The Effect of Skin Pigmentation on the Accuracy of Pulse Oximetry in Infants with Hypoxemia

Elizabeth E. Foglia, MD MSCE[1,2], Robin K. Whyte, MB[3], Aasma Chaudhary, BS, RRT[2], Antonio Mott, MD[4], Jodi Chen, MD[5], Kathleen J. Propert, ScD[6], and Barbara Schmidt, MD, MSc[1,2,6]

To compare pulse oximetry measurement bias between infants with hypoxemia with either dark skin or light skin with Masimo Radical 7 and Nellcor Oximax. There was no significant difference in systematic bias based on skin pigment for either oximeter. *(J Pediatr 2017;182:375-7).*

Pulse oximetry provides a safe and noninvasive method to monitor arterial oxygen saturation (SaO_2) levels continuously in children who are critically ill.[1] Studies of adults have demonstrated that pulse oximetry oxygen saturation (SpO_2) consistently overestimates measured SaO_2 in individuals with hypoxemia who have dark skin.[2,3] The impact of skin pigmentation on the accuracy of pulse oximetry in infants with hypoxemia is unknown.

The primary study objective was to compare the bias in pulse oximetry measurement between infants with hypoxemia with either dark skin or light skin. The secondary objective was to determine the accuracy and precision of 2 commonly used oximeters from 2 different manufacturers in infants with hypoxemia.

Methods

This was a prospective, cross-sectional study conducted at the Children's Hospital of Philadelphia. Infants were enrolled with cyanotic congenital heart disease and baseline oxygen saturation <90% and an indwelling arterial line; we excluded infants with elevated methemoglobin levels, hypotension, or anemia. Each subject was only enrolled once. Written informed consent for study participation was obtained from eligible infants' parents. This study was conducted with approval from the institutional review board of Children's Hospital of Philadelphia.

Arterial co-oximetry samples were analyzed with the Siemens Rapidlab 1265 (Siemens Healthcare, Erlangen, Germany). The Rapidlab uses a polychromator to measure light absorbance at several wavelengths from human blood to detect and quantify total hemoglobin and its derivatives. According to the manufacturer, fetal hemoglobin (tested at 20%, 40%, and 85% levels) does not interfere with oxyhemoglobin or deoxyhemoglobin measurement results.[4]

Pulse oximetry was measured simultaneously with 2 oximeters. The Nellcor Oximax (Covidien, Boulder, Colorado) was used clinically in conjunction with the GE Solar 8000 patient monitor (Version 5.4, Neonatal ICU mode; GE Healthcare, Little Chalfont, United Kingdom) with an averaging time of 6 seconds. In addition, a study-specific Masimo Rainbow SET Radical 7, (V7.9.1.0, with LNOP sensor; Masimo Corp, Irvine, California), was programmed with an averaging time of 10 seconds.

The pulse oximeter sensors were placed on the infant's extremities under the observation of operational rules to prevent a differential from right to left or bidirectional shunting across the ductus arteriosus. An opaque blanket was placed over the pulse oximeter sensors, and a study team member confirmed pulse oximetry measurement stability and signal quality. The study team member recorded the displayed pulse oximetry measurement at the same time that an arterial blood sample was obtained from an indwelling arterial catheter. The blood sample was sent immediately to the hospital laboratory for co-oximetry measurement by technicians who were not connected with the study team.

Baseline demographic data and clinical variables that could affect pulse oximetry accuracy were extracted from the medical record. Consistent with previous studies,[5,6] skin pigment group was allocated with the Munsell System Soil Color Chart (2009 Revision, Munsell Color, Grand Rapids, Michigan), Hue 7.5YR (**Figure 1**; available at www.jpeds.com). The value score that best matched the subject's skin on the dorsal surface of the distal extremities was recorded.

As described previously,[7] the accuracy and precision of the pulse oximeters were assessed with the following terms. Bias was defined as SpO_2-SaO_2 for a given pair of measurements in a subject. Precision was defined as 1 SD of the mean distance between individual data points (plotted SpO_2 vs SaO_2) and the best-fit line. Accuracy root mean square (Arms)

Arms	Accuracy root mean square
SaO_2	Arterial oxygen saturation
SpO_2	Pulse oximetry oxygen saturation

From the [1]Department of Pediatrics, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA; [2]Division of Neonatology, Children's Hospital of Philadelphia, Philadelphia, PA; [3]Department of Pediatrics, Dalhousie University, Halifax, Nova Scotia, Canada; [4]Department of Pediatrics, Baylor Medical College, Houston, TX; [5]Department of Anesthesiology and Critical Care Medicine, Children's Hospital of Philadelphia, Philadelphia, PA; and [6]Center for Clinical Epidemiology and Biostatistics, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA

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accounts for both the accuracy and precision of pulse oximetry measurement. Arms is calculated as follows:

$$\text{Arms} = \sqrt{\frac{\sum_{i=1}^{N} (SpO_{2i} - SaO_{2i})^2}{n}}$$

The US Food and Drug Administration requires that pulse oximeters have Arms ≤3% in SpO_2 range from 70% to 100%,[8] in conformance with the International Organization of Standardization. Arms were calculated for all measurements and for measurements when SaO_2 ≥70%.

Using Stata 14.0 (StataCorp, College Station, Texas), we assessed differences between groups with light and dark pigment for continuous variables using *t* test (parametric) and the Wilcoxon rank sum test (nonparametric). For dichotomous variables, the χ^2 test and Fisher exact test were used as appropriate. Differences in bias were compared between groups with light and dark pigment (Student *t* test) and between oximeters (paired *t* test). Linear regression was used to control for baseline characteristics that significantly differed between pigment groups in univariable analysis with *P* value < .05. The study had 80% power to detect 1 SD difference in measurement bias between pigment groups.

Results

Between April 25, 2013, and December 23, 2015, 101 infants were screened, and 36 were enrolled (**Figure 2**; available at www.jpeds.com). There were 21 infants in the group with light pigment and 14 infants in the group with dark pigment. One infant was classified as intermediate pigment (these data were not included in the skin pigment analysis but were included in the assessment of accuracy). Two Nellcor measurements from the group with light pigment were excluded (one because of concern for right-to-left shunting across the ductus arteriosus and one for poor signal quality).

The group with dark pigment was significantly older at the time of the procedure and had a greater mean arterial blood pressure. Infants were not hypothermic, hypotensive, acidotic, or anemic at the time of the procedure (**Table**). Measured SaO_2 values ranged from 60% to 92%. Measurement bias did not differ significantly between groups with light and dark pigment for either oximeter, with or without adjustment for age at the time of the procedure and mean arterial blood pressure (**Table**).

The mean Masimo measurement bias was 0.8% (SD 4.2%). The precision of Masimo measurement was 2.4%, and calculated Arms was 4.2%. For 32 measurements with SaO_2 values ≥70%, the calculated Arms was 4.2%. The mean measurement bias for the Nellcor was 3.9% (SD 5.0%), and the precision (SD) was 2.0%. The calculated Nellcor Arms for all subjects was 6.3%. For 30 measurements with SaO_2 values ≥70%, the calculated Nellcor Arms was 5.4%. Mean Nellcor bias was significantly greater than Masimo bias, *P* = .0005 (**Figure 3**; available at www.jpeds.com).

Discussion

We undertook this study to evaluate pulse oximetry performance under 2 conditions: hypoxemia and darkly pigmented skin. We did not find evidence of systematic bias in pulse

Table. Baseline characteristics and measurement bias according to skin pigment

	Light pigment (n = 21)	Dark pigment (n = 14)	*P* value
Demographic characteristics			
Gestational ages, wk, median (IQR)	39 (38, 40)	38 (37, 39)	.19
Ages at procedure, d, median (IQR)	6 (5, 66)	118 (80, 141)	<.001
Males	14 (67%)	7 (50%)	.32
Exposure to exogenous red blood cells	16 (76%)	14 (100%)	.07
Hemoglobinopathy	0	1 (7%): Hemoglobin FAS	.40
Diagnoses			.99
Hypoplastic left heart	7	6	
Tetralogy of Fallot	3	1	
Pulmonary atresia	4	2	
Tricuspid atresia	1	1	
Truncus arteriosus	1	1	
Transposition of the great arteries	1	1	
Double outlet right ventricle	1	1	
Pulmonic stenosis	1	1	
Other	2	0	
Clinical characteristics at procedure			
Hemoglobin, g/dL, mean (SD)	14.5 (1.4)	13.8 (1.9)	.23
pH, mean (SD)	7.4 (0.1)	7.4 (0.1)	.73
Skin temperature, °C, mean (SD)	37.0 (0.5)	36.9 (0.6)	.49
Mean arterial blood pressure, mm Hg, mean (SD)	55 (14)	67 (12)	.01
Milrinone	10 (48%)	7 (50%)	.89
Dopamine	2 (10%)	0	.51
Measurement biases, mean (SD)			
Masimo Radical 7	0.2% (3.8%) (n = 21)	1.6% (4.8%) (n = 14)	.39*
Nellcor Oximax	3.0% (5.0%) (n = 19)	5.4% (5.1%) (n = 14)	.39*

*Adjusted in linear regression for postnatal age at procedure and mean arterial blood pressure.

oximetry measurement based on skin pigmentation in infants with hypoxemia. We were able to study this question by enrolling children with cyanotic congenital heart disease and stable hypoxemic physiology. Within a broad range of oxygen saturations from 60% to 92%, we did not find evidence of a systematic difference in the degree of bias in pulse oximetry measurement based on skin pigment.

Using Arms, a combined assessment of accuracy and precision, we found that the calculated Arms of both oximeters were greater than 3% (the US Food and Drug Administration requirement), even when we restricted our analysis to infants with SaO_2 values ≥70%. Furthermore, we found that the Nellcor Oximax systematically overestimated measured SaO_2 in infants with hypoxemia. Other investigators also have demonstrated that pulse oximetry overestimates measured arterial saturation in infants with hypoxemia.[9] These findings suggest that pulse oximetry manufacturers should improve their algorithms for children with cyanosis.

Pulse oximetry is recommended to monitor infants immediately after birth during the transition from hypoxemia to normoxia.[10] Furthermore, pulse oximetry is used to monitor infants with cyanotic heart disease in the hospital, and home monitoring is now used for interstage monitoring of infants with hypoplastic left heart syndrome.[11] Clinicians should be aware of the limitations of pulse oximetry performance in infants with hypoxemia and interpret absolute SpO_2 values obtained by pulse oximetry cautiously in infants with hypoxemia.

This study is limited by its relatively small sample size. In addition, the Nellcor oximeter averaging time was specified by the clinical unit and was slightly shorter than the Masimo averaging time; however, we obtained these samples in infants with stable SpO_2 values for the 2 minutes immediately preceding arterial sampling. A small difference in averaging time is therefore unlikely to influence the study results. Study strengths include the fact that we assigned pigment groups based on the skin pigment rather than relying on racial categories. In addition, we collected data about demographic and clinical characteristics that could affect the accuracy of the pulse oximeter. Last, a study team member was present during all measurements to confirm the quality of the pulse oximetry signal. Skin pigment does not lead to additional systematic bias in pulse oximetry measurement in infants with hypoxemia. ■

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Reprint requests: Elizabeth Foglia, MD, MSCE, Division of Neonatology, Hospital of the University of Pennsylvania, 3400 Spruce Street, 8th Floor, Ravdin Building, Philadelphia, PA 19104. E-mail: foglia@email.chop.edu

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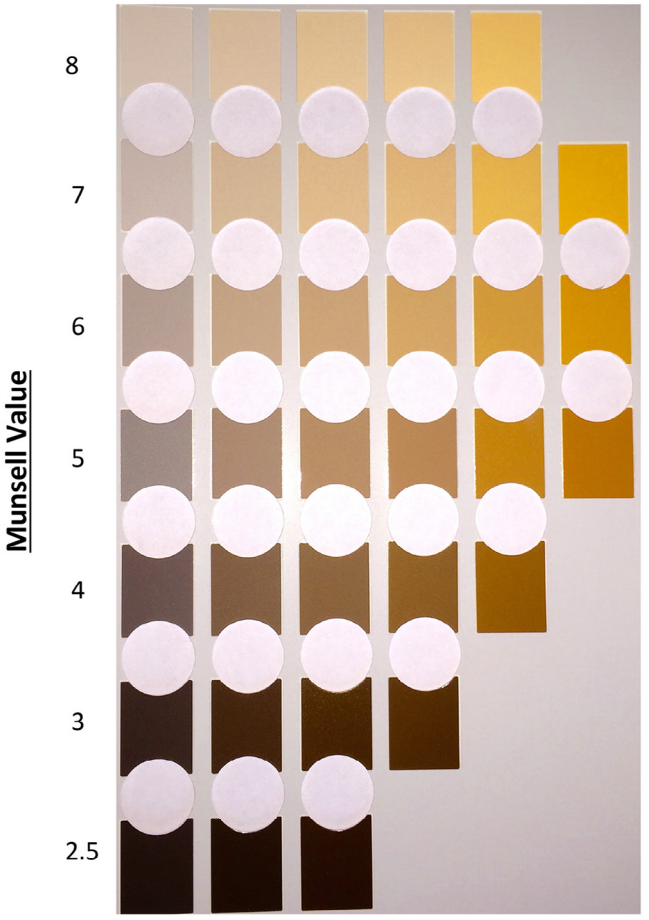

Figure 1. Munsell Soil Book of Color, Hue 7.5YR used to designate pigment group. Light pigment included values 7 and 8. Dark pigment included values 5, 4, 3, and 2.5. Value 6 was considered intermediate and not classified as light or dark. Image reproduced with permission from Munsell Color of X-Rite Pantone inc. (Grand Rapids, Michigan).

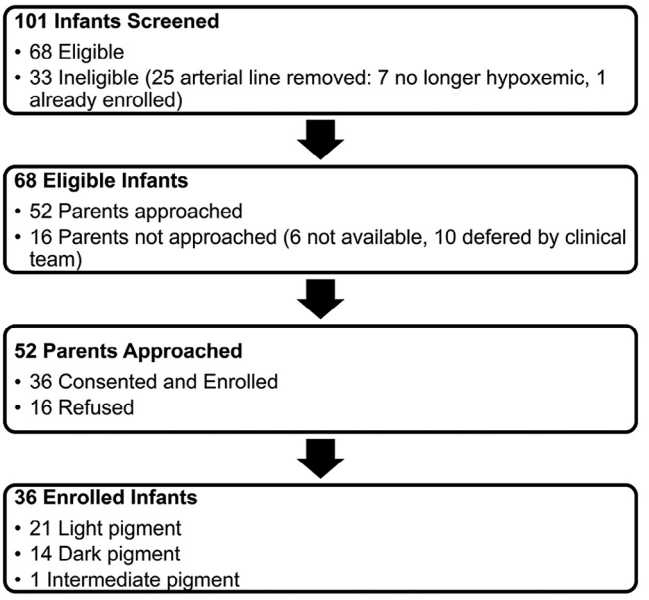

Figure 2. Study screening and enrollment flow diagram.

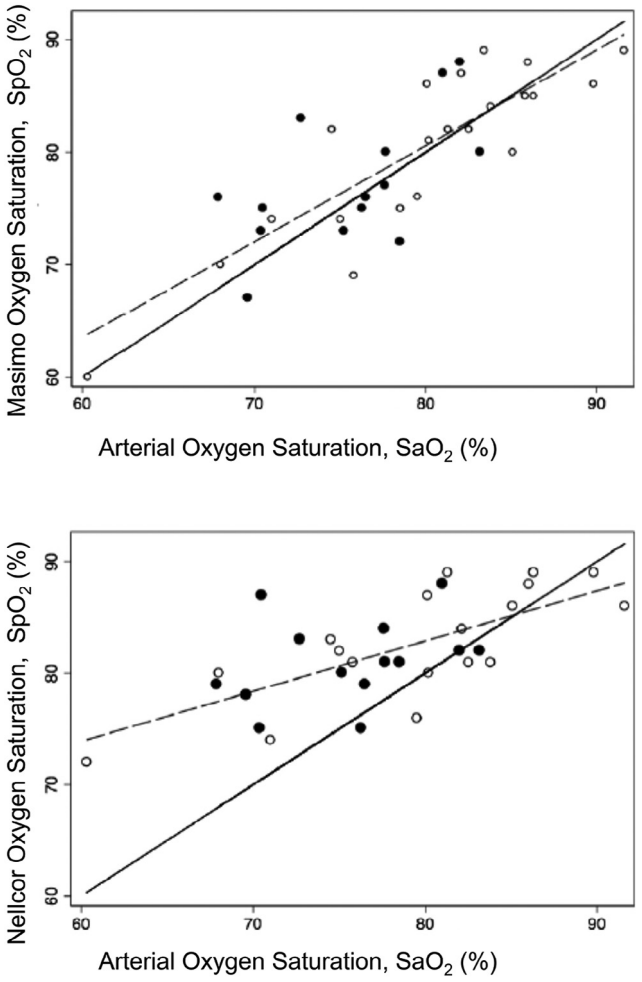

Figure 3. SpO_2 vs SaO_2 for Masimo (*top*) and Nellcor (*bottom*) oximeters with line of equity (*solid*) and fitted line (*dashed*). *Solid circles* indicate dark skin pigment and *open circles* indicate light skin pigment.