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 pressure.
lungs (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 × P(A-a)o2 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, 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).

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 × P(A-a)o2 (r = -0.55, p < 0.05), between Qsp/Qt and PaO₂/FIO₂ (r = -0.74, p < 0.05), and between Qsp/Qt and PaO₂/P(A-a)o2 (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 × P(A-a)o2.

DISCUSSION

Our data demonstrate that the new oxygenation index (PaO₂/FIO₂ × P(A-a)o2), the oxygenation ratio

<table>
<thead>
<tr>
<th>Table 1—Demographics*</th>
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<tbody>
<tr>
<td>Variables</td>
</tr>
<tr>
<td>Patients</td>
</tr>
<tr>
<td>Age, yr</td>
</tr>
<tr>
<td>Male/female gender</td>
</tr>
<tr>
<td>Weight, kg</td>
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<tr>
<td>Height, cm</td>
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<tr>
<td>Smokers/ex-smokers/nonsmokers</td>
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*Data are presented as No. or mean ± SD.

Figure 1. Correlation between intrapulmonary shunt (Qsp/Qt) and new oxygenation index (PaO₂/FIO₂ × P(A-a)o2). Regression line: slope = -0.38, intercept = 18.83.
(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 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 represent 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 × Paw, 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.16 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-

![Figure 2](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/22005/)

**Figure 2.** Correlation between intrapulmonary shunt (Qsp/Qt) and PaO₂/FIO₂ ratio. Regression line: slope = −0.03, intercept = 21.40.

![Figure 3](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/22005/)

**Figure 3.** Correlation between intrapulmonary shunt (Qsp/Qt) and PaO₂/PAO₂ ratio. Regression line: slope = −26.97, intercept = 19.75.

![Figure 4](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/22005/)

**Figure 4.** Correlation between the intrapulmonary shunt (Qsp/Qt) and P(A-a)O₂. Regression line: slope = 0.04, intercept = 0.4.

**Table 2—Comparison of Oxygenation Indices to Intrapulmonary Shunt**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
<th>r Value</th>
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<tbody>
<tr>
<td>Qsp/Qt</td>
<td>8.8 ± 5.1</td>
<td>1.00</td>
</tr>
<tr>
<td>PaO₂</td>
<td>27 ± 11</td>
<td>-0.55</td>
</tr>
<tr>
<td>PAO₂/FIO₂</td>
<td>231 ± 69</td>
<td>-0.74</td>
</tr>
<tr>
<td>PAO₂/PAO₂</td>
<td>0.41 ± 0.13</td>
<td>-0.71</td>
</tr>
<tr>
<td>P(A-a)O₂</td>
<td>198 ± 78</td>
<td>0.66</td>
</tr>
<tr>
<td>FIO₂</td>
<td>48 ± 11</td>
<td>N/A</td>
</tr>
<tr>
<td>Paw</td>
<td>10 ± 3</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*N/A = not applicable.*
In its new form, \( P_aO_2/Fio_2 \times \text{Paw} \) remains easy to determine and to apply at the bedside. In contrast to the shunt fraction, which requires the use of a Swan-Ganz catheter, the new oxygenation index is noninvasive and can be determined with a simple arterial puncture. For the determination of \( P_aO_2/Fio_2 \times \text{Paw} \), the value for the Paw, which is readily available on most modern mechanical ventilators, is needed in addition to the PaO2 and Fio2 values. Through the inclusion of the Paw, \( P_aO_2/Fio_2 \times \text{Paw} \) will account for changes in the functional status of the lung resulting from use and alterations in PEEP and should be useful in the clinical practice. Despite these advantages, one limitation of the new oxygenation index remains that it cannot be used on nonintubated and spontaneously breathing patients since the index will be undefined as Paw will be zero under these conditions.

In the current study, the patient population received mechanical ventilation for postoperative management following open-heart CABG surgeries. The intrapulmonary shunt in our patients ranged from 2 to 20%. This range of shunt fraction does not reflect severe gas exchange disorders. However, the use of PEEP on patients after open-heart surgeries has been shown to increase end-expiratory lung volume, resulting in fewer atelectatic and fewer unperfused lung units, and to improve oxygenation. \( P_aO_2/Fio_2 \times \text{Paw} \), which incorporates PEEP (through the Paw), should better reflect lung function than other oxygenation indexes that do not incorporate PEEP.

Furthermore, the aim of the current study was only to assess the reliability of \( P_aO_2/Fio_2 \times \text{Paw} \) in reflecting intrapulmonary shunt and not to identify a cut-off or a threshold value that will differentiate between clinically acceptable and unacceptable intrapulmonary shunt fractions. For this purpose, the current study was conducted in a group of postoperative CABG patients in whom arterial lines as well as a Swan-Ganz catheters are placed for routine monitoring, which will allow determination of the different oxygenation indexes. We still need to validate the current findings in patients receiving mechanical ventilation for ALI or ARDS for whom a wider and higher range of intrapulmonary shunt fraction would be expected.

**Conclusion**

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, \( P_aO_2/Fio_2 \times \text{Paw} \), might be su-
perior to most common oxygenation indexes in this group of patients. Further studies are needed to evaluate any role of $P_{A\text{O}_2}/F_{I\text{O}_2} \times P^{MV}$ in assessing and following up lung function in patients with ALI or ARDS.

ACKNOWLEDGMENT: We thank the staff of the Department of Inhalation Therapy and the nursing staff in the Cardiac Surgery Unit.

REFERENCES
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