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[Invited Paper] Dynamic 3D image analysis of thoracoabdominal region

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Abstract Motion of thoracoabdominal region due to respiration causes image blur in nuclear imaging modalities such as PET and SPECT. On the other hand, capturing or monitoring such motion provides us useful information. For example, monitoring such motion makes respiration-gated PET and SPECT possible and thus yields less- blurred images. Furthermore, motion of thoracoabdominal region due to respiration may provide us effective information on lung or liver diseases. We have developed a method for estimating lung motion from respiration-gated PET and tried to relate the motion with lung diseases. Recently we have developed a method for reconstructing a four-dimensional magnetic resonance image (4DMRI) of respiratory organ motion from time sequential images of two-dimensional (2D) MR. Those images can also used for dynamic 3D image analysis of thoracoabdominal region. Those techniques are introduced.
Key words thoracoabdominal, respiratory motion, motion analysis

1. Introduction

Motion of thoracoabdominal region due to respiration causes image blurs in nuclear imaging modalities such as PET and SPECT. On the other hand, capturing or monitoring such motion provides us useful information. For example, monitoring such motion makes respiration-gated PET and SPECT possible and thus yields less-blurred images. Furthermore, motion of thoracoabdominal region due to respiration may provide us effective information on lung or liver diseases. For instance, pulmonary emphysema shows an over-expansive lung and the diaphragm adopts a low position and flat shape. Furthermore, there is a tendency for respiratory motion of the lungs to become small. In the field of radiation therapy, knowledge of motion due to respiration can powerfully utilized in such as respiration-gated radiation or respiration-tracking radiation.

We have developed a method for estimating lung motion from respiration-gated PET and tried to relate the motion with lung diseases[1]. Although the original motivation was that we wanted to use the estimated motion vector field (MVF) in lung due to respiration in improving the image quality of PET or SPECT images, we later found that MVF has a relation to lung disease. Recently we have developed a method for reconstructing a four-dimensional magnetic resonance image (4DMRI) of respiratory organ motion from time sequential images of two-dimensional (2D) MR [2,3]. Those images can also used for dynamic 3D image analysis of thoracoabdominal region. These two techniques are introduced.

2 . Motion analysis from respiration-gated SPECT

2.1 Material and Method

In conventional single photon emission computed tomography (SPECT) studies, the lung motion due to respiration during the acquisition makes reconstructed images blurred and may lead to a misdiagnosis [4, 5]. To address this, respiratory-gated SPECT generates reconstructed images at various respiration phases by monitoring the motion of the thoracic or abdominal wall portion of a subject. We introduced an effective technique that synthesizes each phase image after nonlinear correction of the motion of the lungs due to respiration [6]. After motion correction of the lungs is performed, a less blurred and less noisy image can be synthesized by adding each phase image. The schematic illustration of this processing flow is presented in Fig. 1.

Because the nonlinear motion correction process generates displacement vectors at every location of the lungs (MVF), it is also possible to analyze local motion of the lungs caused by respiration. We then investigated a relationship between MVF and lung diseases.

Respiratory-gated imaging was performed using a tripleheaded SPECT unit (GCA 9300 A/PI, Toshiba Medical, Tokyo, Japan) and physiological respiratory synchronizer (AZ-733, Anzai Medical, Tokyo, Japan). Gated end-inspiration and end-expiration SPECT images were reconstructed from the 1/8 thresholds of peaks of inspiration and expiration data from regular respiratory cycles.

Clinical data from actual diagnoses were used to confirm the effectiveness of the proposed motion analysis method. The data consisted of 25 Tc-99m-MAA perfusion SPECT images (18 men, aged 62.2 ± 15.5 years), including two cases of normal lungs, eight cases of pulmonary emphysema and two cases of diffuse panbronchiolitis.

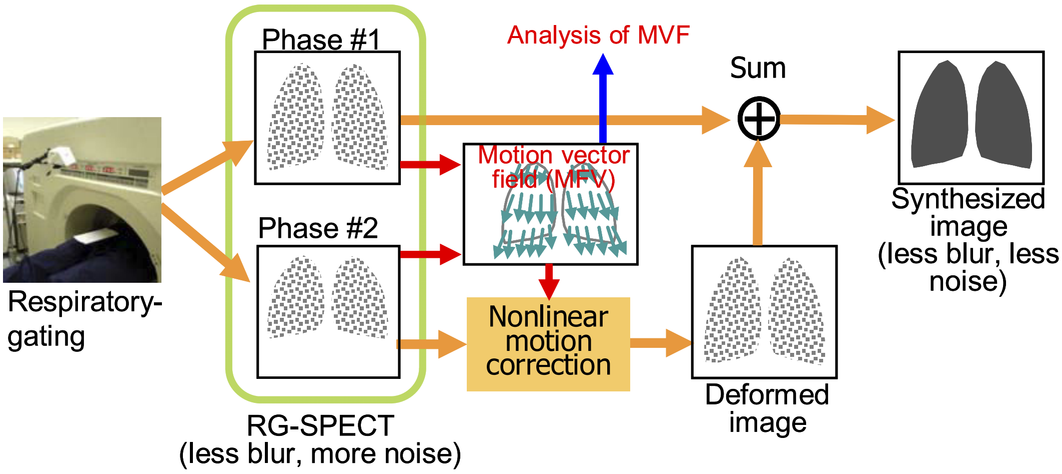
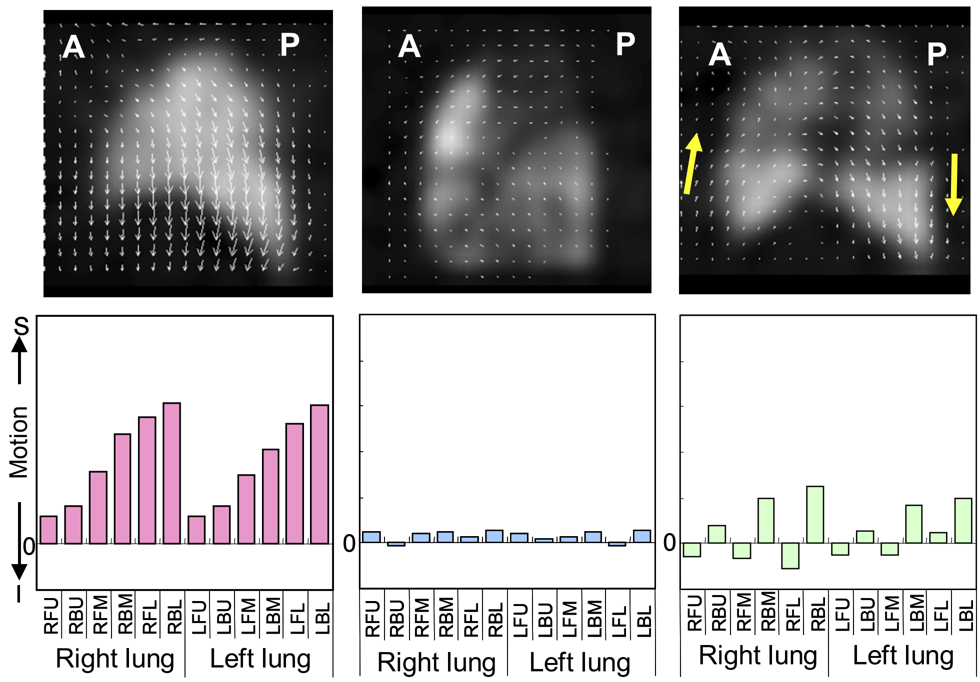


Figure 1. Scheme of image processing.



(a) Normal lung (b) Emphysema (c) Emphysema with paradoxical motion

Figure 2 Examples of motion vector field and the motion analysis. In all bar graphs, positive values indicate motion of the lungs in the downward direction (head to foot) during the inspiration process. R and L indicate right and left lung, F and B indicate front and back part of the lungs, and U, M, and L indicate upper, middle, and lower portion of the lungs.

2.2 Results

For the quantitative motion analysis, the lung region extracted from a motion-corrected respiratory-gated SPECT image is divided into two parts in the x-direction (left to right), two parts in the y-direction (front to back), and three parts in the z-direction (top to bottom, i.e., body axis), resulting in the lung region being divided into 12 parts. Then, the mean value of the body axis component of the respiratory motion vector is calculated for each part.

Because lung sizes differ among patients, it is difficult to compare the individual ventilation function of the lungs directly using absolute values of calculated respiratory lung motion. For this reason, the calculated value for each part is normalized by the length along the body axis (z-direction) of the lung region.

The motion analysis results for normal lungs are shown in Fig. 2a. The motions of the bottom portion of the lungs were larger than those of the top and middle portions and there was no difference in the motions between left and right lungs. These motions of the lungs are natural according to medical knowledge on the general respiratory motion of normal lungs.

The results for a case of pulmonary emphysema are shown in Fig. 2b. The diagnosis results obtained using Tc-99m-Technegas planar images showed that although there were ventilation obstructions in both lungs, the extent of the damage in the right lung was larger. The same results were also obtained by the proposed motion analysis method. The motions of the lungs were very small in all regions.

The results for another case of the pulmonary emphysema are shown in Figs. 2c. From the motion analysis results, it was shown that although the motions of the whole lungs were smaller in comparison with normal lungs, the motions were larger compared with the case of pulmonary emphysema as shown in Fig. 2b. Furthermore, a paradoxical motion could be observed in which the front part of the lungs moved upward and the back part of the lungs moved downward. Iwasawa et al. [7, 8] reported that this paradoxical motion is often observed in the case of pulmonary emphysema. From the motion analysis, it was clear that the paradoxical motion was present in the motion of the right lung in this case.

2.3 Summary

A motion analysis method using Tc-99m-MAA perfusion SPECT images was proposed. Using this method, the respiratory motion pattern of the normal lungs is observed and a ventilation obstruction can be evaluated by comparing its pattern with the pattern of normal lungs. In the case of normal lungs, it was observed that the respiratory motion of the bottom part of the lungs is the largest. Namely, the bar graph representing the characteristics of the motions of the normal lungs is skewed to the right as shown in Fig. 2a.This is the standard pattern for normal lungs.

When a ventilation obstruction exists, the standard motion pattern does not appear. There may be different motions between left and right lungs and the motions may become small. Furthermore, paradoxical motion may also be observed in the case of the pulmonary emphysema as shown in Fig. 2c. From the experimental results, it was confirmed that the difference in the motion between normal lungs and lungs with a ventilation obstruction was appropriately detected and the difference in the degree of the ventilation obstruction between left and right lungs could be detected as well. These results of respiratory lung motion analysis were in good agreement with the diagnostic results.

3 . Reconstruction of a 4DMRI and estimation of a MVF

3.1 Reconstruction method

We proposed a method for reconstructing a four-dimensional magnetic resonance image (4DMRI) of thorax with respiratory motion from a set of time sequential 2D MR images [ref]. In the data collection, first, time sequential 2D MR images are acquired in many coronal planes so as to widely cover the lung region. We call these images data slices. Second, in a proper sagittal plane the time sequential 2D MR images are acquired. We call it the navigator slice. Each time sequential images has one minute long which consists of 10-20 respiration cycles in a general case. If a time frame of data slice and a time frame of the navigator slice are in the same respiration phase, the navigator and data slices should have a similar profile of pixel values on the intersection line of both slices. The proposed method uses this nature as a basic idea for extracting images of data slices which synchronize with the navigator slice.

In fact, consecutive profiles during one respiration cycle rather than one time frame profile are used in the evaluation of similarity. We call this a 2D spatio-temporal image (2DSTI) in which a horizontal axis represents the time and a vertical axis represents the body axis. One proper respiratory pattern (Template) is first extracted from the 2DSTI of the navigator slice. Template matching by normalized cross-correlation is then carried out to search for the most similar pattern from the 2DSTI of a data slice. 4DMRI is created by applying this process to each data slice. A flow of 4DMRI reconstruction is schematically illustrated in Fig. 3.

In order to confirm the effectiveness of the proposed method, MR images of two volunteers were acquired after sufficient informed consent. Data slices were collected in 18 coronal planes. The results can be viewed at the URL, http://www.cfme.chiba-u.jp/~haneishi/demo/MRI/. The results were both successful and the effectiveness of the method was confirmed.

3.2 Calculation of motion vector field

We applied the method for estimating MVF from RG-PET, SPECT images to a 4DMRI. Namely, using arbitrary two respiration phases, the MVF is calculated by the non-linear registration technique.

Figure 4 shows an example of MVF. Not only motion in coronal plane but also that in sagittal plane can be observed. It should be noted that this is a very preliminary result. As seen in the picture, MVF is extended to out of body. In the estimation of MVF, we use smoothness constraint of change of vector and thus the MVF out of body is extrapolated from inner MVF. Additional constraints to MVF would be needed.

Another issue is resolution. Data slices have a spatial resolution of 1.5mm x 1.5 mm per pixel. On the other hand, those slices have 7.5mm thickness and are taken in 6mm pitch. Therefore, the resolution in sagittal plane is poor and the A-P component of motion vector has low accuracy. We need to find any application which tolerates this resolution issue or to develop a method with higher spatial resolution.

4. Conclusions

We have presented a method for estimating lung motion from respiration-gated PET and tried to relate the motion with lung diseases. We also presented a preliminary result of dynamic 3D image analysis of thoracoabdominal region which is obtained from a four-dimensional magnetic resonance image (4DMRI) reconstructed from time sequential images of two-dimensional (2D) MR.

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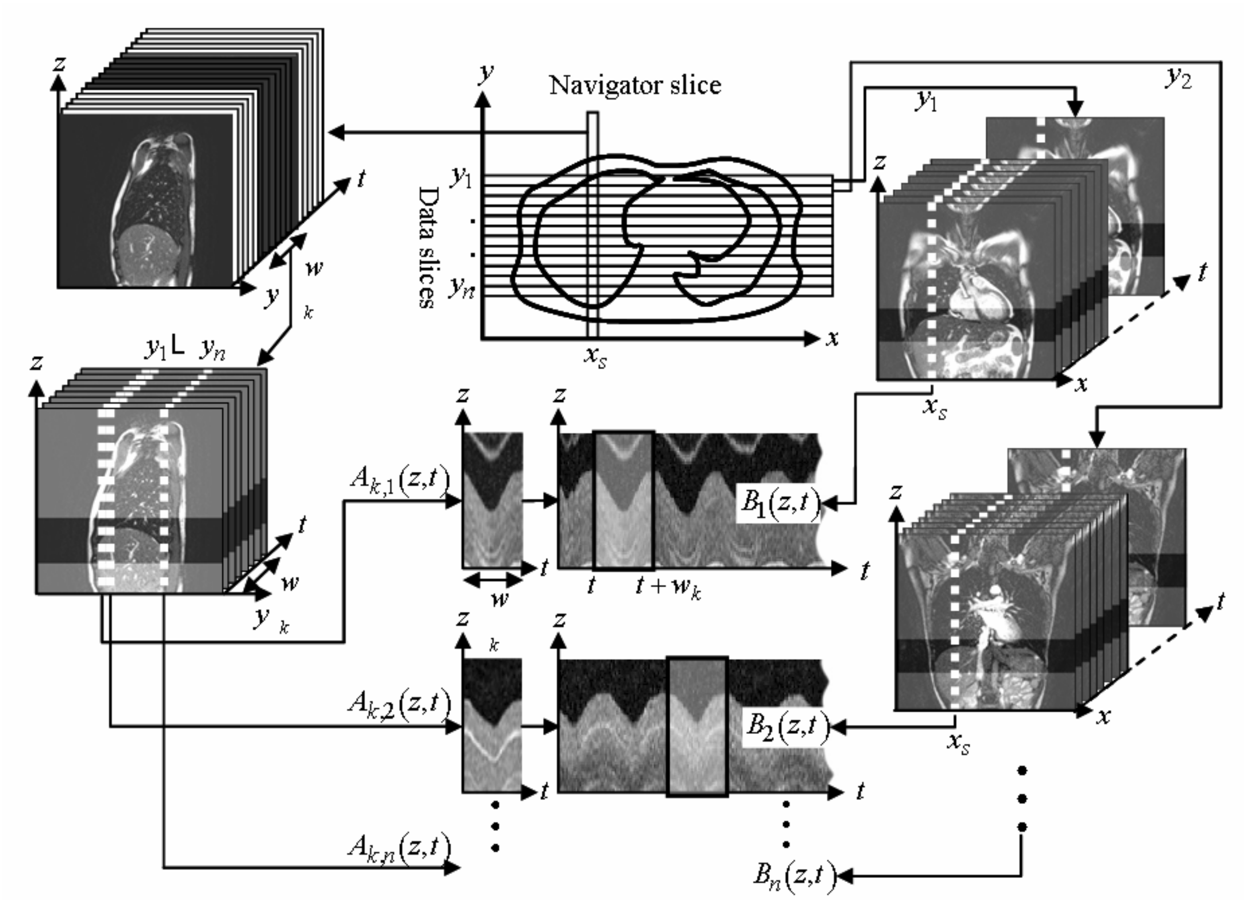

Figure 3 Flow of 4DMRI reconstruction. A sagittal slice is used as the navigator slices. On the other hand, coronal slices are used the data slices. In fact, a 2D spatio-temporal image (2DSTI) in which a horizontal axis represents the time and a vertical axis represents the body axis is used in matching operation. One proper respiratory pattern (Template) is first extracted from the 2DSTI of the navigator slice. Template matching by normalized cross-correlation is then carried out to search for the most similar pattern from the 2DSTI of a data slice. 4DMRI is created by applying this process to each data slice.

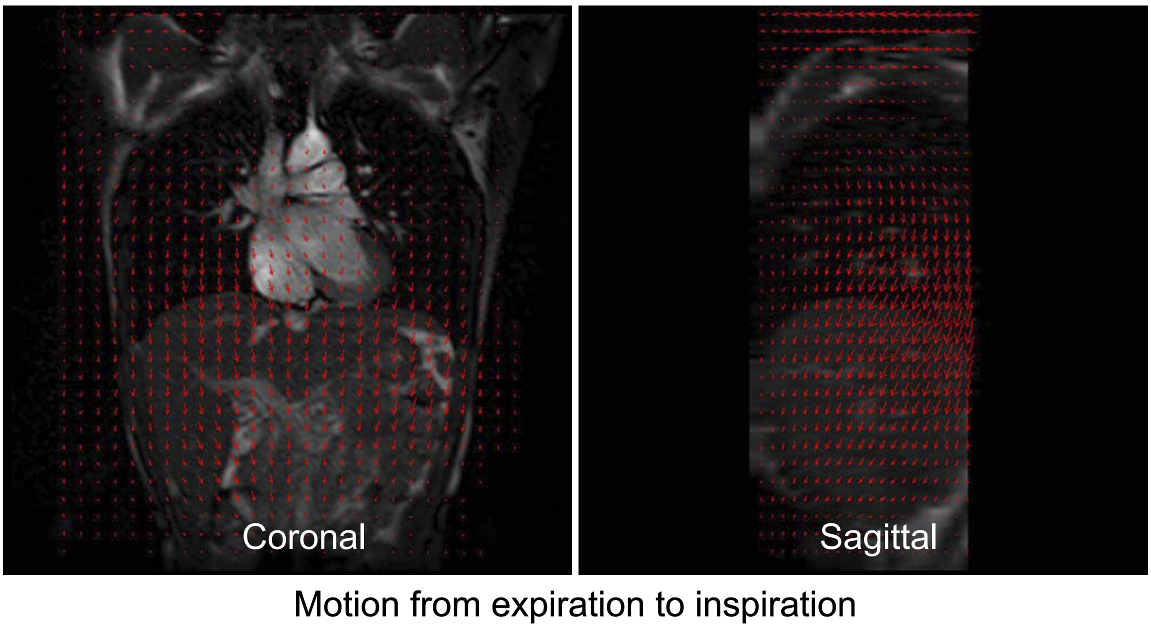

Figure 4 Motion vector field from expiration to inspiration.

Reference

[1] Ue H, Haneishi H, Iwanaga H, Suga K, Respiratory lung motion analysis using a nonlinear motion correction technique for respiratory-gated lung perfusion SPECT images, Ann Nucl Med (2007) 21:175–1835.

[2] Masuda Y, Fujibuchi T, Haneishi, 4D MR Imaging of Respiratory Organ Motion Using a Intersection Profile Method, JAMIT annual conference, CR-ROM C2-03, (2008)

[3] Masuda Y, Fujibuchi T, Haneishi, 4D MR Imaging of Respiratory Organ Motion Using a Intersection Profile Method, Medical Imaging Technology (submitted)

[4] Ketai L, Hartshorne M., Potential of computed tomography - SPECT and computed tomography - coincidence fusion images of the chest. Clin Nucl Med 2001; 26:433-41.

[5] Aquino SL, Asmuth JC, Moore R, Weise SB, Fischman AJ. Improved image interpretation with registered thoracic CT and positron emission tomography data sets. Am J Roentgenol Radium Ther Nucl Med 2002; 178:939-44.

[6] Ue H, Haneishi H, Iwanaga H, Suga K. Nonlinear motion correction of respiratory-gated lung SPECT images. IEEE Trans Med Imaging 2006; 25: 486-95.

[7] Iwasawa T, Yoshiike Y, Saito K, Kagei S, Gotoh T, Matsubara S. Paradoxical motion of the hemidiaphragm in patients with emphysema. J Thorac Imaging 2000; 15:191-95.

[8] Iwasawa T, Kagei S, Gotoh T, Yoshiike Y, Matsushita K, Kurihara H, et al. Magnetic resonance analysis of abnormal diaphragmatic motion in patients with emphysema. Eur Respir J. 2002; 19:225-31.