Dynamic Assessment of Myocardial Flow Reserve: a BOLD Approach

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Dynamic assessments of myocardial flow reserve (MFR) will allow consecutively monitoring dose-responses of myocardium to various therapeutic interventions and may provide important information on the myocardial viability. A myocardial BOLD method was proposed and developed to measure myocardial oxygenation and MFR dynamically during hyperemia using the Fick’s law. This approach was validated in normal dogs by blood sampling. In stenotic dogs, the calculated MFR values were highly correlated with those obtained by first-pass perfusion imaging. Such technical advancement may permit repeatable measurements of MFR in a clinical setting.

Introduction
Recently, myocardial flow reserve (MFR) has been quantified by fast MR imaging during the first-pass of a contrast agent through the myocardium [1,2,3]. However, this method requires at least two contrast injections, at rest and under hyperemia. It is not practical to repeat the study in one session if one injection fails. Moreover, multiple measurements of MFR are not possible. Using deoxyhemoglobin as an endogenous contrast agent, myocardial BOLD effect has shown a potential for assessment of myocardial flow status [5]. The aim of this project is to examine the feasibility of a novel MR BOLD technique for quantification of MFR along a time course in a canine model.

Materials and Methods

Theory
A theoretical model was recently proposed to quantify myocardial oxygen extraction fraction (OEF) during pharmacological induced hyperemia [4]. In brief, with a two-compartment model in myocardium, i.e., capillary blood and tissue, the spin-echo (SE) T2 app can be expressed as:

\[ T2_{app} = \frac{e^{-\frac{T1}{T2}}}{} \]

where MVO2 is myocardial oxygen consumption rate.

MR Studies
Three normal dogs were first examined to validate estimated MFRs during hyperemia. Blood samples were collected simultaneously from both descending thoracic aorta and coronary sinus to measure the oxygen contents for the determination of the global myocardial OEF and MFR. In another three dogs, a Teflon ring was inserted to the left circumflex coronary artery (LCx) to create a diameter stenosis of 70%. Heart rate and blood pressures in all dogs were continuously recorded and the heart rate-pressure product (RPP) was used as the index of MVO2.

All studies were performed at a 1.5 T Siemens Sonata system. A 2D segmented multi-contrast turbo SE sequence was used to acquire myocardial T2 maps within a single breathhold. After a series of baseline T2 scans, a dose of 0.15 mmol/kg/min of dipyridamole (DIP) was infused to the dogs intravenously for 4 min. T2 imaging were acquired consecutively during the hyperemia for 60 min. Blood sampling in normal dogs were performed once at rest and at different time points after the infusion of DIP. In stenotic dogs, MR first-pass perfusion imaging was conducted at rest and around 20 min after the infusion of DIP. The first-pass MFR was calculated as the ratio of the slope of the perfusion curve during hyperemia to the slope of the curve at rest. Student t-test and correlate coefficients (C.C.) were used to compare MFR calculated by different methods.

Results
In normal dogs (n=3), dynamic MFR patterns were clearly demonstrated with a high correlation coefficient of 0.93 between two curves obtained by blood sampling and BOLD approach (Fig. 1). Paired test reveals no significant difference between two sets of MFR values. In stenotic dogs, the MFR values calculated using BOLD T2 contrast (n = 3) were found to be highly correlated with those obtained through first-pass perfusion imaging in both normal (C.C. = 0.99) and flow restricted regions (C.C. = 0.98). Moreover, dynamic MFR changes could be obtained using the BOLD approach, which could not be achieved by the first-pass perfusion imaging method (Fig. 2).

Discussion
We have demonstrated the feasibility of the BOLD approach to detect myocardial flow reserve dynamically during hyperemia. This direct measurement of MFR will allow consecutively monitoring dose-responses of myocardium to various therapeutic interventions. The proposed technique is equally applicable to animals and human subjects. In clinical practice, dynamic evaluation of myocardial oxygen (OEF) and flow states will help to understand the physiology and pathophysiology of the myocardial ischemia and viability and may offer an objective and convenient mean to assess the efficacy of cardiac therapies.

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References