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Measurements of chest wall volume variation during tidal breathing in the supine and lateral positions in healthy subjects

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ABSTRACT

Purpose: To study the feasibility and the laterality of measurements of chest wall volume variation during tidal breathing in the lateral position in healthy subjects.
Methods: Eighteen normal subjects were studied. Chest wall volume changes were measured by optoelectronic plethysmography in the supine and right and left lateral positions during quiet breathing. The accuracy of measuring lung volume was also examined using hot wire spirometry in 10 of the subjects.
Results: The measurement errors between lung volume changes and chest wall volume changes were not significantly different in all positions. There was no significant difference between right and left compartmental volume changes in the supine position. However, chest wall volume changes were lower on the dependent side in the lateral position than on the non-dependent side because of the decrease in abdominal rib cage and abdomen volume changes.
Conclusion: Chest wall volume measurements during quiet breathing in the lateral position have high measuring accuracy and show laterality.

1. Introduction

Turning onto the lateral position from the supine position is known to affect respiratory mechanics, such as the ratio of ventilation to perfusion, hemodynamics, and pulmonary gas exchange (Nelson and Anderson, 1989; Schellongowski et al., 2007; Verbanck et al., 1997; Frerichs et al., 2002). Particularly in regional ventilation, it has been reported that the regional distribution of tidal volume was higher in the dependent lung than in the non-dependent lung (Frerichs et al., 2002). Therefore, the ventilation on the dependent side lung is greater than that on the other side lung in the lateral position; that is, regional ventilation shows "laterality" in that position (Riedel et al., 2005).

Optoelectronic plethysmography (OEP) has been used to measure total and compartmental chest wall volume changes during quiet breathing in several positions because it reflects lung volume changes accurately, and it helps us to understand the chest wall mechanics that consist of the two-compartment rib cage [pulmonary rib cage (RCp), abdominal rib cage (RCa)] and abdomen (AB) model (Cala et al., 1996; Kenyon et al., 1997; Aliverti et al., 1997, 2000, 2001; Wang et al., 2009; Romei et al., 2010). Aliverti et al. (2001) studied the regional chest wall volume changes in the supine and prone positions in normal subjects. They reported that most of the chest wall volume change is distributed in the abdominal compartment both in the supine and prone positions, but it did not show laterality. Romei et al. (2010) studied it in several postures from seated to supine positions, and they reported that the chest wall kinematics were affected by position, with a progressive increase of the abdominal contribution to tidal volume. However, chest wall volume changes in the lateral position have not been reported. In the lateral position, total or compartmental chest wall volume changes during tidal breathing may differ between the two sides because regional ventilation shows laterality in that position.

The purpose of this study was to develop and test the feasibility of measurements of chest wall volume variation during tidal breathing in the right and left lateral positions in healthy subjects. The aim was also to compare the laterality of chest wall volume

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Table 1
Subjects' demographics and anthropometric parameters.

	Male	Female
Age (years)	27.3 ± 4.8	24.6 ± 5.3
Weight (kg)	66.8 ± 9.4	51.8 ± 9.0**
Height (cm)	176.2 ± 7.2	159.3 ± 8.6**
BMI (kg/m^2)	21.5 ± 2.6	20.2 ± 1.5

BMI: body mass index.
All data are expressed as means ± SD.
** $p < 0.01$ vs. male.

changes in the supine and lateral positions. We hypothesized that the measuring accuracy is high not only in the supine position but also in the lateral positions, and that laterality of chest wall volume changes is seen in lateral positions but not in the supine position.

2. Methods

2.1. Subjects

Eighteen normal subjects with normal pulmonary function (nine males, 27.3 ± 4.8 years old; nine females, 24.6 ± 5.3 years old) were studied. Table 1 shows the age and anthropometric data for all subjects. All subjects gave their written, informed consent in advance. All studies were approved by the Ethics Committee of Hyogo College of Medicine.

2.2. Measuring procedure

Chest wall volume was measured by OEP methods using eight infrared cameras (Mac 3D System, Motion Analysis Corporation, San Diego, CA, USA). Passive markers made of thin reflective film on plastic spheres with diameters of 9 mm were used. The markers were fixed to the chest wall surface with each subject lying on the floor.

The position of each marker was determined as described in a previous study (Cala et al., 1996) excluding the hidden part of the chest wall: 66 markers in the supine position excluding the back, and 81 markers in both lateral positions excluding the mid-axillary line on the dependent side. In both lateral positions, each subject was asked to place his upper limb on a cushion over the greater trochanter to avoid hiding the markers on the mid-axillary line on the non-dependent side (Fig. 1).

Before starting the measurements, all subjects were placed in each position (supine position, right lateral position, left lateral position). Then, measurements were taken for 2 min of quiet breathing in each position. All subjects performed the inspiratory capacity maneuver at the start and at the end during quiet breathing to correct "drift" caused by mechanical error (Johnson et al., 1999). The measurement positions were selected randomly. The coordinate data of all reflective markers were sampled at 100 Hz using analysis software (EVaRT5.04, Motion Analysis Corporation). Chest wall volume (V_{CW}), pulmonary rib cage volume (V_{RCp}), abdominal rib cage volume (V_{RCa}), and abdomen volume (V_{AB}) were then calculated using the positions of the chest wall markers (Nozoe et al., 2011). In particular, total and compartmental chest wall volumes were obtained by summing the volumes of a set of tetrahedrons using position vectors based on body surface marker coordinates. The present method differs from other methods based on Gauss' theorem, which have been reported in several papers involving OEP (Cala et al., 1996; Kenyon et al., 1997; Aliverti et al., 1997, 2000, 2001). The method based on the Gauss' theorem calculates the volume enclosed by a surface by calculating a surface integral and converting it into a volume integral. Therefore our tetrahedrons volume might be differ slightly from the volume calculated by the Gauss' theorem.

The measurements during the last 20 s in each position were analyzed, and total and compartmental tidal volume changes (ΔV_{CW}, ΔV_{RCp}, ΔV_{RCa}, ΔV_{AB}) were calculated, as well as the volumes of the left and right sides separately.

2.3. Accuracy of volume measurements

The accuracy of the lung volume measurements was evaluated using hot wire spirometry (AE300-s, Minato Medical Science, Tokyo, Japan) synchronized with OEP in 10 of the subjects (6 males; 23.8 ± 2.6 years old). Measurements taken during the last 20 s in each position were analyzed, and tidal volume (ΔV_{SP}) was

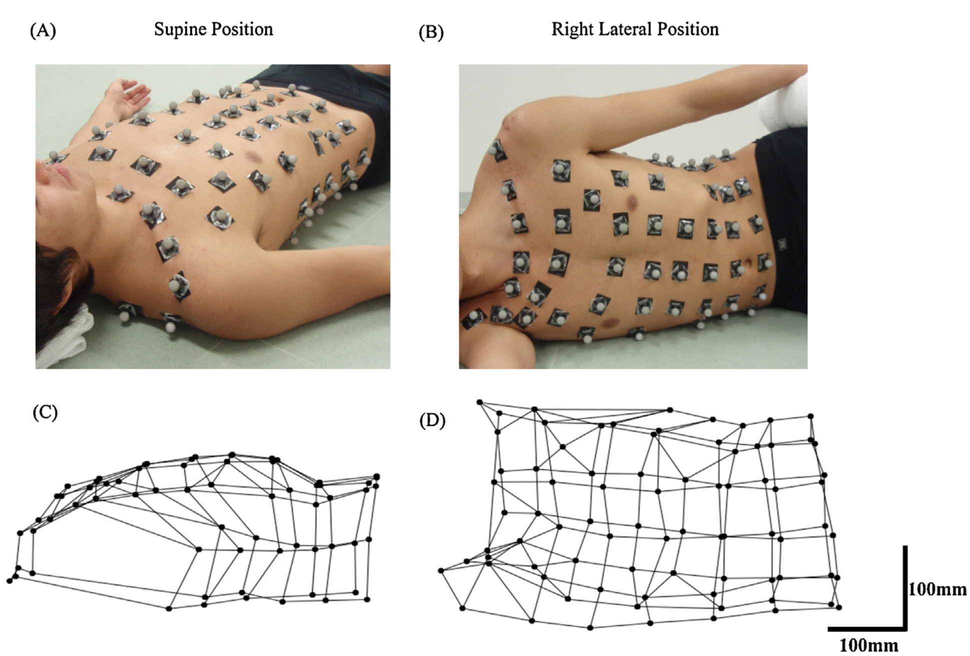

Fig. 1. Marker positioning in the supine and right lateral positions (A, B) and computed models of the chest wall (C, D).