A New Oxygenation Index for Reflecting Intrapulmonary Shunting in Patients Undergoing Open-Heart Surgery*

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Study objectives: To assess the reliability of new and traditional oxygenation measurements in reflecting intrapulmonary shunt.
Design: Prospective study.
Setting: Cardiac surgery unit at a university hospital.
Patients: Fifty-five patients undergoing coronary artery bypass grafting.
Measurements and results: Simultaneous blood samples were collected from an indwelling arterial line and a catheter for determination of blood gases. Standard accepted formulas were utilized to measure a new oxygenation index: PaO2/fraction of inspired oxygen (FIO2) × mean airway pressure (Paw). The standard formulas used were the oxygenation ratio (PaO2/FIO2), PaO2/alveolar partial oxygen pressure (PAO2), alveolar-arterial oxygen tension gradient (P[A-a]O2), and intrapulmonary shunt (venous admixture [Qsp/Qt]). There were significant negative (p < 0.05) correlations between the PaO2/(FIO2 × Paw) and Qsp/Qt (r = −0.85), between the PaO2/FIO2 and Qsp/Qt (r = −0.74), and between the PaO2/PAO2 and Qsp/Qt (r = −0.71). There was a significant positive (p < 0.05) correlation between the P(A-a)O2 gradient and Qsp/Qt (r = 0.66). However, the correlation was strongest between the PaO2/(FIO2 × Paw) and Qsp/Qt.
Conclusion: In this group of patients, PaO2/(FIO2 × Paw) might be more reliable than other oxygenation measurements in reflecting intrapulmonary shunt. (CHEST 2004; 125:592–596)

Key words: intrapulmonary shunt; mean airway pressure; open-heart surgery; oxygenation factor; oxygenation measurements; oxygenation ratio; positive end-expiratory pressure

Abbreviations: ALI = acute lung injury; CABG = coronary artery bypass graft; Cco2 = pulmonary end-capillary oxygen content; FIO2 = fraction of inspired oxygen; P(A-a)O2 = alveolar-arterial oxygen tension gradient; PAO2 = alveolar partial oxygen pressure; Paw = mean airway pressure; PEEP = positive end-expiratory pressure; Qsp/Qt = venous admixture

The ability to accurately assess and measure lung function is essential in the management of patients requiring mechanical ventilation. Such assessments and measurements aid in diagnosis, in optimizing mechanical ventilatory support, and in predicting the likelihood of success of weaning. The PaO2/fraction of inspired oxygen (FIO2) ratio, the PaO2/alveolar partial oxygen pressure (PAO2) ratio, and the alveolar-arterial oxygen tension gradient (P[A-a]O2) are the most common of these measurements. However, PaO2/FIO2 remains the most convenient and widely used bedside index of oxygen exchange.1–3 It was first described by Horovitz et al4 in 1974 as an index used to compare arterial oxygenation at different levels of FIO2. Since then, it has been commonly used to assess respiratory status as well as response to different therapies, whether the therapy is an increase in FIO2 or changes in mechanical ventilation settings.5–7 Moreover, PaO2/FIO2 has been considered as the differentiating factor between establishing a diagnosis for acute lung injury (ALI) or a diagnosis for ARDS.8

However, although simple to obtain, PaO2/FIO2 is affected by changes in mixed venous oxygen saturation and does not remain equally sensitive across the entire range of FIO2, especially when shunt is the major cause of admixture; another oxygenation index, PaO2/PAO2, has been reported to be superior to PaO2/FIO2 in this regard.9 Also, more importantly, this ratio does not account for changes in the functional status of the lung that result from alterations in positive end-expiratory pressure (PEEP), auto-PEEP, or other techniques for adjusting average
lung volume (ie, inverse ratio ventilation or prone positioning) during mechanical ventilation. As such, in patients receiving mechanical ventilation, PaO2/FiO2 might not be a sensitive indicator particularly when assessing the severity of the lung disease or when tracking the oxygen-exchanging status of the lung is desired in the presence of such interventions as PEEP and prone positioning.

The PaO2/[FiO2 × Paw] ratio, a new oxygenation index termed oxygenation factor, which is based on the usual PaO2/FiO2 but takes into consideration some important mechanical ventilatory support variables such as PEEP, inspiratory time fraction, and tidal volume, could be a better and superior indicator for assessing the severity of disease and/or for tracking the oxygen-exchanging status. The aim of this study is to assess the reliability of this oxygenation factor and other oxygenation measurements in reflecting intrapulmonary shunt in patients following open-heart surgery.

**Materials and Methods**

This study was approved by the Institutional Review Board, and a consent was obtained prior to the initiation of the study. Fifty-five hemodynamically and clinically stable patients receiving mechanical ventilation in the cardiac surgery unit following coronary artery bypass graft (CABG) surgery were included in the study. These were consecutive patients in whom CABG surgery was performed with a cardiopulmonary bypass pump. All patients were monitored with continuous electrocardiography, BP, and pulse oximetry during the whole study. All patients were receiving mechanical ventilation (PB-7200ae; Puritan-Bennett, Mallinckrodt; St. Louis, MO). As per routine monitoring, all patients had a Swan-Ganz catheter and an indwelling arterial line. A period of at least 10 min was allowed before data collection, during which the patients were not disturbed by nursing procedures and were not disconnected from the ventilator for suctioning. Within the first hour of admission to the cardiac surgery unit, simultaneous blood samples from the arterial line and the distal and proximal ports of the Swan-Ganz catheter (Arrow; Reading PA) were obtained and immediately subjected to duplicate blood gas analysis in two separate blood gas machines (ABL-720 and ABL-520; Radiometer; Copenhagen; Denmark). All blood samples were collected using the same model and brand of syringes (Preset Vacutainer System; Becton-Dickinson; Plymouth, UK). Blood samples were not obtained more than twice for any one patient. From blood gas measurements, PaO2/[FiO2 × Paw], PaO2/FiO2, PaO2/PaO2, P(A-a)O2, and the intrapulmonary shunt (venous admixture [Qsp/Qt]) were determined. Qsp/Qt was determined from the following formula: (CcO2 - arterial oxygen content)/(CcO2 - mixed venous oxygen content), where CcO2 = end-pulmonary capillary oxygen content.10

Mean values and SD were calculated for each variable. Standard techniques of linear regression and correlation by the least-square method were used to assess the degree of correlation among these variables. Student t test was used for statistical analysis of the correlation coefficients. Statistical significance was considered at the 5% level (p<0.05).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>55</td>
</tr>
<tr>
<td>Age, yr</td>
<td>61 ± 6</td>
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<tr>
<td>Male/female gender</td>
<td>36/19</td>
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<tr>
<td>Weight, kg</td>
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<tr>
<td>Height, cm</td>
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<td>Smokers/ex-smokers/nonsmokers</td>
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</tr>
</tbody>
</table>

*Data are presented as No. or mean ± SD.

**Results**

Patients characteristics are presented in Table 1. A total of 74 sets of data were obtained from 55 patients due to the fact that 1 extra set of data were obtained from 19 patients following changes in their PEEP and/or FiO2, which were clinically indicated and under the discretion of the medical team who were blinded to the study except for the arterial blood gas values.

There was significant negative linear relationships between Qsp/Qt and PaO2/[FiO2 × Paw] (r = −0.55, p < 0.05), between Qsp/Qt and PaO2/FiO2 (r = −0.74, p < 0.05), and between Qsp/Qt and PaO2/PaO2 (r = −0.71, p < 0.05) [Figs 1–3]. However, there was a significant positive linear relationship between Qsp/Qt and P(A-a)O2 gradient (r = 0.66, p < 0.05) [Fig 4]. As shown in Table 2, the correlation was strongest between Qsp/Qt and PaO2/[FiO2 × Paw].

**Discussion**

Our data demonstrate that the new oxygenation index (PaO2/[FiO2 × Paw]), the oxygenation ratio...
(PaO₂/FiO₂), PaO₂/PAO₂, and P(A-a)O₂ are reliable reflectors of intrapulmonary shunt (Qsp/Qt). However, in this group of patients, PaO₂/FiO₂/H₁₁₀₀₃Paw is superior to other oxygenation measurements in reflecting intrapulmonary shunt.

The intrapulmonary shunt fraction index has been considered the "gold standard" for the clinical assessment of lung oxygenation function.¹¹⁻¹⁵ This index most accurately represents the lung oxygenation function when direct measurements of both arterial and pulmonary arterial blood samples are available as well as when the FiO₂ is consistent.¹¹

Indexes of arterial oxygenation, such as PaO₂/FiO₂, PaO₂/PAO₂, P(A-a)O₂, and PaO₂/FiO₂/H₁₁₀₀₃Paw, which do not require mixed venous blood samples, are useful since these indexes can be applied to patients regardless of whether a pulmonary artery catheter is in place.¹⁰ However, PaO₂/FiO₂ remains the mostly used and evaluated index due to its simplicity and the fact that it can be determined in both spontaneously breathing patients and patients receiving mechanical ventilation.

There are conflicting data on the accuracy with which PaO₂/FiO₂ reflects oxygen exchange. PaO₂/ FiO₂ values < 200 mm Hg have been reported to correlate well with Qsp/Qt of > 20%.¹⁷,¹⁸ Gowda and Klocke¹³ have shown that PaO₂/FiO₂ is a useful estimation of the degree of gas exchange abnormality under usual clinical conditions. Also two studies¹⁷,¹⁹ have demonstrated that PaO₂/FiO₂ correlated closely with measured venous admixture, especially in hemodynamically stable patients, and that this ratio correlated better than any other tension-based oxy-

| Table 2—Comparison of Oxygenation Indices to Intrapulmonary Shunt* |
|-------------------------|------------------|----------|
| Variables | Mean ± SD | r Value |
| Qsp/Qt | 8.8 ± 5.1 | 1.00 |
| PaO₂ | 27 ± 11 | -0.55 |
| PaO₂/FiO₂ | 231 ± 69 | -0.74 |
| PaO₂/PAO₂ | 0.41 ± 0.13 | -0.71 |
| P(A-a)O₂ | 198 ± 78 | 0.66 |
| FiO₂ | 48 ± 11 | N/A |
| Paw | 10 ± 3 | N/A |

* N/A = not applicable.
In conclusion, our data show that the currently used oxygenation measurements can be used to reflect intrapulmonary shunt in patients following open-heart surgery. However, a new and simple oxygenation index, \( \text{PaO}_2/\text{FiO}_2 \times \text{PAW} \), might be su-

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prior to most common oxygenation indexes in this group of patients. Further studies are needed to evaluate any role of $\text{PaO}_2/\text{FiO}_2 \times P_{aw}$ in assessing and following up lung function in patients with ALI or ARDS.

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REFERENCES