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 ≥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 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 sO_2, such as global oxygen demand and Fick's cardiac output [1-4].

While the proposed superiority of measured over calculated 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 sO_2 that is particularly pronounced when the partial pressure of oxygen (pO_2) is low.

Index case spurs investigation

Our investigation of measured and calculated sO_2 was motivated by a heart catheterization case in our hospital. In this case, a patient was observed to be hypoxic when sO_2 was measured by CO-oximetry. The severity of hypoxemia (sO_2 = 37 %, see Table I) prompted the physician to check this value against a second value obtained using a calculated sO_2 from a POC test (sO_2 = 55 %). The measured (CO-oximetry) and calculated (POC) sO_2 values were noted to be significantly discrepant; this discrepancy was also observed when paired tests were performed approximately one hour later.

Time	sO_2 (%)	Method
12:27	37	CO-oximetry (measured)
12:32	55	POC (calculated)
13:23	39	CO-oximetry (measured)
13:24	59	POC (calculated)

TABLE I: sO_2 values measured by CO-oximetry or calculated by a POC device during a catheterization procedure.

Comparing measured and calculated sO_2

We began to investigate the source of this discrepancy by comparing measured and calculated sO_2 across many patients. We first accessed 3323 archived 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 sO_2 that would be reported by the POC test for each patient. The necessary inputs to this equation (pO_2, pH, and bicarbonate concentration, the latter derived from pCO_2) were measured by the CO-oximeter simultaneously with sO_2 and so were available in the instrument archives.

Equation 1:

$$sO_2 = \frac{x^3 + 150x}{x^3 + 150x + 23400}$$

where $x = pO_2 \cdot 10^{0.48 \cdot (\mathrm{pH}-7{,}4) - 0.0013 \cdot ([\mathrm{HCO3}^-]-25)}$

Using this procedure, we obtained paired values of measured and calculated 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 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 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 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 pO_2

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was less than 50 mmHg. As shown in Fig. 1, the frequency of discrepancies between measured and calculated sO_2 increased with decreasing pO_2.

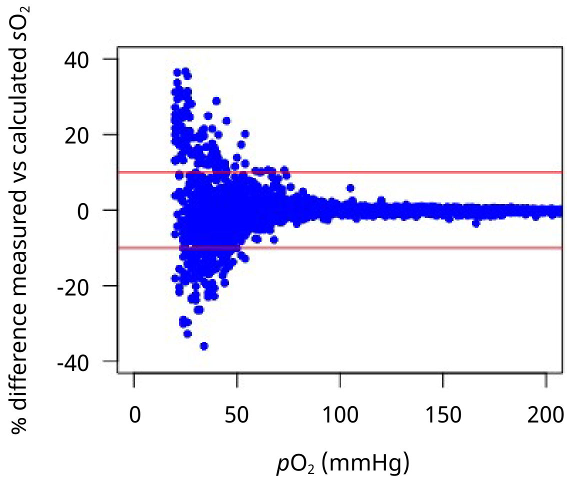

FIG. 1: Agreement between measured and calculated sO_2 values as a function of pO_2. Figure reproduced from Gunsolus IL *et al.* Low pO_2 contributes to potential error in oxygen saturation calculations using a point of care assay, Am J Clin Pathol 2017; 149: 82-86.

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 sO_2 are more likely in patients whose blood parameters deviate significantly from normal, particularly when pO_2 is less than 50 mmHg.

Potential source of discrepancies

We observed that sO_2 values calculated using the model employed by a POC instrument increasingly diverge from sO_2 values measured by CO-oximetry as pO_2 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 sO_2 calculations from measured values under some conditions. One study observed consistently lower calculated than measured sO_2 values in hypoxic blood samples, where pO_2 was set to 10 or 20 mmHg using tonometry [5]. Another study showed that calculated sO_2 values in 21 critically ill patients increasingly diverged from measured values with decreasing pO_2 [1].

Our study did not directly assess the mechanism responsible for the increasing deviation of calculated sO_2 from measured sO_2 as pO_2 decreases. However, we suggest that these deviations result in part from the increasing steepness of the O_2-hemoglobin dissociation curve as pO_2 decreases, together with inter-individual variability in hemoglobin-O_2 dissociation.

While sO_2 calculations assume normal hemoglobin-O_2 dissociation behavior, a precedent study has shown that inter-individual variability in hemoglobin-O_2 dissociation can lead to significant variation in measured sO_2 at a given pO_2 (i.e., sO_2 ranged from 70-99 % when pO_2 was 60 mmHg) [6]. Deviations from normal may therefore introduce error to sO_2 calculations.

This error is expected to be greater at low pO_2, where the O_2-hemoglobin dissociation curve is more sensitive to errors in pO_2 measurement due to its greater slope.

Using measured and calculated sO_2 in clinical practice

Our observations are most relevant to clinicians who treat critically ill patients using POC sO_2 testing employing calculation-based approaches. We recommend that sO_2 be measured by CO-oximetry, rather than calculated, in patients who are

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expected to have low pO_2 or anytime calculated sO_2 appears inconsistent with the clinical picture.

Clinicians cannot expect to correct calculated sO_2 values using a simple correction procedure, since positive and negative deviations from measured values occur with similar frequency. Overall, we recommend that sO_2 be directly measured by CO-oximetry in settings where inaccuracies in sO_2 calculations may have significant consequences on patient care.

References

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