Study of the Respiratory Motion of the Heart using Multiple Navigator Pulses

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Introduction

Adaptive motion correction based on real-time navigator echo respiratory monitoring is a promising approach to reduce motion artifacts in MRI [1]. For coronary artery imaging, it has been shown that slice-tracking can improve image quality [2]. For that purpose, a linear model [3] with patient dependent correction factor [4] is used to map the diaphragmatic motion, which is monitored by a navigator echo, onto the respiratory motion of the heart However, the correction factors are usually estimated from breath-hold MR images obtained in different respiratory phases, which is inconvenient for the patient and the operator. In addition, it has to be proven if the motion states existing during continuous respiration can be frozen by breath-holding.

For the present study multiple navigator echoes [5] were used to study spatial correlations of respiratory motion during continuous respiration.

Materials and Methods

In vivo experiments with several healthy volunteers were performed on a 1.5 T whole body scanner (GYROSCAN ACS NT, Philips Medical Systems) with self-shielded gradients (23 mT in 0.2 ms). The scan software was extended to provide four independent pencil beam navigator pulses, which can be positioned and angulated free in space. A pure navigator sequence allowing high temporal resolution (TR=80 ms, i.e. 20 ms for each of the succeeding pencil beams) was implemented. The displacement of the navigator profiles with respect to the corresponding reference profiles is determined in real-time and stored for subsequent analysis. The respiratory motion of several anatomical regions (heart, right hemidiaphragm, chest wall, abdominal wall, see Fig.1a) was recorded over 10 minutes using pencil beams with diameters of 25-35 mm. The delay of 20 ms between succeeding navigators was corrected by appropriate interpolation of neighboring data points of the breathing curves. The contribution of cardiac motion was filtered out from the oversampled data. The correlation between the different navigators was analyzed in 2D histogram plots (Fig. 1b,c,d). The results where compared to movies of the thoracic-abdominal region, which where acquired in a ECG-triggered single-shot mode (2D-TFE-sequence, 128^2-matrix, 300 mm FOV, 250 ms acquisition window, 200 heart cycles) during continuous breathing of the volunteers. In a post-processing step the frames of the movies were sorted with respect to the diaphragm position, which was monitored in parallel by a navigator echo, to visualize spatial correlations of respiratory motion.

Results and Discussion

For all volunteers a good correlation between the diaphragmatic motion and the respiratory motion of the heart in the coronal plane was found. However, for most volunteers the 2D-histogram plots show an hysteresis loop with different branches for expiration and inspiration (Fig.1a). The hysteresis gap is up to 6 mm, which may be considerable for adaptive motion correction schemes. The analysis of the movie showed that the hysteresis is due to an expansion of the heart in left-right direction in the inspiration phase. A similar hysteresis is present in the correlation chest wall - abdominal wall (Fig. 1c). This indicates that the complex interplay between costal and abdominal breathing may be different during expiration and inspiration phases. The motion of the heart in anterior-posterior (AP) direction, indicated by the chest wall position (Fig.1d), was found to be less well correlated to the diaphragmatic motion. The displacement range of the heart is up to 4 mm for a fixed diaphragm position, which is one third of the total displacement range in this direction. These results indicate that a simple linear mapping of the diaphragmatic motion onto the respiratory motion of the heart may lead to considerable registration errors when used for adaptive motion correction. The hysteretic effects could be taken into account by using a more complex model. The motion in AP direction could be monitored by a second navigator through the chest wall. Another approach to cope with both effects is to place the navigator directly through the heart, as suggested in the literature [6,7].

Conclusion

The present study shows, that multiple navigators are a powerful tool to study respiratory motion both spatially and temporally resolved. The results indicate, that a pure kinematical model of respiratory motion neglecting hysteretic effects and multidimensional motion pattern may lead to considerable errors when used for adaptive motion correction.

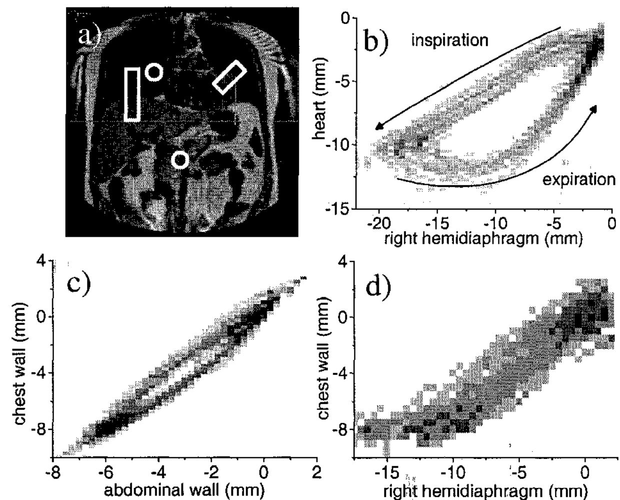

Figure 1. a) coronal scout indicating the pencil beam positions and orientations (rectangle:in-plane, circle:out of plane) b)-d) 2D-histogram plots of the spatial correlations between the displacements of different anatomical regions due to respiratory motion Black bins indicate many counts, white bins indicate no counts

References

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