Highly Accelerated, Millimeter In-Plane Resolution Myocardial Perfusion MRI Using a 32-Channel 3.0 T System

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Purpose

Rapid first-pass contrast-enhanced MRI has become a valuable tool for the assessment of myocardial perfusion (1,2). Remaining obstacles to a broader clinical acceptance of first-pass myocardial perfusion MRI are (i) the limited in-plane spatial resolution of approximately (3 x 3) mm^2, which may result in severe Gibbs ringing artifacts (3) and (ii) the limited anatomic coverage achievable, due to the competing constraints of the short first passage of contrast agent, temporal resolution, anatomic coverage, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). The synergy between the SNR advantages of many element coil arrays and high magnetic field strengths, together with the speed benefit of parallel imaging can overcome these difficulties. In order to approach this goal, this study examines the feasibility of highly accelerated first pass perfusion imaging at 3.0 T with millimeter in-plane spatial resolution while accomplishing single-heart-beat temporal resolution. In order to achieve high accelerations, supporting targeted slice coverage, high spatial and temporal resolutions without the prohibitive noise amplification associated with coil sensitivity encoding, spatio-temporal correlations in dynamic imaging are exploited using *k-t* BLAST (4,5).

Material and Methods:

Studies were performed using a 3.0 Tesla MR system (Philips, Best, Netherlands) and two cardiac-optimized 32-element coil arrays (i: INVIVO Corp, Gainsville, FL, USA, ii: Philips Research-Europe, Hamburg, Germany) each featuring a different matrix design (Fig. 1b) Phantom experiments were carried out (i) to compare the baseline SNR of the two different 32-element coil arrays with a 6-element cardiac coil (Philips, Best Netherlands) and (ii) to estimate improvements in the in-plane spatial resolution possible. A loading phantom (50 x 35 x 27 cm^3) was designed to simulate an average subject (Fig. 1a). Noise was derived pixel-by-pixel from the standard deviation of the signal intensity time course over 60 dynamic scans. Maps were made of the ratio of SNR achieved with the 32 element coils to that achieved with the 6-element coil (SNR_{ratio}). First pass myocardial perfusion studies were conducted with an ECG-gated 2D saturation recovery technique (FOV=(31x31) cm^2, number of slices=3, 1 R-R interval temporal resolution). The acquired in-plane spatial resolution was (1.2x1.2) mm^2 (matrix 256x256) for 8-fold, (1.1x1.1) mm^2 (matrix 288x288) for 12-fold and (1.0x1.0) mm^2 (matrix 320x320) for 16-fold undersampled k-t BLAST. Contrast agent (0.1 mmol/kg b.w. gadopentetate dimeglumine) was injected at 3 ml/s, followed by a 20 ml saline flush at 3 ml/s.

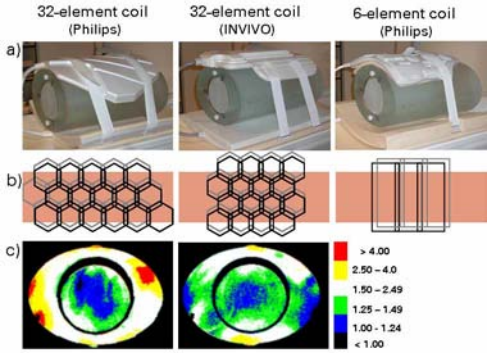

Fig.1: a) Coil positioning in phantom experiments. **b)** Layout of the 32- **(left, middle)** and 6-element **(right)** coil arrays. The red area marks the region included in the SNR measurements. **c)** SNR ratio maps derived from a series of axial slices (F-H coverage=22 cm) illustrating the SNR advantage of the 32-element coil arrays over the 6-element array.

Results:

In phantom studies the 32-element arrays showed baseline SNR gains over the 6-element cardiac coil. Measurements in the central phantom segment, which mimicks the position of the heart in the chest cavity, revealed an SNR gain ranging from SNR_{ratio}=1.00-1.24 to SNR_{ratio}=1.25-1.49 while peripheral regions showed an SNR gain of up to SNR_{ratio}=4 (Fig 1c). The feasibility of highly accelerated 2D first pass myocardial perfusion imaging at 3.0 T using spatio-temporal correlations in the dynamic data is demonstrated in Fig. 2. The *k-t* BLAST approach enabled acceleration factors and image quality that are unattainable with one-dimensional SENSE. The speed advantage of the 8-fold undersampled acquisition over the conventional approach was transferred into an enhanced in-plane spatial resolution of (1.2x1.2) mm^2. Selected short axis first-pass perfusion images from a patient study, encompassing 3 slices per heartbeat using k-t BLAST reconstruction with 16-fold undersampling are shown in Fig. 3a. Susceptibility artifacts were caused by surgical cerclages, since this patient study was conducted after open chest surgery. These images demonstrate the suppression of Gibbs ringing artifacts as well as a high spatial resolution of (1.0 x 1.0 x 8.0) mm^3, highlighted in a magnified segment (Fig. 3b) indicated by the white rectangle in Fig 3a.

Conclusions:

The ability to produce millimeter in-plane spatial resolution holds the promise of improved myocardial perfusion assessment and serves to support an extension of the perfusion assessment to the right ventricle. The highly accelerated approach yielded image quality superior to that of the conventional approach, primarily as a result of the substantial improvement in the in-plane spatial resolution and the suppression of Gibbs ringing artifacts though temporal fidelity remains a concern as very large accelerations are explored. The SNR and speed advantages presented here offer the potential of extending the capabilities of perfusion imaging using single-heart-beat, multi-slice 2D acquisitions to whole heart coverage 3D acquisitions.

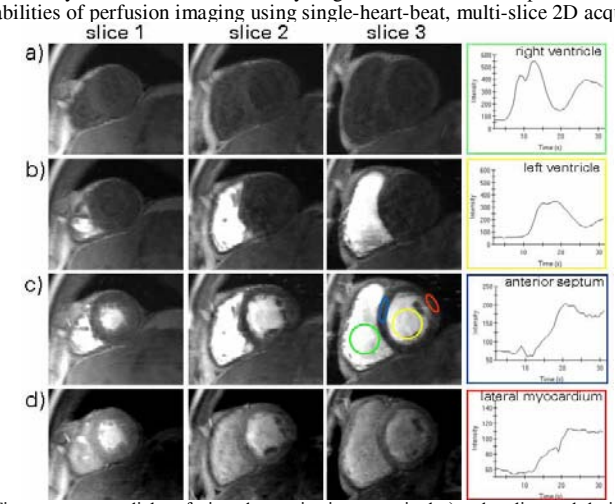

Fig. 2: First pass myocardial perfusion short axis views acquired **a)** at baseline and during **b)** bolus passage in the right **c)** and in the left ventricle and at **d)** equilibrium. Images were acquired using a 32-element coil (IN VIVO Corp., Gainsville, FL, USA), 8-fold undersampling, *k-t* BLAST reconstruction and an acquired in-plane spatial resolution of (1.2x1.2) mm^2. The graphs show the signal intensity time course obtained from regions of interest placed in the right **(green)** and left **(yellow)** ventricles, in an anterior septal **(blue)** and in a lateral segment **(red)** of the myocardium.

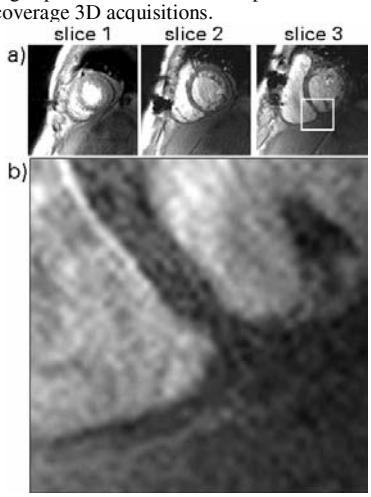

Fig. 3: First pass myocardial perfusion short axis views obtained with a 32-element cardiac array (Philips Research, Hamburg, Germany), 16-fold undersampled , *k-t* BLAST reconstruction and an acquired in-plane spatial resolution of (1.0x 1.0) mm^2. A magnified segment (indicated by the white rectangle in the above image) illustrates the exquisite spatial resolution.

References: 1) Di Bella E.V. et. al., Magn Reson Med 2005; 54:1295-1299, **2)** Schwitter J. et. al., Circulation 2001; 103:2230-2235. **3)** Wolff S.D. et. al., Circulation 2004; 110:732-737, **4)** Tsao J. et. al., Magn Reson Med 2003; 50:1031-1042. **5)** Hansen M.S. et. al. Magn Reson Med 2004; 52:1175-1183.