

The Short-Term Effects of Intermittent Positive Pressure Breathing Treatments on Ventilation in Patients With Neuromuscular Disease

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BACKGROUND: The effects of intermittent positive-pressure breathing (IPPB) and abdominal belt on regional lung ventilation in neuromuscular patients are unknown. We conducted a prospective physiologic short-term study in stable neuromuscular patients to determine the effects of IPPB, with and without abdominal belt, on regional lung ventilation. **METHODS:** IPPB was performed as 30 consecutive deep breaths up to 30 cm H₂O face-mask pressure each: 10 in supine position, 10 in left-lateral position, and 10 in right-lateral position. Each patient received IPPB sessions with and without an abdominal belt, in a random order, at one-day intervals. Patients were then followed-up to 3 hours after IPPB. Lung ventilation was measured via electrical-impedance tomography (tidal volume via electrical-impedance tomography [electrical-impedance V_T], which is reported in arbitrary units) in 4 lung quadrants. Baseline V_T and exhaled V_T after each deep breath were also measured. The primary outcome was maintenance of regional ventilation after 3 hours. **RESULTS:** Global electrical-impedance V_T remained significantly higher than at baseline as long as 3 hours after the IPPB sessions. Global and regional electrical-impedance V_T at the end of the 3-hour study period was significantly higher with the abdominal belt in place. Regional ventilation did not change significantly. With IPPB in the supine position, electrical-impedance V_T was significantly greater in the anterior than the posterior lung regions ($P < .001$). With IPPB in supine position, median and interquartile range V_T values increased from 0.25 L (0.20–0.30) to the exhaled V_T of 1.50 L (1.08–1.96) ($P < .001$). There were no differences in regional ventilation. **CONCLUSIONS:** In patients with neuromuscular disease, supine IPPB treatments, with or without abdominal belt, increased ventilation to anterior lungs regions, compared to the left-lateral and right-lateral positions. Global ventilation 3 hours after IPPB treatments remained higher than at baseline and was best preserved with the use of an abdominal belt. *Key words:* intermittent positive-pressure breathing; hyperinsufflations; neuromuscular dystrophy; regional lung ventilation; electrical-impedance tomography. [Respir Care 2010;55(7):866–872. © 2010 Daedalus Enterprises]

Introduction

Intermittent positive-pressure breathing (IPPB) is commonly used in patients with neuromuscular disease be-

cause the resulting deep breaths prevent and treat atelectasis, prevent thoracic deformities,¹ help remove respiratory secretions, and assist coughing.^{2,3} However, few data support the benefit of IPPB, and at least one study found no benefit.⁴ In schoolchildren with various neuromuscular dis-

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eases, IPPB was associated with an increase in forced inspiratory vital capacity,⁵ and IPPB with an abdominal belt has been advocated to oppose the thoracoabdominal asynchrony commonly observed in spontaneously breathing neuromuscular patients.⁶ Yet the extent to which IPPB, with or without an abdominal belt, may change the distribution of regional ventilation has not been investigated. It is important to know how the ventilation distributes throughout the lungs to assess IPPB's risk of inducing regional hyperinflation, which can harm the lungs. In acute lung injury it is well established that recruiting the atelectatic lung areas must be done without hyperinflating normal lung areas.⁷ The current methods to investigate regional lung ventilation are computed tomography (CT), nuclear medicine techniques, and electrical-impedance tomography. CT and nuclear medicine techniques are expensive and require radiation exposure or radiotracer injection. By contrast, electrical-impedance tomography is noninvasive and free of toxic exposure. Moreover, measurement of regional lung ventilation with electrical-impedance tomography has been validated against CT,⁷ single-photon-emission CT,⁸ and positron-emission tomography.⁹ Therefore, we undertook the present study of patients with various neuromuscular diseases, with the following aims: (1) to determine the regional ventilation in the lung after IPPB treatment and how this is affected by patient position during the treatment (supine, left-lateral, right-lateral) and by use of an abdominal belt, and (2) to determine changes in both global and regional ventilation during the 3 hours following IPPB treatments, both with and without an abdominal belt.

Methods

This study was performed at the Service de Réanimation Médicale et Assistance Respiratoire, Hôpital de la Croix-Rousse, Lyon, France.

Patients

Out-patients regularly followed by 2 investigators (TP, PL) were screened for eligibility. The inclusion criteria were: (1) congenital neuromuscular disease, (2) age 10–55 years, (3) stable respiratory condition in the last 3 months, (4) vital capacity < 60% of predicted, and (5) informed consent obtained from the next of kin or from the patient him/herself. The exclusion criteria were: (1) Steinert's dystrophy, (2) amyotrophic lateral sclerosis, (3) refusal to participate, (4) tracheotomy and mechanical ventilation, and (5) daytime noninvasive mechanical ventilation. The protocol was approved by our institutional review board, and the procedures used conformed to the recommendations in the Helsinki Declaration of 1975.¹⁰ Patients signed written informed consent.

Study Protocol

This is a prospective study that involved out-patients who could communicate normally and drive an electric wheelchair. Once the study aim and design were explained to the patient and his/her relatives, the electrical-impedance tomography electrodes were positioned while the patient was in the wheelchair. The electrodes were positioned 4–5 cm above the xyphoid process because this level has been shown to result in reasonable reproducibility between patients.¹¹ To further improve reproducibility for a given patient, the upper and lower edges of the electrodes were marked with ink on the patient's skin. Then the patient was transferred from the wheelchair to the bed, using an electrical device (Molift Partner, Independent for Life, Peru, Illinois). The IPPB session consisted of 30 consecutive deep breaths at 30 cm H₂O mask pressure of room air: 10 in the supine, 10 in the right-lateral position, and 10 in the left-lateral position, in that order. The IPPB was always performed by the same investigator (BV). At the end of the IPPB session the patient was transferred back to the wheelchair for the next 3 hours.

Equipment

The protocol was performed in our respiratory rehabilitation unit. The electrical-impedance tomography device used was the Goettingen Goe-MF II System (Viasys Healthcare, Höchberg, Germany). A single array of 16 electrodes (AMBU, Blue Sensor BR-80-K, Ballerup, Denmark) was placed on the patient's mid-chest circumference. Electrical currents (50 kHz, 5 mA) were injected through adjacent pairs of electrodes in a rotating mode. After each electrical current injection, the resulting potential differences, and, hence, the resulting impedance (Z) were calculated with the adjacent electrode pairs. Electrical-impedance tomography recordings were sampled at a rate of 13 Hz. Transcutaneous oxygen saturation (S_{pO₂}) was measured with a pulse oximeter (Rad-9, Masimo, Irvine, California). IPPB sessions were performed with an Alpha 200c device (Taema, Anthony, France) and a face mask (Rüsh, Buttigliera Alta, Italy). Exhaled volume after each hyperinsufflation was measured with a portable spirometer (FC 10, L'Air Liquide, Plessis Robinson, France). The pneumatic belt (France Partenaires Medical, St Laurent de Chamoussy, France) was buckled around the mid-abdomen as tightly as the patient could tolerate.

Procedures

The baseline electrical-impedance tomography signal and S_{pO₂} were measured in the wheelchair before performing IPPB, and 15, 60, 120, and 180 min after the end of each IPPB treatment. During the IPPB sessions the elec-

Table 1. Patient Entry Data

Patient	Age (y)	Sex	Diagnosis	Height (cm)	Weight (kg)	NIV	Nasal CPAP	Cardiac Involvement	Spine Surgery
1	15	M	Duchenne dystrophy	154	37	No	No	No	Yes
2	22	M	Duchenne dystrophy	170	51	Yes	No	No	No
3	21	M	Duchenne dystrophy	144	31	Yes	No	No	No
4	43	F	Fascio-scapulo-humeral dystrophy	162	60	No	No	No	No
5	15	M	Spinal muscular atrophy	140	33	No	Yes	No	No
6	25	M	Duchenne dystrophy	160	52	Yes	No	Yes	Yes
7	27	M	Duchenne dystrophy	171	46	Yes	No	No	No
8	19	M	Duchenne dystrophy						
9	17	M	Duchenne dystrophy	167	64	No	No	No	Yes
10	14	M	Duchenne dystrophy	160	60	No	No	Yes	No
11	25	M	Duchenne dystrophy	158	65	No	No	Yes	No
12	34	M	Spinal muscular atrophy	160	60	No	No	No	Yes
13	26	M	Duchenne dystrophy	159	38	Yes	No	Yes	Yes
14	24	M	Duchenne dystrophy	167	70	No	Yes	No	No
15	19	M	Spinal muscular atrophy	149	57	No	Yes	No	Yes

NIV = noninvasive ventilation
 CPAP = continuous positive airway pressure

trical-impedance tomography signal was continuously recorded and the maximum S_{pO_2} value was noted. Exhaled tidal volume (V_T) was measured before each IPPB session with the patient supine. During each IPPB session the exhaled V_T after each hyperinsufflation was recorded from the spirometer. Each patient had one IPPB session with or without the abdominal belt buckled-up, and then the day after had another IPPB session. Each IPPB session was separated by one night spent in the respiratory rehabilitation unit, during which the patient received non-invasive mechanical ventilation or nasal continuous positive airway pressure, as usual (Table 1).

Electrical-impedance tomography scans were generated using the weighted back-projection reconstruction procedure along equipotential lines.¹² The region of interest's contour was defined as 20% of the maximum standard deviation or regression coefficient.¹³ The image resolution was a matrix of 32×32 pixels. The output signals of the image reconstruction were 912-pixel values of impedance changes relative to the reference impedance for the whole measurement period. The electrical-impedance tomography data were evaluated off-line in terms of electrical-impedance V_T in 4 quadrants (anterior, posterior, right, and left lung regions), with Auspex software (version 1.5, Vrije University Medical Center, Amsterdam, The Netherlands). The anterior quadrants, on one hand, and the posterior quadrants, on the other hand, of the right and left lungs were averaged to define the anterior and posterior lung regions, respectively.

Regional electrical-impedance V_T was calculated as the sum of tidal (inspiratory-to-expiratory) differences in relative impedance change in all pixels of each quadrant:

$$\Delta Z = (Z_{\text{instantaneous}} - Z_{\text{reference}}) / Z_{\text{reference}}$$

where $Z_{\text{reference}}$ is the average value of the instantaneous Z of the whole corresponding file.

Statistical Analysis

The study was powered as follows. According to McCool et al,¹⁴ the mean respiratory-system compliance of 7 spontaneously breathing patients with various neuromuscular diseases was 75 mL/cm H₂O. Pressurizing the airway opening at 30 cm H₂O, the level selected for our study, would result in a mean \pm SD lung volume of $2,254 \pm 1,069$ mL, which is $1,810 \pm 978$ mL above the baseline V_T of 444 ± 119 mL in the patients of McCool et al.¹⁴ Our target was to detect a 1,000 mL increase of lung volume with IPPB, which, with first-order and second-order risks of 5% and 10%, respectively, would require 12 patients.

Data are presented as median and interquartile range (25th–75th percentiles) unless otherwise stated. The electrical-impedance tomography values are expressed in arbitrary units. The 10 values of exhaled V_T and electrical-impedance V_T during IPPB were averaged in each patient for each of the 3 positions. The baseline V_T and electrical-impedance V_T values were compared to those of exhaled V_T and electrical-impedance V_T , respectively, during IPPB with Wilcoxon signed-rank test. These baseline values were also compared according to the presence or absence of the abdominal belt.

To quantify the effect of the abdominal belt and the supine, right-lateral, and left-lateral positions on regional

electrical-impedance V_T during IPPB, we used a linear random-intercept model to take into account the correlation of the measurements from a given patient. If the abdominal belt or the position was significant, we introduced an interaction with the lung side (right vs left) and with the lung part (posterior vs anterior) into the model.

To test the effect of time on electrical-impedance V_T , the changes in global and regional electrical-impedance V_T at 15, 60, 120, and 180 min after IPPB relative to the baseline condition before IPPB were taken as the dependent variables. A first model was built to quantify the evolution of the regional electrical-impedance V_T over time and the quadrant effect on the level of electrical-impedance V_T after IPPB, according to presence or absence of the abdominal belt. A second linear random intercept model was built to quantify the evolution of the global electrical-impedance V_T over time and the effect of the abdominal belt on the level of electrical-impedance V_T after IPPB.

The statistical significance threshold was set at $P < .05$. The statistical analysis was performed with statistics software (R version 2.6.2, R Foundation for Statistical Computing). Graphics were launched with other statistics software (SPSS version 15.0, SPSS, Chicago, Illinois).

Results

Patients

Of the 15 patients enrolled, patient 8 did not complete the first IPPB session for reasons of psychological intolerance, and was excluded from the study (see Table 1). All patients were familiar with IPPB, which they had been receiving for months or years and were not using supplemental oxygen at home.

Baseline Ventilation

Spirometry was not done in patient 1 or 2. In the 12 remaining patients the baseline supine V_T of 0.25 (0.20–0.30) L without the abdominal belt was not significantly different to that with the belt. The supine exhaled V_T was 1.50 (1.08–1.96) L, a value significantly higher than that in the right-lateral position (1.49 [1.25–1.96]) ($P = .048$), but not different from that in the left-lateral position. In the supine position exhaled V_T was significantly greater than V_T ($P < .001$), with no difference between the abdominal belt conditions. Baseline S_{pO_2} was 98% (97–99%) and was not significantly altered by the IPPB sessions (data not shown).

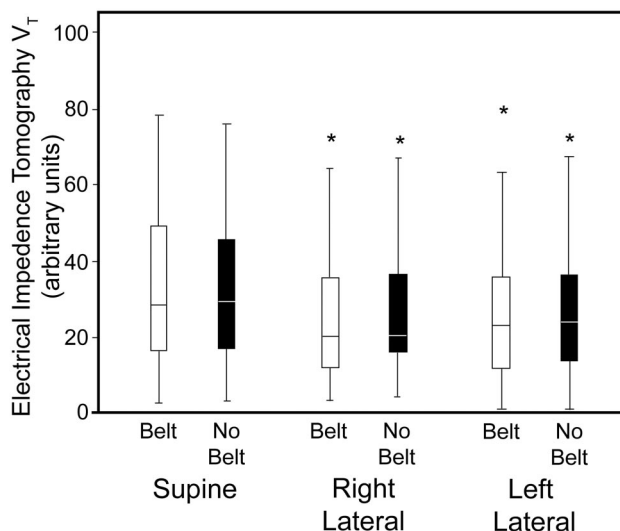


Fig. 1. Box-plots of regional ventilation (tidal volume [V_T] measured via electrical-impedance tomography) during intermittent positive-pressure breathing (IPPB) sessions in the supine, right-lateral, and left-lateral positions, with and without abdominal belt. * $P < .001$ versus supine position.

Effects of Position and Belt on Electrical-Impedance V_T During IPPB

The estimate of mean regional electrical-impedance V_T in the supine position without the abdominal belt was 31.7 (95% CI 24.6–38.7). It was significantly lower in right-lateral position (-4.3 , 95% CI -7.1 to -1.4 , $P = .003$) and in left-lateral position (-4.6 , 95% CI -7.4 to -1.7 , $P = .002$). The regional electrical-impedance V_T was non-significantly lower with abdominal belt (-1.6 , 95% CI -3.9 to 0.5 , $P = .14$) (Fig. 1).

Effects of Lung Side and Part on Electrical-Impedance V_T During IPPB and Interaction With Position

The effect of position on regional ventilation was not significantly modified according to the side (interaction between position and side was not statistically significant, $P = .34$) (Fig. 2). Whatever the position, regional ventilation did not differ significantly according to the lung side ($P = .72$). In the ventral part of the lung, electrical-impedance V_T was 38.4 (95% CI 31.0–45.7) without belt in the supine position. It was significantly lower in the posterior part (-13.9 , 95% CI -18.3 to -9.55 , $P < .001$). In the posterior part of the lung there was no difference in electrical-impedance V_T according to the position. Electrical-impedance V_T was 24.4 (95% CI 17.8 to 31.1) in the supine position, 23.4 (95% CI 16.7–30.0) in the right-lateral position, and 24.7 (95% CI 18.1–31.4) in the left-lateral position. In the anterior part of the lung,

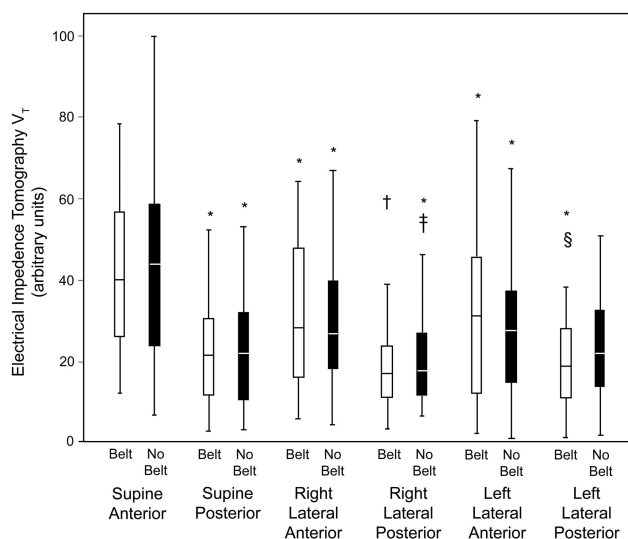


Fig. 2. Box-plots of regional ventilation (tidal volume [V_T] measured via electrical-impedance tomography) during intermittent positive-pressure breathing (IPPB) sessions in the supine, right-lateral, and left-lateral positions, with and without abdominal belt in the anterior and posterior parts of the lungs. * $P < .001$ and † $P < .05$ versus supine-position anterior lung. ‡ $P < .001$ versus right-lateral position anterior lung, § $P < .05$ versus left-lateral position anterior lung.

electrical-impedance V_T differed significantly according to position; it was significantly lower in the right-lateral position than in the supine position, by -8.1 (95% CI -12.9 to -3.4 , $P < .001$), and in the left-lateral position versus the supine position, by -9.8 (95% CI -14.4 to -5.2 , $P < .001$).

Time Course of Electrical-Impedance V_T After IPPB Session

The relative gain in regional electrical-impedance V_T did not change significantly over time (-0.05% for each additional minute, 95% CI -0.16 to 0.07% , $P = .41$) (Fig. 3). The relative gain change over time was not modified by the presence of the belt (interaction between time and belt was not statistically significant, $P = .13$). Without the belt, immediately after the end of the IPPB session the relative gain in regional electrical-impedance V_T was estimated at 29.6% (95% CI -2 to 61%), and was not significantly greater than zero ($P = .07$). This relative gain was significantly higher with the belt (51% , 95% CI 24.0 – 78.7% , $P < .001$). Without the belt, the relative gain of regional electrical-impedance V_T was higher on the left side of the lung than on the right side (20.0% , 95% CI 3.3 – 36.7% , $P = .02$) and in the anterior part than in the posterior part (15.6% , 95% CI -0.95 to 32.2% , $P = .06$). With abdominal belt there was no significant difference according to the lung side or the lung part.

The relative gain in global electrical-impedance V_T did not change significantly (0.02% for one more minute, 95% CI -0.1 to 0.15% , $P = .73$) (Fig. 4). The relative gain change was not modified by the presence of the belt (interaction between time and belt was not statistically significant, $P = .35$). Without the belt, immediately after the end of the IPPB session the relative gain in global electrical-impedance V_T was 26.6% (95% CI -12.4 to 65.6%) and was not significantly different from zero ($P = .18$). With abdominal belt it was 66% (95% CI 21 – 111%), which was significantly greater than without belt ($P = .008$).

Discussion

In this study the regional lung ventilation was assessed using electrical-impedance tomography during and for the 3 hours after the IPPB sessions. During IPPB we found that (1) the regional ventilation was greater in the supine position than in the 2 other positions, specifically in the anterior parts of the lungs, and (2) the abdominal belt did not influence the regional ventilation. After the IPPB sessions the regional ventilation was significantly greater than its baseline value before IPPB and sustained that level for the 3 hours of the follow-up.

Ventilation increased in the anterior parts of the lung when IPPB was performed in the supine position, and this more so than in the posterior parts of lungs. The same findings were obtained for the lateral positions. This response was close to normal subjects receiving positive-pressure ventilation. Hence, the difference in rib-cage configuration, and presumably in chest-wall and abdominal compliance, between patients and normal subjects, as well as between patients in the present study, did not blind the effects of increasing airway pressure on regional ventilation. Greater airway pressure would probably amplify the magnitude of the increase in ventilation to the most anterior parts of the lungs and, hence, may induce hyperinflation in them. IPPB in the right-lateral and left-lateral positions showed a trend toward a more homogeneous distribution of regional ventilation across the lungs. Therefore, our protocol of using several positions during IPPB reduces the risk of hyperinflation in the anterior parts of the lungs.

The fact that the abdominal belt did not significantly change the distribution of regional ventilation during IPPB is rather surprising. This means that increasing the airway pressure increased the lung volume irrespective of the reduction of abdominal-wall compliance. The fact that the abdominal belt was not tightened according to objective criteria did not play any role, as its effect was systematic across the patients.

The increase in regional ventilation 3 hours after IPPB treatments remained significantly greater than baseline when the abdominal belt was used, but not without it. This

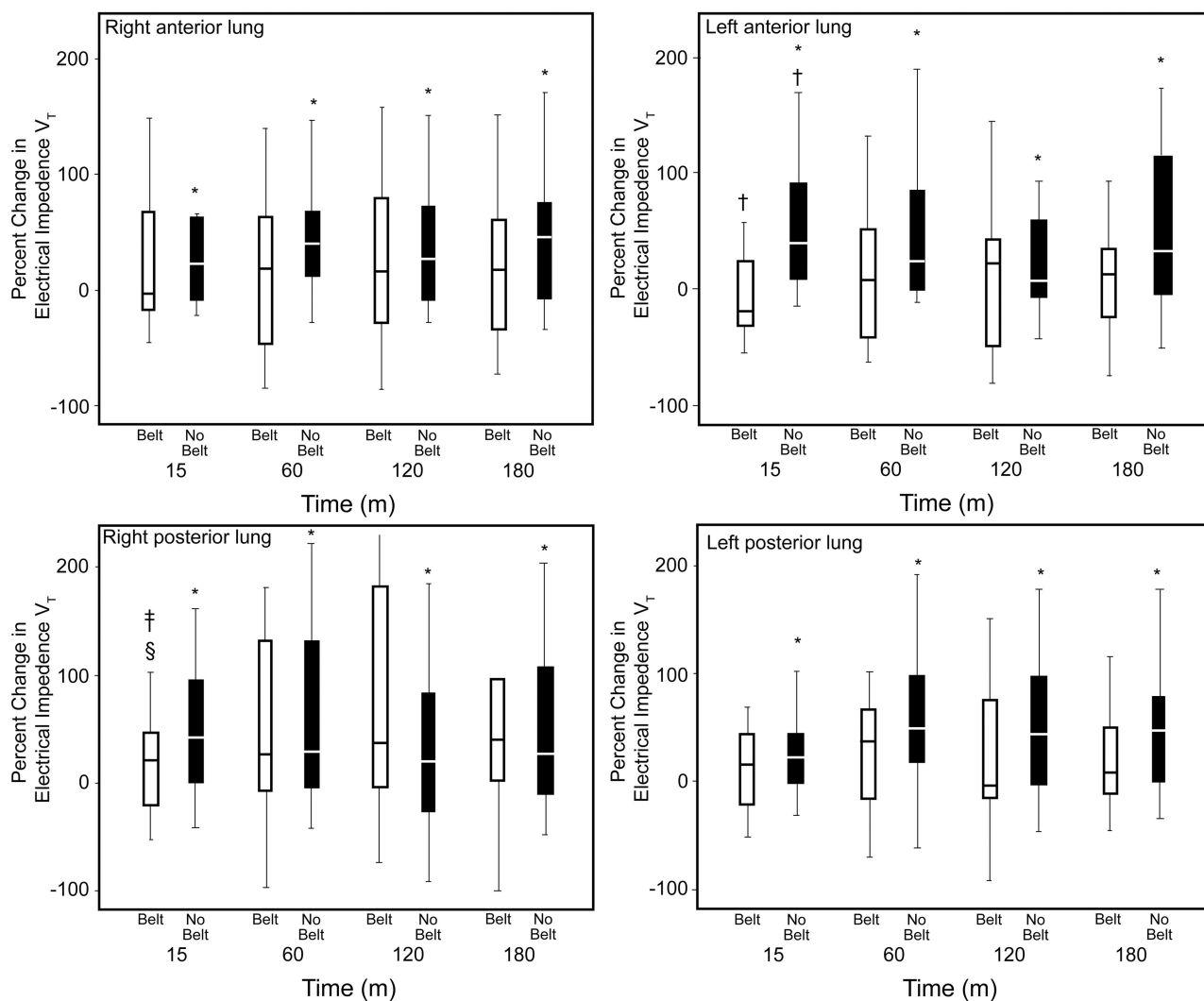


Fig. 3. Percent change in regional ventilation (tidal volume [V_T] measured via electrical-impedance tomography), relative to baseline, over time in 14 patients in whom hyperinsufflations were performed with or without an abdominal belt. * $P < .01$ versus without abdominal belt within the given quadrant. † $P < .05$ versus right anterior without abdominal belt. ‡ $P < .05$ versus left anterior with the abdominal belt. § $P < .05$ versus left anterior without abdominal belt.

apparent discrepancy with the per-IPPB analysis regarding the effect of the abdominal belt can be explained by the fact that the criterion used was not the same for the 2 parts of the analysis: in the per-IPPB we measured the absolute value of electrical-impedance V_T , whereas in the time-course part the change in electrical-impedance V_T relative to baseline was measured. It shows that the abdominal belt should be used during the IPPB to maintain the resulting increase of lung ventilation over time. The interesting finding that increase of ventilation due to IPPB is maintained over time provides a physiological context for the reported clinical benefits of IPPB. The regional ventilation did not significantly change over time. Some statistical differences were noted between some quadrants at some times, but these results are not clinically relevant. The abdominal belt resulted in significantly better ventilation in all quadrants,

which was sustained over time. This suggests that the regional ventilation was kept homogeneously increased due to the abdominal belt and different postures over time. This is important because it suggests that all lung regions may be challenged by hyperinflation over time. Finally, there were no adverse events.

To the best of our knowledge, our study is the first to use electrical-impedance tomography to evaluate regional ventilation during IPPB in patients with neuromuscular disease. Our study has, however, some limitations. The patients were monitored for only 3 hours, so the optimal rate of IPPB sessions cannot be determined based on the present results. We used electrical-impedance tomography to measure regional ventilation in this study. Electrical-impedance tomography measures regional lung-volume change more accurately than does electron-beam CT in

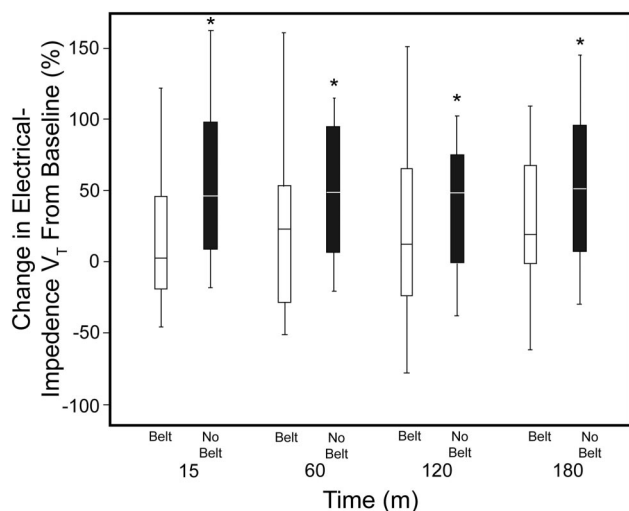


Fig. 4. Change in global ventilation (tidal volume [V_T] measured via electrical-impedance tomography), relative to baseline, over time in 14 patients in whom hyperinsufflations were performed with and without abdominal belt. * $P < .001$ versus no abdominal belt.

mechanically ventilated pigs.¹⁵ Riedel et al obtained reproducible and reliable regional ventilation data with electrical-impedance tomography in healthy subjects receiving positive-pressure breathing assistance in supine and prone position.¹⁶ In mechanically ventilated pigs we recently found that the slope of the relationship of electrical-impedance V_T to the lung ventilation measured with position emission tomography was 1 and 0.81 for the global and regional ventilation, respectively. Therefore, the lung ventilation can be measured accurately by using electrical-impedance tomography.

Conclusions

In patients with neuromuscular disease, IPPB in the supine position increased ventilation to the anterior parts of the lung. The abdominal belt during IPPB maintained the ventilation higher than baseline for 3 hours.

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