Observation of clinically significant errors in oxygen saturation calculations when $pO_2$ is low

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Summary

Calculation-based approaches to determining oxygen saturation, as used in some point-of-care tests, increasingly deviate from values measured directly by CO-oximetry as the partial pressure of oxygen in the blood decreases. Oxygen saturation should be measured by CO-oximetry when inaccuracies in calculations may negatively impact patient care.

This article addresses the accuracy of calculated oxygen saturation ($sO_2$), as used in some point-of-care-testing analyzers, compared to direct measurements by CO-oximetry. Measured and calculated $sO_2$ values were compared for 1180 patients. Discrepancies between measured and calculated $sO_2 \geq 10\%$ were observed in 8\% of cases. Of these discrepant measurements, 94\% occurred when the partial pressure of oxygen ($pO_2$) was less than 50 mmHg.

These results suggest that the potential for clinically significant error in $sO_2$ calculations increases as $pO_2$ decreases. When $pO_2$ is low, $sO_2$ should be measured directly by CO-oximetry to avoid potential errors in calculated values.

Summarized from: Gunsolus IL et al. Low $pO_2$ contributes to potential error in oxygen saturation calculations using a point of care assay. Am J Clin Pathol 2017; 149: 82-86.

Oxygen saturation ($sO_2$) is routinely monitored to assess respiratory status and to calculate other indicators of cardiac and respiratory status, such as global oxygen demand. Three primary methods are used to determine $sO_2$: pulse oximetry, CO-oximetry, and calculations.

Pulse oximetry is used for non-invasive, real-time monitoring of $sO_2$, while both CO-oximetry and calculations are used to quantify $sO_2$ in blood samples. Direct measurement of $sO_2$ by CO-oximetry is performed by many blood gas analyzers, while calculation-based approaches using mathematical models that relate $sO_2$ to other measured blood parameters are used in some point-of-care (POC) tests without CO-oximetry.
A 2014 acutecaretesting.org article by Chris Higgins asserted that \( \text{SO}_2 \) is better measured by CO-oximetry than calculated, since direct measurements avoid errors that can arise from the physiologic assumptions made by calculated methods. As stated previously, these errors can be propagated through to parameters derived from \( \text{SO}_2 \), such as global oxygen demand and Fick’s cardiac output [1-4].

While the proposed superiority of measured over calculated \( \text{SO}_2 \) is based on sound analytical arguments, there has to date been limited evidence directly supporting this assertion. This article presents evidence of discordance between measured and calculated \( \text{SO}_2 \) that is particularly pronounced when the partial pressure of oxygen (\( p \text{O}_2 \)) is low.

Index case spurs investigation

Our investigation of measured and calculated \( \text{SO}_2 \) was motivated by a heart catheterization case in our hospital. In this case, a patient was observed to be hypoxic when \( \text{SO}_2 \) was measured by CO-oximetry. The severity of hypoxemia (\( \text{SO}_2 = 37 \% \), see Table I) prompted the physician to check this value against a second value obtained using a calculated \( \text{SO}_2 \) from a POC test (\( \text{SO}_2 = 55 \% \)). The measured (CO-oximetry) and calculated (POC) \( \text{SO}_2 \) values were noted to be significantly discrepant; this discrepancy was also observed when paired tests were performed approximately one hour later.

<table>
<thead>
<tr>
<th>Time</th>
<th>( \text{SO}_2 ) (%)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:27</td>
<td>37</td>
<td>CO-oximetry (measured)</td>
</tr>
<tr>
<td>12:32</td>
<td>55</td>
<td>POC (calculated)</td>
</tr>
<tr>
<td>13:23</td>
<td>39</td>
<td>CO-oximetry (measured)</td>
</tr>
<tr>
<td>13:24</td>
<td>59</td>
<td>POC (calculated)</td>
</tr>
</tbody>
</table>

**Table I**: \( \text{SO}_2 \) values measured by CO-oximetry or calculated by a POC device during a catheterization procedure.

Comparing measured and calculated \( \text{SO}_2 \)

We began to investigate the source of this discrepancy by comparing measured and calculated \( \text{SO}_2 \) across many patients. We first accessed 3323 archived \( \text{SO}_2 \) values from our laboratory’s CO-oximeter in 1180 patients. We then used the mathematical model employed by our institution’s POC test (Equation 1) to calculate the \( \text{SO}_2 \) that would be reported by the POC test for each patient. The necessary inputs to this equation (\( p \text{O}_2 \), pH, and bicarbonate concentration, the latter derived from \( p \text{CO}_2 \)) were measured by the CO-oximeter simultaneously with \( \text{SO}_2 \) and so were available in the instrument archives.

**Equation 1:**

\[
\text{SO}_2 = \frac{x^3 + 150x}{x^3 + 150x + 23400}
\]

\[x = p \text{O}_2 \cdot 10^{0.48 \cdot (\text{pH}-7.4) - 0.0013 \cdot ([HCO_3^-] - 25)}\]

Using this procedure, we obtained paired values of measured and calculated \( \text{SO}_2 \) for each patient. We then calculated the percent difference between these paired values to assess the expected agreement between the CO-oximeter and the POC test.

To assess the validity of our approach, we applied it to the index case in which \( \text{SO}_2 \) was measured using both CO-oximeter and POC testing at approximately the same time. We calculated that the POC test would report an \( \text{SO}_2 \) of 48 %, compared to the value of 55 % that was observed. This demonstrates that our approach provides a reasonable estimate of the agreement between the CO-oximeter and the POC test.

The results of our analysis showed that 8 % of calculated \( \text{SO}_2 \) values were ≥10 % different from their paired measured value; we refer to these cases as discrepant. Over- and underestimation of the measured value occurred with approximately equal frequency. Notably, the majority of discrepant cases (94 %) occurred when \( p \text{O}_2 \) was less than 50 mmHg. As shown in **Fig. 1**, the frequency of discrepancies between measured and calculated \( \text{SO}_2 \) increased with decreasing \( p \text{O}_2 \).

The frequency of discrepancies did not depend significantly on either the pH or bicarbonate concentration. However, the distribution of pH and bicarbonate concentration did shift to lower values in discrepant vs. non-discrepant cases.
The frequency of pH ≤ 7.4 was 16 % higher in discrepant cases than in non-discrepant cases, and the frequency of bicarbonate concentration ≤ 25 mEq/L was 3 % higher.

These results suggest that discrepancies between measured and calculated sO₂ are more likely in patients whose blood parameters deviate significantly from normal, particularly when pO₂ is less than 50 mmHg.

Potential source of discrepancies

We observed that sO₂ values calculated using the model employed by a POC instrument increasingly diverge from sO₂ values measured by CO-oximetry as pO₂ decreases. Deviations of pH and bicarbonate concentration from physiologic normal were also more common in discrepant vs. non-discrepant cases, though these parameters did not serve as independent predictors of discrepancies.

Precedent studies using smaller sample sets have also observed deviations of sO₂ calculations from measured values under some conditions. One study observed consistently lower calculated than measured sO₂ values in hypoxic blood samples, where pO₂ was set to 10 or 20 mmHg using tonometry [5]. Another study showed that calculated sO₂ values in 21 critically ill patients increasingly diverged from measured values with decreasing pO₂ [1].

Our study did not directly assess the mechanism responsible for the increasing deviation of calculated sO₂ from measured sO₂ as pO₂ decreases. However, we suggest that these deviations result in part from the increasing steepness of the O₂-hemoglobin dissociation curve as pO₂ decreases, together with inter-individual variability in hemoglobin-O₂ dissociation.

While sO₂ calculations assume normal hemoglobin-O₂ dissociation behavior, a precedent study has shown that inter-individual variability in hemoglobin-O₂ dissociation can lead to significant variation in measured sO₂ at a given pO₂ (i.e., sO₂ ranged from 70-99 % when pO₂ was 60 mmHg) [6]. Deviations from normal may therefore introduce error to sO₂ calculations.

This error is expected to be greater at low pO₂, where the O₂-hemoglobin dissociation curve is more sensitive to errors in pO₂ measurement due to its greater slope.

Using measured and calculated sO₂ in clinical practice

Our observations are most relevant to clinicians who treat critically ill patients using POC sO₂ testing employing calculation-based approaches. We recommend that sO₂ be measured by CO-oximetry, rather than calculated, in patients who are expected to have low pO₂ or anytime calculated sO₂ appears inconsistent with the clinical picture.

Clinicians cannot expect to correct calculated sO₂ values using a simple correction procedure, since positive and negative deviations from measured values occur with similar frequency. Overall, we recommend that sO₂ be directly measured by CO-oximetry in settings where inaccuracies in sO₂ calculations may have significant consequences on patient care.

FIG. 1: Agreement between measured and calculated sO₂ values as a function of pO₂. Figure reproduced from Gunsolus IL et al. Low pO₂ contributes to potential error in oxygen saturation calculations using a point of care assay, Am J Clin Pathol 2017; 149: 82-86.
References


