Respiratory Movement for Health Assessment by Using Internal-external Cross Correlation Investigation

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***Abstract*—Respiratory belt is a full-service home medical equipment to monitor respiration for homecare. Respiratory belt indicates breathing strength and characterizes breathing patterns. This paper describes a noninvasive respiratory movement monitoring using Magnetic Resonance Imaging (MRI) and respiratory belt simultaneously to investigate internal-external correlation. Twenty healthy subjects participated in this study and they all performed paced breathing (12 cycles/minute) during experiment. The diaphragmatic movement area and the anterior-posterior (AP) diameter of the body contour were represented as indexes of internal respiratory movement. The respiratory belt signal was represented as the external index. Cross correlation was used to evaluate the similarity between internal and external respiratory movement. The results indicated that diaphragmatic movement area versus respiratory belt signal performed strong negative correlation (R value is -0.847±0.06). The AP diameter of the body contour versus respiratory belt performed strong positive correlation (R value is 0.837±0.09). In conclusion, respiratory belt correlates strongly with diaphragmatic movement area and AP diameter of the body contour. Therefore, respiratory belt is a reliable external respiratory monitoring technique to detect respiratory movement in homecare.**

Keywords-cross correlation; respiratiory movement; respiratory belt; internal-external information

I. INTRODUCTION

The measurement of lung function is predominantly based on conventional spirometry that measures the lung volume at the corresponding flow. Such measurement provides an averaged performance of the lungs at a point. There is no information that reflects the contributions from various regions of the lungs [1]. Therefore, a non-invasive method for recording lung function that primarily relies on cross sectional area of both thorax and abdomen called respiratory belt. Respiratory failure is too difficult to predict. Continuous monitoring of respiratory activity and appropriate monitoring equipment could be life-saving. Therefore, respiratory belt is a full-service home medical equipment to monitor respiration for homecare [2]. With such a device, the changes in the volumes of the thoracoabdominal compartments respectively measures anterior-posterior and lateral diameter changes of different conditions. It can provide respiratory volume, respiratory rate and pulmonary ventilation [3].

Applications of respiratory belt are the most widely used technique and play an essential role in clinic. For examples, respiratory belt measures the variation of thoracic or abdominal circumference during respiration which indicated breathing strength and characterized breathing patterns. Synchrony of the breathing pattern has promised to evaluate chest wall movement and stability in preterm infants [4]. Thoracoabdominal asynchrony during upper airway obstruction in small children can be documented by phase angle analysis of the Lissajous figure from the output of a respiratory inductance plethysmography as respiratory belt [5]. In gated radiotherapy, the accuracy of respiratory-gated treatments based on external body monitoring usually relies upon the assumption of a strong correlation between the external motion and internal respiratory motion [6]. However, there are several studies to verify the time series correlation of internal and external movement by Magnetic Resonance Imaging (MRI).

MRI is a feasible technique to investigate the anatomy and physiology of the body, especially diaphragmatic movement. The technique is widely used in hospitals for medical diagnosis, staging of cancers and for follow-up without exposure to ionizing radiation.

Cross correlation is commonly used for measuring the similarity of two waveforms [7]. Therefore, this study used

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cross correlation to analyze the interaction between internal and external respiratory movement. The diaphragmatic movement area represents the respiratory movement. The AP diameter of the body contour represents the internal index. The respiratory waveform measured by respiratory belt represents the external index.

Section II presents the methods about data collection and imaging processing. Section III presents the results about cross correlation. Section IV presents the discussion and Section V presents the conclusion.

II. METHODS

A. Subjects and data collection

Twenty healthy subjects (10 males and 10 females; age: 23±1.8; height: 167±9.3 cm; weight: 60±11.45 kg) participated in this study and they all performed paced breathing (12 cycles/minute) during experiment. All subjects followed the instruction during breathing for 2 minutes in MRI exam room (Figure 1).

The diaphragmatic movement represented the internal respiratory index. And the images were projected in the sagittal plane with the subject in the supine position. The projection plane was placed sagittally in the coronal scout view directed through on the right side, midway through the most highest of the right diaphragm. All imaging experiments were performed on a Siemens 1.5-T Magnetom Sonata scanner (Siemens Medical Solutions, Erlangen, Germany) with a two-channel body array coil. No intravenous contrast medium was administrated. We have used Fast Low Angle Shot pulse sequence to acquire MRI images configured as follows: TR= 2.18 ms, TE= 0.74 ms, slice thickness=10 mm, field of view= 400 mm. The length of each trial recorded sequence was 129 s. During this time, 512 images were recorded at regular intervals; one image was acquired every 0.252 s.

The respiratory belt (Siemens "Physiological Measurements Unit") located on xiphoid was used to measure the external respiratory movement. This study was approved by institutional review board of National Chiao Tung University and Chung Shan Medical University Hospital. Informed consent was obtained from all participants before the experiment.

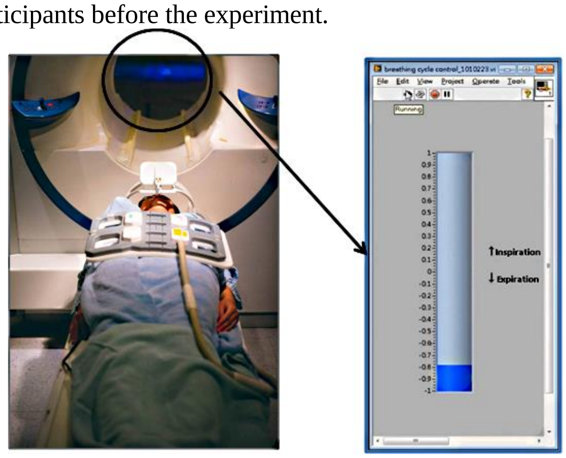

Figure 1. Left picture showed experimental environment and right picture showed the following instruction.

B. Imaging and signal processing

The MRI image files were converted to analyze format with DicomWork 1.3.5 software. The imaging processing programs in this study were developed by using commercial software platform (LabVIEW version 2013, National Instruments Corp., Austin, USA). The experimental analysis was assessed under the following.

1) Diaphragmatic movement area

The diaphragmatic area movement is an internal respiratory movement. The images analysis contains several steps as follows. First, the boundaries of the diaphragm are extracted from edge detection algorithm [8]. Edge detection is aimed to identify points in the MRI image, where the image brightness changes sharply. Green color is diaphragm which is extracted from edge detection (Figure 2). Secondly, it demonstrates the "cresent" shaped image of diaphragm area during paced breathing cycle and converts to the waveform. The calculated area method is maximum inspiratory volume as a reference to calculate the ups and downs area of diaphragmatic movement.

2) AP diameter of the body contour located on xiphoid

Drawing the horizontal line at the location of respiratory belt as a reference recorded AP diameter of the body contour in sagittal MRI image. The AP diameter of the body contour represents the internal respiratory movement (Figure 3). The anterior-posterior boundary is extracted from edge detection algorithm. Then, it measures the diameter of the boundary.

3) Respiratory belt signal

The respiratory belt was used to measure the external respiratory movement (Figure 4).

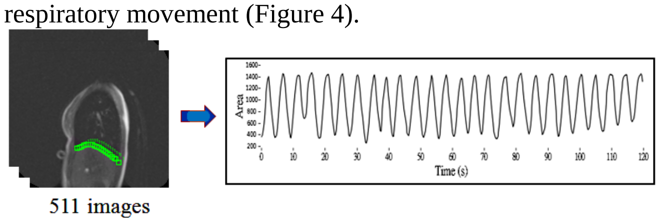

Figure 2. Diaphragmatic movement area as internal index during paced breathing cycle.

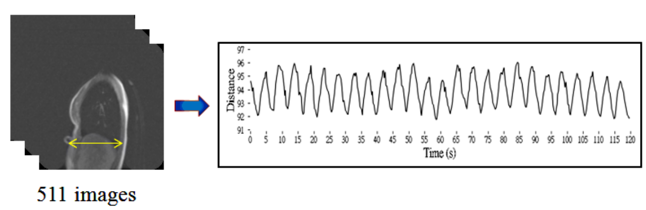

Figure 3. AP diameter of the body contour as internal index during paced breathing cycle.

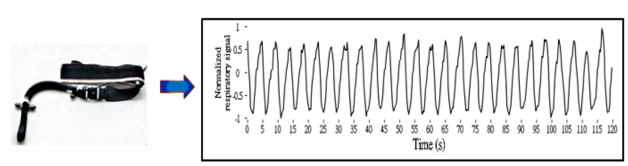

Figure 4. Respiratory signal which was extracted by respiratory belt based on pressure difference as external index.

Three indexes represent different meanings on physiology. Diaphragmatic area movement means pulmonary efficiency. The AP diameter of the body contour is that it outlines AP diameter of the body contour changes at sagittal MRI images. Respiratory belt means AP and lateral diameter changes.

C. *Cross correlation function*

Cross correlation function is commonly used for measuring the similarity of two waveforms as a function of a time-shift applied to one of them. The process of calculation opened a fixed window size about one breathing cycle then calculated the quantity R, called correlation coefficient with time shift point by point. The mathematical formula for R is:

$$R = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\left(\sum_{i=1}^{n}(y_i - \bar{y})\right)^2}} \quad (1)$$

where n is number of points data during a breathing cycle and x, y are two different waveforms data respectively. The value of R is such that $-1 \leq R \leq 1$.

III. RESULTS

Cross correlation is commonly used for measuring the internal-external correlation. The results of cross correlation were illustrated in one of the participants as an example (Figure 5,6,7) and the statistical results of 20 subjects are summarized in Table I. Diaphragmatic movement area versus AP diameter of the body contour performed strong negative correlation (R value is -0.908±0.09) after time shift zero. Diaphragmatic movement area versus respiratory belt signal performed strong negative correlation (R value is -0.847±0.06). Diaphragmatic movement itself versus AP diameter of the body contour and respiratory belt is opposite direction during breathing. AP diameter of the body contour versus respiratory belt performed strong positive correlation (R value is 0.837±0.09).

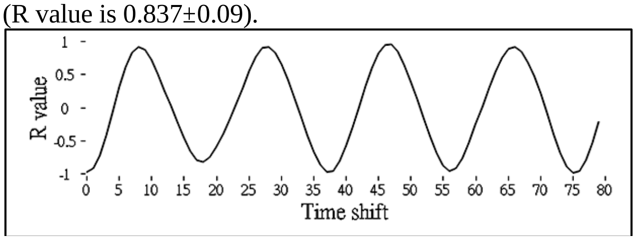

Figure 5. R value of diaphragmatic area versus AP diameter of the body contour in MRI images.

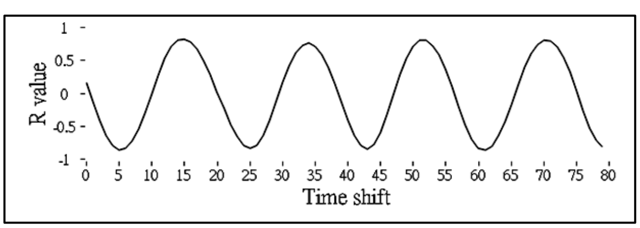

Figure 6. R value of diaphragmatic area in MRI images versus respiratory belt signal.

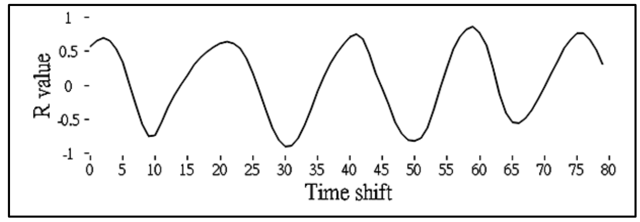

Figure 7. R value of AP diameter of the body contour in MRI images versus respiratory belt signal.

TABLE I. THE RESULTS OF CROSS CORRELATION

	Correlation coefficient	
	Diaphragmatic movement area	***AP diameter of the body contour***
AP diameter of the body contour	-0.908±0.09	-
Respiratory belt signal	-0.847±0.06	0.837±0.09

The form is (mean±standard deviation)

IV. DISCUSSION

Cross correlation is commonly method for quantifying the internal-external correlation. This research verified the correlation of organ movement (internal index) and respiratory belt signal (external index) in the sagittal MRI images. There are two indexes from MRI images. One is the internal diaphragm represented soft tissue and the other is external body contour represented rigid structure. Therefore, diaphragmatic movement area versus AP diameter of the body contour performed strong negative correlation but no time shift. However, respiratory belt is another respiratory reference to discuss. Cross correlation about respiratory belt performed strong positive correlation but had several time shifts. The result showed that there is time difference between internal and external. Vedam *et al.* [9] measured the correlation between the respiratory signal and the superior-inferior location of the diaphragm. Results from statistical analysis indicated a strong linear relationship between the respiratory signal and diaphragm motion ($p < 0.001$) but this only gave one dimensional internal information. Ionascu *et al.* [6] studied the internal-external correlation investigation of respiratory induced motion of lung cancers. The results showed that internal-external correlation along the anterior-posterior with values larger than 0.97 was better than along superior-posterior with values in the range 0.77-0.88.

In other studies of quantifying the internal-external correlation, they have been tried to get the internal information by fluoroscopy, sonography or other imaging techniques for synchronization. Gierga *et al.* [10] showed that the information of internal organs by fluoroscopy and the correlation of the respiratory motion of external patient markers as body contour are important for image-guided therapy techniques, such as respiratory gating, that monitor the movement of external fiducials. However, fluoroscopy which uses X rays to obtain real-time overlapping flat plane. The limitation of fluoroscopy is on spatial orientation. Sawada *et al.* [11] carried out that using a moving-target phantom simulated a patient respiratory movement and observing the variation of the calculated real-time correlation index synchronizes with the periodical motion of the moving-target. Though sonography is able to obtain the good time resolution, it is unable to set the same anatomy landmark on free hand mode. The research is a precise verification for analyzing the correlation of internal-external on fixed landmark by MRI images. It is hoped to investigate the correlation of internal-external information during breathing patterns such as thoracic breathing or abdominal breathing further. However, MRI has been limited in acquisition speed, so the pulse sequence of good time resolution is to be considered for the future.

The physiology or imaging monitoring is often used respiratory belt as recording the external information. Ya-Chen *et al.* [12] acquired the respiratory movement with four respiratory effort transducers based on using ensemble empirical mode decomposition for breathing patterns recognition. A long-term monitoring of respiration particularly becomes suitable for homecare application for chronic pulmonary diseases [13]. Respiratory belt helps a person who has obstructive sleep apnea breathe to monitor respiration. Therefore, respiratory monitoring is essential for health assessment.

The location of respiratory belt is an important impact on the changing of the external information. For example, the displacement changes largely, which respiratory belt tied on abdomen during abdominal breathing. It is obvious changing of the belt as xiphoid during thoracic breathing. Therefore, the aim of our research is to investigate the correlation of different breathing types such as thoracic breathing or abdominal breathing in future work.

V. CONCLUSION

Based on cross correlation, this study attempts to verify that diaphragmatic movement versus signal of respiratory belt assumes a better similarity on correlation coefficient and can be a reliable non-invasive respiratory monitoring system to detect internal respiratory movement. Therefore, respiratory belt can be a home medical equipment to monitor respiration for homecare.

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