinated Contrast Material

Sam Heye, MD
Geert Maleux, MD
Guy J. Marchal, MD, PhD

Purpose:
To determine prospectively the diagnostic performance of CO₂ venography, by using conventional venography with iodinated contrast material as the reference standard, for the preoperative evaluation of upper-limb and central veins before creation of fistulas for hemodialysis access.

Results:
For CO₂ venography, global interobserver agreement was good, with a κ value of 0.90 (range, 0.71–1.00; 95% confidence interval: 0.84, 0.95). A κ value of 0.96 (range, 0.86–1.00; 95% confidence interval: 0.93, 0.99) was calculated for global interobserver agreement for conventional venography. The sensitivity, specificity, and accuracy of CO₂ venography for all vein segments were 97%, 85%, and 95%, respectively.

Conclusion:
CO₂ venography had a sensitivity of 97% and a specificity of 85% in the assessment of upper-limb and central vein patency and stenosis, with conventional venography used as the reference standard.
CARDIAC RESYNCHRONIZATION TREATMENT
Contrast-induced acute kidney injury in patients undergoing cardiac resynchronization therapy—incidence and prognostic importance. Sub-analysis of data from randomized TRUST CRT trial

Jacek Kowalczyk - Radoslaw Lenarczyk - Oskar Kowalski - Tomasz Podolec - Pawel Francuz - Patrycja Pruszkowska-Skrzep - Mariola Szulik - Michal Mazurek - Ewa Jedrzejczyk-Patej - Beata Sredniawa - Zbigniew Kalarus - for the Triple-Site Versus Standard Cardiac Resynchronization Trial (TRUST CRT) Investigators

Received: 5 December 2013 / Accepted: 12 February 2014 / Published online: 14 March 2014

- 98 patients/30 months f/u
- CIN 10.2%
- GFR < 60, CIN double those > 60
- Mortality  CIN 50%, no CIN 17%
- CIN = number one risk factor for death
log-rank $P=0.012$
CO$_2$ IVC FILTER PLACEMENT
DIALYSIS ACCESS
RENAL FAILURE PATIENT ON DIALYSIS

• Advantage of maintaining some renal function
• Patients are much easier to manage
• Tolerate a missed dialysis much better
• Fluid and potassium management is much easier in this group of patients
• A one point drop in GFR = increase in mortality of 12%
DIALYSIS IS TOO LATE TO NEGATE THE NEGATIVE EFFECTS OF CONTRAST ON THE KIDNEYS!!
CAVEATS IN DIALYSIS ACCESS

• The mission is to visualize the access without refluxing CO₂ into the cerebral vessels!!!!

• Has reportedly led to seizures and short term semi consciousness
DIALYSIS ACCESS GUIDELINES

• View central venous outflow first
• Don’t explosively deliver in venous limb especially if thrombus present, avoids reflux in to artery
• Can inflate occlusion balloon to see venous outflow and prevent arterial reflux
• Don’t purposely reflux into arterial limb to see anastomosis
• Place microcatheter in arterial limb to deliver small, gentle injection
• Place patient in Trendelenburg to limit central arterial reflux
• Or use small amount of dilute contrast $\frac{1}{4}$ to see arterial anastomosis
$\text{CO}_2$ FISTULULA\textsc{GRAM}
FOGARTY BALLOON
CO$_2$ GUIDED SPLENOPORTAL VEIN INTERVENTION

- Portal vein embolization
- Portal vein thrombosis
- Portal vein stricture
- TIPS
CO₂ PORTOGRAM
CO$_2$ GUIDED TIPS

- Hepatic vein evaluation
- Intraparenchymal portal venogram
- Entry site verification
- Portal venogram
- Post procedure portogram
DIRECT INTRAPARENCHYMAL CO₂
SPLENIC INTERVENTION
PRE-OP LIVER TX
152

CO

2

10-20 cc through 25 gauge spinal needle to determine patency of portal vein prior to transplant

PATENT

OCCLUDED
NEW HORIZONS
Intraosseous Venography with Carbon Dioxide Contrast Agent in Percutaneous Vertebroplasty

**OBJECTIVE.** Our objectives were to ascertain whether CO\(_2\) can be used as a contrast agent in venography during percutaneous vertebroplasty and to evaluate whether it might be capable of replacing nonionic iodinated contrast agents.

**CONCLUSION.** Intraosseous venography with CO\(_2\) contrast agent was slightly inferior to iodine venography in terms of its ability to visualize the vertebral bodies and perivertebral veins, but it remains a useful technique because no interference with optimal visualization of bone cement occurs during the cement injection when CO\(_2\) remains within the fracture cleft.

Percutaneous vertebroplasty has an excellent pain-relieving effect on compression fracture due to various causes [1–7] and has therefore attracted much attention as a new therapeutic technique for this condition. It is a relatively simple technique that involves advancing a needle through the skin and into the affected vertebral body, injecting a cement-like substance that can be used to stabilize the vertebral body. It is a common technique in the treatment of osteoporotic vertebral fractures, as it can significantly reduce pain and improve mobility. Our objectives were to ascertain whether CO\(_2\) can be used as a contrast agent in venography during percutaneous vertebroplasty and to evaluate whether it might replace nonionic iodine contrast agents.
Case Reports

Splanchnic neurolysis using carbon dioxide as the contrast agent

Kazuhiko Hirata M.D., Kazuo Higa M.D., Shinjiro Shono M.D., Kazunori Hirota M.D., Tetsuya Shinokuma M.D.

Abstract

Background and Objective: Iodinated contrast agents are
Carbon Dioxide-Contrasted Computed Tomography Angiography: High Pitch Protocols and Adapted Injection Parameters Improve Imaging Quality

Kohlendioxid-kontrastierte computertomografische Angiografie: Protokolle mit hohem Pitch und angepassten Injektionsparametern verbessern die Bildqualität.

320-row multidetector CT angiography for hepatocellular carcinoma using CO2 gas instead of iodinated contrast agents: Experiment and preliminary clinical study

High-Pitch Carbon Dioxide Contrasted CT Angiography: Pilot Study

Tobias Penzkofer · Karin Slebocki · Jochen Grommes · Philipp Bruners · Peter Isfort · Thomas Schmitz-Rode · Stephan Langer · Christiane K. Kuhl · Andreas H. Mahnken

Carbon Dioxide Contrast Enhancement for C-Arm CT Utility for Treatment Planning during Hepatic Embolization Procedures

Adrian A. Wong, MD, Resmi A. Charalel, MD, John D. Louie, MD, and Daniel Y. Sze, MD, PhD
Carbon Dioxide Flushing Technique to Prevent Cerebral Arterial Air Embolism and Stroke During TEVAR

Tilo Kölbel, MD, PhD, Fiona Rohlffs, MD, Sabine Wipper, MD, PhD, Sebastian W. Carpenter, MD, Eike Sebastian Debus, MD, PhD, and Nikolaos Tsilimparis, MD, PhD
CO₂ angiography is safe when used appropriately

The new delivery system is user friendly

CO₂ has unique properties as a contrast agent

These properties make it a useful tool in both diagnosis and intervention alone or in combo with liquid contrast
THANKS FOR YOUR ATTENTION