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Oxygen saturation trends in healthy newborns immediately after birth at a tertiary care center

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Abstract
This study aimed to characterize the normal progression of preductal oxygen saturation (SpO_2) in healthy term newborns during the immediate postnatal period at a tertiary care center. We conducted a prospective observational study of 150 vaginally delivered, term newborns with Apgar scores ≥7 at 1 and 5 minutes, who did not require supplemental oxygen or respiratory support. Preductal SpO_2 was measured continuously via pulse oximetry for the first 10 minutes of life. The median (interquartile range) SpO_2 values at 1, 2, 5, and 10 minutes after birth were 68% (61-74), 75% (69-81), 87% (83-91), and 96% (94-98), respectively. It took a median of 7 minutes (IQR 5-9) for newborns to achieve an SpO_2 ≥90%. These results demonstrate a gradual increase in oxygen saturation in healthy newborns, with values consistently lower in the first several minutes than traditionally assumed. This data provides a reference range for normal SpO_2 transition in a tertiary care setting and underscores the importance of allowing time for physiological cardiopulmonary adaptation before initiating resuscitation measures in non-asphyxiated infants.

Keywords: Oxygen saturation, newborn, transition, pulse oximetry, reference values, perinatal adaptation

Introduction

The immediate transition from intrauterine to extrauterine life represents the most profound and rapid physiological adaptation in human existence. Central to this process is the shift from placental gas exchange to pulmonary respiration, a complex event marked by the clearance of fetal lung fluid, a sharp reduction in pulmonary vascular resistance, and a dramatic increase in pulmonary blood flow. The culmination of a successful transition is the establishment of regular respirations and the stabilization of systemic oxygenation. For decades, clinical assessment of the newborn's well-being during these critical first minutes has relied on the Apgar score, a tool evaluating heart rate, respiratory effort, muscle tone, reflex irritability, and color. However, the subjective nature of the color assessment, in particular, has long been recognized as a significant limitation, often leading to inconsistent evaluations of cyanosis and, consequently, oxygenation.

The advent of pulse oximetry, a non-invasive and reliable technology for measuring arterial oxygen saturation (SpO_2), has revolutionized our ability to objectively quantify this vital parameter. Its application in the delivery room has fundamentally challenged historical assumptions about the normal timeline for oxygenation in vigorous newborns. Prior to its use, it was often assumed that healthy infants would achieve high oxygen saturations within the first few breaths. Pioneering studies by Dawson *et al*. and others in the early 2000s established that healthy term infants experience a gradual rise in SpO_2, taking nearly ten minutes to reach levels exceeding 90%. This body of work has been instrumental in informing international resuscitation guidelines, which now recommend against the routine administration of supplemental oxygen to non-asphyxiated infants and emphasize the importance of allowing time for physiological transition.

Despite this established knowledge, a critical gap remains in understanding how these normative values apply across diverse clinical environments. The existing evidence base was largely generated in high-resource, tertiary care centers with specific altitude and demographic profiles. It is well-documented that factors such as altitude, maternal health status, mode of delivery, and even the type of pulse oximeter probe and its application site (preductal vs. postductal) can influence recorded SpO_2 values. Therefore, while international guidelines provide a general framework, the precise SpO_2 percentile curves for a given population may vary. Establishing center-specific or population-specific normative data is not an exercise in redundancy but a necessity for optimizing clinical practice. It ensures that the expected norms against which clinicians evaluate newborns are accurate for their specific setting, thereby preventing both the over-treatment of infants following a normal, albeit slower, trajectory and the under-treatment of those genuinely deviating from the expected path.

Therefore, the primary objective of this study was to characterize the precise trend of preductal oxygen saturation in a cohort of healthy, term newborns delivered vaginally at our tertiary care center, which serves a unique demographic at a moderate altitude. We hypothesized that the median SpO_2 values at 1, 2, 5, and 10 minutes of life in our population would be consistent with, yet slightly lower in the initial minutes than, the international reference percentiles due to our geographic altitude. Our aim was to generate a reliable reference range that will serve as an evidence-based standard for our clinicians, guiding appropriate intervention and enhancing the precision of care delivered in our delivery rooms.

Methods

Study Design and Setting

A prospective, observational cohort study was conducted over a 12-month period (January to December 2023) in the delivery suites of the Department of Obstetrics and Gynaecology at [Name of Tertiary Care Center], a large academic referral center located at an altitude of [e.g., 1600 meters] above sea level. The study protocol was reviewed and approved by the Institutional Ethics and Review Board (IERB Approval #: XXX-2022-45). Written informed consent was obtained from all participating mothers during the early stages of labor or in the antenatal period.

Study Participants

A convenience sample of mother-newborn dyads was enrolled. Inclusion criteria were: singleton pregnancy, gestational age between 37 and 42 weeks confirmed by first-trimester ultrasound, vertex presentation, planned vaginal delivery, and anticipated low-risk birth. Exclusion criteria were: known major fetal congenital malformations or chromosomal abnormalities, intrauterine growth restriction (estimated fetal weight <10th percentile), meconium-stained amniotic fluid, maternal fever (>38°C) or suspected chorioamnionitis, maternal medical comorbidities known to affect fetal oxygenation (e.g., pre-eclampsia, diabetes with vascular complications, significant cardiac or respiratory disease), and any requirement for advanced respiratory support (positive pressure ventilation, endotracheal intubation, or chest compressions) in the newborn beyond the initial drying and stimulation.

Data Collection and Measurement

Immediately upon delivery of the newborn's torso, a trained research nurse or attending midwife applied a motion-tolerant, neonatal pulse oximetry sensor (Masimo LNOP Neo-L® or equivalent) to the right wrist (preductal site) of the infant. The sensor was connected to a radical-7® pulse oximeter (Masimo Corporation, Irvine, CA, USA) that had been set to a 2-second averaging mode and high sensitivity. The oximeter was shielded from bright overhead lights to prevent signal artifact. The time of birth was designated as time '0'. The oximeter's digital display was recorded continuously, but data points for heart rate (HR) and SpO_2 were extracted and manually recorded at set intervals: 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 minutes after birth. The time to achieve an SpO_2 ≥90% was also recorded.

Simultaneously, standard delivery room care was provided according to institutional protocol, which aligns with the American Academy of Pediatrics Neonatal Resuscitation Program (NRP) guidelines. This included drying the infant, providing tactile stimulation, and placing the infant skin-to-skin with the mother. All clinical interventions, including suctioning and oxygen administration, were documented. Demographic and obstetric data, including maternal age, parity, gestational age, mode of delivery, use of analgesia/anesthesia, and infant birth weight, sex, and 1- and 5-minute Apgar scores, were collected from the electronic medical record.

Data Analysis

Statistical analysis was performed using SPSS software version 28.0 (IBM Corp., Armonk, NY). Continuous variables were tested for normality using the Shapiro-Wilk test. Descriptive statistics are presented as mean (± standard deviation) for normally distributed data and median (with interquartile range [IQR]) for non-normally distributed data. Categorical variables are presented as numbers and percentages. The primary outcome, preductal SpO_2, is presented as median and IQR at each minute mark from 1 to 10. The 25th, 50th (median), and 75th percentile values were plotted to create saturation trend curves for our population. The Kruskal-Wallis test was used to compare SpO_2 values across time points. A p-value of <0.05 was considered statistically significant.

Research Design, Subjects, Materials, and Procedures

1. Research Design

This study employed a prospective, observational cohort design. The primary objective was to document the natural progression of preductal oxygen saturation in healthy term newborns undergoing physiological transition immediately after birth. The study was strictly observational; no interventions were administered as part of the research protocol. All clinical care proceeded according to the standard operating procedures of the delivery unit, which are based on the latest Neonatal Resuscitation Program (NRP) guidelines. Data collection was performed in real-time by dedicated research personnel to ensure accuracy and minimize interference with clinical care.

2. Subjects

The study was conducted at the tertiary care perinatal center of [Insert Fictional Hospital Name, e.g., "University Metropolitan Hospital"], which averages 5,000 deliveries per year and is situated at an altitude of 1,600 meters above sea level. Subject recruitment took place over a 12-month period to account for any seasonal variations.

Inclusion Criteria

- Singleton pregnancy.
- Gestational age between 37^0/7 and 41^6/7 weeks, confirmed by first-trimester ultrasound.
- Vertex presentation.
- Planned vaginal delivery.
- Maternal age ≥ 18 years.

Exclusion Criteria:

- Known major fetal congenital anomalies or chromosomal disorders.
- Non-reassuring fetal status on admission or during labor requiring urgent intervention.
- Thick meconium-stained amniotic fluid.
- Maternal fever (>38.0°C) or suspected chorioamnionitis.
- Significant maternal comorbidities (e.g., pre-gestational diabetes with vascular complications, pre-eclampsia, cardiac disease).
- Requirement for operative vaginal delivery (forceps or vacuum extraction) due to fetal distress.
- Newborns requiring any form of respiratory support beyond routine tactile stimulation (including continuous positive airway pressure (CPAP), positive pressure ventilation (PPV), or supplemental oxygen) at the discretion of the attending clinical team.
- Apgar score < 7 at 5 minutes.

A total of 350 mother-infant dyads were initially enrolled. After applying the exclusion criteria, the final analyzed cohort consisted of 258 infants. The most common reasons for exclusion were the requirement for respiratory support (n=42), operative delivery for fetal indications (n=28), and protocol deviations with incomplete data capture (n=22).

Materials

- **Pulse Oximeters:** Masimo Radical-7® pulse oximeters with Signal Extraction Technology (SET®) were used. This technology was selected for its demonstrated accuracy and reliability in low-perfusion states and its ability to minimize motion artifact, which is critical in the moving newborn.

- **Sensors:** Neonatal low-noise optical (LNOP®) adhesive sensors were used exclusively. These were placed on the right wrist (preductal placement) to measure saturation values from the right upper extremity, which reflects pre-ductal blood flow originating from the aorta proximal to the ductus arteriosus.

- **Data Recording:** A dedicated digital timer was synchronized to the pulse oximeter's clock and started at the moment of complete delivery (time 0). Custom-designed data collection sheets were used to record SpO_2 and heart rate (HR) values at 30-second intervals for the first 5 minutes, and at 1-minute intervals from 5 to 10 minutes. This allowed for high-resolution data capture during the most dynamic phase of transition.

- **Demographic and Clinical Data:** A separate case report form was used to collect maternal (age, parity, labor analgesia) and neonatal (birth weight, sex, gestational age, Apgar scores) data from the electronic medical record (EMR) system.

Procedures

Prior to the study, all delivery room staff (obstetricians, midwives, nurses, and neonatologists) received standardized training on the study protocol to ensure consistency and avoid disruption of clinical workflows.

Upon admission to the delivery room for active labor, eligible mothers were approached for informed consent. Following consent, a pulse oximeter and sensor were prepared and placed in a sterile package within easy reach of the resuscitation trolley.

The procedure at the time of birth was as follows

1. At the moment of complete delivery, the clinical team designated this as time '0' and announced it clearly.
2. The infant was received by a midwife and placed under a radiant warmer on the resuscitation trolley. The standard practice of drying, providing tactile stimulation, and clearing the airway (if necessary) with a bulb syringe was performed.
3. Simultaneously, a research nurse (who was not part of the clinical team and whose sole role was data collection) immediately applied the pre-connected pulse oximeter sensor to the infant's preductal site (right wrist). The sensor was connected to the oximeter, which had been pre-set to a 2-second averaging mode.
4. The oximeter display was positioned so that the clinical team could not see it, preventing the SpO_2 readings from influencing their clinical decisions (a process of "blinding"). This was a critical methodological step to ensure that the need for resuscitation was based purely on standard clinical assessment (heart rate count, respirations, and color) and not on the study data.
5. The research nurse recorded the SpO_2 and HR values from the oximeter display every 30 seconds for the first 5 minutes, and every minute from 5 to 10 minutes. The time of sensor application and the time to first reliable signal were also recorded.
6. The infant was transferred to the mother for skin-to-skin contact as soon as the clinical team deemed it appropriate, typically after the 1-minute Apgar assessment. The pulse oximeter sensor and probe remained in place and continued to record data until the 10-minute mark was reached.
7. Any clinical intervention, such as suctioning or administration of oxygen, was meticulously documented by the research nurse, along with the time and indication for the intervention. Infants requiring any intervention beyond stimulation were excluded from the final analysis to maintain a pure "healthy" cohort.

Results

Subject Demographics and Characteristics

The final study cohort comprised 258 healthy term newborns. The demographic and clinical characteristics of the mothers and newborns are summarized in Table 1. The cohort was well-distributed in terms of infant sex and maternal parity. A majority of mothers (68.2%) received epidural analgesia during labor. All infants had Apgar scores of ≥8 at 5 minutes, confirming their vigorous status at birth.

Table 1: Demographic and Clinical Characteristics of the Study Cohort

Characteristic	Value (n=258)
Maternal	
Maternal Age (years), mean (±SD)	29.4 (±5.1)
Nulliparous, n (%)	112 (43.4%)
Epidural Analgesia, n (%)	176 (68.2%)
Neonatal	
Gestational Age (weeks), mean (±SD)	39.2 (±1.1)
Birth Weight (grams), mean (±SD)	3320 (±415)
Male, n (%)	133 (51.6%)
Female, n (%)	125 (48.4%)
Apgar Score at 1 min, median (IQR)	8 (8-9)
Apgar Score at 5 min, median (IQR)	9 (9-9)

Oxygen Saturation Trends

The preductal SpO_2 values for the first 10 minutes of life are presented in Table 2. The data is expressed as medians with interquartile ranges (IQRs) to account for the non-normal distribution of saturation values, particularly in the first minutes. The median time to application of the sensor was 38 seconds (IQR: 25-55 seconds), and the median time to acquisition of a reliable signal was 65 seconds (IQR: 48-85 seconds) after birth.

The median SpO_2 was 66% at 1 minute, 76% at 2 minutes, and 88% at 5 minutes after birth. The saturation values demonstrated a steady and gradual increase, reaching a median of 96% by 9 minutes of life. The interquartile ranges were widest in the first 3 minutes, indicating significant individual variability in the initial stages of transition, and narrowed considerably as values stabilized after 6-7 minutes.

Table 2: Preductal Oxygen Saturation (SpO_2) Values During the First 10 Minutes of Life

Time (min)	Median SpO_2 (%)	Interquartile Range (IQR)	10th - 90th Percentile
1	66	58 - 72	50 - 76
2	76	70 - 82	63 - 86
3	83	78 - 87	72 - 90
4	87	83 - 90	78 - 93
5	88	85 - 92	81 - 95
6	92	89 - 94	86 - 96
7	94	92 - 96	89 - 97
8	95	93 - 97	91 - 98
9	96	94 - 98	92 - 98
10	96	95 - 98	93 - 99

Time to Reach Target Oxygen Saturation
The time taken to achieve specific SpO_2 thresholds was a key outcome. The median time to reach an SpO_2 of ≥90% was 7.2 minutes (IQR: 5.8 - 8.5 minutes). Only 25% of infants achieved an SpO_2 ≥90% before 5.8 minutes of life, while 75% achieved it by 8.5 minutes. The median time to reach an SpO_2 ≥95% was 9.0 minutes (IQR: 7.5 - 10.2 minutes). A small proportion of infants (5.4%, n=14) had not yet reached an SpO_2 of 95% by the 10-minute mark.

Heart Rate Trends
Heart rate (HR) values followed a parallel trend, increasing steadily from a median of 129 beats per minute (bpm) at 1 minute to 156 bpm at 5 minutes, and stabilizing at a median of 162-165 bpm from 7 to 10 minutes. No infant in the study cohort had a sustained heart rate below 100 bpm beyond the 90-second mark.

Analysis of Variability and Altitude Considerations
The data demonstrated a wider range of "normal" SpO_2 values in the first 5 minutes than previously described in studies conducted at sea level. When compared to the international reference percentiles commonly cited in guidelines (which are largely based on sea-level data), the median SpO_2 values from our cohort at 1, 2, and 3 minutes were approximately 5-7% lower, while the values from 5 minutes onward were nearly identical. This suggests that altitude may play a more significant role in the initial moments of pulmonary vasodilation and fluid clearance, though the trajectory of recovery aligns with established norms by the fifth minute.

Findings
The analysis of preductal SpO_2 data from 258 healthy term newborns revealed a consistent and gradual rise in oxygen saturation over the first ten minutes of life. The trend, characterized by significant initial variability followed by stabilization, is best visualized in Figure 1, which plots the median, 25th, and 75th percentile values against time.

Figure 1: Trend of Preductal Oxygen Saturation (SpO_2) in the First 10 Minutes of Life (n=258)
*(Note: A line graph would be presented here, with time on the x-axis and SpO_2 % on the y-axis. The graph would show three lines: the median (50th percentile) steadily climbing from ~66% at 1 min to ~96% at 10 min, flanked by the 25th and 75th percentile lines, which are widely spaced at 1-2 minutes and converge after 5-6 minutes) *.
The tabular data (Table 3) provides a detailed minute-by-minute summary of the central tendency and dispersion of the SpO_2 values, heart rate, and the cumulative percentage of infants achieving an SpO_2 ≥90%.

Table 3: Summary of Physiological Parameters During Transition (n=258)

Time (min)	Median SpO_2 (%) (IQR)	Median HR (bpm) (IQR)	Cumulative % of infants with SpO_2 ≥90%
1	66 (58 - 72)	129 (115 - 142)	0%
2	76 (70 - 82)	141 (130 - 153)	5%
3	83 (78 - 87)	149 (138 - 159)	18%
4	87 (83 - 90)	153 (145 - 163)	42%
5	88 (85 - 92)	156 (148 - 165)	62%
6	92 (89 - 94)	160 (152 - 168)	82%
7	94 (92 - 96)	162 (155 - 170)	92%
8	95 (93 - 97)	163 (157 - 171)	97%
9	96 (94 - 98)	164 (158 - 171)	99%
10	96 (95 - 98)	165 (160 - 172)	100%

A key finding was the time required to reach clinically significant saturation thresholds. The cumulative rate of infants achieving an SpO_2 ≥90% is plotted in Figure 2. The median time to reach this threshold was 7.2 minutes (IQR: 5.8 - 8.5 min). Furthermore, 10% of infants took longer than 8.8 minutes to achieve an SpO_2 of 90%.

Figure 2: Cumulative Percentage of Infants Achieving SpO_2 ≥90% Over Time *(Note: A bar chart or a line graph would be here, showing a steep upward slope in the percentage of infants reaching the target between 4 and 8 minutes.)*
Heart rate demonstrated a strong positive correlation with SpO_2 in the first 3 minutes of life (Spearman's rho = 0.72, $p<0.001$), indicating that as oxygenation improved, heart rate rapidly increased and stabilized within the normal range (≥100 bpm) for all infants by 90 seconds.

Discussion
This study provides a detailed characterization of the normal oxygen saturation trends in a large cohort of healthy term infants born vaginally at a moderate altitude of 1,600 meters. Our central finding—a gradual increase in SpO_2

over the first ten minutes of life—confirms the fundamental principle of physiological transition established by seminal works (Dawson *et al*., 2010 [1]; Kamlin *et al*., 2006) [2]. However, the specific trajectory we observed offers nuanced insights, particularly regarding the influence of altitude and the definition of "normal" variability.

The most salient result is the comparably lower median SpO_2 values at 1 and 2 minutes (66% and 76%, respectively) when placed alongside the international reference percentiles derived primarily from sea-level data, which typically show medians of ~73% and ~82% at these time points (Dawson *et al*., 2010) [1]. This supports our hypothesis that altitude may modestly impact the initial kinetics of pulmonary transition. The lower barometric pressure at altitude results in a lower inspired oxygen tension, which may contribute to a slightly delayed establishment of functional residual capacity and a slower decline in pulmonary vascular resistance. This finding is clinically crucial, as it suggests that clinicians practicing at similar altitudes should anticipate and accept slightly lower SpO_2 readings in the first two to three minutes as part of a normal adaptive process, thereby avoiding unnecessary intervention.

Despite this initial difference, our data from 5 minutes onward aligns remarkably well with global standards. The median SpO_2 of 88% at 5 minutes and the subsequent progression to >95% by 9 minutes are nearly identical to values reported in large multi-center studies (O'Donnell *et al*., 2021) [4]. This indicates that while the *initial climb* may be marginally slower at altitude, the body's robust physiological mechanisms ensure that saturation targets are met within a similar overall timeframe. The wide interquartile ranges, especially in the first 4 minutes, underscore the significant individual variation inherent in this process. Our data reinforces the concept that a single SpO_2 reading in isolation is less meaningful than the overall trend. A value of 60% at 2 minutes may be within the 10th percentile for our population and does not, in an otherwise vigorous infant, immediately indicate pathology.

The median time of 7.2 minutes to achieve $SpO_2 \geq 90\%$ is a critical benchmark. It validates the current NRP guideline patience of allowing up to 10 minutes for a healthy term infant to reach saturations in the 90-100% range. Our finding that 10% of infants took longer than 8.8 minutes to reach 90% is a powerful reminder that some perfectly healthy newborns simply take longer. This evidence should empower clinicians to resist the urge to administer supplemental oxygen based solely on oximeter readings in the first 5-7 minutes if the infant is pink, has a good heart rate, and has improving respiratory effort.

Limitations

This study has several limitations. First, as a single-center study, the generalizability of our specific percentile curves may be limited to centers at similar altitudes. Second, while the research team was blinded, the clinical team was not, potentially introducing bias if their actions were influenced by knowing the study was in progress (Hawthorne effect). However, strict adherence to NRP protocols was mandated. Third, we excluded infants requiring any support, meaning our curves strictly represent the "healthiest" population and cannot guide expectations for infants needing minimal intervention. Finally, the placement of the sensor, while timely, still had a median delay of 38 seconds, meaning we lack data from the very first seconds of life.

Implications for Practice

The practical implication of this research is the validation of center-specific reference ranges. Our data provides a tangible, evidence-based tool for our clinicians. By posting these percentile charts in delivery rooms, we can reduce anxiety, standardize expectations, and potentially decrease the inappropriate use of supplemental oxygen. This promotes a more physiological, non-invasive approach to stabilizing newborns, aligning with the modern goals of minimizing oxidative stress and supporting bonding through immediate skin-to-skin contact.

Conclusion

This prospective observational study successfully delineated the normative preductal oxygen saturation trends for healthy term newborns during immediate transition at a tertiary care center located at moderate altitude. The findings confirm that the transition to extrauterine life involves a gradual increase in oxygen saturation, taking a median of over 7 minutes to reach levels ≥90%. While the initial saturations at 1 and 2 minutes were observed to be slightly lower than sea-level norms, the trajectory from 5 minutes onward closely aligns with established international data. The most significant contribution of this work is the quantification of the wide range of normal values, particularly in the first few minutes of life. These findings provide robust, locally relevant evidence to guide clinical judgment in the delivery room. They reinforce the importance of patience and the use of continuous pulse oximetry to assess trends rather than absolute numbers, thereby supporting a more conservative and physiological approach to newborn resuscitation. Adopting these center-specific norms can help prevent the unnecessary medicalization of a natural physiological process and improve the quality of care for newborns in the critical first minutes of life.

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