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A Method of Rapid Robust Respiratory Synchronization for MRI

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Abstract

Respiratory motion degrades MRI exams. Adequate detection of respiratory motion with pneumatic respiratory belts in small children is challenging and time-consuming.

Introduction

Respiratory motion degrades magnetic resonance images. This compromise in image quality can be addressed by navigator echoes [1], but is most commonly addressed by synchronizing magnetic resonance data acquisition to the respiratory cycle [2,3]. To do so, a method of detecting the respiratory cycle is required, which often consists of a pneumatic belt or pad placed around the patient's abdomen. When the pneumatic device is stretched or expanded by expansion of the chest or abdomen, pressure within it drops, and this pressure change serves as a sensor of respiratory motion. In this article, an alternative method of directly interfacing an end-tidal carbon dioxide (etCO₂) port to an MRI scanner is presented that has minimal setup time.

Methods

With small children, the pressure change in pneumatic devices is often small, resulting in suboptimal synchronization. Though these devices are undergoing continued refinement [4], often, obtaining an adequate respiratory waveform with these devices on small children requires a time-consuming trial-and-error approach of repositioning the device, sometimes with no success. This leads to prolonged examinations, prolonged anesthesia, decreased MRI schedule predictability, decreased MR scanner throughput, and suboptimal image quality.

Alternative approaches to detecting respiratory motion have been described. Methods based on optical sensors with electronics to generate a logic signal have been developed [5]. Recently, the group at Cincinnati Children's used a combination of a nasal mask, flow sensor and pressure transducer to record respiration on a laptop computer and retrospectively synchronize it with time-stamped respiratory images [6].

Direct respiratory synchronization with the MRI scanner has also been described with the use of a dedicated pneumotachograph applied to a well-fitted face mask [7].

To address this issue, we have developed a novel method of sensing the respiratory cycle in patients who have a supportive airway (e.g. an endotracheal tube, laryngeal mask airway, nasal canula with etCO₂ sampling port, or face mask with etCO₂ sampling port). The

method consists of sensing pressure changes from the etCO₂ port of the airway. To realize the technique, a three-way stopcock is placed on the etCO₂ port. The etCO₂ was monitored with one port of the stopcock attached to the patient's airway device, the second port attached to the etCO₂ tubing, and the third port attached to the respiratory trigger tubing. A filter (Invivo Filter Hydro 0.8 μ m) that permits air pressure to be transduced, but not respiratory droplets, was connected to the third port of the three-way stopcock, followed by tubing from the filter to the MR scanner (GE 1.5T Signa or GE 3T 750). This is shown in Figure 1.

A photograph of the waveform using conventional pneumatic belt on a seven month old male is shown in Figure 2. In this case the waveform was only obtained after a lengthy trial-and-error repositioning of the belt, yet was inadequate for reliable triggering of data acquisition. Finally, waveform using etCO₂ port in the same patient is shown in Figure 3, proving feasibility of this method. Furthermore, obtaining the final waveform required minimal time, avoiding the time-consuming process of positioning the pneumatic belt. Figure 4 shows resulting T₂ weighted images obtained with respiratory triggering enabled by exploiting the etCO₂ port.

Discussion

A simple approach of exploiting an etCO₂ port for respiratory motion compensation in abdominal MRI is demonstrated in this paper. The method has the advantage of a minimal and predictable setup time. Although we have only shown an example with ventilated patients, our experience is that the method works for spontaneously breathing patients with an endotracheal tube or laryngeal mask, but not so well if there is only a facemask.

A potential concern with this method is compromise of the accuracy of etCO₂ for monitoring purposes. However, the etCO₂ monitor samples at a nominal aspiration rate of 200 mL/min. Since the MRI transducer is not aspirating and since there is very little dead space in the microbore etCO₂ sample tubing leading to the MRI transducer, there should be no difference in the etCO₂ tracing. We have not noticed any change to the etCO₂ measurement when turning the valves to close the system off to the scanner, though we have not exhaustively recorded this information in many patients.

One caveat to this approach is that the waveform is inverted relative to the respiratory belt, i.e. expiration results in the scanner detecting increased pressure. Hence, either inspiratory images may be obtained or the trigger delay can be adjusted to obtain expiratory images.

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Figure 1.
Method for sensing respiratory cycle for MRI data synchronization from endtidal carbon dioxide port.

Figure 2.
Waveform for synchronization using conventional pneumatic belt in a 7 month old male.

Figure 3.

Waveform from end-tidal port on same patient as in Figure 2. (A) Ventilator set to a rate of 24, which is accurately reflected in the waveform. (B) Ventilator rate adjusted to 34, which is still accurately reflected in the waveform. Vertical white lines shows MR scanner using this waveform to synchronize data acquisition to respiratory cycle.

Figure 4.

Images of same patient discussed in figures 2 and 3. (a) Axial respiratory-triggered fat suppressed T₂ weighted images with minimal respiratory ghosting artifacts. (b) Coronal volumetric T₂ with fat suppression shows a sharp diaphragm (thin arrow), sharp duodenum (asterisk), and well defined left mainstem bronchus (arrowhead), and aliased arm (thick arrow).