An analysis of the chest wall motions using the dynamic MRI in healthy elder subjects

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The objective of this study was to compare respiratory motions of the chest wall in the healthy elder subjects (N = 5; mean age, 71 years old) with those in healthy young subjects (n = 9; mean age, 29 years old). Thirty sequential images (scanning time, 0.4s per image) of dynamic MRI on sagittal and coronal planes were obtained while the subjects were deeply breathing. Lung volume change was simultaneously measured with pneumotachometer. In the elder subjects, dimensions of the middle and posterior parts of the diaphragm were linearly related to instantaneous lung volume. There were poor correlation between motion of the anterior diaphragm and transverse motions of the upper rib-cage and lower rib-cage. The contribution of individual part of the chest wall motion to a unit lung volume change, assessed by slope of the linear regression line, in elder subjects were not significantly different from those in young subjects. Either in the elder or young subjects, the middle and posterior parts of the diaphragm moved coordinately. We conclude that chest wall motion in the healthy elder subjects is not different from that in healthy young people and that middle and posterior parts of the diaphragm act as one functional unit during deep breathing.

Key words : pneumotachometer, aging, diaphragmatic motion, non-invasive analysis

INTRODUCTION

Aging deteriorates lung functions. For example, forced expiratory volume at 1 sec ($FEV_{1.0}$) gradually decreases as age progression [1]. In one study [2], approximately 5300,000 peoples above 40 years old have obstructive lung function in Japan. These observations infer that the respiratory-related chest wall motion may also be altered by aging. However, there have been scarce studies on age-related changes of chest wall motions. We, in the previous study [3], analyzed the relationship between the chest wall motion and lung volume changes during either quiet or deep breathing using dynamic MRI in healthy young subjects. Both rib-cage and diaphragmatic motions linearly related to lung volume change, and contribution of the diaphragmatic motion to lung volume change was a few-fold larger than that of rib-cage motion. In the present study, we planned to compare chest wall motions in the healthy elder subjects with those of the young subjects.

SUBJECTS AND METHOD

Five healthy male persons above 60 years old were newly recruited for this study (Table 1) and written informed consent was obtained from them. Their mean age was 71.0 years old. The mean forced vital capacity (FVC) was 3.37 l and the mean $FEV_{1.0}$ over FVC ($FEV_{1.0}$%) was 78.4%. As the healthy young subjects, the data in the previous study [3] was used. Although the mean height, mean FVC and mean $FEV_{1.0}$ of the healthy elder subjects were significantly lower than those of the healthy young subjects, FEV_1% of the subjects in both groups

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Table 1 Physiological parameters of the subjects (mean ± SD)

	Young	Elder
n	9	5
Age (y.o.)	28.6 ± 3.2	71.0 ± 4.5*
Height(cm)	171.6 ± 5.8	163.0 ± 6.5*
FVC(l)	4.62 ± 0.36	3.37± 0.54*
FEV_1(l)	3.68 ± 0.31	2.67 ± 0.49*
FEV_1%(%)	79.6 + 5.1	78.4 + 3.8NS

*: P<0.05

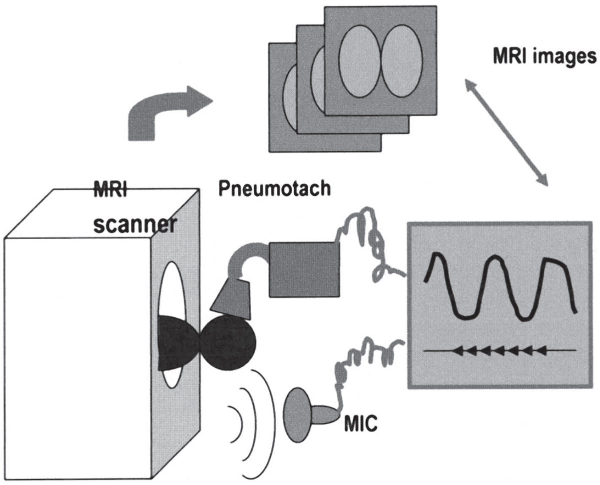

Fig. 1 Schematic presentation of the MRI-image acquisition and matching individual images to instantaneous lung volume.

were in the normal range.

The method for data acquisition was the same as that reported previously [3]. Figure 1 shows outline of the method. The subject lied in the MRI scanner (Philips, Gyroscan ACS NT15) breathing through an air-tight face mask for nasal CPAP (continuous positive airway pressure). The mask was connected to a Fleisch pneumotachograph whose stainless steel shell was replaced by a teflon one. The T1-weighted images were obtained by single shot fast spin echo method (repetition time of 400 ms, echo time of 60 ms, 73 × 256 phase-encoding steps, flip angle of 90 degrees, turbo factor of 32, half scan factor of 0.625, and thickness of 12 mm). The time to scan one slice was 0.4 s. Thirty sequential sagittal images at the right mid-clavicular line were obtained during maximal deep breathing. Then, 30 sequential coronal images at the tracheal bifurcation level were obtained during maximal deep breathing. The MRI scanner generated sounds which were augmented during each of the image acquisitions. We recorded these sounds simultaneously with respiratory volume, and thus matched each MRI image to the instantaneous respiratory volume. Each MRI image was transferred to a personal computer. Using a software (NIH-image, ftp://zippy.nih.gov/pub/nih-image/), the inner contour of the thoracic wall in each image was automatically detected.

In the sagittal images (Fig. 2), the axial

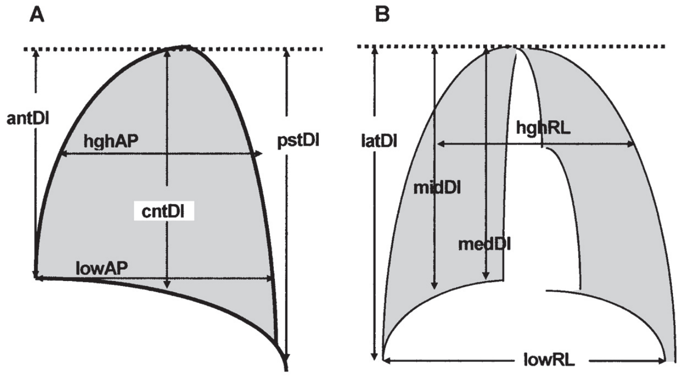

Fig. 2 Chest wall dimensions in the MRI analyses. **A**: The distances from the thoracic apex to the diaphragm at the anterior chest wall margin (antDI), at the tracheal bifurcation level (cntDI), and at the posterior chest wall margin (pstDI). Thoracic anteroposterior diameter at the tracheal bifurcation (hghAP) and at the boundary of the anterior rib cage (lowAP). **B**: The distances from the thoracic apex to the diaphragm at the lateral chest wall margin (latDI), at the right mid-clavicular line (midDI), and at the mediastinal margin (medDI). The transverse diameter at the level of the tracheal bifurcation (hghRL), and at the right costo-phrenic angle (lowRL).

distances between the thoracic apex and the diaphragm at the anterior chest wall margin (antDI), at the tracheal bifurcation level (cntDI), and at the posterior chest wall margin (pstDI) were measured as the parameters of diaphragmatic motion. Thoracic antero-posterior diameters at the level of the tracheal bifurcation (hghAP) and at the boundary of the anterior rib cage (lowAP) were also measured. In the coronal images, the distances from the thoracic apex to the diaphragm at the right lateral chest wall margin (latDI), at right mid-clavicular line (midDI), and at the mediastinal margin (medDI) were measured. Thoracic transverse diameters at the level of the tracheal bifurcation (hghRL) and at the level of costophrenic angle (lowRL) also were measured.

In the previous study we found that there was good linear relationship between chest wall motion and lung volume at any of the evaluated site in the healthy young subject during deep breathing [3]. Therefore in the present study we adopted the first-order regression of the chest wall motion to lung volume change. As the second analysis, we calculated partial correlation coefficient of individual part of the chest wall motion to that of the central part of the diaphragm, i.e. cntDI or midDI. Motion of the central part of the diaphragm exhibited the highest linear relationship with respiratory volume changes in the previous study [3]. When the partial correlation coefficient was high, the portion was regarded as functionally single unit to the central diaphragm. Finally, we compared the slopes of the linear regression line of the chest wall motion vs. lung volume change of the elder subject with those of the young subjects.

The processed data were expressed as mean ± SD. Statistical analysis was performed using the paired t test. Values of $P < 0.05$ were considered significant.

RESULTS

Figure 3 shows an example of chest wall motions against lung volume change in a 68 years-old male. As seen in the young subject [3], there were linear relationships between any parts of the chest wall dimension and instantaneous lung volume. Among them motions of the middle (cntDI) and posterior (pstDI) parts of the diaphragm developed the highest dimension changes against lung volume changes suggesting that motion of these parts mostly contributed to ventilation.

Figure 4 shows correlation coefficients

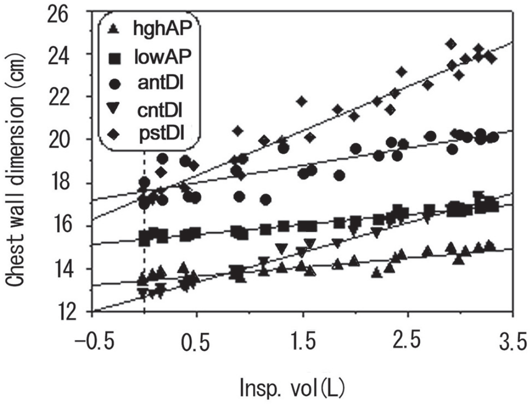

Fig. 3 Changes in chest wall dimensions during maximal deep breathing in the sagittal images. The volume 0 represents end-expiration level. Linear regression lines are drawn for each of the parameters. Abbreviations are the same as in Fig. 2.

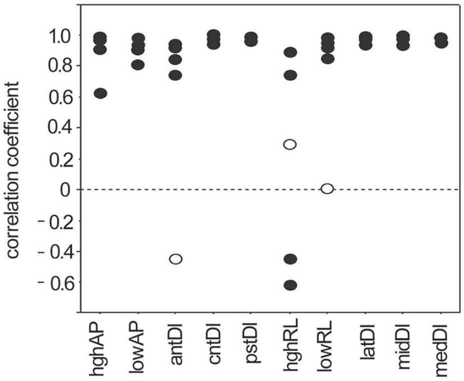

Fig. 4 Correlation coefficient and P-values of the linear regressions on chest wall dimensions vs. lung volume changes in each subject. ●: P-values <0.05. ○: P-values ≥ 0.05. Abbreviations are the same as in Fig. 2.

(Rs) of linear regression lines assessing relationship between chest wall motions and lung volume changes in the elder subjects. They had excellent linear relationships ($R > 0.8$, $p < 0.05$) during deep breathing at many parts of the chest wall. Among them posterior (pstDI) and middle parts (cntDI, latDI, midDI and medDi) of the diaphragm exhibited extremely high Rs. In one patient R of antDI was low and in this subject p-value of the regression line was also high ($p = 1.14$). Rs of the rib-cage motion were tended to be low.

Figure 5 shows partial correlation coefficients of chest wall motions against motion of the central part of the diaphragm (cntDI) in the sagittal plane (A), and those against midDI motions in the coronal plane (B). In panel A, either in the elder or young subjects, pstDI motions had the highest correlation to that of cntDI, suggesting that the posterior diaphragm moved in parallel with the central diaphragm. Although antero-posterior motion of the lower rib-cage always had poor correlation with cntDI in the young subject the motions had good correlation in some elder subjects and did not in others. In panel B, either in the elder or young subjects, intDI motions and medDI motions had good correlation to that of the midDI. However, motions of upper and lower rib-cage had no good correlation to motion of

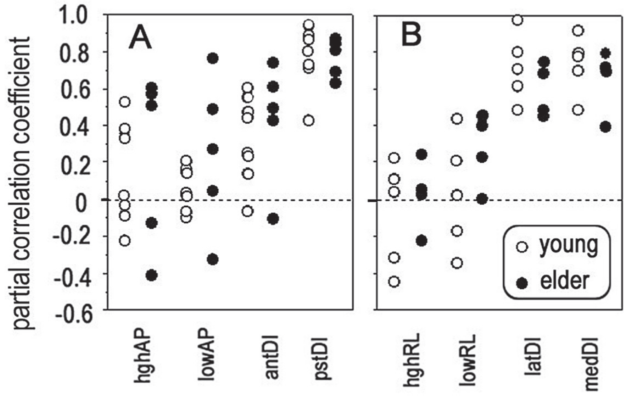

Fig. 5 Partial correlation coefficient of the linear regressions on chest wall dimensions to motion of the central part of the diaphragm in each subject obtained from the sagittal (A) and coronal (B) images. Abbreviations are the same as in Fig. 2. ●: elder subjects. ○: younger subjects.

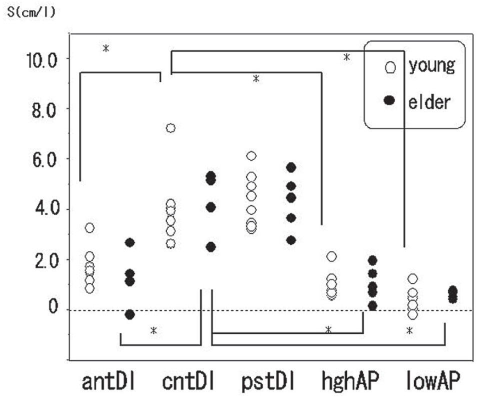

Fig. 6 Slope of the linear regression lines on chest wall dimensions vs. lung volume changes in each subject. Abbreviations of the parameters are the same as in Fig. 2. ●: elder subjects. ○: younger subjects. *: $P < 0.05$.

either cntDI or midDI. These findings were true both in young and elder subjects. Tidal ventilations during acquisition of sagittal plane were 2.03 ± 1.05 L (elder) and 2.04 ± 0.49 L (young) and those during acquisition of coronal images were 2.10 ± 1.02 L (elder) and 2.19 ± 0.91 L (young). They were not significantly different.

Figure 6 shows slopes (Ss) of the linear regression lines drawn between the chest wall motions and lung volume changes in the sagittal images. The slope represents chest wall motion for change of a unit of lung volume change. At any part of the chest wall Ss of the elder persons were not significantly different from those of the corresponding parts in the young subjects. The S of cntDI was significantly higher than that at antDI, hghAP, or lowAP in either elder or young subject group. However, there was no significant difference between S of cntDI and that of pstDI.

DISCUSSION

The major findings in the present study were; 1) there was liner correlation between lung volume change and chest wall motion in the elder subjects. 2) Lateral motions of the rib-cage and anterior diaphragmatic motion had less linearity to lung volume changes. 3) The middle and posterior parts of the diaphragm mostly contributed to lung volume change assuming as one functional unit.

Aging changes in lung function have been described as an increase in residual volume, and decreases in $FEV_{1.0}$ and static lung compliance [4]. Compliance of the diaphragm or abdominal wall is also decreased by aging [5]. However, effects of aging on these parameters are not so large and changes in lung function by aging are less than that by emphysema [6]. Verschakelen and Demedts [7] analyzed effects of aging on thoraco-abdominal motions using the inductive plethysmography. In their male subjects above 60 years old, the mean slope representing motions between rib-cage and abdominal wall was 20% less than that of 20-30 years old subject in the supine position. In the present study, rib-cage motions to the diaphragmatic motions in the elder subjects were not apparently different from those of young subjects. The reason of this difference is unclear. However, in their report the change of thoraco-abdominal motion by aging did not reach statistical significance, and furthermore in their previous study they described that direct measurement of diaphragmatic displacement exhibited higher resolution than inductive plethymographic analysis [8]. Another finding in the present study was that in some elder subjects antero-posterior motion of the lower rib-cage moved in concert with diaphragmatic motions. This finding was not observed in the young subjects. Paradoxical motion of lower rib-cage is one of major finding of severe emphysema [9]. Thus coordination of lower rib-cage with diaphragmatic motion may be an important difference of healthy elder subject to that of emphysema patients.

In elder subjects, the central part of the diaphragm worked as one functional unit with posterior part of the diaphragm. This finding is the same as seen in healthy young subjects [3]. This result is supported by an observation by Verschakelen *et al.* [8] who semi-statically analyzed thoraco-abdominal motions in healthy subjects using inductive plethysmogaphy and cine X-ray. Anatomically central part of the diaphragm belongs to the costal diaphragm while posterior part belongs to the crural diaphragm. There are many differences in the two parts of the diaphragm. They include innervations, array of muscular fibers and fiber attachments to the tendon. According to the functional study by DeTroyer *et al.* [9], the inspiration is mostly driven by the costal diaphragm while the crural diaphragm plays an assistive role in supine dogs. Our study suggested that these two different parts of the diaphragm act as one functional unit in vivo either in elder or young human subjects.

In conclusion, this study using dynamic MRI revealed that the respiratory-related chest wall motion does not much change by aging. In either groups subjects the posterior diaphragm acted as one functional unit with central part of the diaphragm.

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