Gas exchange measurement during pediatric mechanical ventilation – agreement between gas sampling at the airway and ventilator exhaust

Simultaneous Gas Exchange Comparison using the E-COVX® and Vmax®- Expected Error

The following describes the error that one can expect when comparing two metabolic monitors: the first with proximal airway sensor and gas sample and the second with conventional ventilator exhaust flow and gas sampling. These equations could be adapted in order to calculate expected error with any such devices and not necessarily the ones explored in the present study.

This is meant to calculate the error of the exhaust device (Vmax) introduced by airway sampling by the proximal device (E-COVX).

**Haldane Transformation**

Equation 1:

\[ F_j N_2 = 1 - F_j O_2 - F_j CO_2 \]

Equation 2:

\[ F_E N_2 = 1 - F_E O_2 - F_E CO_2 \]

Equation 3:

\[ \dot{V} O_2 = \left( \dot{V}_E \times \left( \frac{F_E N_2}{F_j N_2} \right) \times F_j O_2 \right) - \left( \dot{V}_E \times F_E O_2 \right) \]

Equation 4:

\[ \dot{V} CO_2 = \left( \dot{V}_E \times F_E CO_2 \right) - \left( \dot{V}_E \times \left( \frac{F_E N_2}{F_j N_2} \right) \times F_j CO_2 \right) \]

**Corrected Haldane Transformation for Simultaneous Gas Exchange Monitoring**

The correction is based on the following assumptions:

1. Sample flow rate from the proximal metabolic monitor (in this case, E-COVX) is stable and continuous.
2. Aspiration of gas (by the E-COVX) during inspiration will not reduce the effective tidal volume (that volume of gas that travels past the adapter and participates in gas exchange)
3. Expired gas is routed to 2 places:
   a. E-COVX sample flow
   b. Ventilator circuit/exhaust
4. The proportion of sampled gas that is aspirated by the E-COVX during expiration will vary depending upon the time spent during the expiratory portion of the respiratory cycle and the sample flow rate.

Equation 5:

\[ \dot{V}O_2(\text{corrected}) = \left( \dot{V}_E + \dot{V}_{\text{sample}} \times \left( \frac{T_e}{(T_e + T_i)} \right) \right) \times \left( \frac{F_E N_2}{F_i N_2} \right) \times F_i O_2 \]

\[ - \left( \dot{V}_E + \dot{V}_{\text{sample}} \times \left( \frac{T_e}{(T_e + T_i)} \right) \right) \times F_E O_2 \]

Equation 6:

\[ \dot{V}CO_2(\text{corrected}) = \left( \dot{V}_E + \dot{V}_{\text{sample}} \times \left( \frac{T_e}{(T_e + T_i)} \right) \right) \times F_E CO_2 \]

\[ - \left( \dot{V}_E + \dot{V}_{\text{sample}} \times \left( \frac{T_e}{(T_e + T_i)} \right) \right) \times \left( \frac{F_E N_2}{F_i N_2} \right) \times F_i CO_2 \]

Where:

\[ \dot{V}_E = \text{minute ventilation (L/min)} \]

\[ F_i O_2 = \text{fraction of inspired oxygen} \]

\[ F_E O_2 = \text{fraction of expired oxygen} \]

\[ F_E CO_2 = \text{fraction of inspired carbon dioxide} \]

\[ F_i CO_2 = \text{fraction of expired carbon dioxide} \]

\[ T_e = \text{expiratory time (s)} \]

\[ T_i = \text{inspiratory time (s)} \]

\[ (T_e/(T_e + T_i)) \] is the faction of time spent during expiration.

\[ \dot{V}_{\text{sample}} = \text{continuous sample flow rate of proximal gas exchange monitor (in this case, E-COVX).} \]

\[ \dot{V}_{\text{sample}} = 0.210 \text{ L/min (measured using a mass flow sensor, FMA-2605A, Omega Engineering, Inc., Stamford, CT)} \]
We identified 3 subjects from our data set that represented the smallest, closest to average and largest size (see Table S1). All subjects were female and in controlled mode of ventilation.

### Table S1.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Sex</th>
<th>Ve (L/min)</th>
<th>VO₂ Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0.55</td>
<td>49</td>
<td>6.2</td>
<td>F</td>
<td>1.32</td>
<td>10.8</td>
</tr>
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<td>3</td>
<td>7.6</td>
<td>107</td>
<td>30.0</td>
<td>F</td>
<td>4.83</td>
<td>2.82</td>
</tr>
<tr>
<td>2</td>
<td>15.4</td>
<td>137</td>
<td>60.0</td>
<td>F</td>
<td>6.33</td>
<td>2.28</td>
</tr>
</tbody>
</table>

For each subject the following were calculated:

\[ F_{1}N_{2} \text{ and } F_{E}N_{2} \text{ (from equations 1 and 2)} \]

\[ \dot{V}O₂ \text{ and } \dot{V}CO₂ \text{ per standard Haldane (from equations 3 and 4)} \]

\[ \dot{V}O₂_{\text{corrected}} \text{ and } \dot{V}CO₂_{\text{corrected}} \text{ (from equations 5 and 6)} \]

### Figure S1.

VO₂ error (%) plotted against exhaled minute ventilation of the Vmax (VE).

The percentage error (due to sample rate of the E-COVX) of measurements obtained utilizing the Vmax were calculated:

\[ Error \% = 100 - (\text{corrected/actual} \times 100) \]
Other observations to consider:

- 3.0L/min was the mean VE observed in our study
- Error <5% when VE >3.0L/min