Estimation of Gd-DTPA concentration in vivo for MR perfusion measurements in pig lungs by means of computed tomography

F. Risse[1], M. Puderbach[2], J. Ley-Zaporozhan[2], S. Ley[2], H-U. Kauczor[2], and W. Semmler[1]

[1]Medical Physics in Radiology, Deutsches Krebsforschungszentrum, Heidelberg, Germany, [2]Radiology, Deutsches Krebsforschungszentrum, Heidelberg, Germany

Introduction

In quantitative contrast-enhanced perfusion studies of the lung, a linear relationship between the MR signal and the contrast agent (CA) concentration is crucial. Centric-reordered saturation recovery turbo-FLASH sequences in particular offer an extended range of linearity but can't provide complete coverage of the lung as needed for clinical diagnostics. Therefore, many studies used 3D FLASH techniques without any preparation [1-4]. Independent of the chosen technique, it is difficult to determine the CA concentration in vivo. CA dilution series show the range in linearity but can't be directly compared to the measured signal. The use of vials filled with CA close to the measurement subject suffers from inhomogenous coil sensitivity and fails to provide a real estimate of the in vivo concentration.

In contrast to MRI, CT offers absolute signal and a linear relation between signal and CA concentration, also for MR CAs such as Gd-DTPA. Thus, it provides a good estimation of the maximum CA concentration in the large pulmonary artery. The aim was, therefore, to amend the MR perfusion measurement in pig lungs by taking additional CT measurements to estimate the real maximum CA concentration in vivo.

Material and Methods

Contrast-enhanced perfusion measurements (MR scanner: 1.5T Symphony, Siemens, Erlangen, Germany) were performed in 5 pigs (mean weight 32.6 kg) with a clinical 3D FLASH sequence with the following parameters: TE/TR/flip angle: 0.7 ms/1.8 ms/40°, FOV: 450×338 mm², acquisition matrix: 192×144, slice thickness: 4mm, 40 partitions, bandwidth: 1000Hz/px, GRAPPA: acceleration factor 2, 20 reference lines. 30 consecutive measurements were performed with a temporal resolution of 1.1 s after the administration of a 0.05 mmol/kg b.w. and a 0.07 mmol/kg b.w. (only in 4 pigs) Gd-DTPA bolus. The CA was administered with a catheter inserted in the inferior vena cava. A break of at least 30 minutes was maintained between the bolus injections. In addition, perfusion measurements were performed with CT (Aquilion 16, Toshiba, Japan) in the same way as the MR measurements. Heart rate and oxygen saturation were monitored during all measurements to control the blood circulation.

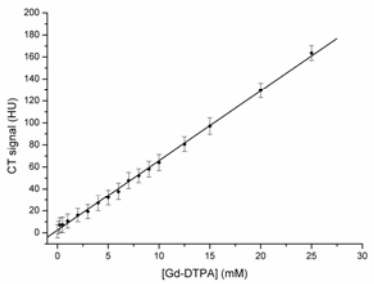

Figure 1: *Relation between the measured CT signal and contrast agent concentration of the dilution series.*

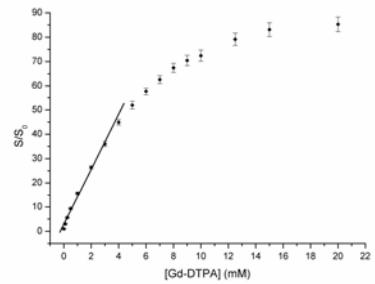

Figure 2: *Relation between the measured MR signal and contrast agent concentration of the dilution series. Only a limited range between 0-4 mM shows a linear relation.*

Phantom measurements were carried out to determine the relation between signal and CA concentration for CT and MRI. Different CA dilutions (0-25 mM) were measured with the same settings as the CT and MRI perfusion measurements. An arterial input function (AIF) was defined in the A. pulmonalis in the CT and MRI perfusion measurements. The maximum values of the AIFs (S_{max}) were taken to estimate the maximum CA concentration in vivo (C_{max}) by means of the CT phantom measurement. The linearity of the MR measurements was then controlled using C_{max} and the MR phantom measurements, and assuming a constant blood circulation.

Table 1: *Results of CT and MRI in vivo measurements including monitored physiological parameters. For MRI only physiological parameters are shown since MR phantom and in vivo measurements aren't directly comparable.*

			CT				MRI	
	Dose (mmol/kg)	Volume (ml)	HR (min^{-1})	S_pO_2 (%)	S_{max} (HU)	C_{max} (mM)	HR (min^{-1})	S_pO_2 (%)
#1*	0.05	3.2	72	100	25,4	3,6	71	99
#2	0.05	2.9	92	98	32,0	4,7	90	100
	0.07	4.1	89	99	44,0	6,6	87	100
#3	0.05	3.0	104	100	44,8	6,7	104	100
	0.07	4.2	100	99	63,4	9,8	98	100
#4	0.05	3.0	86	99	21,9	3,0	84	98
	0.07	4.3	82	98	32,3	4,7	84	97
#5	0.05	3.5	70	99	50,6	7,6	67	100
	0.07	4.9	71	99	70,8	10,9	70	100

HR: heart rate; S_pO_2: oxygen saturation. *Only the 0.05 mmol/kg bolus was administered in pig #1.

Results

Monitoring of the heart rate and oxygen saturation showed no significant differences between the CT and the MRI measurements (Table 1). Absolute differences in heart rate were no more than 3 min^{-1}. The calculated C_{max} of the AIFs for the CT perfusion measurements are shown in table 1. The increase of C_{max} of the CT measurements was proportional to the increase in dose.

The CT measurement of the Gd-DTPA dilution series revealed a linear relation between the CT signal and CA concentration (R=0.999, $P < 0.0001$) for the entire CA concentration range (Fig. 1).

The MR phantom measurement showed a linear relation only for a limited range of 0-4 mM (R=0.994, $P < 0.0001$), whereas some bolus injections led to in vivo concentrations greater than 4 mM in the CT measurements (table 1). The typical signal saturation was found for higher doses (Fig. 2).

Discussion

The CT examinations revealed a wide range of CA concentrations in the A. pulmonalis for the same doses. In three pigs, even the lower dose of 0.05 mmol/kg caused a CA concentration above the range of linearity of the MR sequence used, whereas the lower dose can be assumed to be in the linear range in the other pigs. The higher dose of 0.07 mmol/kg exceeded the linear range in all animals.

Since the monitored circulation parameters showed no or only minor changes between the CT and MR measurements, the measurement conditions can be assumed to be comparable. It should be possible to transfer these results to measurements in humans, since the CA doses were normalized to the body weight.

In conclusion, the examination provides an estimation of the CA concentration in vivo which is otherwise challenging. The results showed that the CA dose must be chosen carefully as even low doses do not ensure a CA concentration in the large pulmonary arteries within the range of linearity between MR signal and CA concentration in some subjects.

References

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