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Quantitative myocardial perfusion imaging using a step arterial-input function

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Background

Modern MRI myocardial perfusion protocols use rapid venous bolus injections, typically 3-5 ml/s of 5-15 ml of agent over a few seconds. The resulting arterial input functions are rapidly varying with high agent concentrations (Fig. 1A and 1B) and thus typically require high temporal resolution acquisitions (~1 sec), custom pulse sequences and complex processing methods for perfusion quantification. A new myocardial perfusion approach, based on a pseudo step arterial-input function (Magn Reson Med. 2005 Aug;54(2):289-98), is introduced that offers simplified and lower concentration input functions, simplified quantitative data processing and reduced demands for high temporal resolution.

Methods

Numerical simulations of whole body vascular systems were used to design optimized venous injection protocols for the generation of step-input-like arterial-input functions targeting the idealized step-input function show in Fig. 1C. A two-compartment numerical model was used to estimate myocardial contrast agent concentration dynamics for conventional (bolus) and step-input protocols.

In-vivo experiments were performed on a Siemens Aera 1.5T (Siemens Healthcare, Erlangen, Germany). ECG-gated saturation-recovery (TS=100 ms) bSFFP images were acquired for 120 heartbeats (1 image/beat, diastasis). Matrix size 224 × 136, rate 2 GRAPPA, 8 mm slice, 1.03 ms TE, 2.5 ms TR, 70° flip. All contrast injections were single dose (0.1 mmol/kg) of Magnevist (Bayer). In-vivo data was acquired in 3 healthy controls and 3 CAD patients, all ~90 days post MI (LVEF = 45%-66%, 61-92 kg). Blood/tissue signal intensities were converted to contrast agent concentrations using a Bloch equation look-up-table approach and myocardial perfusion was estimated with an exponential deconvolution approach.

Results

Optimized venous injection protocols comprised decaying injection rates over ~1 min. with contrast agent dilution to ~60 ml (same protocol for all subjects). Sample blood and tissue time-intensity curves (normalized to baseline) in a healthy subject are shown in Fig. 1B and 1D, for a standard rapid bolus and an optimized step-input injection protocol. Fig. 2A shows arterial inputs for all subjects, and a sample perfusion map in a healthy control and patient are shown Fig. 2B and 2C.

Conclusions

A generalizable injection protocol can generate a pseudo arterial step-input function for a range of subject sizes and heart function, offering several advantages over conventional bolus injections: slower tissue dynamics enable multi-slice imaging with single-slice per heart-beat acquisitions, lower concentrations mitigate T_2* and T_1 saturation effects and long injection duration avoids recirculation effects. The conventional short tissue "dynamic" window (~10 seconds, Fig. 1B inset) reflects complex bolus injection dynamics; the pseudo-step arterial input reveals a longer window (~60 seconds, Fig. 1D) over which the contrast agent redistributes to the tissue via perfusion (as predicted with compartmental modeling in Fig. 1C).

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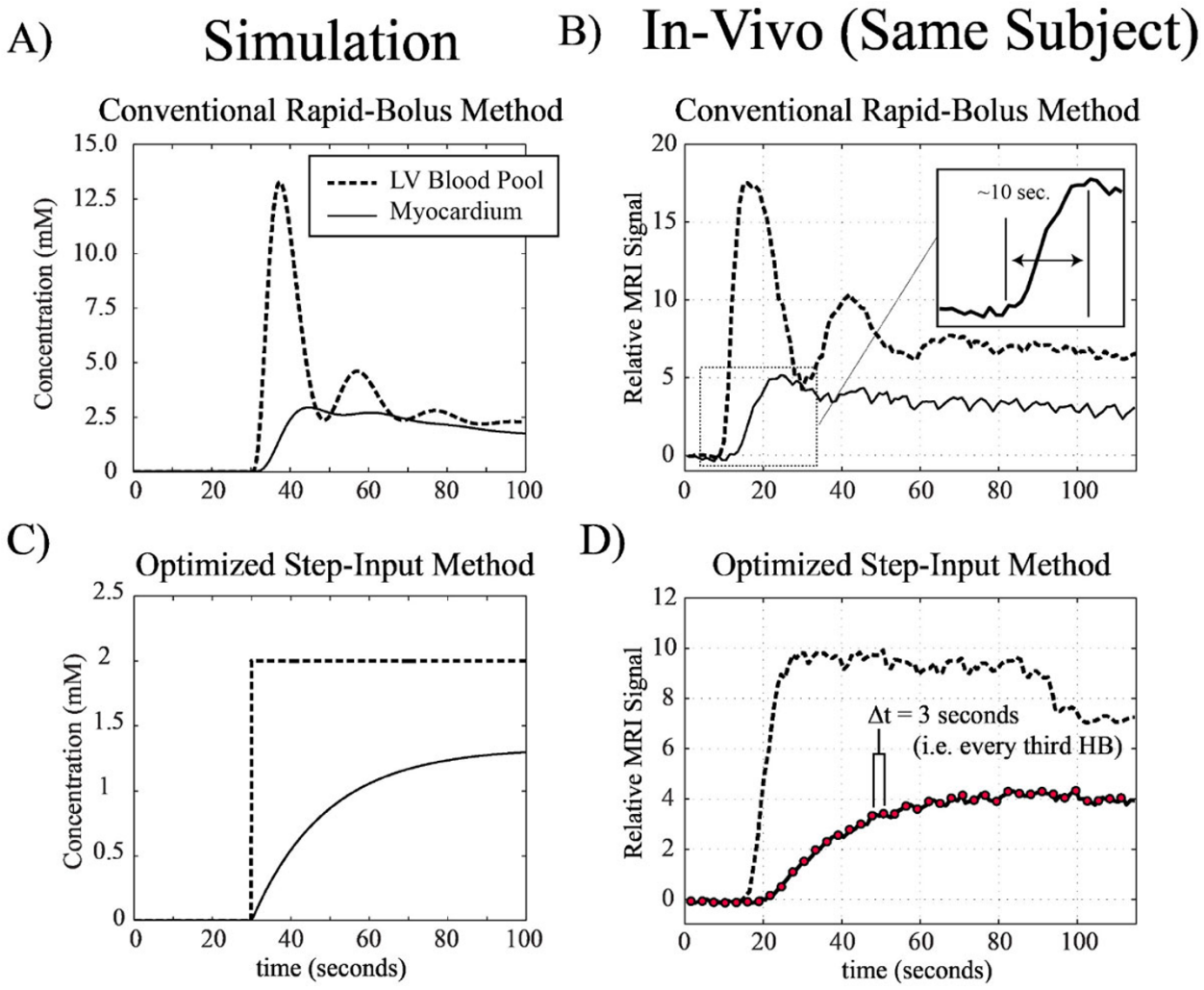

Figure 1 A) Simulated arterial input and tissue contrast agent concentration (based on 5 ml/s bolus injection and 1 ml/g/min perfusion). **B)** In-vivo blood (LV pool) and myocardial signal (normalized to baseline) for a bolus injection (XX ml at 5 ml/s) in a healthy control. **C)** Myocardial tissue response for an idealized step-input for 1 ml/g/min perfusion. **D)** In-vivo blood (LV pool) and myocardial signal (normalized to baseline) for an optimized pseudo-step-input protocol (same subject as **B**).

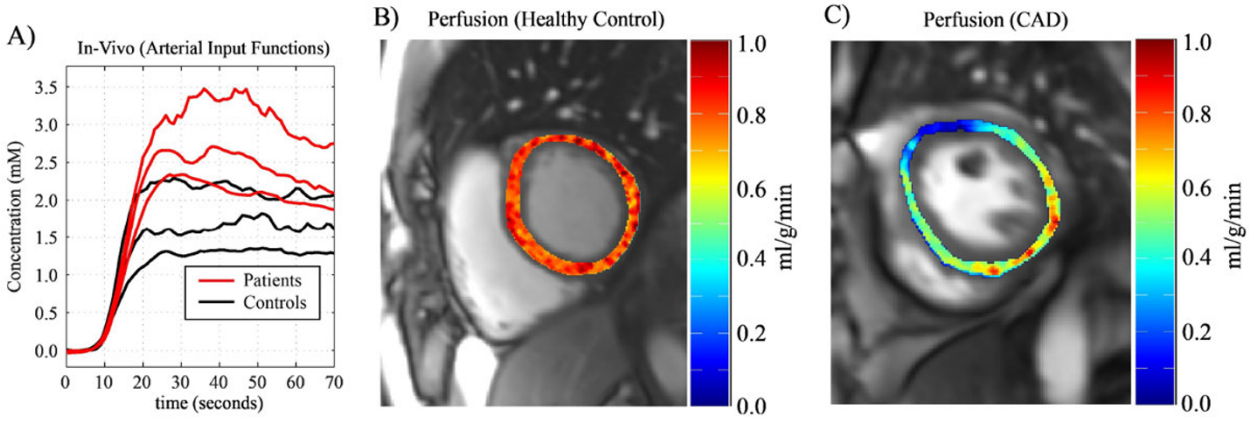

Figure 2 A) Left ventricular arterial input functions for the 6 study subjects using the optimized step input venous injection protocol. Sample quantitative perfusion images for a healthy control subject and a patient with coronary artery disease (CAD) are shown in **B)** and **C)**, respectively.

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