Diaphragm Motion During Suspected Breathing: Implications for MR Imaging of the Heart

A. Holland‡, J.W. Goldfarb†, J.O. Barentsz* and R.R. Edelman‡
St. Radboud University Hospital Nijmegen, Netherlands
Beth Israel Deaconess Medical Center‡, Harvard Medical School† Boston, MA‡

Purpose
The purpose of this study was to investigate and quantify the motion of the diaphragm and heart during suspended breathing at end-inspiration and end-expiration.

Introduction
Although many advances have been made in magnetic resonance imaging of the heart, motion of the heart during the image acquisition is still a major source of artifacts. Motion of the heart is a combined product of normal respiration and the cardiac cycle itself. Image artifacts range from periodic ghosting to local image blur. Many investigators have used cardiac triggering and breath-holding to image at a single point in the respiratory and cardiac cycle. Assumptions are made that the heart will return to the same position on consecutive heartbeat. We have observed a significant upward movement of the diaphragm during suspended breathing. This will result in a complex movement of the heart and cause the heart to return to a slightly different location.

Methods
The movement of the diaphragm and the resulting motion of the heart during suspended breathing was assessed in five male and five female healthy volunteers. Age: mean = 31.9 years; range= 26 - 48. Imaging was done on a 1.5T Siemens VISION scanner with two techniques: 1) Line scan imaging provided high temporal and spatial resolution one-dimensional positional measurements of the dome of the right hemi-diaphragm. 2) Turbo-flash imaging provided lower temporal and spatial resolution two-dimensional images of the heart and diaphragm at one period of the cardiac cycle over several heartbeats.

Line scan imaging: A line scan technique consisting of a slice selective 90 degree and slice selective 180 degree rf pulse was used. The intersection of the excited slices was placed over the dome of the right hemi-diaphragm. Imaging parameters were TR=200msec, TE=22msec; FA=90 ; MA = 1x256; FOV=128mm. The line scan measurement had a temporal and spatial resolution of 200 msec and 0.25 mm respectively. The line scans were collected over a 44 second interval while the breathing instructions were given.

Turbo-flash imaging: Single shot imaging was done over 20 heartbeats in the coronal plane. Sequence parameters: TR=2.4msec; TE=1.2msec; FA=8; MA=100x128; FOV = 240x320mm; TH=8mm. The image resolution was 2.40mmx2.50mm. Measurements were performed at end-inspiration and end-expiration with the same breath-holding commands as the line scan imaging.

Results
An example of a line scan obtained in a subject during suspended respiration at end-expiration is shown in Figure 1A. As opposed to current assumptions that during breath-holding the diaphragm remains in the same position, this line scan image shows a linear upward movement of the diaphragm throughout the entire 20 second breath-hold. Using the diaphragm-position-versus-time curves diaphragm motion velocities could be calculated.

The average diaphragm velocity during end-expiration was 0.15 mm/s (Std=0.07,range=0.01-0.3) The total diaphragm displacement during a breath-hold of 20 seconds was on average 3mm.

In Figure 1B and 1C images are shown of line scans which were acquired during breath-holding at end-inspiration demonstrating an upward displacement of the diaphragm. In contrary to the diaphragm motion versus time curves at end-expiration which were consistently linear, many volunteers had diaphragm motion with time varying velocities. The displacement curves were segmented into different temporal regions each with linear velocities. During the first phase there is an initial high velocity motion of the diaphragm (mean=5.0mm/s; range= 2.77-7.9mm/s) followed by phases with lower velocities. It was calculated that the average total diaphragm displacement during a 20 second breath-hold at end-inspiration is 11 mm whereas at end-expiration it is 3 mm.

Turbo-flash imaging revealed a complex motion of the heart during breath-holding (Fig 2)

Discussion
Breath-holding does not eliminate motion of the diaphragm. This motion causes a potential beat-to-beat variation in the position of the heart and may cause image blurring. Diaphragm motion is different during breath-holding at end-inspiration and end-expiration.

References