Respiratory Self-Gated Phase-Contrast MRI for Free-Breathing Flow Measurements in the Portal Venous System

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Introduction

Abdominal phase-contrast (PC) flow measurements commonly require breath-holding to avoid respiratory motion artifacts. However, for cardiac-gated, high-resolution PC measurements, overall scan times may be prohibitive. Alternative free-breathing methods may be necessary, particularly for severely ill patients unable to comply with breath-hold commands. Self-gating approaches, sampling additional central *k*-space lines for respiratory synchronization, have permitted free-breathing acquisition of MR imaging data for both cardiovascular [1] and abdominal [2] applications. We recently developed a respiratory self-gated (RSG) imaging strategy for free-breathing abdominal PC flow measurements. The purpose of our study was to compare conventional breath-hold (BH) PC flow measurements to free-breathing RSG PC flow measurements in the portal venous system.

Methods

RSG PC A 2D RSG-PC sequence was developed based upon a modified retrospectively-gated segmented cine FLASH sequence with through-plane flow encoding. A projection line (k_y=0) was acquired every 8 TRs to provide respiratory gating information. Each *k*-space segment was repeatedly measured for 5sec to roughly cover a single respiratory cycle. All images were reconstructed off-line using the MATLAB software package (The Mathworks, Inc., Natick, MA). The center-of-mass (COM) of the Fourier transform of each RSG projection line reflects both cardiac and respiratory motion [3]. This COM was filtered (0.5Hz cut-off frequency) to remove cardiac motion. RSG-PC images were reconstructed at expiration according to the COM values. The k-space lines acquired at end of expiration were mapped to their nearest cardiac cycle calculated according to ECG time stamps.

MRI According to an IRB approved protocol, experiments were performed in six healthy volunteers using a 1.5T clinical scanner (Magnetom Sonata, Siemens Medical Solutions) with an anterior 2-channel array coil and a posterior spinal array coil. Blood flow was measured in the main portal vein of three volunteers and a major branch of the portal vein in three volunteers. Before PC scans, an SSFP scout localizer was obtained to select an oblique imaging plane perpendicular to the vessel of interest (**Fig.1**). For PC scans, RO orientation was in superior-inferior direction and PE orientation in the anterior-posterior direction. Common imaging parameters: TR/TE = 8.5/2.55ms, slice thickness = 5mm, BW = 500 Hz/pixel, 350x284mm^2 FOV, 256x146 matrix (1.37x1.37 mm^2 in plane resolution), 20° flip angle, VENC = 71cm/s. Venous flow was measured during breath-hold conditions, free-breathing with RSG and signal averaging (5 averages).

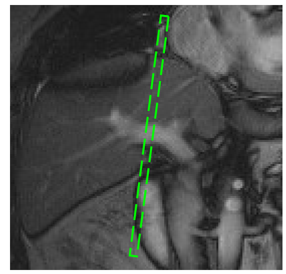

Fig 1. Scout image to position scan plane for PC flow measurement in portal vein.

Data Analysis Within magnitude images, vessel sharpness at the lumen-parenchyma border was measured [4] to validate improved suppression of motion artifacts with the RSG approach compared to simple signal averaging (pair-wised t-test at 95% confidence level). Blood vessels were manually outlined on the magnitude images and venous blood flow calculated by multiplying vessel area (cm^2) x mean velocity x 60 for RSG-PC and PC with breath-hold at expiration. Linear regression was used to evaluate the correlation of the blood flow calculated by the two methods. Statistics tests were performed using Minitab software package (Minitab Inc., USA).

Results

Our abdominal RSG approach clearly depicted respiratory motion in each volunteer study. **Fig. 2a** shows a portion of RSG projection lines (at diaphragm interface). **Figs. 2b and 2c** show the corresponding COM and low-pass filtered COM signals, respectively. Peak values (red) represent expiration positions. **Fig. 3** shows magnitude images from RSG-PC (a, d), PC with breath hold at expiration (b, e) and PC with free-breathing with 5 averages (c, f). Each study the overall liver anatomy and vessel boundaries were blurred due to respiration motion (c, f). Branches of the portal vein were clearly more sensitive to respiratory motion. The vessel sharpness of RSG-PC (0.103 ± 0.0125) was higher than using free-breathing PC with 5 signal averages (0.060 ± 0.01) (mean ± SD, $p<0.000$). RSG-PC effectively suppressed blurring induced by respiratory motion. Flow rate of the main portal vein was 935 ± 172 ml/min (12.60 ± 0.86 ml/min per kilogram) using RSG-PC compared with 967 ± 152ml/min (13.23 ± 1.37 ml/min per kilogram) using PC with breath hold at expiration, quite similar results in previous healthy volunteer studies [5]. For portal branches, flow rate varied from 156.83 ml/min to 430.90 ml/min depending upon anatomic vessel position. Flow rate measured by RSG-PC and PC with breath hold at expiration demonstrated a strong linear correlation (r =.990, $p<0.000$, **Fig. 4**).

Conclusion and discussion:

RSG-PC effectively suppresses respiratory induced blurring of abdominal blood vessels allowing flow measurements without a breath-hold. Further development may be necessary to improve efficiency with respiratory-ordered-phase-encoding methods [6] and future studies should compare RSG-PC with existing navigator echo (NAV) approaches. RSG-PC also offers the potential to increase spatial resolution for blood flow measurements within small vessels (hepatic and gastroduodenal arteries etc).

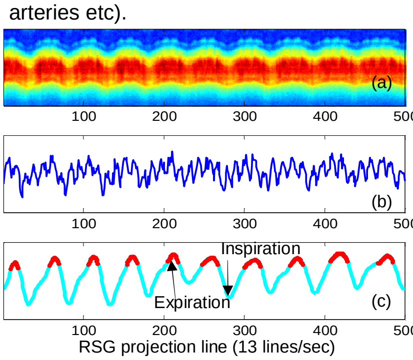

Fig 2. Respiratory projection lines (a), center-of-mass signal (b), and low-pass filtered center-of-mass signal (c) track motion vs. time.

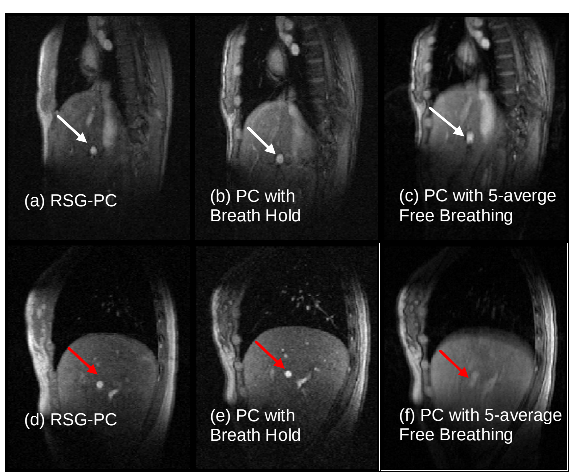

Fig 3. Upper row shows images of main portal vein (white arrow); lower row shows images of the main branch of portal vein (red arrow). RSG-PC effectively removed respiratory induced blurring compared to free-breathing phase-contrast.

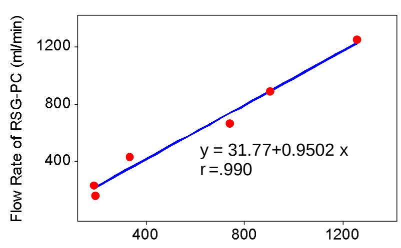

Fig 4. Regression plot demonstrates strong correlation between flow measured with RSG-PC and PC at expiration breath-hold.

Reference:
[1] Larson et al. MRM. 2005; 53(1): 159-168
[2] Brau et al. MRM. 2006; 55(2): 263-270
[3] Larson et al. MRM. 2004; 51(1):93-102
[4] D Li et al. Radiology. 2001; 219:270-277
[5] Ehman et al. AJR. 1993; 160: 1113-1118
[6] Bailes et al. J Comput Assist Tomogr. 1985; 9(4):835-8