Pulse oximeter measurements vary across ethnic groups: an observational study in patients with COVID-19

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To the Editor:

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 coronavirus disease 2019 (COVID-19) 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 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 infection [4]. Pulse oximetry measurements with a paired blood gas measurement within a 30-min time window were used as the primary outcome. A 10-min 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” and “black”, and also stratified by level of oxygen saturation as measured by arterial blood gases. A mixed effects linear model 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 belonging to the black, Asian and mixed ethnic groups, 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. Approval for this work was granted *via* an NUH Clinical Effectiveness Team audit (reference: 21-294C) and IRAS (REC: 20/WM/0142, project ID: 282490, amendment number SA02 20/07/21).

We identified 2997 eligible patients with 5374 paired oxygen saturations recorded in their routine electronic observations within 30 min 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% 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-min 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

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Be aware that pulse oximeters overestimate oxygen saturation measurements in patients with hypoxaemia, and that this error is larger in individuals from black and Asian ethnic groups
https://bit.ly/3fCeJP7

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underestimated these when arterial blood gas oximetry measured saturations were above 95% (two way ANOVA excluding unknown ethnicity p<0.0001) (table 1). 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 ethnicity +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 ethnicity +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 of 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.

TABLE 1 Mean differences in oxygen saturation stratified by the oxygen saturation measured by oximetry

	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 S_{O_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 S_{O_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 S_{O_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 S_{O_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)

Data are shown as mean difference in oxygen saturation (S_{O_2}) in paired arterial and pulse oximetry samples within a 30-min time window with 95% confidence intervals and range values. 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-min 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).

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 triggered an expression of warning by the Food and Drug Administration in the USA on 19 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 higher 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.

Colin J. Crooks[1,2,3], Joe West[2,3,4,5], Joanne R. Morling[2,3,4], Mark Simmonds[3], Irene Juurlink[3], Steve Briggs[3], Simon Cruickshank[3], Susan Hammond-Pears[3,5], Dominick Shaw[3,6], Timothy R. Card[2,3,4] and Andrew W. Fogarty[2,3,4]

[1]Nottingham Digestive Diseases Centre, School of Medicine, University of Nottingham, Nottingham, UK. [2]NIHR Nottingham Biomedical Research Centre (BRC), Nottingham University Hospitals NHS Trust and the University of Nottingham, Nottingham, UK. [3]Nottingham University Hospitals NHS Trust, Nottingham, UK. [4]Population and Lifespan Sciences, School of Medicine, University of Nottingham, Nottingham, UK. [5]East Midlands Academic Health Science Network, University of Nottingham, Nottingham, UK. [6]Division of Respiratory Medicine, School of Medicine, University of Nottingham, Nottingham, UK.

Corresponding author: Andrew W. Fogarty (andrew.fogarty@nottingham.ac.uk)

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