

Radiological aspects of CO₂ peripheral DSA: Preliminary analysis on the dedicated protocols

Pier Luca Rossi^{1,2}, David Bianchini³, Alessandro Lombi^{1,2}, Sonia Sapignoli², Manami Zanzi², Ivan Corazza²

¹O.U. Medical Physics, University of Bologna, Viale Berti Pichat 6/2, 40124 Bologna, ²Experimental, Diagnostic and Specialty Medicine Department, University of Bologna, Via Massarenti 9, 40138 Bologna, ³Medical Physics Unit, Istituto Scientifico Romagnolo per lo Studio e la Cura dei Tumori IRCCS, Meldola, FC, Italy

Correspondence: Dr. Ivan Corazza, Experimental, Diagnostic and Specialty Medicine Department, University of Bologna, Via Massarenti 9, 40138 Bologna, Italy. E-mail: ivan.corazza@unibo.it

Abstract

Objectives: Thanks to its lack of allergic reactions and renal toxicity, CO₂ represents an alternative to iodine as a contrast medium for peripheral subtraction angiography. Since CO₂ has a lower and negative contrast than iodine, postprocessing DSA and stacking are mandatory. So, it seems that higher doses than traditional iodine angiography are required. We addressed the dosimetric aspects of CO₂ angiography for two different commercial DSA-apparatus. **Materials and Methods:** Two different radiological suites were analyzed by recreating the same setup on all the apparatuses: we used a PMMA slabs phantom with a MPD Barracuda dosimeter on its side to collect all radiological parameters. **Results:** Results show that the irradiation parameters were left completely unchanged between the traditional and CO₂ angiographic programs. **Conclusions:** This leads to thinking that these CO₂ protocols do not operate on the X-ray emission, but only differ on image manipulation. The possibility of improvements by changing radiological parameters are still not explored and really promising.

Key words: Carbon dioxide contrast medium; digital subtraction angiography; X-ray spectrum

Introduction

The increasing of number and complexity of radiological medical procedures^[1-3] start to involve patients with serious clinical conditions, such as renal impairment and allergies to iodinated contrast medium (CM),^[1,3-6] introducing the necessity to study the performance and usage of alternative contrast mediums during interventional procedure, such as carbon dioxide (CO₂).

The biomechanical aspects involved in CO₂ angiography were previously studied, with great attention on gas flow

control and possible damages at the vessel walls during the gas injection^[7,8] and the possibility to simulate operative conditions.^[9]

In fact, the visualization of a gas inside a vessel requires different considerations if compared with typical liquid CM (i.e., iodine contrast medium). While iodine mixes with blood, full-fills the vessel and has a k-edge absorption peak at photon energy of 33.2 keV, CO₂ is inflated into the vessel

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Cite this article as: Rossi PL, Bianchini D, Lombi A, Sapignoli S, Zanzi M, Corazza I. Radiological aspects of CO₂ peripheral DSA: Preliminary analysis on the dedicated protocols. Indian J Radiol Imaging 2020;30:372-5.

Received: 12-Apr-2020
Accepted: 18-Aug-2020

Revised: 12-Aug-2020
Published: 15-Oct-2020

Access this article online	
Quick Response Code: 	Website: www.ijri.org
	DOI: 10.4103/ijri.IJRI_247_20

in form of “moving bubbles” with a negative contrast^[4,6,10] without any edge absorption in the linear attenuation coefficient curve.

Furthermore, the CO₂ is 400 times less viscous than iodine: this characteristic is a great advantage for angiographies not only as it allows the quick injection of large volumes of the gas through very small catheters, but it also allows CO₂ to pass through small vessels, visualize tight stenosis and collaterals, and small bleeding.

Moreover, inflated CO₂ cannot completely displace the blood and runs along the anterior part of the vessel, potentially underestimating the diameter of a vessel and introducing a nonoptimal contrast due to the incorrect fill. The gas buoyancy may also cause preferential filling of some branches, based on patient positioning. It is therefore fundamental to choose carefully the patient’s position or change it during the procedure.

The aim of this work was to study the radiological aspects of the procedures, analyzing different fluoroscopy equipments and their automatic irradiation conditions when CO₂ protocols are used, in particular analyzing if these differences are stressed to optimize imaging in CO₂-peripheral DSA.

Materials and Methods

To study the irradiation parameters applied during CO₂ protocols, we worked on two fluoroscopy suites from different manufacturers [Ziehm VISION RFD, GE INNOVA GS - Figure 1 and Table 1], used for peripheral DSA CO₂-angiography. We have chosen these two apparatuses because both ZIEHM and GE implement dedicated protocols for CO₂ contrast medium: other manufacturers perform the DSA with the same program independently of the contrast medium used.

We are interested in investigating how different equipments perform fluoroscopy with DSA, in both traditional and CO₂ specific program, to evaluate if implemented protocols are optimized or not.

The inspected equipments operate in pulsed-mode, allowing the operator to choose the pulse rate (in frames per second). To analyze the behavior of different radiological suites, we have recreated the same set-up on all the apparatus: instead of patient, we used a PMMA slabs phantom (thickness of

12 cm), with a multipurpose MPD Barracuda dosimeter on its side to collect all parameters (such as kV, exposure time, dose rate waveforms). All radiological parameters are settled automatically by the automatic exposures control system.

Results

Ziehm Vision RFD

On the Ziehm equipment, we measured the dose rate waveforms in DSA fluoroscopy with 25, 12.5, 8, and 4 frames per second and for both traditional and CO₂ programs [Figure 2]. During the acquisition, all data (as kV, mA) are settled automatically and collected [Table 2].

GE Innova IGS

The same measurements were performed on the GE equipment with pulse rates of 7.5 and 4 frames per second. The dose-rate waveforms for the traditional DSA fluoroscopy and for the CO₂ specific program are shown in Figure 3.

As in the Ziehm equipment, even here we found no actual difference between the traditional DSA and the CO₂ DSA programs. In this case, however, the emission parameters changed for different pulse rates [Table 3]. As for the previous apparatus, no clear phases can be seen in the waveforms, thus the mask image is acquired at the selected pulse rate.

Conclusions

Results show that the irradiation parameters were left completely unchanged between the traditional and CO₂

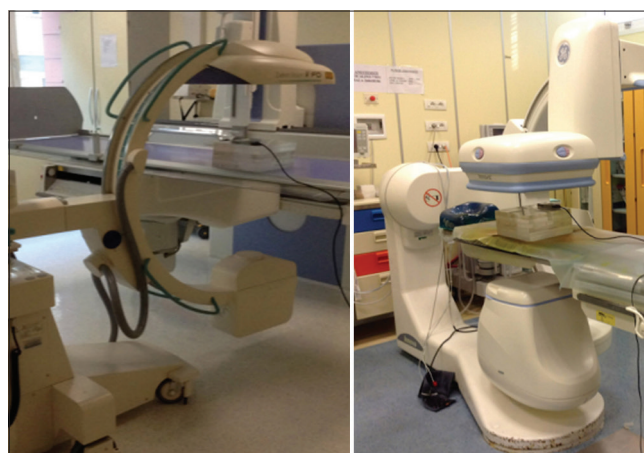


Figure 1: The fluoroscopic suites during the tests (from left to right: ZIEHM and GE)

Table 1: Specifications of the fluoroscopic suites

Manufacturer	Name	Power	Focal spot size	Anode angle	Total filtration (mmAl)	Detector type and size
ZIEHM	Vision RFD	20 kW	0.3/0.6 mm	10°	5	Flat Panel 30 × 30 cm
GE	Innova IGS	100 kW	0.3/0.6/1 mm	11°	1.8 + 0.2 mmCu	Flat Panel 31 × 31 cm

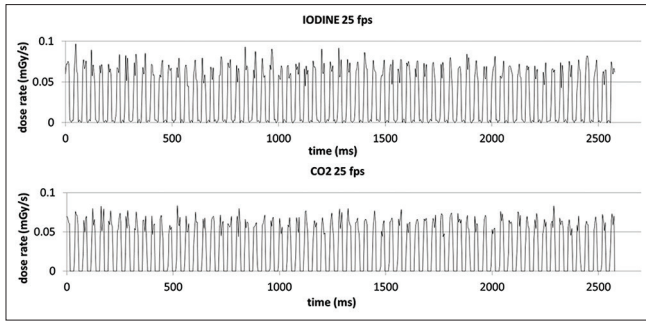


Figure 2: Examples of dose rate waveforms for ZIEHM (25 fps, iodine protocols and CO₂ protocols)

Table 2: Comparisons between protocols for ZIEHM

Protocols	kV	mA	Pulse rate (fps)	Pulse length (ms)
Iodine	67	58.8	25,12.5,8,4	20
CO ₂	67	58.8	25,12.5,8,4	20

Table 3: Comparisons between protocols for GE Innova

Protocols	kV	mA	Pulse rate (fps)	Pulse length (ms)
Iodine	83	144	7.5	42
CO ₂	83	144	7.5	42
Iodine	81	160	4	42
CO ₂	81	160	4	42

angiographic programs. This leads to thinking that these CO₂ protocols do not operate on the X-ray emission but only differ on image manipulation level to enhance contrast.

These measures disprove the hypothesis that, on currently employed equipment, CO₂ angiography is intrinsically more dose-heavy than traditional DSA, as described by authors. The only parameter that could lead to an actual increment of the patient dose is an augmented fluoroscopy time, probably due to the clinical staff's lack of experience with CO₂ injection and its technical difficulties, therefore requiring multiple repetitions during the acquisition.

During the tests, emission parameters are settled by the automatic exposure control system, and their choice is a trade-off between administered dose and image quality but optimized for traditional ICM. However, CO₂ is quite different from traditional contrast media for both X-ray absorption characteristics, such as the absence of a K-edge, and for its dynamical and mechanical characteristics.

Moreover

1. Emission spectra for DSA are traditionally set considering the use of iodinated contrast media, hence they try to maximize the emission at energies corresponding to a higher iodine-tissue contrast. Considering that CO₂ does not have such limits, as it doesn't have a K-edge, and considering that modern flat panel detectors have wider

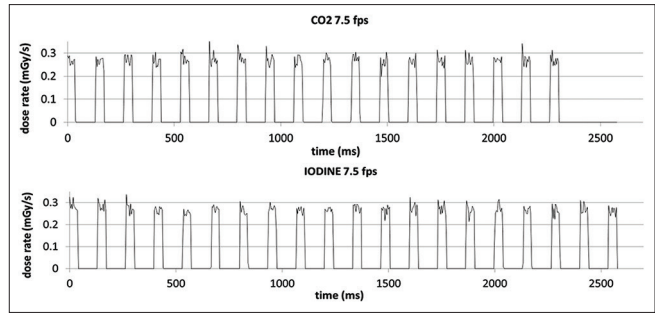


Figure 3: Examples of dose rate waveforms for GE Innova (7.5 fps, iodine protocols and CO₂ protocols)

dynamical ranges than traditional systems, higher tube voltages could be taken into consideration

2. The frame rate and the pulse length became very important parameters to optimize images. Due to its physical properties, it seems to be advisable for CO₂ DSA protocols a long pulse time, as the main interest did not lay in the imaging of the single bubble, but in obtaining an image of a contrail of bubbles, realized by averaging over the length of the pulse. Since modern fluoroscopes can perform complex image manipulations without significant time lag, new protocols could be taken into consideration. For example, we could evaluate whether acquiring with higher frame rates and shorter pulse lengths, and then stacking the resulting images, could give an interesting or better outcome. More complex stacking algorithms could be tested, e.g., a thresholded algorithm that emphasizes the bubble signal by adding where the signal exceeds a certain threshold, while averaging if it doesn't
3. The transit of CO₂ bubbles inside the vessels could be very fast, thus it might be captured in just a few of the images. In this case, a simple stacking of all the acquired photograms does not represent the best solution, and a selective addition of the interesting imaged would be advisable. This process could even be implemented as an automatic system, for example by selecting an ROI around the vessel and only stacking the images in which this ROI has a change of contrast
4. An important consideration on patient dose should also be made. As already stated, the patient dose for diagnostic and interventional procedures should be kept as low as reasonably achievable, based on a careful risk-benefit evaluation. In some clinical cases, however, it is clear that the minimization of dose is secondary to the need of good angiographic images. This is the case of the growing number of senior patients with relatively short life expectancy, serious vascular diseases with a concrete risk of gangrene, and with risk factors for contrast medium nephrotoxicity. For such patients, CO₂ DSA could be the only possibility of intervention, and therefore an eventual increase in administered dose would be negligible when compared to the clinical benefits

In conclusion, we believe that there is room for further researches and improvements on the choice of the optimal emission parameters for CO₂ DSA.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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