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Original Article

Characteristics of Vibration Response Imaging in Healthy Koreans

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Background: Vibration response imaging (VRI) is a new technology that records energy generated by airflow during the respiration cycle. Analysis of lung sound using VRI may overcome the limitations of auscultation.
Objectives: To set a VRI standard for healthy Koreans, we conducted a clinical assessment to evaluate breath sound images and quantification in healthy subjects and compared the findings with reported breath sound characteristics.
Methods: Recordings were performed using the VRIxp. Eighty subjects took a deep breath four times during a 12-second interval while sitting upright. The quantitative aspect was analyzed using the VRI quantitative lung data (QLD) for total left lung, total right lung and for six lung regions: left upper lung (LUL), left middle lung (LML), left lower lung (LLL), right upper lung (RUL), right middle lung (RML), right lower lung (RLL). The qualitative aspect was provided through image assessments by three reviewers.
Results: In all regions the left lung had significantly higher QLD than the right lung ($P<0.005$, paired t-test). The inter-rater agreement was 0.78. 84% of the images were found normal by the final assessment. Among the 16% (n=13) of images with abnormal final assessment, the most common flawed features were dynamic image (77%, n=10) and maximum energy frame (MEF) shape (77%, n=10). No significant differences were found between males and females for QLD but there were significant differences in qualitative aspects including dynamic images, MEF shape, and missing LLL.
Conclusion: The characteristics of healthy Koreans are similar to those of Western subjects reported previously. VRI is easy to use and objective, and so is helpful to diagnose patients with respiratory diseases and to monitor the progress of diseases after medical treatments.

Key Words : Vibration response imaging (VRI), QLD, MEF shape, respiratory disease diagnosis

Introduction

Auscultation is a simple and easy way to diagnose patients with respiratory diseases. However, the information from a stethoscope is not always as accurate or objective as anticipated[1,2]. To overcome these weaknesses, analysis of lung sound using vibration energy has been explored[3-5]. Vibration response imaging (VRI) is a new technology that records energy generated by airflow during the respiration cycle. Vibration energy from the respiratory cycle can be quantified for any lung region. The VRIxp system is a computer-based acoustic lung imaging system, developed to acquire, quantify, monitor and store breath sounds, and has been described in detail elsewhere[6]. The sole study concerning VRI in healthy subjects was conducted using Westerners[7]. As lung size and lung capacity of Koreans are smaller than those of Westerners[8], a

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VRI study in healthy Koreans is needed.

To set the VRI standard of healthy Korean, we conducted a clinical assessment to evaluate breath sound images and quantification in healthy subjects and compared the findings with reported breath sound characteristics.

Methods

1. Subjects

Healthy adults without a history of respiratory diseases were enrolled. We received approval from the Institutional Review Board of Kyunghee Oriental Medical Center to conduct studies in healthy subjects and written informed consent was obtained from each subject. Chest radiography, spirometry and auscultation were checked to confirm healthy subjects.

2. VRIxp Recording

Recordings were performed using the VRIxp (DeepBreeze, Israel)[6]. Forty sensors assembled in two planar arrays and vacuum-adhered to the posterior chest on each side of a subject's back were used to acquire lung sound signal data over both lungs during a single 12-second recording period. Subjects, who were seated upright, took a deep breath four times during this period.

3. Image Analysis and Quantitative Data Analysis

VRI was assessed quantitatively and qualitatively. The quantitative aspect was analyzed using the VRI quantitative lung data (QLD) for total left lung (TL) and total right lung (TR) and for six lung regions: left upper lung (LUL), left middle lung (LML), left lower lung (LLL), right upper lung (RUL), right middle lung (RML), and right lower lung (RLL). The qualitative aspect was provided through image assessments by three reviewers. An example of a VRI result image is shown in Fig. 1. Each reviewer independently assessed the images using the features summarized in Table 1. The major approach was used and the final assessment was the mode of the three reviewers' assessments.

4. Statistical analyses

Inter-rater agreement was defined as the level of consensus among the raters' evaluations. The statistical method used has been previously described[7, 9]. For each evaluation category, the evaluation that appeared most often across raters was counted and specified as number of agreements (N_a). For all of the features of each subject, the sum of N_a was calculated. The average inter-rater agreement for all features was calculated using the following equation:

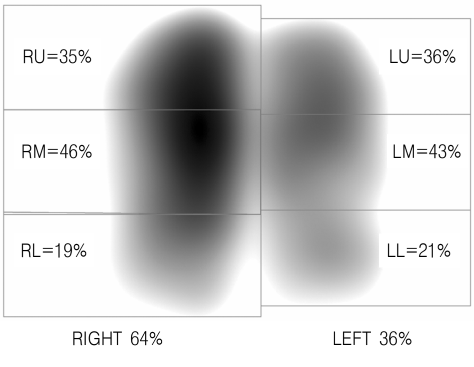

Fig 1. Example of VRI result

Table 1. Qualitative aspects of VRI assessment.

	Category	Feature	Quality
1	Dynamic image	Dynamic appearance	Good, Disturbed
2	Image development	Frame by frame - frame 1 to Maximal Energy Frame (MEF)	Good, Medium, Poor
3	MEF	Shape	Good, Medium, Poor
4	MEF area	Right (R) Side compared to Left (L)	R > L, R = L, R < L
5	MEF intensity	Right Side compared to Left	R > L, R = L, R < L
6	MEF missing parts	Location	R Upper: Yes □ No □; L Upper: Yes □ No □; R Lower: Yes □ No □; L Lower: Yes □ No □
7	VRI	Final assessment	Normal, Abnormal

$$= \frac{1}{80} \times \sum_{j=1}^{80} \frac{\Sigma_{i=1}^{10}(N_a) - \Sigma_{i=1}^{10}\min(N_a)}{\Sigma_{i=1}^{10}\max(N_a) - \Sigma_{i=1}^{10}\min(N_a)}$$

Inter-rater agreement was analyzed using one way ANOVA and interclass correlation coefficient (ICC). ICC is a quadratically modified form of the kappa correlation, which is applied when multiple raters judge the same data. ICC results > 0.6 are considered as substantial and > 0.8 are considered as very high to excellent correlated status[10,11]. Subgroup analysis comparing men with women was performed using a two-sided Fisher's exact test and Mann-Whitney test. Among the 80 subjects (62 males and 18 females), 20 of the males were smokers (pack years >0). None of the females were. Although smoking status would not bias the results, the smokers were filtered out and only the non-smokers were analyzed (42 males, 18 females). All statistical tests were two-sided with a 5% significance level. Analyses of data were performed using SPSS version 12.0.

Results

Eighty healthy subjects (62 males and 18 females) were analyzed using the VRIxp. The 20 smokers were significantly higher in height and weight. Subject characteristics are summarized in Tables 2 and 3.

1. VRI

In all regions (upper, middle and lower) the left lung had significantly higher QLD than the right lung (P<0.005, paired t-test) (Table 4). TL and TR QLD were distributed normally (P>0.05, one-sample Kolmogorov-Smirnov test; Fig. 1).

Table 2. Characteristics of the study population.

	Male	Female
Number	62	18
Age (years)*	25.9±4.0	25.4±3.2
Height*	176.5±5.3	161.9±5.2
Weight*	69.4±9.3	52.9±7.5
FVC	5.19 (96.8%)	3.46 (92%)
FEV1.0	4.38 (102.2%)	3.09 (101.1%)

* mean ± standard deviation
FVC: forced expiratory vital capacity
FEV1.0: forced expiratory volume in 1 second

Table 3. Comparison of smokers and non-smokers.

	Smoker	Non-smoker
Number	20	42
Age (years)*	26.6±4.8	25.6±3.5
Height*	178.6±5.5	175.5±4.9
Weight*	74.2±8.5	67.2±8.8
FVC	5.39 (99.0%)	5.09 (96%)
FEV1.0	4.37 (101.2%)	4.37 (102.8%)

* mean ± standard deviation
FVC: forced expiratory vital capacity
FEV1.0: forced expiratory volume in 1 second

Table 4. Results of the lung region QLD.

	Left			Right		
	Average	Median	95% CI	Average	Median	95% CI
Upper	12 ± 2	13	12 – 13	8 ± 2	8	8 – 9
Middle	19 ± 2	19	18 – 19	15 ± 2	15	14 – 15
Lower	25 ± 4	24	24 – 25	22 ± 4	21	21 – 23
Total	55 ± 5	55	54 – 57	45 ± 5	45	43 - 46

2. Inter-rater reliability

The inter-rater agreement was 0.78, while the dynamic features had inter-rater agreement lower than the static features (0.75 vs. 0.78 respectively). The ICC of the dynamic and static features were 0.72 and 0.71 respectively (and overall 0.72).

3. VRI qualitative assessment

The lower rate was found in ‘good MEF shape’ (71%) and the higher rates for ‘no missing parts’ (94%-98%). 84% of the images were found ‘normal’ by the final assessment (Fig. 2). Among the 16% (n=13) with abnormal final assessment the most common flawed features were dynamic image (77%, n=10) and MEF shape (77%, n=10) (Fig. 3).

4. Sub-group analysis: gender

No statistically significant differences were found

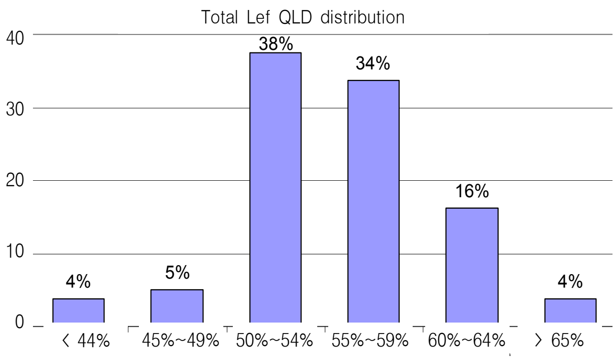

Fig. 2. TL distribution.

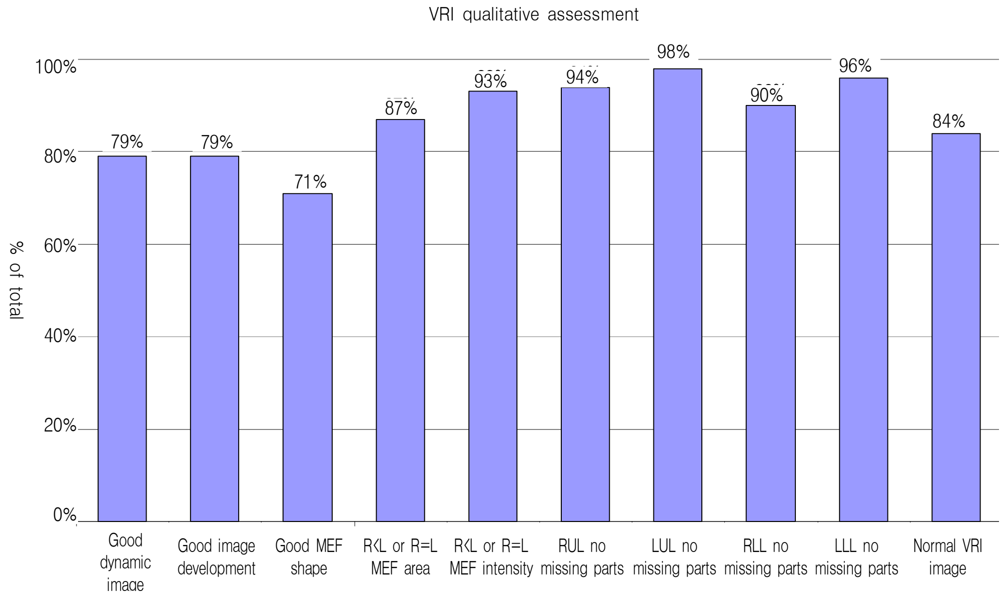

Fig. 3. VRI qualitative assessment. Bars denote the percent of the normal observations by each VRI image feature.

between males and females at the different QLD lung zones (P>0.05, Mann-Whitney test), except at upper right zone (females 7%±2% vs. males 9%±2%) (Table 5, Fig. 4). Qualitatively, significant differences were evident for three aspects (P<0.05, Fisher's exact test). Concerning dynamic images, males had higher rates of good dynamic images. Concerning MEF shape, males had higher rates of good MEF shape. Concerning the LLL image, no male had missing LLL, while 17% of females were assessed with decreased LLL. No significant differences were found at the final assessment (P>0.05, Fisher's exact test) (Fig. 5).

Discussion

The present study evaluated breath sound images of healthy subjects 20–40 years of age to study the VRI characteristics of healthy Koreans. VRI QLD was 55% in the left lung and 45% in the right lung. The QLD of the upper lobe was higher than that of the lower lobe. Three reviewers assessed the movement and shape of VRI. Most images had simultaneous movements, unanimous shapes during inhalation and exhalation, smooth rounded contours, and bilateral symmetry as the normal expectation.

These characteristics of healthy Koreans were

Table 5. VRI QLD [%] by lung zone and gender.

Lung region	Female (n=18)	Male (n=42)	P-value
TL	57±5	56±4	0.423
TR	43±5	44±4	0.423
LUL	13±2	13±3	0.788
LML	20±2	18±3	0.079
LLL	24±3	25±4	0.709
RUL	7±2	9±2	0.005*
RML	15±3	14±2	0.625
RLL	21±3	21±3	0.783

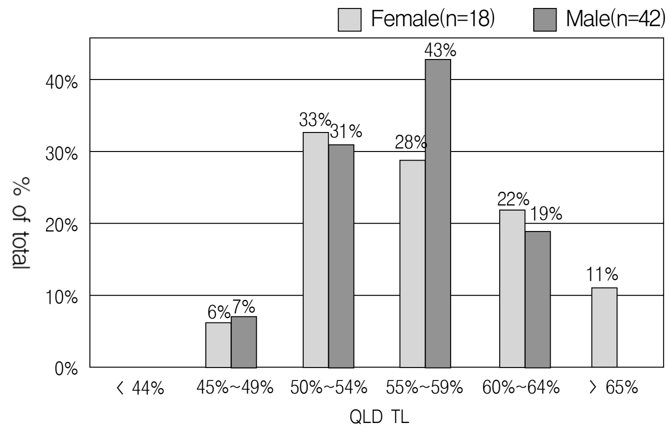

Fig. 4. QLD TL distribution by gender.

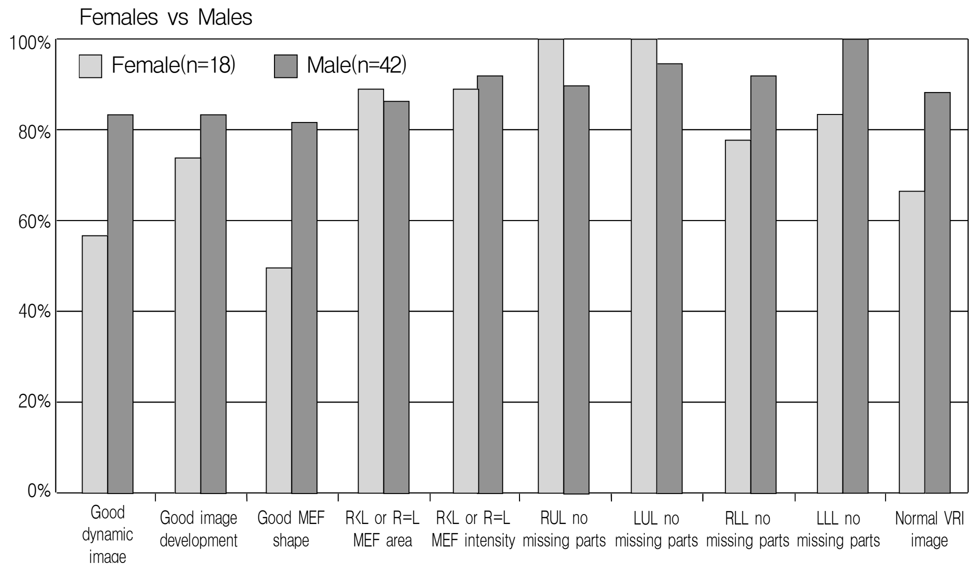

Fig. 5. VRI qualitative assessment by gender.

similar to the characteristics of Westerners reported previously[7]. Concerning QLD, both studies obtained the same result for the percent ratio of the left lung to right lung (55:45). Nevertheless, in this study the percentage of dynamic image that was considered as ‘good’ in females was lower than in males. There are two possible explanations for this finding. Firstly, as the sensor of the VRI machine is basically for the body shape of Westerners, and not designed for the smaller body type of Korean women, it is conceivable that the sensor did not exclusively monitor the lung, but other parts of the body as well. Secondly, unlike the men who can take off their top completely during examination, women revealed only their back and covered the front with a cloth. The noise that occurred in this process could artifactually affect the result.

While the inter-rater agreement was a substantial 0.78, the dynamic features had an inter-rater agreement of 0.75, which was lower than the static features.

The static feature had less error between reviewers because they observed bisymmetry of lungs in freeze-frame. On the other hand, for the dynamic feature, there was no exact object of comparison, and each reviewer made a subjective judgment on the moving lung, so the reliability was relatively lower. Further studies with more reviewers are needed.

When the final assessment of VRI was judged abnormal (16%), dynamic image and development of the dynamic image were considered as problems in most cases. In addition, MEF shape was often considered as a problem. For the dynamic feature, more specific standards between reviewers would be helpful. As the ratio of right and left lung QLD was 55:45 (i.e. the left lung seemed to be bigger or darker), shape was also considered to be not good. In the comparison of the differences between non-smoker males and females, there were no significant differences, except for the RUL, which was significantly higher in males The lower region might be lower in females because of their body shape, although no significant difference was evident. However, in the qualitative analysis, the dynamic feature and the MEF shape were considered as abnormal in a higher percentage of females compared to males, although the difference was not significant. More studies with more female subjects would be useful in determining if a significant difference really exists.

In this study, we only did auscultation, X-ray, and pulmonary function test to screen healthy subjects, and did not do chest computed tomography scan for the further evaluation of lung diseases. Thus, it remains unanswered whether patients whose VRI were regarded as abnormal also had normal computed tomography images.

This study was deliberately conducted on normal healthy subjects. Further studies using patients afflicted with different diseases are needed for clinical application. Such studies have been done for Westerners concerning pneumonia[12], chronic obstructive pulmonary disease[13], pleural effusion[14], and in lung transplant recipients[15].

Results concerning the reproducibility of VRI[9] and its' reliability, have laid the groundwork for further studies of the clinical use of VRI. Reflecting the importance of auscultation, the ease of use and objectivity of VRI will be helpful to diagnose patients with respiratory diseases. In addition, it will be useful for monitoring the progress of diseases after medical treatments.

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