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Radiological aspects of CO_2 peripheral DSA: preliminary analysis on the dedicated protocols

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Abstract

Objectives: Thanks to its lack of allergic reactions and renal toxicity, CO_2 represents an alternative to iodine as contrast medium for peripheral subtraction angiography. Since CO_2 has

a lower and negative contrast than iodine, post-processing DSA and stacking are mandatory. So, it seems that higher doses than traditional iodine angiography are required.
We addressed the dosimetric aspects of CO_2 angiography for 2 different commercial DSA-apparatus.

Materials and methods: Two different radiological suites were analysed by recreating the same set-up 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 CO_2 angiographic programs.

Conclusions: This leads to think that these CO_2 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.

Keywords: digital subtraction angiography; X-ray spectrum; carbon dioxide contrast medium.

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 (CO_2).

The biomechanical aspects involved in CO_2 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, CO_2 is inflated into the vessel in form of “moving bubbles” with a negative contrast (4, 6, 10) without any edge absorption in the linear attenuation coefficient curve.

Furthermore, the CO_2 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 CO_2 to pass through small vessels, visualise tight stenosis and collaterals, and small bleeding.

Moreover, inflated CO_2 cannot completely displace the blood and runs along the anterior part of the vessel, potentially underestimating the diameter of a vessel and introducing a non-optimal 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 is to study the radiological aspects of the procedures, analysing different fluoroscopy equipments and their automatic irradiation conditions when CO_2 protocols are used, in particular analysing if these differences are stressed to optimise imaging in CO_2-peripheral DSA.

Materials and methods

To study the irradiation parameters applied during CO_2 protocols, we worked on 2 fluoroscopy suites from different manufacturers (Ziehm VISION RFD, GE INNOVA GS - Fig. 1 and Table 1), used for peripheral DSA CO_2-angiography. We have chosen these 2 apparatuses because both ZIEHM and GE implement dedicated protocols for CO_2 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 CO_2 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 analyse the behaviour 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 CO_2 program (Fig. 2). During the acquisition, all data (as kV, mA) are settled automatically and collected.

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 CO_2 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 CO_2 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 CO_2 angiographic programs. This leads to think that these CO_2 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, CO_2 angiography is intrinsically more dose-heavy than traditional DSA, as described by authors. The only parameter that could lead to an actual increment of patient dose is an augmented fluoroscopy time, probably due to the clinical staff's lack of experience with CO_2 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, CO_2 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 CO_2 does not have such limits, as it doesn't have a K-edge, and considering that modern flat panel detectors have wider 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 CO_2 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 CO_2 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 a 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 CO_2 DSA.

Competing Interests

The authors declare that they have no competing interests.

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7. to 10. blinded

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

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

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

Figure 2: Examples of dose rate waveforms for ZIEHM (25 fps, iodine protocols and CO_2 protocols)

Figure 3: Examples of dose rate waveforms for GE Innova (7.5 fps, iodine protocols and CO_2 protocols)