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Introduction

Dynamic lung MR imaging has been used to assess chest [1,2] or tumour motion [3,4,5]. However, in these studies either a single or a small series of orthogonal two-dimensional (2D) acquisitions were obtained, due to limitations in the image acquisition time. Dynamic volume imaging has been used to investigate lung volumetry [6] in a study where volunteers were instructed to breathe slowly during scanning to compensate for the acquisition rate of one image per second. Parallel magnetic resonance imaging (MRI) techniques such as SMASH, SENSE and GRAPPA make use of coil-arrays to accelerate image acquisition. There is a current drive to multiply the number of detector coils (and receive channels on the scanner) to achieve high acceleration factors. Currently, commercial MRI scanners with 32-receive channels are becoming available, allowing a fast acquisition of a large body area or a specific organ like the heart [7].

The aim of this study is to dynamically image both lungs with a temporal resolution sufficient to sample the normal variation of breathing patterns (i.e. without asking for slow breathing) using a 32-channel coil. The target application is lung radiotherapy, where the tumour to be irradiated is subject to respiratory motion, and this motion is likely to vary from one cycle to the next due to changes in the patient's mode of breathing. Models of breathing motion which incorporate information about variability will be very valuable for radiotherapy planning [8]. To form models from MR data, spatial resolution and image quality should be sufficient to allow for non-rigid image registration, and the whole chest should be imaged without gating. It is also important to assess the relationship between the motion of internal structures and external structures which may be monitored during treatment delivery.

Method

MRI Equipment:

All experiments were performed on a 1.5T Achieva MR-scanner (Philips Medical Systems, Best, The Netherlands) in conjunction with a 32-channel coil array (Philips Research, Hamburg, Germany). The coil [7] consists of two individual sections, each containing 16 elements; the posterior part was placed centrally on the patient bed with the anterior part placed on the patient covering the complete thorax (Figure 1).

Figure 1. A volunteer with 32-channel coil in place.

MRI Sequence:

A dynamic three-dimensional Balanced Steady State Free Precession (SSFP) sequences was applied using with the following parameters: flip angle 30°, TE 0.96ms, TR 1.92ms, matrix 96×96×45-55, rectangular field of view 45-65 %, partial-Fourier in both phase encode directions, 60 dynamic scans, SENSE factor 2 AP, 3 RL. This lead to a 5×5×5mm^3 spatial resolution and a volume acquisition time of 0.53-0.59s. Volumes were acquired axially and with sufficient planes to cover the expansion of the lungs in the foot-head direction. The number of "slices" and rectangular field of view were adjusted for each individual in order to maximise coverage whilst maintaining the temporal resolution.

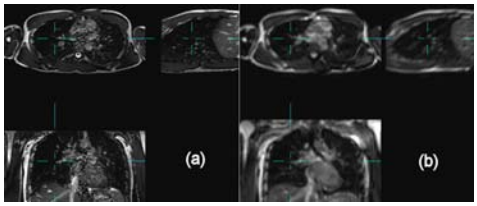

Figure 2. Example images: (a) reference breath-hold at exhale (b) free-breathing scan aligned to reference image.

Volunteers:

Five healthy volunteers, 4 males (31 ± 3 years) and one female (67 years) were imaged using this method. Example images are shown in figure 2. The volunteers were asked to breathe in a variety of different ways: normally, abdominal/thoracic, deep/shallow, and self-regularised breathing. A reference volume was also acquired at exhale breath-hold.

Image Analysis:

Initial analysis of this data was carried out to examine the relationship between the external motion of the skin surface and the internal motion of structures within the chest during different types of breathing. The motion of internal structures may be investigated by aligning each of the free-breathing images from every dynamic sequence to the higher-quality reference image using a non-rigid registration algorithm based on B-splines [9]. Any point within the image can be tracked as it moves throughout the breathing cycle.

External measures of "abdominal" and "thoracic" respiratory motion were derived from automatic detection of the skin surface. Two external regions of interest, one in the abdominal region, and one in the upper thorax, were defined for each patient. A simple threshold was used to detect the skin surface in the A-P direction in each of these regions. These measures of skin height were summed over each of these two regions, for every dynamic scan, to obtain simple respiratory signals for each breathing sequence.

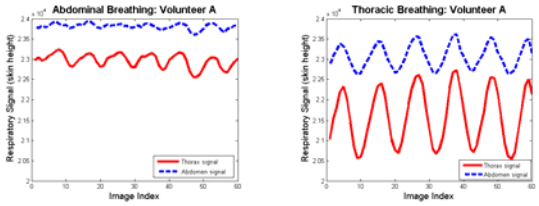

Figure 3. Example respiratory traces: (a) during abdominal breathing (b) during thoracic breathing. These plots show skin surface motion which can be monitored externally.

Results

For all volunteers and all type of breathing dynamic lung volumes were successfully acquired. In all cases it was possible to visualise distal vessels in the pulmonary tree (figure 2). Co-registration of the dynamic volumes to the reference image was carried out on all datasets. Respiratory traces were extracted for every type of breathing performed by all volunteers. Examples of the "abdominal" and "thoracic" respiratory traces, for one volunteer carrying out two very different types of breathing, are shown in figure 3.

Conclusions

The use of highly parallel imaging enables fast acquisition of data over the entire chest with sufficient spatial and temporal resolution to carry out non-rigid motion modelling and analysis of the relationship between the motion of external and internal structures. At present such data cannot be obtained using any other imaging modality and so this development is likely to be of great interest to the radiotherapy community.

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