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Oxygen Saturation Reference Value by Percutaneous Pulse Oximetry in Asymptomatic Newborn Babies in Nigeria: A Cross-Sectional Study

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Abstract: About 1/4 of all neonatal deaths in Nigeria are caused by birth asphyxia. Normal values of oxygen saturation vary according to regional altitudes. They are important for the screening of cyanotic congenital heart diseases and during newborn resuscitation. There is a dearth of such information in Nigeria. We determined reference values for oxygen saturation by pulse oximetry (SpO_2) in asymptomatic newborns aged ≤7 days in Enugu at an altitude of 180 m. The study was cross-sectional. Neonates weighing ≥1500 g at birth were enrolled consecutively. Pre-and post-ductal oxygen saturation was measured using a Datex-Ohmeda Tuffsat® pulse oximeter with neonatal probes. Five hundred and fourteen babies comprising of 24 (4.4%) preterm and 490 (95.3%) term neonates were studied. The mean pre-ductal SpO_2 of all babies was 96.1% ± 1.4% and higher than mean post-ductal SpO_2 of 95.9% ± 1.4% (p = 0.022). The mean pre-ductal SpO_2 were 96.1% ± 1.5% and 96.1% ± 1.3%, (p = 1.000) for males and females, respectively. The mean pre-ductal SpO_2 values were higher than the mean post-ductal SpO_2 for the corresponding post-natal ages.

Keywords: newborn babies; oxygen saturation; pulse oximetry; reference value

1. Introduction

Pulse oximetry offers a reliable, non-invasive, real-time, and objective method for monitoring oxygen saturation, and has been found to be very useful even in dark-skinned populations where cyanosis is often difficult to recognize with naked eyes only [1–3]. Additionally, assessing skin colour for cyanosis is difficult, and skin colour is a poor proxy for tissue oxygenation during the first few minutes of life [4]. The efficacy and sensitivity of pulse oximetry in assessing the cardiopulmonary adaptation of the newborn, both in normal and asphyxiated newborn infants at birth is well documented [4–8]. Dawson et al. showed in their review that during the first few minutes of life, oxygen saturation (saturation by pulse oximetry, SpO_2) increases from intrapartum levels of 30%–40% to normal values [4,9,10], and advocated that for routine use of pulse oximetry in the delivery room, more research was needed to define normoxia so as to properly apply SpO_2 readings to clinical practice to improve short-term and long-term outcomes [4]. The American Academy of Pediatrics (AAP) and the World Health Organization (WHO) recommend that the assessment following positive pressure ventilation during neonatal resuscitation should consist of simultaneous evaluation of three (3) vital characteristics: heart rate, respirations, and the state of oxygenation—the latter optimally determined by a pulse oximeter [11–13]. Other recommendations for use of the pulse oximeter include when cyanosis is persistent or when supplementary oxygen is administered. This helps to monitor if babies achieve age-related targets of oxygen saturation. It is therefore important to have reference

values for these targets [12]. Clinical guidelines suitable for settings with limited resources based on the reference values of oxygen saturation will be very important for effective and efficient use of the pulse oximeter during resuscitation at birth [14].

These have been established in many other countries [15–17]. Lozano et al. [15] published a study on the reference values of pulse oximetry for children aged 5 days to 24 months and living at Bogota at an altitude of 2640 m above sea level. They found that the values were normally distributed with a mean (SD) of 93.3% and 95% confidence intervals (CI) of 93.0% to 93.6%. Bakr et al. [16] also studied oxygen saturation of term newborns at birth, one hour, and at 24 h at an altitude of 1640 m above sea level. They showed that these values were significantly lower than those at sea level (94.3% SpO_2 at one hour of birth and 95.4% at 24 h of birth). Balasubramanian et al. [17] determined the reference values for children between 1 month and 5 years in India living at sea level. They showed the reference value for mean of SpO_2 in those healthy children to be 98.5% with a −2SD of 96.6%. However, the values from these countries apply to the regions where they were determined with their specific geography, such as altitude and atmospheric pressure [15–17].

Knowing well that oximeter performance deteriorates with increasing skin pigmentation [18,19] and that our region is predominantly dark skinned, and also knowing that there are no reference values for oxygen saturation in our environment, it becomes expedient to determine the reference values for oxygen saturation to guide pulse oximeter use in this environment.

This study was carried out to determine the reference values for pre- and post-ductal oxygen saturation using pulse oximetry in asymptomatic newborns aged 0–7 days in Enugu, a city at an altitude of 180 m above sea level in southeast Nigeria [20].

2. Materials and Methods

This was a cross-sectional, observational study carried out in the post-natal wards of three hospitals in the city of Enugu, Nigeria. These were, University of Nigeria Teaching Hospital, Ituku Ozalla, Enugu State University Teaching Hospital, and the Mother of Christ Specialist Hospital, Enugu, southeast Nigeria between July 2007 and June 2008. These hospitals offer regular obstetric and paediatric care to residents of Enugu and its environs. Consecutive healthy newborn babies aged 0–168 h, weighing ≥1500 g at birth, and whose parents gave informed consent were enrolled. No baby was enrolled more than once during the study. Single measurements of the pre- and post-ductal oxygen saturation of the newborns were taken using a Datex-Ohmeda Tuffsat® hand-held pulse oximeter with a re-usable arterial oxygen saturation sensor, Ameritus® E203-02 Flex-Site SpO_2 neonatal sensor. The neonatal sensor probe was connected to the pulse oximeter before being applied to the newborn at the ulnar border of the right palm. A post ductal pulse oximetry reading was obtained immediately afterwards with the sensor applied to the foot on the same subject. Newborn babies were allowed at least 10 min immediately after delivery to undergo post-natal transition before applying probes, as there are age-related differences (in minutes) in normal target values of oxygen saturation [12,21]. Analysis was done with Statistical Package for Social Sciences (version 16.0.; SPSS Inc., Chicago, IL, USA). Means and standard deviations were determined as appropriate, and differences were tested for statistical significance using the student *t*-test. A one-way analysis of variance (ANOVA) was used to compare means of pre-ductal SpO_2 between different age groups.

3. Results

Five hundred and fourteen neonates aged 0–7 days were enrolled for the study. There were 249 (48.4%) males and 265 (51.6%) females, giving a male to female ratio of 1:1.1 (See Table 1).

The gestational age (GA) of the population is shown in Table 2, with twenty-four (4.7%) neonates delivered before 37 completed weeks of gestation, and four hundred and ninety (95.3%) delivered at term. Other demographic characteristics of the study subjects are shown in Table 3.

Table 1. Sex distribution of the study subjects.

Age Group (Hours)	Sex		Total (*N*)
	Male (%)	Female (%)	
0–24	58 (23.3)	57 (21.5)	115
25–48	59 (23.7)	61 (23.0)	120
49–72	42 (16.9)	56 (21.1)	98
73–96	47 (18.9)	48 (18.2)	95
97–120	25 (10.0)	20 (7.5)	45
121–144	11 (4.4)	12 (4.5)	23
145–168	7 (2.8)	11 (4.2)	18
Total	249	265	514

Table 2. The gestational age (GA) at birth of the study population.

GA at Birth (Weeks)	Number (*N*, %)	
33	1	(0.2)
34	0	(0.0)
35	5	(1.0)
36	18	(3.5)
37	52	(10.1)
38	96	(18.7)
39	160	(31.1)
40	106	(20.6)
41	54	(10.5)
42	22	(4.3)
Total	514	(100.0)

Table 3. Demographic characteristics of the study subjects.

Variable	Overall Mean	Range	Males (Mean ± SD)	Females (Mean ± SD)	*t*-Test
GA (weeks)	38.9 ± 1.7	33–42	39.1 ± 1.7	38.7 ± 1 8	2.41
Postnatal age (hours)	60.9 ± 39.0	0–168	60.5 ± 39.0	61.0 ± 39.2	−0.16
Weight (kg)	3.3 ± 0.5	2.1–4.4	3.3 ± 0.5	3.3 ± 0.5	−0.07
Length (cm)	49.1 ± 2.2	40–55	49.2 ± 2.3	49.1 ± 2.1	1.04
* OFC (cm)	34.8 ± 2.3	30–38	35.0 ± 2.9	34.6 ± 1.3	1.75

* OFC = Occipito frontal circumference.

3.1. Pre- and Post-Ductal SpO_2 of Study Subjects

Table 4 shows the pre- and post-ductal SpO_2 of the study subjects. The range of SpO_2 for each of the two sites was 89%–100%. The overall mean pre-ductal SpO_2 was 96.1% ± 1.4% and was significantly higher than the overall mean post-ductal SpO_2 of 95.9% ± 1.4% ($p = 0.02$). The highest mean pre-ductal SpO_2 percentage was 96.5% ± 1.3% in the 121–144 h age group, while the lowest was 95.4% ± 1.8% in the 145–168 h age group. The highest mean post-ductal SpO_2 percentage was 96.3% ± 1.4% in the 121–144 h age group, while the lowest was the lowest was 95.3% ± 1.8% in the 145–168 h age group. For all groups, the mean pre-ductal SpO_2 were higher than the post-ductal values.

Table 4. Comparison of pre- and post-ductal saturation by pulse oximetry (SpO_2) of the study subjects.

Age Group (Hours)	Number	Mean ± SD Pre-Ductal SpO_2 (%)	Mean ± SD Post-Ductal SpO_2 (%)	Mean Difference	*t*-Test	*p*-Value
0–24	115	96.0 ± 1.4	95.8 ± 1.4	0.20	1.08	0.280
25–48	120	96.0 ± 1.2	95.8 ± 1.3	0.20	1.24	0.217
49–72	98	96.4 ± 1.5	96.0 ± 1.5	0.40	1.87	0.063
73–96	95	96.3 ± 1.4	96.0 ± 1.4	0.30	1.48	0.141
97–120	45	95.9 ± 1.4	95.8 ± 1.5	0.10	0.33	0.744
121–144	23	96.5 ± 1.3	96.3 ± 1.4	0.20	0.50	0.618
145–168	18	95.4 ± 1.8	95.3 ± 1.8	0.10	0.17	0.869
Total	514	96.1 ± 1.4	95.9 ± 1.4	0.20	2.29	0.022 *

* *p*-Value is significant if $p \leq 0.05$.

3.2. The GA at Birth and Pre-Ductal SpO_2

Table 5 shows the impact of GA at birth on pre-ductal SpO_2. The highest SpO_2 of 96.4% ± 1.4% was seen in neonates delivered at 40 weeks gestation, while the lowest was 95.6% ± 1.0%, seen in the neonates delivered at 42 weeks gestation.

Table 5. The GA at birth and pre-ductal SpO_2.

GA at Birth (Weeks)	Number Studied (*n*)	Mean Pre-Ductal SpO_2 ± SD (%)
33	1	96.0
34	-	-
35	5	96.1 ± 1.5
36	18	95.8 ± 1.1
37	52	95.9 ± 1.6
38	96	96.3 ± 1.3
39	160	96.0 ± 1.4
40	106	96.4 ± 1.4
41	54	96.0 ± 1.3
42	22	95.6 ± 1.0

Statistical comparison of the data using ANOVA showed that there was no difference between pre-ductal SpO_2 and GA ($F = 0.81$, $p = 0.61$).

3.3. Pre-Ductal SpO_2 in Relation to Postnatal Age of Infants

Table 6 shows a one-way analysis of variance (ANOVA), which was computed to compare the mean pre-ductal SpO_2 of infants of different postnatal age groups. A small but significant difference was found among the different postnatal age groups ($F = 2.16$, $p = 0.045$, df = 6).

Table 6. Mean values of pre-ductal pulse SpO_2 in relation to postnatal age of infants.

Age Group (Hours)	*n*	Mean Pre-Ductal SpO_2	95% CI	
			Lower Boundary	Upper Boundary
0–24	115	96.0 ± 1.4	95.74	96.26
25–48	120	96.0 ± 1.2	95.82	96.26
49–72	98	96.4 ± 1.5	96.05	96.65
73–96	95	96.3 ± 1.4	95.96	96.54
97–120	45	95.9 ± 1.4	95.45	96.28
121–144	23	96.5 ± 1.3	95.97	97.07
145–168	18	95.4 ± 1.8	94.48	96.29
Total	514	96.1 ± 1.4	95.99	96.23

A statistical comparison of the data using ANOVA showed that there was a statistically significant difference between pre-ductal SpO_2 and post-natal age, ($F = 2.16$, $p = 0.045$, df = 6).

4. Discussion

The reference value of SpO_2 for asymptomatic newborns aged 0–7 days in the study population is 96.1% ± 1.4%, and this value represents the overall mean pre-ductal SpO_2 for all study subjects. It is lower than the reference value of SpO_2 of 98.5% obtained at sea level in Chennai city, India, but higher than the reference values of SpO_2 of 92.6% and 87.8% obtained at Bogota, Colombia and El Alto, Bolivia, respectively, which are high altitude regions [14–16,21]. The altitude of a region affects the oxygen saturation levels. At high altitudes, there is a fall in arterial oxygen saturation which is due to a reduction in atmospheric oxygen tension. This fall in atmospheric oxygen tension is a consequence of a fall in barometric pressure at high altitudes [22]. The findings in this present study are also consistent with what Gonzales and Salirrosas obtained in Lima (150 m above sea level), who compared the SpO_2 in healthy newborns delivered at term in Lima to the SpO_2 of neonates delivered in Cerro de Pasco (4340 m above sea level) and found that at all times, the SpO_2 values were higher at or near sea levels than at high altitudes [23].

The majority of the deliveries for our study subjects occurred at or near term, and this study did not demonstrate any significant difference in SpO_2 between neonates delivered preterm and those delivered at term. The preterm neonates (4.7% of the study subjects) had mean SpO_2 levels of about 96%, which is comparable to those of the term infants. Ng and Subhedar [24] showed that healthy preterm infants maintain a relatively high baseline SpO_2 values. They argued that it is due to the fact that these preterm infants have a predominance of haemoglobin F (HbF) in their blood, which has a greater affinity for oxygen than haemoglobin A (HbA) [24]. However, Pologe and Raley in a previous study suggested that the amount of HbF does not have a clinically significant effect on SpO_2 [25]. Notably, this study showed lower SpO_2 levels for neonates delivered at 42 completed weeks of gestation when compared to those delivered earlier. This could possibly be because these infants may have some compromise due to their GA at birth. More so, these neonates after 42 weeks of gestation mostly likely will have assisted delivery or Caesarean section, and some studies show that neonates delivered by Cesarean section have lower SpO_2 values than those delivered vaginally [26–28], even though this study did not examine the impact of different modes of delivery on oxygen saturation. This may be secondary to the delayed clearance of lung fluid during operative delivery without an adequate period of labour. Other studies found no significant difference in SpO_2 measurements in infants delivered vaginally or by caesarean section, regardless of the presence or type of anaesthesia [6,29,30].

Postnatally, the mean pre-ductal SpO_2 ranged between 95.4%–96.5% for the first week of life. Even though the mean SpO_2 on the 3rd, 4th, and 6th days were noted to be higher than that of the 7th day, no definite pattern was noted; rather, one would suggest an overall fairly stable pre-ductal SpO_2 during this first week of life. This agrees with the pattern of stable or increasing oxygen saturation reported by Mok, Hak, and McLaughlin in infants at sea level [31]. It does, however, differ from the pattern observed in Han and Tibetan neonates by Niermeyer and co-workers in Lhasa [32], Tibet and also that observed by Niermeyer et al. [33] in Colorado infants at 3100 m above sea level. Here, the oxygen saturation levels fall gradually up to the end of the first week. They suggested that increased periodic breathing may underlie the fall in SpO_2 observed at one week of life, and this periodic breathing is increased in infants at high altitudes [32,33]. Importantly, the SpO_2 on the first day of life of 96.1% ± 1.4% compares favourably with the saturations on the rest of the days of the first week of life, in agreement with the findings of a study by O'Brien et al. that during the first day of life, healthy term infants have baseline SpO_2 values that are very similar to those of older infants with a range from 89%–100% [34].

Studies [27,35] have documented a difference in oxygen saturation between upper extremity (pre-ductal) and lower extremity (post-ductal) sites, with lower oxygen saturation seen in the post-ductal sites. This is similar to the findings in the present study, where the mean pre-ductal SpO_2 were slightly but consistently higher than the post-ductal values. The observed difference in the overall mean values of the pre- and post-ductal SpO_2 was statistically significant. Toth et al. [36] found in their study that pre-ductal SpO_2 rose more quickly soon after birth to normal values than the

post-ductal SpO_2. This may account for the lower values of post-ductal SpO_2, especially for values obtained on the first few days of life. Other factors that may be responsible include better perfusion of the upper extremities and higher blood pressure and oxygenation in pre-ductal vessels [28,29]. The process of transitional physiological cyanosis, which can occur during postnatal adaptation, has also been suggested by Rabi et al. [28] to also account for this finding, and this sometimes manifests clinically as acrocyanosis with bluish coloration of extremities. These healthy babies undergo a phase of prolonged transitional circulation, and so, the administration of 100% oxygen to a spontaneously breathing neonate based on visual assessment of cyanosis may be unnecessarily invasive and can lead to potentially dangerous hyperoxaemia. As ductal-dependent congenital heart disease may not be apparent at discharge [37,38], post-ductal arterial pulse oximetry screening during the first 24 h of life has been shown to be the most useful strategy to prevent circulatory collapse or death [39–42]. Therefore, a statistically significant difference between the pre-ductal and post ductal SpO_2 in a particular subject should raise the suspicion of a possible critical congenital cardiovascular disease [43–46]. However, such values of pulse oximetry for both upper and lower limbs should be obtained simultaneously. A two-dimensional echocardiograph will be required to confirm or rule out such suspicions. The pre- and post-ductal oximetry in our subjects were not obtained simultaneously, but within minutes of each other. Merberg et al., however, showed in their recent study that first day of life post-ductal pulse oximetry screening will promote early detection of critical congenital heart diseases with high sensitivity and low false positive rate [47]. Additionally, de Wahl Granelli et al., in a prospective screening study designed to evaluate the use of pulse oximetry in screening for early detection of life-threatening congenital heart disease, showed that introducing pulse oximetry screening before discharge improved total detection rate of duct-dependent circulation to 92%, and would at long-term be a cost-effective procedure if adopted routinely [41].

5. Conclusions

We suggest the reference value for oxygen saturation in newborn babies in Nigeria to be $96.1\% \pm 1.4\%$ and $95.9\% \pm 1.4\%$ (pre- and post-ductal, respectively). Measurement of SpO_2 is useful in routine monitoring of oxygen saturation, which should be done even in resource-limited countries to minimize the risk of hyperoxaemia, hypoxaemia, or fluctuations between both.

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Conflicts of Interest: The authors declare no conflict of interest.

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