



Early View

Research letter

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Please cite this article as: Crooks CJ, West J, Morling JR, *et al.* Pulse oximeters' measurements vary across ethnic groups: An observational study in patients with Covid-19 infection. *Eur Respir J* 2022; in press (<https://doi.org/10.1183/13993003.03246-2021>).

This manuscript has recently been accepted for publication in the *European Respiratory Journal*. It is published here in its accepted form prior to copyediting and typesetting by our production team. After these production processes are complete and the authors have approved the resulting proofs, the article will move to the latest issue of the ERJ online.

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**Pulse oximeters' measurements vary across ethnic groups:
An observational study in patients with Covid-19 infection**

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Word count: 1195

The pulse oximeter provides regular non-invasive measurements of blood oxygenation and is used in a wide range of clinical settings [1]. The light wave transmission that this technology uses is modified by skin pigmentation and thus may vary by skin colour. A recent study of paired measures of oxygen saturation from pulse oximetry and arterial blood gas reported differing outputs in patients with black skin compared to patients with white skin that has the potential to adversely impact on patient care [2].

The natural history of Covid-19 infection is modified by ethnic group and individuals with more pigmented skin generally have a higher risk of severe disease [3]. We have used data from patients with Covid-19 infection to explore the differential in difference of blood oxygen levels as measured by pulse oximetry and arterial blood gases stratified by different ethnic groups over a wide range of oxygen saturations.

We used routinely collected electronic data for patients admitted to Nottingham University Hospitals NHS trust between 1 February 2020 and 5 September 2021 with either suspected or confirmed SARS-CoV-2 [4]. Pulse oximetry measurements with a paired blood gas measurement within a 30-minute time window were used as the primary outcome. A 10-minute window between paired samples was assessed as a sensitivity analysis. Data from Intensive Care Units were not available.

Mean differences between oximetry and blood gas were stratified by recorded ethnicity of White, Mixed, Asian, Black and also stratified by level of oxygen saturation as measured by arterial blood gases. A mixed effect linear models of the difference between oximetry and blood gas oxygen saturation by ethnicity (Either White or Black, Asian or Mixed ethnicity) using patient as a random intercept were fitted. Due to the small numbers of individuals labelled as Black, Asian and Mixed ethnic group, a final comparison of these combined categories was compared with the much larger White ethnic group for a final analysis to generate a simple output that can be disseminated to increase clinical awareness of these issues, while concurring with current guidance on describing and reporting ethnicity [5].

Analyses were performed using R statistical software. NUH Clinical Effectiveness Team audit (reference: 21-294C) gave approval for these analyses.

We identified 2997 eligible patients with 5374 paired oxygen saturations recorded in their routine electronic observations within 30 minutes of an arterial blood gas. There were differences in the mean difference between oxygen saturations as measured by pulse oximetry compared to arterial blood gas ($p=0.02$, ANOVA) with the highest differential in the Mixed ethnic group (+6.9%; 95%

Confidence Interval CI: -21.9 to +35.8) and the lowest in the White group (+3.2%; 95% CI: -22.8 to +29.1), with those in the Black group (+5.4; 95% CI: -25.9 to +36.8) and Asian group (+5.1%; 95% CI: -23.8 to 34.0) having intermediate differentials. A sensitivity analysis restricting to a 10-minute window did not alter these differences.

Pulse oximetry overestimated the oxygen saturations compared to blood gas measurement across all ethnicity groups when arterial blood gas oximetry measured saturations were below 90%, and underestimated these when arterial blood gas oximetry measured saturations were above 95% (Table: two way ANOVA excluding unknown ethnicity $p < 0.0001$). These mean differences were particularly marked in the clinically important range when the arterial blood gas demonstrated a true oxygen saturation of 85 to 89%; individuals with a Black ethnicity had a mean pulse oximetry reading that was +3.9% higher (95% CI: -8.0 to +15.9), those with an Asian ethnicity 5.8% higher (95% CI: -1.6 to +13.2) and individuals with a White ethnicity +2.4% (95% CI: -14.2 to +19.0) higher, when compared to arterial blood gas oxygenation.

Similarly, in a mixed effects linear model, individuals with Black, Asian or mixed ethnicity had a higher reading for oxygen saturation as measured by pulse oximetry than blood gas compared to individuals with a White ethnicity (excluding patients without ethnicity recorded) and adjusting for arterial blood gas oxygen saturation (Black +1.8%; 95% CI: +0.2 to +3.4, $p = 0.04$; Asian +1.9%; 95% CI: +0.6 to + 3.2, $p = 0.005$; Mixed +3.2%; 95% CI: -0.1 to +6.6, $p = 0.06$).

A final mixed effects model of the size of the difference between oxygen saturation measured by pulse oximetry compared to arterial blood gases demonstrated that pulse oximetry over-estimated arterial oxygen saturation by a mean +1.4% (95% CI: +0.5 to +2.3, $p = 0.003$) in patients with Black, Asian or Mixed ethnicity compared to patients with White ethnicity, after adjustment for sex, age and arterial blood oxygen level.

In an unselected cohort of patients admitted for Covid-19 infection, pulse oximetry measurement of oxygen saturation was consistently higher compared to arterial blood gas measurement in patients with a recorded Black, Asian or Mixed ethnicity compared to a White ethnicity reference group. These differences were particularly marked in the clinically important range of 85 to 89%, with mean values as measured by pulse oximeter being almost 5% higher than reality in individuals with a recorded Black, Asian or Mixed ethnicity. These observations extend previous concerns on this issue regarding those with Black ethnicity to those from a south-east Asian background, across a wide range of oxygen saturations.

The strengths of these data are that they were collected prospectively in a well-defined cohort of individuals. These represent a relatively homogenous group of patients with the same disease process.

This analysis builds upon earlier observations from intensive care units in 1990 which reported that to maintain satisfactory oxygen saturation as measured by arterial blood gases, target saturations of 92% were adequate in white patients, yet target saturations of 95% were required in black patients [6]. Similarly, paired oxygen saturations as measured by pulse oximetry and arterial blood gases, in healthy volunteers with hypoxaemia created in controlled conditions, varied from 2.3% to 4.3% higher than the true value in black individuals compared to white individuals [7].

These initial observations demonstrating that the higher values of oxygen saturation generated by pulse oximetry in individuals with more pigmented skin compared to those with less pigmented skin may be clinically important were supported by an analysis of two cohorts of patients [2]. This reported that 17% of patients with black skin had 'occult hypoxaemia' as defined as the proportion of patients who had a true oxygen saturation of less than 88% on arterial blood gas measurement while this status was observed in 6.2% of white patients in an unadjusted analysis. These results have triggered an expression of warning by the Food and Drug Administration in the USA on 19th February 2021 [8].

Our analysis extends the concerns about pulse oximeters giving a falsely high reading in patients with Black ethnicity to those from Asia as well. This is important, as high levels of skin pigmentation are associated with the ethnic groups who have a poorer outcome from Covid-19 infection [3], and hence would require the most accurate oxygen measurements available to titrate supplemental oxygen and deliver timely treatment. Although these data cannot quantify the impact of these measurement errors of pulse oximetry on clinical care, our experience is that any delay in appreciating the severity of Covid-19 pneumonitis is likely to be detrimental to patient care, especially now that new therapeutic options are becoming available.

Author contributions

All authors contributed, in part, to the planning, conduct, and reporting of the work described in the article and all authors approved the final submitted draft. Colin Crooks is the guarantor. CJC, JW and SB had full access to the data and attest to its veracity. The guarantor accepts full responsibility for the work and the conduct of the study, had access to the data, and controlled the decision to publish. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Support statement

This work was funded by Nottingham University Hospitals NHS Trust and the University of Nottingham.

Conflict of interest

All authors have completed the ICMJE uniform disclosure form and declare; no financial relationships with any organisations that may have an interest in the submitted work in the past three years; no other relationships or activities that could appear to have influenced the submitted work.

Table. Mean differences in oxygen saturation stratified by the oxygen saturation measured by oximetry. 30 minute time windows between oximetry and blood gas measurements shown

Difference (oximetry – arterial O ₂ %)	Mean difference in oxygen saturation in paired arterial and pulse oximetry samples within a thirty minute time window [95% confidence intervals] (range)				
Ethnicity	Not recorded	White	Black	Asian	Mixed
Overall difference	(n=995) +3.1% [-21.6,+27.7] (-64.1,+80.9)	(n=3946) +3.2% [-22.8,+29.1] (-87.7,+80.1)	(n=151) +5.4% [-25.9,+36.8] (-57.3,73.4)	(n=246) +5.1% [-23.8,+34.0] (-31.4,74.8)	(n=36) +6.9% [-21.9,+35.8] (-2.2,+68.6)
Arterial SO ₂ 95-100%	(n=355) -2.2% [-9.3,+4.9] (-29.8,3.9)	(n=1451) -2.4% [-10.7,+5.8] (-38.1,4.9)	(n=47) -1.0% [-6.8,+4.9] (-11.6,4)	(n=82) -1.3% [-8.2,+5.6] (-24.1,3.1)	(n=15) +0.5% [-3.7,+4.7] (-2.2,4.8)
Arterial SO ₂ 90-94%	(n=404) -0.1% [-7.2,+7.0] (-29.8,+8.6)	(n=1436) -0.4% [-8.7,+7.9] (-52.3,+10.1)	(n=62) +0.5% [-15.2,+16.3] (-57.3,+8.8)	(n=103) +1.0% [-6.4,+8.4] (-17,+10.3)	(n=11) +1.7% [-2.1,+5.4] (-1.9,+4.4)
Arterial SO ₂ 85-89%	(n=93) +3.4% [-7.3,+14.1] (-22.8,13.9)	(n=418) +2.4% [-14.2,+19] (-87.7,15.9)	(n=17) +3.9% [-8.0,+15.9] (-10.8,15.4)	(n=23) +5.8% [-1.6,+13.2] (-0.7,14)	<5 patients
Arterial SO ₂ <85%	(n=143) +24.9% [-16.1,+66.0] (-64.1,80.9)	(n=641) +24.4% [-15,+63.8] (-73.9,80.1)	(n=25) +30.7% [-16.8,+78.2] (-28.7,73.4)	(n=38) +29.8% [-18.3,+77.8] (-31.4,74.8)	(n=7) +30.1% [-12.0,+72.2] (5.2,+68.6)
p<0.0001 for ethnic group (excluding unknown ethnicity), p <0.0001 for blood gas categories (two way ANOVA of saturation difference across individual ethnic group and blood gas categories)					
Sensitivity analysis restricted to 10 minute interval between measurements: p = 0.003 for ethnic group (excluding unknown ethnicity), p <0.0001 for blood gas saturation categories (two way ANOVA of saturation difference across individual ethnic group and blood gas categories)					

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