Magnetic Resonance in Medicine 45:346–348 (2001)

Effect of Breath Holding on Blood Flow Measurement Using Fast Velocity Encoded Cine MRI

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Breath-hold MR measurement of cardiac output was compared with results from respiratory triggered MR acquisitions, since flow measurement during breath-holding may be different from physiological blood flow. Cardiac output during large lung volume breath-holding (4.47 ± 0.63 l/min in the aorta and 4.53 ± 0.59 l/min in the pulmonary artery) was significantly lower than that measured during normal breathing (6.09 ± 0.49 l/min and 6.48 ± 0.67 l/min, $P < 0.01$). In contrast, no significant difference was found between measurements conducted with small lung volume breath-holding (5.87 ± 0.53 l/min and 6.41 ± 0.75 l/min) and normal breathing. In conclusion, breath-hold MR flow measurement using small lung volume by shallow inspiration can provide a blood flow quantification that is close to physiological blood flow. Magn Reson Med 45:346–348, 2001. © 2001 Wiley-Liss, Inc.

Key words: magnetic resonance imaging; velocity encoding; rapid imaging; breath-holding; blood flow measurement

Velocity encoded cine (VEC) MRI can provide a noninvasive assessment of blood flow in the heart and great vessels (1–2). MR measurement of blood flow in the coronary artery has been very challenging because of the small diameter and respiratory motion of the vessel. Recently, breath-hold MR assessment of coronary blood flow and flow reserve has become feasible by using ultra-fast MRI techniques such as segmented *k*-space acquisition (3–8) and spiral MRI (9). However, there is a possibility that blood flow measurement with breath-hold MRI may be different from physiological blood flow during normal breathing since breath-holding can change intrathoracic pressure, which may considerably influence systemic venous return to the heart (10–11). The purpose of the current study was to determine if breath-hold MR blood measurements in the aorta and pulmonary artery using large lung volume and small lung volume (10) are significantly different from non-breath-hold MR measurements with respiratory triggered acquisition.

MATERIALS AND METHODS

Eight healthy volunteers (6 males and 2 females, mean age = 33.8 ± 10.2 years) were studied. Informed consent was obtained from all subjects. MR images were acquired with a 1.5 Tesla imager (gradient strength = 23 mT/m, slew rate = 120 mT/m/msec; Signa, GE Medical System, Milwaukee, WI). The subjects were situated in a supine position with four channel cardiac multi-coil arrays placed around the chest. The pulse sequence used for MR blood flow quantification was a phase contrast fast gradient echo sequence with segmented *k*-space acquisition (12). The data were acquired on imaging planes which were perpendicular to the aorta or the main pulmonary artery, with slice thickness = 5 mm, field of view (FOV) = 28 × 21 cm, repetition time (TR) = 14 msec, echo time (TE) = 4.5 msec, velocity window (Venc) = ± 150 cm/sec, phase-encoding steps = 96, views per segment = 4, and a sequential sampling in *k*-space. The true temporal resolution of VEC MR image acquisition was 112 msec. Magnitude and phase-difference VEC MR images with 11 to 19 temporal phases were obtained with a view sharing reconstruction. Blood flow in the aorta ($N = 7$) and main pulmonary artery ($N = 8$) was measured with three different protocols: 1) single breath-hold acquisition with large lung volume by deep inspiration, 2) single breath-hold acquisition with small lung volume by shallow inspiration, and 3) non-breath-hold acquisition with respiratory triggered acquisition during the expiration phase using bellows. Imaging time was approximately 25 sec with breath-hold acquisition, and 2–3 min with respiratory triggered acquisition. Imaging parameters, such as slice thickness, FOV, TR, TE, Venc, phase-encoding steps, and views per segment, were identical in three MR acquisitions.

Blood flow in the aorta and pulmonary artery was quantified using Xphase software (Stephan E. Maier, M.D., Ph.D., Brigham and Women's Hospital, Boston, MA) (13). Contours of the aorta and main pulmonary artery were manually traced on all cine frames individually to correct in-plane displacement. Phase offset correction was performed at each cine frame by placing the region of interest in the anterior chest wall near the ascending aorta or main pulmonary artery. Volume flow rate was quantified by integrating the product of area and mean velocity within the artery.

All values were expressed as mean value ± standard error (SE). Statistical significance of the differences between means of the variables in two groups was evaluated with a paired standard *t*-test.

RESULTS

Figure 1 shows fast VEC MR images of the ascending aorta acquired with small lung volume breath-holding (Fig. 1a) and with respiratory triggered acquisition (Fig. 1b). Breath-hold and non-breath-hold VEC MRI methods demonstrate equivalently good image quality permitting flow measurements in the aorta and pulmonary artery. Figure 2 summarizes MR blood flow measurements in the ascending aorta

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Received 29 September 1999; revised 2 August 2000; accepted 7 September 2000.

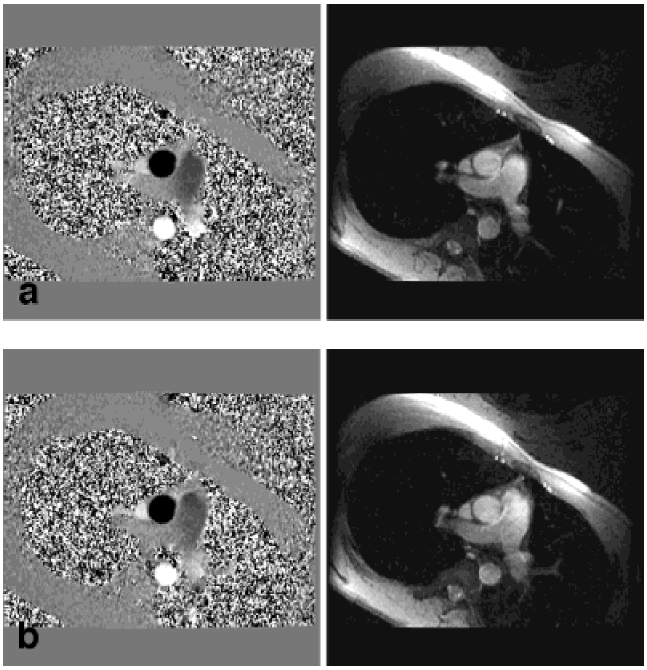

FIG. 1. Magnitude (right) and phase-difference (left) velocity-encoded cine MR images of the ascending aorta acquired with small lung volume breath-holding (**a**) and respiratory triggered acquisition during normal breathing (**b**). Reconstructed MR images were rotated because of double oblique acquisitions.

(Fig. 2a) and in the main pulmonary artery (Fig. 2b) with large lung volume breath-holding, small lung volume breath-holding, and during normal breathing with a respiratory triggered acquisition. Cardiac output during large lung volume breath-holding (4.47 ± 0.63 l/min in the aorta and 4.53 ± 0.59 l/min in the pulmonary artery) was significantly lower than that measured during normal breathing (6.09 ± 0.49 l/min and 6.48 ± 0.67 l/min, $P < 0.01$). No significant difference was found between measurements conducted with small lung volume breath-holding (5.87 ± 0.53 l/min and 6.41 ± 0.75 l/min) and normal breathing.

DISCUSSION

The results in the current study demonstrated that MR measurements of blood flow in the aorta and main pulmonary artery using large lung volume breath-holding were significantly lower than measurements conducted during normal breathing. In contrast, no significant difference was found in cardiac output between small lung volume breath-holding and normal breathing, indicating that use of small lung volume breath-holding by shallow inspiration is important to obtain blood flow quantification that is close to physiological blood flow.

Recently, it has been shown that a breath-hold version of VEC MRI can provide noninvasive assessment of blood flow and flow reserve in the coronary artery and coronary artery bypass graft (3–8). MR blood flow measurements in the coronary artery might be achieved with respiratory triggered acquisition. When compared with the respiratory triggered method, however, the breath-hold method can potentially provide images with minimal respiratory motion and requires much shorter acquisition time, which is critically important in MR flow measurement with pharmacological stress. Our current study indicates that an inspiratory maneuver can have a significant influence on breath-hold blood flow quantification and can be a pitfall in clinical applications of this technique.

The reduction in cardiac output with deep inspiration can be explained by decreased venous return to the heart. Ferrigno et al. (10) reported that the most important consideration in determining effect of breath-holding on cardiac performance is the differences in intrathoracic pressure during the measurement. They measured cardiac output and intrathoracic pressure in six healthy volunteers using impedance cardiography, and observed a 24% decrease in cardiac index with breath-holding at large lung volumes produced by breath-hold divers due to increased intrathoracic pressure and decreased venous return. In another study by Pailev et al. (11), a 20–40% decrease in cardiac output was observed with deep inspiration and high intrathoracic pressure, while cardiac output was not changed with shallow inspiration and normal intrathoracic pressure.

The maximal duration of breath-holding was approximately 25 sec using the current MR data acquisition parameters. All volunteers, as well as most patients with ischemic heart disease in our previous studies, could achieve breath-

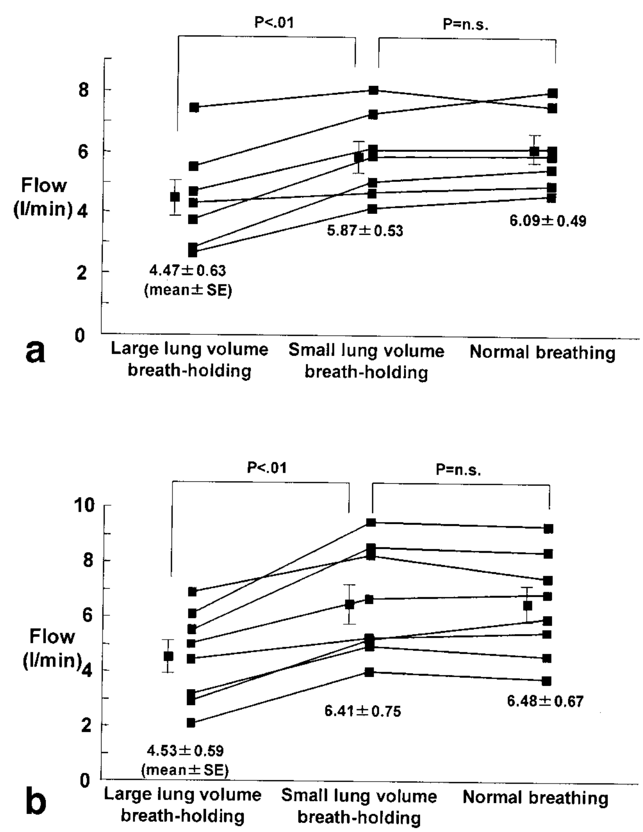

FIG. 2. Cardiac output measured in the ascending aorta (**a**) and in the main pulmonary artery (**b**) by using large lung volume breath-holding, small lung volume breath-holding, and respiratory triggered method during normal breathing.

holding with either large lung volume by deep inspiration or small lung volume by shallow inspiration.

In this study, the effect of breath-holding on MR blood flow measurement was not directly measured in the coronary artery because error due to respiratory blurring may substantially differ between breath-hold and respiratory triggered acquisitions in the coronary artery. Since deep inspiration will have a similar negative effect on blood flow in the systemic arterial branches as well, small lung volume breath-holding by shallow inspiration seems to be essential to obtain more accurate and physiological blood flow quantification in the coronary artery and coronary arterial bypass graft by using breath-hold VEC MRI.

ACKNOWLEDGMENTS

We express our appreciation to Charles B. Higgins, M.D. (Department of Radiology, University of California–San Francisco, San Francisco, CA), for critically reviewing this manuscript; and to Stephan E. Maier, M.D., Ph.D. (Department of Radiology, Brigham and Women's Hospital, Boston, MA), for allowing us to use Xphase flow analysis software.

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