Analysis of Diaphragmatic Motion with Prone Positioning Using Dynamic MRI

KAZUHIDE TOMITA1*), YASUTOMO SAKAI2), MASAHIKO MONMA3), HIROTAKA OHSE4), SHIGEYUKI IMURA5)

1)Graduate School of Health Sciences, Ibaraki Prefectural University of Health Science, Japan.
*Department of Physical Therapy, Gunma Paz Gakuen College: 6859-251, Nakayama, Takayama-mura, Agatsuma-gun, Gunma 377-0702, Japan.
TEL +81 279-63-3376  FAX +81 279-63-3477  E-mail: k-tomita@paz.ac.jp
2)Department of Physical Therapy, Ibaraki Prefectural University of Health Science, Japan.
3)Department of Radiological Sciences, Ibaraki Prefectural University of Health Science, Japan.
4)Department of Internal Medicine, Ibaraki Prefectural University of Health Science, Japan.
5)Professor of Graduate School of Health Sciences, Ibaraki Prefectural University of Health Sciences, Japan.

Abstract. The objective of this study was to quantitatively analyze differences in diaphragmatic motion between supine and prone positioning during resting breathing using dynamic Magnetic Resonance Imaging. Total diaphragmatic motion (TDM), defined as total excursion of the anterior (ANT), central (CNT), and posterior (PST) diaphragm, was 61 mm in the supine position and 63 mm in the prone position. No significant difference in TDM was apparent in response to change in positioning. Diaphragmatic motion was greatest in the PST > CNT > ANT with supine positioning, and PST > ANT ≈ CNT with prone positioning. In both positions, motion tended to be greatest in the posterior diaphragm. However, relative changes in CNT and PST were less with prone than with supine positioning. These findings suggest that ventilation in the posterior lung fields is decreased to a greater extent with prone than with supine positioning.

Key words: Diaphragmatic motion, Prone positioning, Dynamic MRI

INTRODUCTION

Prone positioning for set periods of time is used in clinical practice for treatment of hypoxemia in patients with severe acute respiratory distress1–4). In a recent randomized controlled trial,Gattiononi et al. reported that placement in the prone position improved oxygenation but had no significant effect on survival5). Factors involved in the mechanism of improvement of pulmonary oxygenation by prone positioning include changes in diaphragmatic motion, pulmonary capillary hydrostatic pressure7–9), and the ventilation/perfusion ratio,10 as well as the impact of positional drainage11). For one of these factors, alterations in diaphragmatic motion, studies have shown that prone positioning increases excursion of the posterior aspect of the diaphragm, thus leading to changes in the lung ventilatory distribution6). In the present study, dynamic MRI11,12) was used to quantitatively analyze changes in diaphragmatic motion during resting breathing in supine and prone positions.
MATERIALS AND METHODS

Subjects
Eleven healthy male volunteers with no history of cardiopulmonary, thoracic, or systemic musculoskeletal disease were enrolled in the study. Mean age was 23.9 ± 3.5 years, mean height was 166.9 ± 5.6 cm, mean weight was 61.2 ± 9.9 kg and mean BMI was 21.9 ± 2.9 kg/m². Mean chest expansion was 3.2 ± 1.0 cm at the axilla, 5.2 ± 2.3 cm at the xiphoid process, and 3.2 ± 2.0 cm at the 10th rib. Mean pulmonary function parameters were as follows: vital capacity (VC), 4.33 ± 0.82 L; %VC, 103.5 ± 19.1%; forced expiratory volume in one second (FEV₁₀), 3.43 ± 0.35 L; and FEV₁₀%, 88.4 ± 8.7%. This study was approved by the Ethics Committee of Ibaraki Prefectural University of Health Sciences. The purpose and methods of the study were explained to all prospective subjects and informed consent was obtained prior to their participation.

Magnetic Resonance Imaging (MRI) technique
The MRI scanner used in this study was a Gyroscan ACS-NT Power Track 3000 (Philips Medical System, Best, The Netherlands). Imaging technique included fast spin echo with T2 weighting; repetition time (TR), 480 msec; echo time (TE), 40 msec; flip angle (FA), 90°; slice thickness, 5 mm; field of view (FOV), 380 mm; matrices, 256 × 256; and number of signals averaged (NSA): 2. Sixty MR images were acquired over a 30-second period, with an image time of 480 msec per slice.

The spirometry used in this study was an AS-600 (Minato Medical Science, Osaka, Japan).

Procedure
Spirometry (Minato Medical Science), including measurement of tidal volume in the supine and prone position, was performed in all subjects prior to entering the MRI suite. The MRI was then performed with imaging of diaphragmatic motion during resting breathing for 30 seconds in both the supine and prone positions. Each subject was instructed to breathe in a normal relaxed manner during MRI imaging in both positions. Images were orientated in a midsagittal plane through the center of the right clavicle. The acquired image data was input into a personal computer and analyzed using imaging software (ScionImage; Scion Corporation, Maryland, USA).

MRI analysis and statistics
For MRI imaging, the position of the diaphragm was defined as the interface between the lung fields and abdominal organs (Fig. 1). We used the following method described by Kondo et al.13) to analyze diaphragmatic motion. A line was drawn tangential to the lung apex and perpendicular to the MRI platform. The distances from this line to the diaphragm at the anterior chest wall margin (ANT), tracheal bifurcation (CNT), and posterior chest wall margin (PST) were then measured as parameters of diaphragmatic motion. The total distance of motion (TDM) is the sum of excursion of the ANT, CNT, and PST diaphragm.

Data for each parameter of diaphragmatic motion were examined using analysis of variance and differences were considered statistically significant at p values of less than 1%.

RESULTS

MRI images (over 30 seconds) were acquired for an average of 6.1 breath cycles during supine positioning, and 5.4 breath cycles during prone
positioning. Tidal volume did not significantly differ between supine (1.14 ± 0.93 L) and prone (0.93 ± 0.30 L) positioning. Figure 3 shows parameters for MRI imaging in the mid-sagittal plane in a representative subject.

Table 1 shows changes in diaphragmatic motion in the mid-sagittal plane. Mean excursion in the craniocaudal direction for the different regions of the diaphragm was as follows: ANT, 13.8 ± 4.6 mm; CNT, 20.6 ± 7.0 mm; and PST, 26.9 ± 11.4 mm in the supine position; and ANT, 19.4 ± 8.8 mm; CNT, 19.3 ± 7.7 mm; and PST, 24.0 ± 9.1 mm in the prone position. Although the changes in diaphragmatic motion did not significantly differ, in the supine position, motion was greatest in the PST, followed by the CNT and ANT diaphragm, and in the prone position, motion was about the same in the ANT and CNT diaphragm, and slightly greater in the PST diaphragm. Thus, diaphragmatic motion tended to be greatest in the PST in both positions.

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Fig. 2. Diaphragmatic motion dimensions for magnetic resonance image analyses. The distances from thoracic apex to the diaphragm at the anterior chest wall margin (ANT), at the tracheal bifurcation level (CNT), and at the posterior chest wall margin (PST)\(^\text{[13]}\).

Fig. 3. MRI during resting breathing in a representative subject. In each panel, the right side is cephalad and the left side is caudal. In both the supine and prone position, motion of the posterior (dorsal) exceeds that of the anterior (ventral) diaphragm.
Analysis of changes in diaphragmatic motion at each site following a shift from the supine to prone position showed a slight increase for the ANT diaphragm and a slight decrease for the CNT and PST diaphragm. However, no statistically significant differences were observed for any site with respect to supine and prone positioning. TDM (i.e., the sum of diaphragmatic motion at each site) was 61.4 ± 21.6 mm in the supine position and 62.7 ± 24.3 mm in the prone position (no statistically significant difference).

**DISCUSSION**

The present study showed no significant changes in tidal volume in response to moving from the supine to prone position. In addition, MRI analysis of changes in diaphragmatic motion, based on a comparison of changes in TDM, showed no significant difference in positional changes. These findings indicate no change in total diaphragmatic motion with a shift from supine to prone positioning. Analysis of motion of the ANT, CNT, and PST diaphragm showed that diaphragmatic motion was greatest in the PST > CNT > ANT with supine positioning, and PST ≈ ANT > CNT with prone positioning. In both positions, motion tended to be greatest in the posterior diaphragm. Our findings are in agreement with results reported previously by Krayer et al.\(^6\) using a dynamic spatial reconstructor, namely, greater excursion in the posterior diaphragm. However, a comparison using a value of 1 for motion of the ANT diaphragm showed relative values of 1.5 and 1.9, respectively, for the CNT and PST diaphragm in the supine position, and 1.0 and 1.2, respectively, for the CNT and PST diaphragm in the prone position. Relative changes in CNT and PST were thus less for prone than for supine positioning. If we assume that increased ventilation occurs at sites of greater diaphragmatic motion, then ventilation in the posterior lung fields decreases more with prone versus supine positioning.

The results of the present study show that prone positioning, which is used for treatment of hypoxemia in patients with severe acute respiratory distress, decreases ventilation in the posterior lung fields. Therefore, the mechanism of improvement in oxygenation with prone positioning may involve factors other than changes in posterior diaphragmatic motion associated with the prone position. However, as the subjects in our study were healthy volunteers we would caution against direct extrapolation of these results to patients with respiratory distress. Our findings require verification in further studies in such patients.

**ACKNOWLEDGMENTS**

We would like to express our appreciation for a Sasagawa Scientific Research Grant to help conduct this study.

**REFERENCES**


| Table 1. Diaphragmatic motion in supine and prone positions |
|---------------------------------|--------|--------|--------|--------|
|                                 | ANT    | CNT    | PST    | TDM    |
| supine                         | 13.8 ± 4.6 | 20.6 ± 7.0 | 26.9 ± 11.4 | 61.4 ± 21.6 |
| prone                          | 19.4 ± 8.8 | 19.3 ± 7.7 | 24.0 ± 9.1  | 62.7 ± 24.3  |

Date are presented as mean ± SD (mm). The distances from the thoracic apex to the diaphragm at the anterior chest wall margin (ANT) tracheal bifurcation (CNT), and posterior chest wall margin (PST) were measured as parameters of diaphragmatic motion. The total distance of motion (TDM) is the sum of excursion of the ANT, CNT, and PST diaphragm.