Contrast-Enhanced Magnetic Resonance Angiography of the Iliac Arteries: Optimization by Injection Simulation

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Introduction

The image quality in Contrast-Enhanced Magnetic Resonance Angiography (CE-MRA) is critically affected by contrast-agent infusion timing and k-space acquisition ordering. Different protocols and infusion schemes have been employed in CE-MRA of the iliac arteries to grade stenosis; comparison with either conventional MRA or X-ray Digital Subtraction Angiography (DSA) has yielded variable rates of success [1,2,3]. Artifacts associated with timing errors have also been described [4].

Some variability in CE-MRA image quality is expected to be associated with subject-dependent physiological parameters, which affect the progressive dilution of the contrast agent in the bloodstream. Cardiac output, in particular, may respond to stress and other factors, and cause significant variations in image quality even in CE-MRA examinations of the same subject. The optimisation of CE-MRA (injection rate, timing and pulse sequences) would thus benefit from a model to predict enhancement patterns for different infusion schemes. The objective of this work is to develop computer simulations of the contrast agent (CA) concentration following a given infusion, taking into account the characteristics of the subjects' circulation, and to optimise CE-MRA examinations of the iliac arteries.

Methods

Twelve patients with stenosis over 50% (diagnosed by DSA) had CE-MRA examinations at 1.5T (GE-SIGNA), with a dose of either 0.3 or 0.5 mmol/kg b.w. Gadodiamide (Omniscan, Nycomed) assigned at random. Initially an injection at maximum rate of 10% of the allocated dose (bolus injection) was used to assess the delay between the injection and delivery of contrast-agent to the iliac arteries. The delay to peak enhancement was calculated from a series of consecutive coronal images of the abdominal aorta. The main injection was subsequently synchronised with the CE-MRA pulse sequence (3D gradient-echo, FOV 380x280 mm, TE=2.8s, TR =14.3s, slab thickness 60x1.5mm).

The image intensity over the abdominal aorta following the bolus injection was used to produce an estimated Impulse Response Function (IRF) of contrast agent concentration as a function of time. Measurements were done above the bifurcation, and the calculation assumed that the blood magnetisation had achieved a steady-state before the arrival of the contrast agent. The IRF was used to simulate injections of different durations, and the main sources of errors were estimated. Maximum infusion rate and centric k-space coverage could then be compared to slower infusions of contrast agent and sequential k-space coverage. Variations in enhancement measured for different patients provided information on inter-subject variability of physiological parameters.

Results

For every individual measurement of image intensity as a function of time following the bolus injection, blood T1 and the contrast agent concentration were calculated. Figure 1 shows the typical results; contrast agent concentration decreases very slowly after reaching approximately 1/3 of the peak concentration. Figure 1c thus estimates the IRF.

![Figure 1](image1.png)

**Figure 1** - a. Image intensity measured over the abdominal aorta. b. Blood T1 and c. CA concentration calculated for the same subject.

Using the IRF, the contrast agent concentration was simulated for different infusions of the full contrast agent dose. Infusion at the pump's highest rate (5ml/s) and infusions over 30s, 45s and 60s were considered. Resulting profiles indicate that the recirculation of contrast agent is significant, and that peak contrast agent concentration is not inversely proportional to the total injection time (Figure 2). The same model can be used to design infusions at variable injection rates which can generate more symmetric CA concentration profiles.

![Figure 2](image2.png)

**Figure 2** - Simulated contrast agent concentration for infusions at different rates for same subject shown in Figure 1.

The simulated concentration profiles were used to calculate vessel enhancement profiles for centric and sequential acquisition schemes and the infusions considered in Figure 2, assuming that the k-space centre is synchronised with the maximum enhancement. Our results suggest that CE-MRA with longer injections and sequential k-space coverage is less sensitive to timing errors than centric k-space coverage, with comparable vessel enhancement. Overall the iliac CE-MRA examinations obtained with 60s injection and sequential k-space coverage provided images of diagnostic quality.

Conclusions

The simulation of CA concentration using an estimated IRF is a useful method to optimise injection rates and acquisition parameters for CE-MRA. CE-MRA of the iliac arteries with sequential k-space coverage and relatively long contrast-agent infusions is an effective technique.

References