Intraindividual comparison of different contrast agent application schemes and their influence on concentration, signal and bolus geometry

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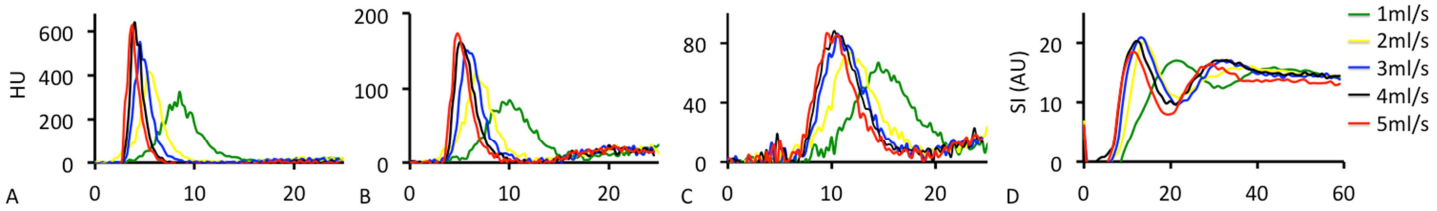
Purpose: Although contrast enhanced (CE) techniques are well accepted as the standard of reference for most magnetic resonance angiography (MRA) applications, very little is known about the influence of contrast agent (CA) application schemes on CA bolus shape. Unlike iodinated CAs in computed tomography angiography (CTA) or conventional digital subtraction angiography (DSA), gadolinium (Gd) based CAs (GBCA) have a non-linear relationship between CA-concentration and MR signal. Published CA application approaches are highly variable between institutions and are based on anecdotal evidence only. Purpose of this study was to evaluate the influence of different injection schemes on GBCA concentration, signal and bolus geometry.

Methods: 18 Minipigs (36.5±7.1kg) were scanned twice each with 5 different injection schemes (1, 2, 3, 4 and 5ml/s) with a dose of 0.1mmol/kg bodyweight gadobutrol. The first round of experiments consisted of dynamic computed tomography (CT) imaging (1 axial slice block covering superior vena cava, pulmonary artery as well as ascending and descending aorta, 80kV, 180mAs, temporal resolution 0.25s). Since CT density values are proportional to Gd-concentration this measurements enabled calculation of CA-concentration at different locations. The second round of experiments consisted of dynamic magnetic resonance imaging (MRI, 1 coronal slice covering jugular veins, superior vena cava, aortic arch and carotid arteries; 2D GRE, 40mm slice thickness, TR32.56ms, TE 1.19ms, flip angle 30°). MRI measurements enabled to evaluate arterial and venous signal as well as bolus configuration. Because no parallel imaging was applied signal changes could be measured without the influence of inhomogeneous noise distribution. To keep the influence of prior injected GBCA on measurements negligible injection schemes were applied in a randomized fashion and time between injections was at least 45 minutes. For CT measurements phantom experiments performed prior to this study revealed that 49.6 Hounsfield Units (HU) equal 1 mg Gd/ml or 6.4mM. Statistical analysis of the different injection schemes was done with a t-test with a significance level of 0.05.

Results: Mean GBCA bolus peak concentration in the superior vena cava was 54.5mM, 79.9mM, 94.0mM, 100.3mM and 109.2mM at 1ml/s, 2ml/s, 3ml/s, 4ml/s and 5ml/s respectively. Concentrations for the different injection schemes in the pulmonary artery were 14.1mM, 20.9mM, 24.1mM, 24.9mM and 25.6mM, in the ascending Aorta 11.1mM, 13.1mM, 14.2mM, 14.5mM and 14.1mM, respectively. In MRI high concentration of GBCA in the superior vena cava led to saturation effects and thus T2* artifacts. Mixture of contrast enhanced blood coming from the superior vena cava and non-contrast enhanced blood from the inferior vena cava lead to significant lower GBCA concentration and MRI signal values in the pulmonary artery. Pulmonary passage further diluted the applied GBCA and thus the GBCA concentration and MRI signal again decreased significantly. Mean MRI signal increase in carotid artery was 21.4, 22.9, 23.0, 21.7 and 21.3 respectively for the different injection schemes. Differences in GBCA concentration and MRI signal between different injection schemes decreased from the venous side towards the arterial system. In the aorta GBCA concentrations were significantly lower for 1 ml/s compared to all other injection schemes. For MRI signal enhancement in the carotid arteries this difference is quantitatively visible but not statistically significant. Between the 2ml/s, 3ml/s and 4ml/s scheme no differences in the bolus shape were visible whereas the 5ml/s scheme already shows non-significantly lower MRI signal values.

Discussion: Because of the non-linear relation of GBCA concentration and MRI signal optimization of GBCA application is of high interest. However, published application schemes vary significantly. Our results reveal that injection rates of more than 2ml/s show no benefit as compared to injection rates between 1ml/s and 2ml/s. Actually, injection rates of more than 4ml/s result in very high GBCA concentrations in the region of interest, already leading to T2* effects and thus a decrease in signal. The bolus shape in the aorta after injection of 2ml/s, 3ml/s and 4ml/s is not significantly different showing that the influence of blood mixture in the right ventricle and the pulmonary passage is more eminent than the influence of different injection velocities when handling small injection volumes like in contrast enhanced MRI.

Conclusion: An injection rate between 1 and 2 ml/s deliver highest signal increase, an injection rate of > 4ml/s lead to T2* effects because of a too high Gd-concentration.



Graphs showing density increase in CT (Δ HU) after application of GBCA in the superior vena cava (A), the pulmonary artery (B) and the ascending aorta (C) as well as the MRI signal increase in the carotid arteries (D) with the used injection schemes 1ml/s, 2ml/s, 3ml/s, 4ml/s and 5ml/s. Note the decrease of density increase after the pulmonary passage as well as the similarities in the bolus shape after using the 2ml/s, 3ml/s and 4ml/s injection rate.