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_2 values with the reference SaO_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_2 readings due to lung recruitment*

The time delay between the lung recruitment phenomenon (the cause) and the change in SpO_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_2O, a respiratory rate of 15 breaths min^{-1}, PEEP of 5 cmH_2O and I:E ratio of 1:2. We decreased FiO_2 until a SpO_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_2O. We calculated the time from this change of PEEP (T0) until SpO_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:

441-450). After inflating the lung to the distending pressure of 20 cmH_2O, 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_2O of PEEP prior to the PEEP step and once at the end of the recordings taken at 10 cmH_2O 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_2O of PEEP and $PA\text{-}aO_2$ 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/m^2.

Data showed that SpO_2 and SaO_2 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 SpO_2 are shown in table A. During the change from 5 to 10 cmH_2O of PEEP, EELV increased by 236%, Cdyn increased by 40% and $V_TCO_{2,br}$ increased by 28 % (all $p < 0.05$). Raw decreased by 17 % and $PA\text{-}aO_2$ decreased by 14% (both $p <0.05$).

As shown in table A, SpO_2 increased by 1.3% when PEEP was changed from 5 to 10 cmH_2O with a T90 of 30 (6) seconds (median and interquartile range).

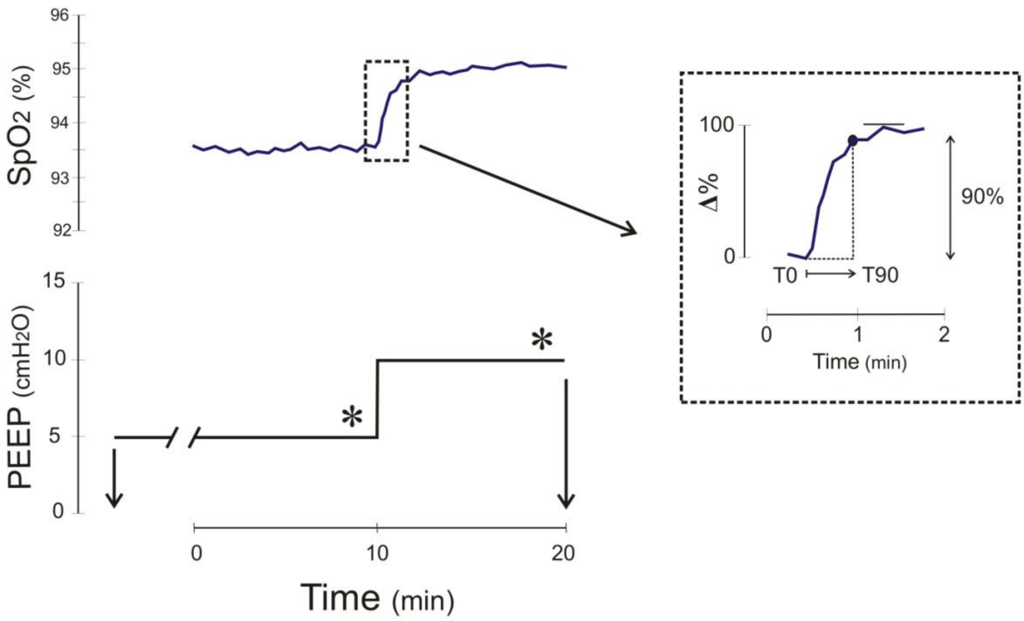
At the predefined opening pressure, SpO_2 was 97.40 (0.4) % and SaO_2 97.15 (0.3) % (p NS).

Comments

These results show that: 1) NICO's SpO_2 raw data are closely correlated with the invasive standard SaO_2 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 SpO_2 induced by recruitment interventions. 3) Similarity between SpO_2 and SaO_2, even at high airways pressures, confirms that a cut-off SpO_2 value of ≥ 97 % can represent an open lung condition with sufficient accuracy. During application of low FIO_2 the median arterial oxygenation found at the opening pressures resulted in a calculated PaO_2/FIO_2 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).

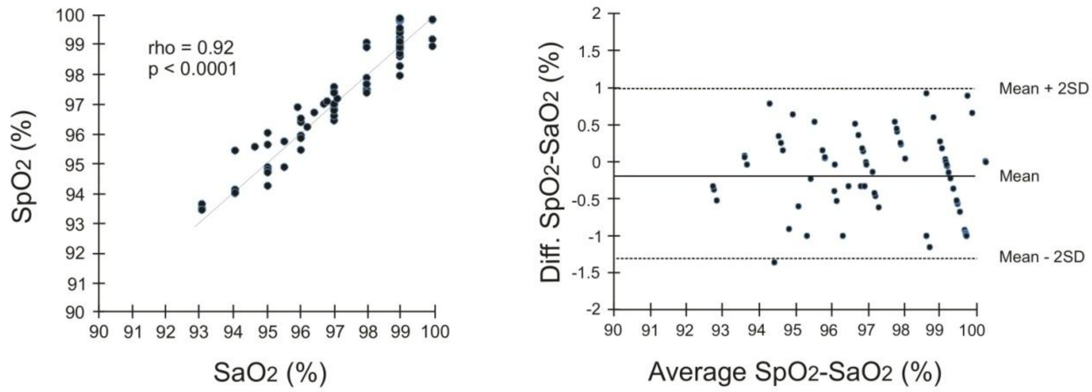
It is important to highlight that the SpO_2 raw data obtained with NICO's DataColl software is not the *averaged* SpO_2 value that appears on NICO's display. SpO_2 raw data were obtained continuously, providing approximately one real SpO_2 measurement per breath (one SpO_2 value every 4 seconds at a 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 SpO_2



The response in SpO_2 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 SpO_2 was determined from the change in PEEP (T0) till the moment when SpO_2 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 SpO_2 and the reference value of SaO_2 obtained by arterial blood sampling.

Table A: Additional variables studied during the stepchange in PEEP

	5-PEEP	**10-PEEP**	**Δ-PEEP**
V_T (mL)	469 (64)	628 (71)	159 *
EELV (mL)	85 (74)	286 (129)	201 *
$V_TCO_{2,br}$ (mL)	12.9 (2)	16.5 (3)	3.6 *
Cdyn (mL/cmH_2O)	25 (4)	35 (6)	10 *
Raw (mL/cmH_2O/sec)	12 (3)	10 (3)	-2 *
$PA\text{-}aO_2$ (mmHg)	66 (32)	57 (31)	-11 *
SpO_2 (%)	94.6 (1.8)	95.9 (1.3)	1.3*
SaO_2 (%)	94.9 (2.3)	95.9 (1.4)	1.0
T90 (sec)	30 (6)		

VT = tidal volume, EELV = end-expiratory lung volume, $V_TCO_{2,br}$ = elimination of CO_2 per breath, Cdyn = respiratory dynamic compliance, Raw = airways resistance to expiratory flow, $PA\text{-}aO_2$= difference between alveolar and arterial partial pressure of O_2, SpO_2= hemoglobin saturation measured by pulse oximetry, SaO_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_2O until SpO_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_2O 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.