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The big consequences of small discrepancies: Why racial differences in pulse oximetry errors matter

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The COVID-19 pandemic has highlighted the need for reliable, point-of-care blood oxygen assessment among hospitalized patients at high risk of acute hypoxemic respiratory failure. However, biases in pulse oximetry measurement among racial minorities has been a concern for at least three decades. (1) The principles of pulse oximetry rely on differential light absorption of oxyhemoglobin and deoxyhemoglobin in capillary blood to indirectly estimate arterial oxygen saturation (SaO₂). (2) However, skin pigmentation can impact light absorption independent of the proportion of deoxyhemoglobin, which could lead to erroneous pulse-oximetry-derived oxygen saturation (SpO₂) values (measurement bias) in darker-skinned persons. (3) Jubran and colleagues (1) were among the first to identify inaccuracies in oxygen readings inferred from pulse oximetry measurements. Black patients in the ICU had more than a 2-fold higher probability of falsely higher pulse oximetry readings compared to White patients in the ICU. Most studies in the 1990s and 2000s reaffirmed those concerns in various clinical settings. (3–5) Adler and colleagues (6) did not find differences in pulse oximetry measurement bias by skin color among patients in the emergency department, but one-third of darker skinned patients had “suboptimal” signals that could have been erroneous.

The precision and calibration of pulse oximetry concerns many investigators in recent years. (7–9) Sjoding and colleagues (7) found that patients who self-identified as Black and were in the ICU or hospitalized needing oxygen support experienced disproportionately more occult hypoxemia compared to White patients. These findings persisted even after controlling for age, sex, and the cardiovascular score from the sequential organ failure assessment (SOFA). Wong and colleagues (10) also demonstrated racial differences in occult hypoxemia among

ICU patients, and found that occult hypoxemia was independently associated with more organ dysfunction and higher in-hospital mortality. By contrast, Wiles and colleagues (9) found no difference in the agreement of paired SaO₂- and SpO₂ values from ICU patients across racial groups admitted for COVID-19. However, this was in comparison to the mean SaO₂ of all 6216 samples from the entire cohort of 194 patients. The reference group always included the group of interest, potentially reducing any demonstrable differences in measurement bias between groups. The divergent findings of this paper may also have been due to the relatively small sample size.

A recent publication by Henry and colleagues (11) in this issue of *Critical Care Medicine* is a timely and relevant clinical inquiry about the generalizability of pulse oximetry-based oxygen estimation and its association with poor outcomes. The authors wanted to identify racial differences in measurement bias of pulse oximetry that could have caused disparities in occult hypoxemia (SaO₂<88% with SpO₂≥92%) among postoperative and ICU patients. They also tested whether occult hypoxemia was associated with meaningful differences in patient outcome. The authors found statistically significant differences in occult hypoxemia among patients who self-identified as Black, Asian, or American Indian (6.2% [5.1-7.6%], 6.6% [4.9-8.8%], and 6.6% [4.4-10.0%] respectively) compared to those who identified as White (3.6% [3.4-3.8%]). (11) Furthermore, occult hypoxemia was associated with higher odds of death among ICU and post-operative patients with occult hypoxemia (OR 1.36 and 2.96, respectively), and with fewer hospital-free days in post-operative patients with occult hypoxemia compared to those without hypoxemia. (11)

The work by Henry and colleagues is significant for a number of reasons. It analyzed one of the largest cohorts published on this topic to date, with a total of 128,285 SpO₂-SaO₂ pairs from 26,603 unique patients. (11) The authors also highlighted their inclusion of perioperative patients, who are among those at highest risk for hypoxemia. Most importantly, the paper by Henry and colleagues is one of two very recent studies to demonstrate an association between occult hypoxemia and clinically relevant outcomes such as hospital length of stay and mortality. (10) The odds ratio of death among patients with occult hypoxemia was higher in post-surgical compared to ICU patients, presumably because the post-surgical population in this cohort included patients in lower-acuity settings. Moreover, perioperative survivors with occult hypoxemia had fewer hospital-free days compared to those with normal oxygenation. Based on these results, one could infer that Black patients suffered a disproportionate burden of the morbidity and mortality in the study cohort since they were at higher risk of occult hypoxemia than White patients.

There were some limitations in the work by Henry and colleagues. The authors did not account for technical factors like signal quality, differences in sensors (clip-on vs. adhesives), or whether different manufacturers created devices with different calibration errors within the same racial group. Older studies attempted to address these factors, (4, 5) but further study would be needed with contemporary pulse oximetry devices in larger, more racially and ethnically diverse cohorts. The most noteworthy limitation was the use of race as a surrogate for skin pigmentation, but this limitation is found in most studies of pulse oximetry measurement bias. Others have tried to segment skin pigmentation into groups such as dark- or light-skinned patients, but this has historically been very subjective. (1, 4, 5)

The disparities of occult hypoxemia among patients from racial minority groups were almost 2-fold higher than White patients, but the prevalences were quite low (1 in every 82 measurements and 1 in every 55 measurements for White and Black patients, respectively); (11) so why are racial differences in occult hypoxemia a major problem? Henry and colleagues found that occult hypoxemia was associated with prolonged hospitalization and death, (11) so the stakes of identifying and correcting occult hypoxemia could be very high. Clinicians rely on pulse oximetry to triage and make medical decisions about treatment for COVID-19, as well as other diseases that cause hypoxemia. Non-White patients with COVID-19 have a higher risk of ICU hospitalization and death compared to their White counterparts. (12) While these outcome disparities are probably multifactorial, occult hypoxemia may contribute to the different outcomes between Whites and non-Whites. Failure to detect and treat those conditions could adversely affect the care and outcome of individuals with pigmented skin.

Knowledge about racial differences in occult hypoxemia could erode trust in the healthcare system among some in the Black community. According to Henry and colleagues (11), occult hypoxemia occurred more frequently among Black patients, a racial group that has experienced unfair or biased treatment by the medical community. (13, 14) Obviously, pulse oximetry devices cannot invoke racial bias in the social sense. Differences in occult hypoxemia across racial groups is an inadvertent consequence of differences in measurement bias. Still, detection of acute hypoxic respiratory failure can be added to the list of medical conditions with racial disparities. (14) Timely correction of those disparities may improve confidence in the medical system among members of historically disadvantaged racial groups.

What can we do to address this issue? Clinicians should have a low threshold to obtain an arterial oxygen saturation from a blood sample in Black patients in clinical settings where hypoxemia may be encountered, despite how “okay” they may appear. For instance, perhaps one should order an arterial blood gas (ABG) panel on a semi-arousable Black patient who had a recent appendectomy, and is coughing with a SpO₂ of 94% while receiving supplemental oxygen via nasal cannula at a flow rate of 2 liters/minute. Similarly, one might consider ordering an ABG panel on a Black patient admitted to the ICU with COVID receiving oxygen supplementation via high flow nasal cannula who is able to speak, but is mildly tachypneic to 26 breaths/minute with a SpO₂ of 95%. In the long-term, researchers and device companies will need to develop objective ways to measure skin pigmentation and correct for it when using pulse oximetry to estimate arterial oxygen saturation. Though companies that make pulse oximetry devices are required to include a representative mix of patients with different skin pigmentations for their reference standards, (15) the current requirements seem insufficient. Perhaps multiple reference standards are needed for different degrees of skin pigmentation to provide better calibration for patients with darker skin. The entire medical community will need to participate in ending disparities in occult hypoxemia to improve the outcomes of all patients.

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