On-line supplement

NON-INVASIVE MONITORING OF LUNG RECRUITMENT IN MORBID OBESES: THE ROLE OF PULSE OXIMETRY AND VOLUMETRIC CAPNOGRAPHY

(Pilot study)

Performance of SpO$_2$ readings for the evaluation of the recruitment effect

Pulse oximetry is a known and validated tool for non-invasive assessment of arterial oxygenation in mechanically ventilated patients. However, technical information related to the time-response and performance characteristics of pulse oximeters during lung recruitment maneuvers is lacking and is likely to vary between oximeters. As we could neither find such information in the literature nor in the technical documentation of the NICO’s SpO$_2$ sensor (Respironics, Wallingford, CT USA), we performed this pilot study to support the use of SpO$_2$ as marker of changes in the area of gas exchange in our protocol. The below points were analyzed:

1. *Correlation between NICO SpO$_2$ readings and SaO$_2$.**
To test the accuracy of NICO’s readings, we compared SpO\textsubscript{2} values with the reference SaO\textsubscript{2} obtained by arterial blood samples during the main study (T1, T5 and T8; \(n = 60\) pair of samples).

2. **Calculation of time-delay of SpO\textsubscript{2} readings due to lung recruitment**

The time delay between the lung recruitment phenomenon (the cause) and the change in SpO\textsubscript{2} readings (the effect) is a critical factor in our protocol. To shed light on this crucial point, we performed a small pilot study in 10 additional MO patients using the same patient’s criteria of inclusion, anesthesia and monitoring than in the original protocol.

Patients were ventilated in pressure control mode using a driving pressure of 20 cmH\textsubscript{2}O, a respiratory rate of 15 breaths min\(^{-1}\), PEEP of 5 cmH\textsubscript{2}O and I:E ratio of 1:2. We decreased FiO\textsubscript{2} until a SpO\textsubscript{2} fell within the range of \(\geq 92\) and \(< 97\%\). After ventilation with the above settings for 10 minutes, we abruptly changed the level of PEEP from 5 to 10 cmH\textsubscript{2}O. We calculated the time from this change of PEEP (T0) until SpO\textsubscript{2} reached 90\% of the maximum change induced by this recruitment step (T90) (figure A).

(Figure A near here)

The PEEP-related alveolar recruitment was assessed as follow:

- The volume gained by PEEP was measured using the principle of the “equal pressure method” described by Mergoni and colleagues (J Appl Physiol 2001; 91:}
After inflating the lung to the distending pressure of 20 cmH$_2$O, we measured the end-expiratory lung volume (EELV) disconnecting the patient from the ventilator keeping the NICO’s flow sensor at the airway opening. We performed this maneuver twice: once at 5 cmH$_2$O of PEEP prior to the PEEP step and once at the end of the recordings taken at 10 cmH$_2$O of PEEP (arrows in figure A). Difference between these EELVs was considered the PEEP-induced recruited lung volume.

- Arterial blood gases were obtained at 5 and 10 cmH$_2$O of PEEP and PA-aO$_2$ was calculated.
- Dynamic respiratory compliance (Cdyn), airways resistance (Raw) and the elimination of CO$_2$ per breath (V$_{tCO_2,br}$) were measured.

3. **Definition of the open-lung condition at highest airway pressure using SpO$_2$**

To test whether NICO’s SpO$_2$ reading of $\geq$ 97% at the highest airway pressures truly represented an open lung condition, we reproduced the ascending limb of the recruitment maneuver as described for T3 of our main protocol. We took an arterial blood sample when the lung’s opening pressure - defined as SpO$_2$ $\geq$ 97% according to our rationale – was reached.
**Results**

We analyzed ten ASA II MO patients (F = 6/ M = 4), aged 43 ± 7 years old and with a BMI of 45 ± 2 kg/m².

Data showed that SpO₂ and SaO₂ were closely correlated (rho = 0.92, 95% CI for rho [Fisher’s Z transformation] between 0.8811 and 0.9476, p < 0.0001) with a bias of -0.24% and limit of agreement between -1.36 and 0.88 % (Figure B).

(Figure B near here)

Results regarding the effect of PEEP-induced lung recruitment on SpO₂ are shown in table A. During the change from 5 to 10 cmH₂O of PEEP, EELV increased by 236%, Cdyn increased by 40% and VtCO₂br increased by 28 % (all p < 0.05). Raw decreased by 17 % and PA-aO₂ decreased by 14% (both p <0.05).

As shown in table A, SpO₂ increased by 1.3% when PEEP was changed from 5 to 10 cmH₂O with a T90 of 30 (6) seconds (median and interquartile range).

At the predefined opening pressure, SpO₂ was 97.40 (0.4) % and SaO₂ 97.15 (0.3) % (p NS).
Comments

These results show that: 1) NICO’s SpO₂ raw data are closely correlated with the invasive standard SaO₂ and can thus be used as a non-invasive surrogate of hemoglobin saturation. 2) A study periods of ≥ 60 seconds should be enough to detect changes in SpO₂ induced by recruitment interventions. 3) Similarity between SpO₂ and SaO₂, even at high airways pressures, confirms that a cut-off SpO₂ value of ≥ 97 % can represent an open lung condition with sufficient accuracy. During application of low FIO₂ the median arterial oxygenation found at the opening pressures resulted in a calculated PaO₂/FIO₂ index of 492 mmHg, a value that represents an open lung condition according to the classical definition of Lachmann (Intensive Care Med 1992; 18: 319-321).

It is important to highlight that the SpO₂ raw data obtained with NICO’s DataColl software is not the averaged SpO₂ value that appears on NICO’s display. SpO₂ raw data were obtained continuously, providing approximately one real SpO₂ measurement per breath (one SpO₂ value every 4 seconds at a respiratory rate of 15 bpm with a heart rate ≥ 60 beats per minute) under the protocol conditions.
**Figure A:** Effect of a step change in PEEP on SpO₂

The response in SpO₂ is depicted in the context of a step change in PEEP. Arrows indicate the moments when end-expiratory lung volumes were measured and (*) mark the moments when arterial blood samples were obtained. The time response of SpO₂ was determined from the change in PEEP (T₀) till the moment when SpO₂ reached 90% of the maximum change (T₉₀).
Figure B: Performance of NICO’s pulse oximeter sensor

Spearman’s rank correlation (left) and Bland-Altman plot (right) between NICO’s SpO₂ and the reference value of SaO₂ obtained by arterial blood sampling.
Table A: Additional variables studied during the step change in PEEP

<table>
<thead>
<tr>
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<th>5-PEEP</th>
<th>10-PEEP</th>
<th>Δ-PEEP</th>
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<tbody>
<tr>
<td>VT (mL)</td>
<td>469 (64)</td>
<td>628 (71)</td>
<td>159 *</td>
</tr>
<tr>
<td>EELV (mL)</td>
<td>85 (74)</td>
<td>286 (129)</td>
<td>201 *</td>
</tr>
<tr>
<td>VTCO2,br (mL)</td>
<td>12.9 (2)</td>
<td>16.5 (3)</td>
<td>3.6 *</td>
</tr>
<tr>
<td>Cdyn (mL/cmH₂O)</td>
<td>25 (4)</td>
<td>35 (6)</td>
<td>10 *</td>
</tr>
<tr>
<td>Raw (mL/cmH₂O/sec)</td>
<td>12 (3)</td>
<td>10 (3)</td>
<td>-2 *</td>
</tr>
<tr>
<td>PA-aO₂ (mmHg)</td>
<td>66 (32)</td>
<td>57 (31)</td>
<td>-11 *</td>
</tr>
<tr>
<td>SpO₂ (%)</td>
<td>94.6 (1.8)</td>
<td>95.9 (1.3)</td>
<td>1.3*</td>
</tr>
<tr>
<td>SaO₂ (%)</td>
<td>94.9 (2.3)</td>
<td>95.9 (1.4)</td>
<td>1.0</td>
</tr>
<tr>
<td>T90 (sec)</td>
<td></td>
<td>30 (6)</td>
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VT = tidal volume, EELV = end-expiratory lung volume, VT\textsubscript{CO}_2\textsubscript{br} = elimination of CO\textsubscript{2} per breath, C\textsubscript{dyn} = respiratory dynamic compliance, Raw = airways resistance to expiratory flow, PA-\textsubscript{aO}_2 = difference between alveolar and arterial partial pressure of O\textsubscript{2}, Sp\textsubscript{O}_2 = hemoglobin saturation measured by pulse oximetry, Sa\textsubscript{O}_2 = arterial hemoglobin saturation measured directly by a co-oximeter using arterial blood samples, and \( T90 \) = time from the change in PEEP from 5 to 10 cmH\textsubscript{2}O until Sp\textsubscript{O}_2 reached 90% of the maximum change induced by the recruitment effect. Δ-PEEP indicates the difference in the variables between 5 and 10 cmH\textsubscript{2}O of PEEP. Wilcoxon’s rank sum test was used to analyze the effects of the PEEP step. * p< 0.05 was considered a significant change.