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Impact of Skin Tone on Pulse Oximetry Performance and Its Agreement with Arterial Oxygen Saturation in Hospitalized Indian Children

(Skin tone and Pulse oximetry)

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The data sets generated and analysed during the current study are available from the corresponding author upon reasonable request.

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KEYWORDS

Fitzpatrick Skin Type, Oxygen Saturation, Pulse Oximetry.

ABSTRACT:

Background: Pulse oximetry (SpO_2) is a non-invasive method for estimating arterial oxygen saturation (SaO_2). However, growing evidence suggests that darker skin pigmentation may impair its accuracy, leading to overestimation of true oxygen levels. This phenomenon remains under-investigated in paediatric populations with diverse skin pigmentation.

Methods: We conducted a study of 133 hospitalized children. Skin tone was classified for each participant using the Fitzpatrick Skin Type Scale (Types 1-6).Simultaneous measurements of SpO_2 and SaO_2 (via arterial blood gas analysis) were obtained. Participants were grouped for analysis: lighter skin (Fitzpatrick Types 1-2), moderate skin (Types 3-4), and darker skin (Types 5-6).

Results: The study population predominantly had moderate to darker skin tones (Types 4, 5, and 6 collectively 60.1%). A significant discrepancy was found between SpO_2 and SaO_2 that correlated with skin pigmentation .The mean bias (SpO_2 - SaO_2) increased from 0.51% ± 1.02 in lighter-skinned children to 1.52% ± 1.40 in those with moderate skin, and peaked at 2.62% ± 0.59 in darker-skinned children (*p=0.0001*).

Conclusion: Pulse oximetry significantly overestimates true arterial oxygen saturation in hospitalized Indian children with darker skin tones. This systematic error increases with the degree of pigmentation, indicating a risk of occult hypoxemia in this population. These findings highlight a critical limitation of pulse oximetry that must be considered in clinical decision-making to avoid undertreatment of hypoxemia in children with darker skin.

Introduction:

Pulse oximetry is a non-invasive technique used for tracking arterial oxygen saturation (SpO_2) in hospital settings. It is now an essential tool for the management of children with acute illnesses and respiratory distress due to its quick and painless application. It works by emitting light waves through skin measuring how much oxygen is bound to haemoglobin in the blood. However, growing data has highlighted pulse oximetry's possible drawbacks, particularly with regard to its accuracy across skin tones [1]. According to recent research, pulse oximeters have a tendency to overestimate arterial oxygen saturation (SaO_2) in people with darker skin tones. This occurs because devices use light absorption to measure oxygen levels and increased melanin can interfere with the transmission and absorption of light. This can cause hypoxaemia to go unnoticed and care to be delayed in clinical settings [2,3].

It is widely known that the correlation between arterial blood gas measurements and pulse oximetry readings—which are the gold standard for determining oxygenation—varies depending on perfusion, probe placement, and, most importantly, skin pigmentation [4,5]. Most published studies addressing this bias have come from high income countries. Data in children, especially from low and middle income settings, remain scarce. In the Indian paediatric population, where skin tones vary greatly and few studies have thoroughly examined the effect of skin pigmentation on the accuracy and agreement of pulse oximetry with arterial SaO_2, this problem is especially pertinent [6,7]. Accurate clinical assessment, evidence-based management, and health policy decisions all depend on an understanding of these subtleties.

The purpose of this study is to methodically examine how skin tone affects the accuracy of pulse oximetry and how well it correlates with arterial oxygen saturation in Indian children who are hospitalised. Clarifying the degree and clinical relevance of measurement bias in this population will help to enhance patient safety, maximise the use of pulse oximetry, and provide all children, regardless of skin tone, with equitable access to healthcare.

Methodology:

Clinical trial number: Not applicable

This cross-sectional study was conducted over six months in the Department of Paediatrics at Chettinad Hospital and Research Institute, Chennai, to evaluate the impact of skin tone on pulse oximetry performance and

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its agreement with arterial oxygen saturation (SaO_2) in hospitalized Indian children under 12 years of age. Participants were selected via simple random sampling, with a sample size of 133 based on a study by Andrist E et al[8], calculated by formula Estimation of population proportion , ensuring representation across varying skin tones categorized using the Fitzpatrick Skin Type Scale.

Inclusion and Exclusion criteria:

Inclusion criteria encompassed

- Children less than 12 years of age.
- Children who are cooperative
- Children with a range of skin tones categorized using Fitzpatrick skin scale.

Exclusion criteria encompassed

- Children with chronic illnesses that could cause hypoxia.
- Children with skin conditions that could interfere with pulse oximetry measurements.
- Children with behavioural issues

Pulse oximetry (SpO_2) was performed using a calibrated device, while simultaneous arterial blood gas analysis provided SaO_2 values for comparison. Standardized protocols ensured consistency in measurements, and data were analyzed to assess agreement between SpO_2 and SaO_2 across different skin tones, accounting for potential biases. This methodology aimed to objectively determine whether skin pigmentation influences pulse oximetry accuracy in a pediatric Indian population.

Statistical analysis:

Excel was used to enter the gathered data, while SPSS was used for analysis. While qualitative factors are expressed in frequency, quantitative variables are expressed in mean and standard deviation. One statistical method for comparing groups is the ANOVA test.

Results:

Table 1: Characteristics of Children

Variable	No of Patients (n = 133)
Age (years)	6.73 ± 2.94
Boy	73 (45.1)
Girl	60 (54.9)
Weight (kg)	22.23 ± 11.95
Height (cm)	118.58 ± 19.75

The mean & SD of age among our study children are 6.73 ± 2.94 years. The majority of the children were boys. The mean & SD of weight & height are 22.23 ± 11.95 kg and 118.58 ± 19.75 cm.

Table 2: Fitzpatrick Skin Chart[9]

Skin Type	Skin reaction
1	**Always burn, never tan**
2	**Usually burn, tan less than average (with difficulty)**
3	**Sometimes mild burn, tan about average**
4	**Rarely burn, tan more than average (with ease)**
5	**Brown skin**
6	**Black skin**

The table presents the distribution of skin tones among the 133 hospitalized children, classified using the Fitzpatrick Skin Type Scale (ranging from Type 1 [lightest] to Type 6 [darkest]). The majority of children fell into Type 4 (19.5%), Type 5 (21.8%), and Type 6 (18.8%), indicating a predominance of moderate to darker skin tones in the study population. Type 3 (18%) also represented a significant proportion, while Type 1 (9.8%) and Type 2 (12%)—representing lighter skin tones were less common.

Table 3: Comparison of SpO2 and SaO2 between Fitzpatrick skin type

Variable	Fitzpatrick skin type 1 & 2 (n = 30)	Fitzpatrick skin type 3 & 4 (n = 50)	Fitzpatrick skin type 5 & 6 (n = 54)	p-value

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Average SpO2	98.31 ± 0.60	98.16 ± 0.54	98.12 ± 0.58	0.3330
SaO2	97.79 ± 0.90	96.64 ± 1.33	95.50 ± 0.69	***0.0001****
SpO2–SaO2	0.51 ± 1.02	1.52 ± 1.40	2.62 ± 0.59	***0.0001****

p = <0.05 considered as significant

The mean SpO_2 readings were similar across all skin tone groups (~98%), suggesting that pulse oximeters report comparable oxygen saturation values regardless of skin pigmentation.

Our study revealed a significant decline in true arterial oxygen saturation (SaO_2) with increasing skin pigmentation, despite pulse oximetry (SpO_2) readings remaining consistent across all skin tones. SaO_2 was notably lower in children with darker skin—averaging 97.79 ± 0.90 in lighter-skinned (Types 1 & 2) children, 96.64 ± 1.33 in moderate skin tones (Types 3 & 4), and just 95.50 ± 0.69 in darker-skinned (Types 5 & 6) children (*p=0.0001). This discrepancy was further highlighted by the widening gap between SpO_2 and SaO_2 as skin tone darkened: the overestimation by pulse oximetry increased from 0.51 ± 1.02 in lighter skin to 1.52 ± 1.40 in moderate skin, and peaked at 2.62 ± 0.59 in darker skin (*p=0.0001).

Discussion:

Despite similar mean SpO_2 readings across all Fitzpatrick skin types, our results show that pulse oximetry consistently overestimates true arterial oxygen saturation (SaO_2) in Indian children as skin pigmentation increases. In particular, true SaO_2 decreased from 97.79% in the lightest-skinned children to 95.50% in the darkest, and the SpO_2–SaO_2 discrepancy grew linearly with darker pigmentation, whereas SpO_2 values averaged approximately 98% regardless of skin tone.

Similarly a large prospective pediatric study by Starnes JR et al enrolled over 300 children study demonstrated that bias in SpO_2 readings relative to SaO_2 was 1.32–1.88 percentage points higher in children with darker skin, and occult hypoxemia ($SaO_2 < 88\%$ but $SpO_2 > 92\%$) was found far more often in children with ITA category 5 or 6 skin types than in lighter-skinned children [10]. Andrist E et al did a study among younger patients and found the mean & SD of SpO2–SaO2 among whites and blacks are 3.5 ± 5 and 4.3 ± 5 respectively, whereas in our study the mean & SD of SpO2–SaO2 among Fitzpatrick skin type 1 & 2, Fitzpatrick skin type 3 & 4 and Fitzpatrick skin type 5 & 6 are 0.51 ± 1.02, 1.52 ± 1.40 and 2.62 ± 0.59. In both the study it is found to be significant ($p<0.05$) [11].

Additionally, systematic review by Burnett GW et al confirm that the majority of published studies report some degree of overestimation of SaO_2 by pulse oximetry among darker-skinned individuals or those from non-white ethnic groups [12]. Our data further support these conclusions by showing that the SpO_2–SaO_2 gap in darker-skinned children (Types 5&6: 2.62 ± 0.59) falls within the range observed in the study by Sjoding MW et al often ranging from 1–2.5 percentage points, and sometimes higher in the most pigmented subgroups [13] .The observed gaps are also in agreement with studies in adult populations by Feiner JR et al, where bias can reach or exceed 2–3% at low saturations[14]. Several reports argue that the magnitude of bias may be trivial when saturations are high, but clinically significant occult hypoxemia and consequent undertreatment are more likely in cases of severe hypoxemia, and most studies including ours show the overestimation is largest in those settings [15,16]. This is particularly important in children with lower respiratory tract infection where hypoxia is a major concern. In a study by Dhayalan et al a total of 59.3% of children with cough had hypoxia, 68.6% of children with tachypnoea had hypoxia[17].

Limitations:

Among the study's drawbacks is its small sample size, which might not accurately reflect the range of skin tones among Indian kids. Subjectivity may be introduced by using a visual skin tone scale (such as Fitzpatrick) in place of an objective melanin measurement. Despite efforts to account for them, variables like sensor location, perfusion condition, and motion artefacts might have affected SpO_2 readings.

Conclusion:

Despite similar reported SpO_2 values across all Fitzpatrick skin types, this study shows that pulse oximetry overestimates arterial oxygen saturation (SaO_2) in hospitalised Indian children with darker skin tones. As skin pigmentation rises, the SpO_2–SaO_2 gap steadily

widens; children with the darkest skin tones exhibit the most noticeable overestimation. When evaluating oxygenation in children with darker skin, care should be taken when using pulse oximetry alone due to its clinical significance, especially the possibility of undetected hypoxaemia. To guarantee precise and secure care for a variety of paediatric populations, advancements in device technology and additional study into fair monitoring techniques are crucial.

What is already known in this Topic?

Several studies from western adult populations has shown that Pulse oximetry overestimates oxygen saturation in dark skinned individuals leading to occult hypoxemia.

What this Study Adds –

- Provides critical data on a previously understudied population—hospitalized Indian children—demonstrating that the known issue of pulse oximetry inaccuracy is a global concern affecting diverse ethnic and racial groups.
- Clearly documents a "dose-response" relationship between increasing skin pigmentation (as classified by the Fitzpatrick Scale) and the magnitude of pulse oximeter error. The overestimation of true oxygen levels grew progressively larger from lighter to darker skin tones.

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