Noninvasive motion ventilation (NIMV): a novel approach to ventilatory support

JOSE A. ADAMS, MARTIN J. MANGINO, JORGE BASSUK, D. MICHAEL INMAN, AND MARVIN A. SACKNER.

Noninvasive motion ventilation (NIMV): a novel approach to ventilatory support. J Appl Physiol 89: 2438–2446, 2000.—A motion platform was developed that oscillates an animal in a foot-to-head direction (z-plane). The platform varies the frequency and intensity of acceleration, imparting periodic sinusoidal inertial forces (pGz) to the body. The aim of the study was to characterize ventilation produced by the noninvasive motion ventilator (NIMV) in animals with healthy and diseased lungs. Incremental increases in pGz (acceleration) with the frequency held constant (f = 4 Hz) produced almost linear increases in minute ventilation (V̇E). Frequencies of 2–4 Hz produced the greatest V̇E and tidal volume (VT) for any given acceleration between ±0.2 and ±0.8 G. Increasing the force due to acceleration produced proportional increases in both transpulmonary and transdiaphragmatic pressures. Increasing transpulmonary pressure by increasing pGz produced linear increases in V̇E, similar to spontaneous breathing. NIMV reversed deliberately induced hypventilation and normalized the changes in arterial blood gases induced by meconium aspiration. In conclusion, a novel motion platform is described that imparts periodic sinusoidal inertial forces (due to acceleration) on the body in the spinal axis or z-plane (pGz) and creates noninvasive motion ventilation (NIMV). The purpose of this investigation was to determine whether NIMV, which does not depend on positive pressure inflation of the lung, could effectively ventilate anesthetized and paralyzed animals with normal and diseased lungs, thereby potentially mitigating lung injury sometimes associated with conventional positive pressure mechanical ventilation.

METHODS

Platform design. The motion platform was constructed around a linear displacement direct current motor (model 400, 12 volt; APS Dynamics, Carlsbad, CA). The motor is powered by a dual-mode power amplifier (model 144, APS Dynamics) connected to a sine-wave controller (model 140-072; NIMS, Miami Beach, FL). The controller allows for control of the frequency of the table oscillation, the amplitude of the voltage reaching the motor and subsequent acceleration of the stroke, and the duty cycle of the motor. The motor is secured in the bottom and center of a frame constructed from treated pine lumber. The table platform is directly driven by the underlying motor and articulates across the frame on stainless steel tracks and nylon wheels. The unit has a maximum weight capacity of ∼30 kg.

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Animal preparation. These studies were approved by the Institutional Animal Care and Use Committee and comply with the Animal Welfare Act. Juvenile piglets weighing between 3 and 12 kg were used for these studies. The animals were anesthetized with intramuscular ketamine (10 mg/kg) followed by intravenous pentobarbital sodium (20 mg/kg) titrated until a surgical plane of anesthesia was obtained. Paralysis was induced with pancuronium bromide at 0.1 mg/kg and supplemented throughout the experiment along with sedation as necessary. A tracheostomy was performed, and a 3.5-mm (ID) endotracheal tube was inserted. The proximal end of the endotracheal tube was allowed for measurements of airway flow and pressure by interposing a pneumotachograph (Fleisch model 5751) and pressure transducer (Validyne, model MP45, full scale range $\pm 50$ cmH$_2$O), respectively. The airway pressure transducers were oriented so that the diaphragm of the transducer was $90^\circ$ relative to the $z$-axis. The pneumotachograph was calibrated by moving known volumes of air through the unit by use of a 60-ml syringe. The femoral artery was cannulated for the measurements of arterial blood pressure using pressure transducers (Transpac, Abbott Critical Care Systems, North Chicago, IL) and for arterial blood sampling. All fluid-filled transducers were stabilized at the level of the heart and away from the motion platform. Fluid and drugs were administered via a cannula inserted into the femoral vein, and the animals were maintained at $38^\circ$C with a thermostatically controlled warming pad. The animals were placed on the motion platform in the supine posture, with the front and hind legs tied securely to the table so that they were closely coupled to the platform. The tracheostomy tube was connected to a conventional pressure-limited ventilator (Bear Cub BP-200, Inter Med) at frequency 14–20 breaths/min, peak inspiratory pressure 18–24 cmH$_2$O, and positive end-expiratory pressure (PEEP) 5 cmH$_2$O. Initial settings on the mechanical ventilator were adjusted to achieve arterial partial pressure of CO$_2$ (PaCO$_2$) at $\sim 38$ Torr. To minimize any effect from hypoxia, all animals were placed on 100% oxygen during the entire protocol. Arterial blood gases were measured every 30 min or as needed during the experiment. An accelerometer (NIMS, model 140-060) was placed on the snout of the pig to determine the G forces applied to the $z$-plane (spinal axis) of the animal during NIMV. Another accelerometer oriented to the $z$-plane was placed on the platform. The values of acceleration on the snout of the animal and the table were identical during NIMV. An electrocardiogram was continuously monitored in a standard three-wire lead configuration. The analog signals from the transducers, accelerometer, and electrocardiogram were continuously recorded on a data-acquisition processor (Respirtrace PT, NIMS). During the experiment and for playback afterward, the data were viewed on a personal computer using RespiEvents software (NIMS).

Effects of motion platform frequencies and accelerations on ventilation, gas exchange, and blood pressure. The first series of experiments were designed to determine the effects of various platform frequencies and accelerations. To maintain continued oxygenation and prevent alveolar collapse during NIMV, a bias flow of 100% oxygen with continuous positive airway pressure (CPAP) of 5 cmH$_2$O was applied. A diagram of the airway connections in this preparation is shown in Fig. 1. The effects of various platform frequencies on airway flow, blood gases, and blood pressure were determined while acceleration was held constant. Increased frequency slightly decreased acceleration, although the voltage applied to the motor remained constant. Next, the effects of various platform accelerations on ventilation, blood gases, and blood pressure were determined. These relationships were analyzed to determine optimal frequency and acceleration for ventilation of paralyzed, anesthetized animals.

Ventilatory efficiency of NIMV in normal lungs. The settings of NIMV obtained above were then used to test its effects on gas exchange and blood pressure in animals with normal lungs over a 2-h period. Eight juvenile piglets were anesthetized as previously described. The ventilator settings were placed on 100% oxygen during the entire protocol. Arterial blood gases were measured every 30 min or as needed during the experiment. An accelerometer (NIMS, model 140-060) was placed on the snout of the pig to determine the G forces applied to the $z$-plane (spinal axis) of the animal during NIMV. Another accelerometer oriented to the $z$-plane was placed on the platform. The values of acceleration on the snout of the animal and the table were identical during NIMV. An electrocardiogram was continuously monitored in a standard three-wire lead configuration. The analog signals from the transducers, accelerometer, and electrocardiogram were continuously recorded on a data-acquisition processor (Respirtrace PT, NIMS). During the experiment and for playback afterward, the data were viewed on a personal computer using RespiEvents software (NIMS).

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were intentionally adjusted to induce hypoventilation characterized by elevated \( P_{\text{aCO}_2} \), and reduced pH, as well as increased heart rate and systemic central blood pressure. After hypoventilation on conventional mechanical ventilation (CMV) and PEEP of 5 cmH\(_2\)O, the animals were switched to NIMV at a frequency of 4.0 Hz and an amplitude of pGz, at about ±0.6 g, with CPAP of 5 cmH\(_2\)O. The animals remained at these settings for 120 min, with arterial blood sampling every 30 min, while physiological variables were recorded continuously.

**Ventilatory efficiency of NIMV in diseased lungs.** Eight piglets were placed on CMV with PEEP of 5 cmH\(_2\)O and the ventilator adjusted to obtain normal blood gases (\( P_{\text{aCO}_2} = 38 \) Torr). After recording with CMV and PEEP for 30 min, 25% human meconium solution (6 ml/kg) was instilled into the endotracheal tube at the carinal level. The animals were maintained on the same CMV and PEEP settings for 30 min, after which respiratory and cardiovascular variables were again collected. This period defined the aspiration phase of the experiment. The animals were then placed on NIMV with settings identical to those used for the previous animals without aspiration, i.e., frequency = 4.0 Hz, ±0.6 g, and CPAP of 5 cmH\(_2\)O. The motion platform was continuously actuated for 120 min, and arterial blood samples and physiological variables were measured every 30 min.

**Effects of NIMV on transpulmonary and transdiaphragmatic pressures.** Four pigs were instrumented to obtain pleural and abdominal pressures during NIMV. In two of the animals, uncalibrated respiratory inductive plethysmography was utilized to measure phase angles between rib cage and abdominal movements (2). Phase angles were determined from Lissajous plots of the abdomen vs. rib cage compartments (with the abdomen leading). Pigs were anesthetized as previously described but without paralysis, and a balloon catheter was placed into the esophagus with its tip at the midthorax to estimate intrapleural pressures. Placement of the catheter was verified by the occlusion technique (4). The endotracheal tube was occluded during spontaneous ventilation, and changes in both esophageal and airway pressures were observed. Proper placement of the esophageal catheter was signified at the level at which the esophageal pressure swings during inspiratory efforts equaled airway pressure swings. Subsequently, a balloon cannula was passed into the stomach until the pressure during spontaneous inspiration became positive. Intragastric pressure measured at this level was assumed to equal intra-abdominal pressure. Both cannulas were sutured in place and secured. The difference between esophageal and gastric pressures represented transdiaphragmatic pressure (Pdi). Abdominal and pleural pressures were then measured during spontaneous breathing, CMV and PEEP of 5 cmH\(_2\)O, and NIMV. The motion platform settings were varied from frequencies of 1–8 Hz, and the amplitude settings were adjusted to produce forces of about ±0.05–0.8 g. Figure 2 shows a representative sample of data from an experiment in which all of these variables were recorded. At the end of the experiments, the animals are killed with pentobarbital sodium (120 mg/kg iv).

**Data analysis.** Data were analyzed for frequency distribution and were found to have followed a Gaussian distribution. The data were then analyzed by ANOVA with Bonferroni’s post test for repeated measures. Data comparisons between animals were performed by using the unpaired t-test. Frequency, amplitude, and pressure response curves were subjected to nonlinear regression analysis. Differences in sample means were considered statistically significant if \( P < 0.05 \).

**RESULTS**

**Thoracoabdominal motion during NIMV.** The ventilatory cycle during NIMV caused paradoxical motion of the rib cage and abdomen at all cycling frequencies (see Fig. 3), whereas, in spontaneous breathing, these compartments moved in phase. The phase angles between rib cage and abdomen were <10° during spontaneous breathing at 12–18 breaths/min. The phase angles measured during NIMV with the abdomen leading ranged from 164 to 176° at 4 Hz at all levels of pGz. Phase angles approached 90° as cycling frequencies rose to 6 Hz. The studies were done in paralyzed animals, but even in anesthetized, nonparalyzed animals, there was paradoxical motion between the rib cage and abdomen. NIMV produced an inspiratory, inward displacement of rib cage volume along with outward displacement of abdominal volume and vice versa during expiration.

**Minute and tidal ventilation responses.** The relationships of both motion platform acceleration (G\(_z\)) and frequency of movement on minute ventilation (V\(_t\)) were determined. The effect of the motion platform G\(_z\) on V\(_t\) when the frequency of oscillation was held constant is shown in Fig. 4A. As the force due to periodic acceleration was increased, V\(_t\) increased linearly until a plateau was reached. This plateau occurred at a force and acceleration dependent on animal size and lung volume. Increasing acceleration further did not increase V\(_t\). The maximum acceleration observed in these studies to achieve maximum V\(_t\) and, therefore, maximum V\(_t\) with constant frequencies was about ±1.0 G\(_z\). Conversely, when the acceleration of the motion platform was held constant, increased frequency of the platform oscillation reduced V\(_t\) (Fig. 4B). The relationship shown in Fig. 4B did not strictly apply to constant acceleration but rather to accelerations that were held as constant as possible during altered frequency. This is because frequency inversely altered the length of the stroke displacement with the motion platform employed in this study and, in turn, slightly decreased the maximum attainable acceleration for any constant mass. At extremely high frequencies, i.e., above 12 Hz, V\(_t\) was dramatically reduced and approached zero. Families of these types of curves shown in Fig. 4 can be generated for any given value of either frequency or amplitude of acceleration when one is held constant and the other varies, although only one constant value is shown for each. Manipulating both frequency and force amplitude produced an overall algebraic effect on V\(_t\) (Fig. 3); this was typically done when the platform was used to achieve adequate ventilation. The effects of pGz on V\(_t\), shown in Fig. 5, were similar to the observed effects of pGz on V\(_t\). Specifically, increased pGz produced linearly increased V\(_t\) but was modified by platform frequencies. Figure 5 shows that, for any given pGz, the V\(_t\) decreased as the frequency of oscillation increased.

**Transpulmonary and transdiaphragmatic responses to NIMV.** The effects of periodic acceleration on transpulmonary pressure (Ptp) and Pdi during NIMV...
revealed direct relationships between acceleration from the motion platform and both Ptp (Fig. 6A) and Pdi (Fig. 6B). Accelerations between ±0.1 and ±0.6 Gz proportionally increased pressures across both the diaphragm and the lungs. In all experiments, NIMV produced negative esophageal pressure, with no significant change in mean airway pressure during inspiration, similar to spontaneously breathing animals. The

Fig. 2. Data sample from a representative experiment where pleural and gastric pressures were measured and plotted against time. Pres, pressure.

Fig. 3. Effects of a pGz cycle during NIMV on changes in the abdomen (Ab) and rib cage (Rc) compartments. The paradoxical movements of the 2 compartments are depicted during inspiration and expiration.
increases in Ptp also produced proportional increases in VT during both spontaneous breathing and NIMV (Fig. 7). However, ventilation with NIMV was less efficient than spontaneous breathing. Although the slope of the VT-Ptp relationship was the same, the paradoxical movement lowered the intercept.

Gas exchange in normal lungs during NIMV. The effect of NIMV on gas exchange in animals with normal lungs is shown in Table 1. The animals were deliberately hypoventilated on CMV to observe the responses to subsequent NIMV. The motion platform was set to the optimized values determined in the previous experiments (f = 4.0 and ±0.6 pGz). NIMV rapidly reversed the hypercapnia produced by hypoventilation and corrected the acidosis. These responses occurred within 5 min, and arterial blood gas values remained normal throughout the 120-min observation period.

Gas exchange in diseased lungs during NIMV. To test the efficiency of the NIMV under adverse pulmonary conditions, meconium solution was instilled into the lung. The effects of NIMV on blood gases are summarized in Table 2. Thirty minutes after instillation of 25% meconium solution during CMV and PEEP of 5 cmH₂O arterial blood pH and arterial partial pressure of oxygen (PaO₂) declined, whereas PaCO₂ significantly rose. Placing the animals on NIMV at frequencies of 4.0 Hz and ±0.6 pGz significantly reduced PaCO₂ and increased pH and PaO₂ over the 150-min

\[ \text{Ptp} = 14.4 \cdot \text{pGz} + 0.067, \quad R^2 = 0.63 \]

\[ \text{Pdi} = 9.26 \cdot \text{pGz} + 0.727, \quad R^2 = 0.41 \]
Effects of the NIMV on gas exchange in anesthetized and paralyzed normal piglets over time

Table 1. Effects of the NIMV on gas exchange in anesthetized and paralyzed normal piglets over time

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>5</th>
<th>15</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
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<tr>
<td>pH</td>
<td>7.212 ± 0.13</td>
<td>7.37 ± 0.101</td>
<td>7.432 ± 0.087*</td>
<td>7.471 ± 0.105*</td>
<td>7.485 ± 0.158*</td>
<td>7.382 ± 0.101*</td>
<td>7.386 ± 0.11*</td>
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<tr>
<td>PCO₂</td>
<td>56.9 ± 12.4</td>
<td>32 ± 8.15*</td>
<td>27.9 ± 7.92*</td>
<td>26.4 ± 10.1*</td>
<td>26.2 ± 12*</td>
<td>30.2 ± 14*</td>
<td>32 ± 15.1*</td>
</tr>
<tr>
<td>PO₂</td>
<td>295 ± 116</td>
<td>383 ± 70.5</td>
<td>377 ± 66.9</td>
<td>377 ± 68.1</td>
<td>356 ± 70.7</td>
<td>320 ± 108</td>
<td>328 ± 121</td>
</tr>
<tr>
<td>HCO₃</td>
<td>22 ± 3.43</td>
<td>18.3 ± 4.71</td>
<td>18.3 ± 4.82</td>
<td>18.7 ± 5.17</td>
<td>18 ± 4.63</td>
<td>17 ± 5.1</td>
<td>17 ± 5.08</td>
</tr>
<tr>
<td>HR</td>
<td>147 ± 43</td>
<td>153 ± 51.6</td>
<td>154 ± 57.4</td>
<td>139 ± 29.2</td>
<td>140 ± 27.7</td>
<td>144 ± 39.4</td>
<td>130 ± 8.74</td>
</tr>
<tr>
<td>MAP, mmHg</td>
<td>113 ± 41.6</td>
<td>109 ± 41.9</td>
<td>108 ± 45.1</td>
<td>111 ± 43.7</td>
<td>101 ± 46.6</td>
<td>101 ± 43.3</td>
<td>106 ± 45.8</td>
</tr>
</tbody>
</table>

Values are means ± SD, n = 7. NIMV, noninvasive motion ventilator; HCO₃, bicarbonate. HR, heart rate; MAP, mean arterial blood pressure. *P < 0.05 relative to baseline.
of air driven in and out of the airway was 46 ml at 5 Hz. Ptp was 1.9 cmH2O at 2 Hz and 5.4 at 5 Hz. Measurements of thoracic and abdominal displacement during vertical accelerations indicate that, as the abdominal viscera move upward, displacing the diaphragm cephalad, the abdominal wall moves inward and the thoracic wall outward. The opposite took place when the abdominal viscera move downward (22). Although electrohydraulic vibration in the previous study and mo-

Table 2. Effects of NIMV on gas exchange in anesthetized and paralyzed piglets over time after meconium aspiration

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Meconium</th>
<th>5</th>
<th>15</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.309 ± 0.082</td>
<td>7.117 ± 0.079</td>
<td>7.165 ± 0.088</td>
<td>7.189 ± 0.125</td>
<td>7.242 ± 0.207</td>
<td>7.258 ± 0.232</td>
<td>7.328 ± 0.233</td>
<td>7.321 ± 0.21</td>
</tr>
<tr>
<td>PCO₂</td>
<td>35.7 ± 7.67</td>
<td>71 ± 19.2*</td>
<td>59.7 ± 21.8</td>
<td>56.9 ± 25.4</td>
<td>52.4 ± 28.9</td>
<td>49.7 ± 30.2</td>
<td>41.7 ± 27.1</td>
<td>41 ± 26.2</td>
</tr>
<tr>
<td>PO₂</td>
<td>370 ± 41.8</td>
<td>62.4 ± 19.9*</td>
<td>73.4 ± 28.2*</td>
<td>89.2 ± 48.3*</td>
<td>108 ± 76.6*</td>
<td>124 ± 84.9*</td>
<td>152 ± 78.8*</td>
<td>166 ± 80.2*</td>
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<tr>
<td>HCO₃</td>
<td>18.5 ± 3.76</td>
<td>21.7 ± 4.06</td>
<td>20.3 ± 4.93</td>
<td>19.6 ± 4.65</td>
<td>19.1 ± 4.96</td>
<td>18.2 ± 5.81</td>
<td>18.7 ± 6.34</td>
<td>17.8 ± 5.71</td>
</tr>
<tr>
<td>HR</td>
<td>136 ± 20.7</td>
<td>146 ± 25.1</td>
<td>162 ± 29.5</td>
<td>150 ± 36.7</td>
<td>166 ± 25.1</td>
<td>158 ± 29.5</td>
<td>152 ± 34.9</td>
<td>150 ± 41.5</td>
</tr>
<tr>
<td>MAP, mmHg</td>
<td>77.8 ± 6.07</td>
<td>72.4 ± 13.6</td>
<td>89 ± 3.39</td>
<td>84.2 ± 3.83</td>
<td>81.4 ± 3.13</td>
<td>81.6 ± 2.19</td>
<td>81.8 ± 1.64</td>
<td>77 ± 3.39</td>
</tr>
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</table>

Values are means ± SD; n = 7. *P < 0.05 relative to baseline.

V̇E (Fig. 4B) and VT (Fig. 5) with NIMV are inversely related to the frequency of the motion platform oscillations. As the frequency increases, the VT decreases and V̇E falls. This occurs although the number of breaths per minute increases. Similar responses in pressure-controlled conventional ventilation are observed when high ventilation rates inhibit V̇E because the minimum time required for the movement of air in and out of the lungs exceeds the imposed time demands of the frequency. Although V̇E and tidal ventilation volumes are low at the frequencies selected for the motion platform, ventilation may be promoted by non-convective means, similar to gas exchange observed with high-frequency jet ventilation and high-frequency vibration. This is because the dead space gas, conducting airways, and lungs “vibrate” in response to the high-frequency sinusoidal motion. The motion platform may also promote mucociliary movement and clearance of airway debris through two-phase gas-liquid pumping (5, 18). Such effects have not yet been investigated during NIMV.

Ventilation by NIMV can be compared with ventilation by other modes of high-frequency ventilation such as high-frequency oscillation (12, 19), jet ventilation (17), and high-frequency vibration (8, 10). The approximate ventilator frequencies for these modes are: CMV, 0.3 Hz; high-frequency oscillation ventilation, 12 Hz; high-frequency jet ventilation, 2 Hz; high-frequency vibration, 22 Hz; and NIMV, 4 Hz. Thus the operational frequency for the motion platform that was determined to be best for ventilation in this study using
juvenile piglets (4 Hz) is intermediate among high-frequency modes of ventilation, although clearly higher than CMV. The optimal frequency in larger animals or humans may be different than 4 Hz. Although all high-frequency modes of ventilation used small volumes, only NIMV used negative pleural pressures to generate airflow, thereby reducing the possibility of barotrauma and volutrauma via excessive lung stretch. Mean airway pressures during both NIMV (Fig. 2) and high-frequency vibration (10), however, remained low and have been attributable only to the imposed CPAP (~5 cmH₂O) that was used during operation. The CO₂ removal or gas-exchange capacities of high-frequency modes of ventilation were usually equal to or better than CMV at lower airway pressures (8, 10, 12, 17, 19). Gavieli et al. (10) found that constant-flow or -pressure modes such as CPAP or intratracheal pulmonary ventilation produce most effective air transport in the trachea but not in the peripheral airways, whereas high-frequency chest vibration was most effective at the periphery. Combining tracheal gas insufflation with vibration produced the optimal gas exchange with minimal pulmonary pressure or mechanical changes. Because of the intermediate frequencies, NIMV probably produces good gas exchange by some chest wall movements but not to the extent observed with high-frequency oscillation or chest vibration ventilation. Also, NIMV does not produce pejorative changes in vascular pressures (1) commonly observed with high-frequency ventilation (3, 19).

This study has demonstrated that NIMV ventilates paralyzed piglets. This is a model most useful to describe ventilation on NIMV of human infants and small children but not larger animals. The use of paralysis may not be necessary because NIMV has been successfully performed in nonparalyzed anesthetized piglets (unpublished observations). However, activation of respiratory muscles during NIMV is often not synchronized with the rapid frequency of the motion platform and thus impedes airflow. The use of NIMV for humans or animals of larger mass is limited. Larger animals probably require different platform settings to achieve adequate ventilation because of both increased mass and differences in the configuration and geometry of the lungs and thoracic compartments. In fact, two conscious human adults subjected to NIMV at a pG₅ of ±0.3 and frequencies up to 3 Hz produced V₆ of 50–70 ml (preliminary experiments). Clearly, these volumes are not sufficient for adequate ventilation, and it may be necessary to sedate or paralyze humans on NIMV, similar to the animals described in this study.

The motion platform ventilates anesthetized and paralyzed animals both with normal lungs and with severe lung injury induced by the aspiration of meconium (Tables 1 and 2).

Carbon dioxide removal, after either intentional hyperventilation in animals with normal lungs or in animals compromised by aspiration, occurred rapidly and was sustained over the 2-h experiment. The CO₂ removal is comparable to what may be achieved with conventional pressure-controlled mechanical ventilation (18). In fact, we found that PaCO₂ levels in these animals could be driven down to values as low as 5 Torr by altering the motion platform acceleration and frequency settings. Similar normalization also occurs for PaO₂ and pH. These changes in arterial blood gases all occur at mean airway pressures equivalent to atmospheric pressure raised by the CPAP pressure. In contrast, conventional ventilation of diseased lungs often requires high peak inspiratory pressures to achieve adequate gas exchange and may result in barotrauma with subsequent pulmonary inflammation and fibrosis. On the other hand, the concept of “protective CMV” using low V₆ (~< 6 ml/kg) has proven very valuable in patients with acute respiratory distress syndrome (16). In protective ventilation, the low volumes and pressures protect the diseased lungs from further stretch-induced injury, thus allowing repair to occur. The permissive hypercapnia and lower oxygen tensions attendant with low-volume protective ventilation (16) are tolerated in an overall trade-off of pejorative effects. NIMV, as used in this experimental setting, produces both low-volume ventilation and adequate gas exchange in meconium aspiration and may be a superior approach to the protective ventilation concept. The possibility of shearing trauma with NIMV, however, cannot be ruled out. The ability of NIMV to produce adequate ventilation and exchange gas has been established in injured lungs over short time periods (2 h). The effectiveness or complications of the motion platform in ventilating injured lungs over longer times, when lung compliance further declines, has not yet been established.

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M. A. Sackner is the chief executive officer of Non-Invasive Monitoring Systems and owns 52% of the shares.

REFERENCES


