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Jennifer A. Dawson, C. Omar F. Kamlin, Maximo Vento, Connie Wong, Tim J. Cole,
Susan M. Donath, Peter G. Davis and Colin J. Morley

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Defining the Reference Range for Oxygen Saturation for Infants After Birth



WHAT'S KNOWN ON THIS SUBJECT: Fetal Sp_o₂ is ~60% and can decrease to 30% during labor. After birth, preductal Sp_o₂ increases, taking ≥8 minutes to exceed 90%. The fraction of inspired oxygen can be titrated in the DR by using Sp_o₂ target ranges.



WHAT THIS STUDY ADDS: This study documents 3rd to 97th percentile changes in preductal Sp_o₂ after birth for term and preterm infants with no medical interventions. These findings can be used to monitor changes in Sp_o₂ and to titrate oxygen treatment in the DR.

abstract

OBJECTIVE: The goal was to define reference ranges for pulse oxygen saturation (Sp_o₂) values in the first 10 minutes after birth for infants who received no medical intervention in the delivery room.

METHODS: Infants were eligible if a member of the research team was available to record Sp_o₂ immediately after birth. Infants were excluded if they received supplemental oxygen or any type of assisted ventilation. Sp_o₂ was measured with a sensor applied to the right hand or wrist as soon as possible after birth; data were collected every 2 seconds.

RESULTS: We studied 468 infants and recorded 61 650 Sp_o₂ data points. The infants had a mean ± SD gestational age of 38 ± 4 weeks and birth weight of 2970 ± 918 g. For all 468 infants, the 3rd, 10th, 50th, 90th, and 97th percentile values at 1 minute were 29%, 39%, 66%, 87%, and 92%, respectively, those at 2 minutes were 34%, 46%, 73%, 91%, and 95%, and those at 5 minutes were 59%, 73%, 89%, 97%, and 98%. It took a median of 7.9 minutes (interquartile range: 5.0–10 minutes) to reach a Sp_o₂ value of >90%. Sp_o₂ values for preterm infants increased more slowly than those for term infants. We present percentile charts for all infants, term infants of ≥37 weeks, preterm infants of 32 to 36 weeks, and extremely preterm infants of <32 weeks.

CONCLUSION: These data represent reference ranges for Sp_o₂ in the first 10 minutes after birth for preterm and term infants. *Pediatrics* 2010;125:e1340–e1347

AUTHORS: Jennifer A. Dawson, MN,^{a,b,c} C. Omar F. Kamlin, MBBS, MRCPCH,^{a,b,c} Maximo Vento, PhD, MD,^d Connie Wong, BApplNrsSci,^a Tim J. Cole, PhD, ScD,^{d,e} Susan M. Donath, BSc, MA,^{c,f} Peter G. Davis, MD, FRACP,^{a,b,c,f} and Colin J. Morley, MD, FRACP^{a,b,c}

^aNeonatal Services, The Royal Women's Hospital, Melbourne, Australia; ^bDepartments of ^fPaediatrics and ^bObstetrics and Gynaecology, University of Melbourne, Melbourne, Australia; ^cMurdoch Children's Research Institute, Melbourne, Australia; ^dResearch Unit, Division of Neonatology, Hospital La Fe, Valencia, Spain; and ^eMedical Research Council Centre of Epidemiology for Child Health, University College London Institute of Child Health, London, England

KEY WORDS

newborn infant, resuscitation, oximetry, oxygen saturation, delivery room

ABBREVIATIONS

Sp_o₂—pulse oxygen saturation

IQR—interquartile range

LMS—skewness-median-coefficient of variation

DR—delivery room

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Address correspondence to Jennifer Dawson, MN, Royal Women's Hospital, Neonatal Services, Newborn Research, 20 Flemington Rd, 7th Floor, Parkville, Victoria, Australia. E-mail: jennifer.dawson@thewomens.org.au

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Traditionally, oxygenation levels of newly born infants have been assessed clinically. However, O'Donnell et al¹ showed that there is substantial interobserver and intraobserver variability in assessments of color. Therefore, experts have recommended the use of pulse oximetry to measure oxygenation in this setting.² Several studies reported pulse oxygen saturation (SpO₂) changes in term or near-term infants not requiring resuscitation in the first minutes after birth.^{3–17} Although the studies used different oximeters and methods of applying the sensor, the SpO₂ measurements during the first minutes after birth were remarkably similar. The average SpO₂ value in studies in which measurements were available at 1 minute was ~60% to 70%, and many infants required ≥10 minutes to achieve >90%.^{3–17} Those authors presented data at 1-minute intervals, with the spread of values around the mean or median being described as SE,^{7,8} SD,^{4,6,16–18} or interquartile range (IQR).^{9,10,12,14,19} Altuncu et al³ tabulated the 10th, 25th, 50th, 75th, and 95th percentile values. We aimed to measure SpO₂ in the first minutes after birth in newly born infants who did not receive any resuscitation, to use those values to define reference ranges, and to present the data as percentile charts for use in the delivery room (DR).

METHODS

This prospective observational study was conducted at 2 tertiary centers, the Royal Women's Hospital (Melbourne, Australia) and University Children's Hospital La Fe (Valencia, Spain). Both hospitals have level 3 neonatal intensive care nurseries and have ~5000 to 6000 births per year.

Three data sets were used in the analysis, as described by Kamlin et al,⁹ Dawson (unpublished data 2009), and Vento (unpublished data 2009). Infants

were included if a member of the research team was available at the delivery to record the SpO₂. Infants were excluded if they received any supplemental oxygen or assisted ventilation in the minutes after birth. Infants also were excluded if they had a congenital anomaly that might interfere with the normal transition to extrauterine life. Infants born preterm or through cesarean section were placed on a resuscitation trolley, and the remaining infants were placed on their mother's chest. Before birth, parents gave verbal consent for their infants to participate. The study was endorsed by the relevant research and ethics committees at each hospital.

Immediately after birth, the Apgar timer was started, and a pulse oximeter sensor (LNOP Neo Masimo SET [Masimo, Irvine, CA]) was placed on the infant's right hand or wrist as soon as possible and then was connected to an oximeter (Radical [Masimo]).²⁰ We noted the time after birth at which data were first available on the oximeter. For all infants, the pulse oximeter was set to acquire data with maximal sensitivity and data were averaged over 2-second intervals, because this combination allowed rapid detection of changes in SpO₂ and heart rate during periods of low perfusion.²¹ For the Dawson and Vento data sets, SpO₂ and signal quality (normal, low identification and quality signal, low perfusion, sensor off, and ambient light) data were stored by the oximeter every 2 seconds.

In the data set described by Kamlin et al⁹ SpO₂ data were collected manually from the oximeter display at each minute after birth until 5 minutes or until the SpO₂ was >90%. The SpO₂ measurement at each minute for which data were available was entered into individual Excel (Microsoft, Redmond, WA) spreadsheets. In the Dawson data set, data in a text format from

the oximeter (SpO₂ and signal quality) were downloaded to a computer by using the neO2M program (G Malcolm, Royal Prince Alfred Hospital, Sydney, Australia). In the Vento data set, oximetry data were downloaded by using Profox software (Profox, Escondido, CA).

All resuscitation measures at the Royal Women's Hospital or Hospital La Fe (eg, supplemental oxygen administration, positive pressure ventilation, continuous positive airway pressure treatment, intubation, external cardiac massage, and administration of drugs) were at the discretion of the clinical staff members involved, following hospital protocols based on national resuscitation council guidelines.^{22,23} If infants were active, with good respiratory effort and heart rate, then the clinicians supported the infant's transition with warmth and stimulation. The clinical team could see the pulse oximetry data. The researchers collecting oximetry data were independent of the clinical team members and their decisions.

For percentile chart preparation, individual infant data, including the time to first measurement, were entered into a customized Excel spreadsheet. Individual spreadsheets from each data set were merged and analyzed with Stata Intercooled 10.0 (Stata, College Station, TX). We used the SpO₂ data only when the signal was determined to be of good quality, with no alarm messages (low identification and quality signal, low perfusion, sensor off, or ambient light).

The SpO₂ percentiles were calculated by using the skewness-median-coefficient of variation (LMS) method described by Cole and Green²⁴ and were fitted by using LMSChartMaker Light Version 2.3 (Institute of Child Health, London, England). We used the LMS method to summarize the changing distribution of SpO₂ measurements

after birth. This method uses 3 curves, representing the median, coefficient of variation, and skewness; the latter is expressed as a Box-Cox power. The LMS method was modified to deal with the truncated Sp_o₂ percentage scale; Sp_o₂ values of 100 were changed to 99.9, and then all Sp_o₂ values were logistically transformed as follows: $\text{logit} = \log[\text{Sp}_{\text{o}_2}/(100 - \text{Sp}_{\text{o}_2})] + 5$. Five was added to ensure positive values for LMSChartmaker. Percentiles for logit values were fitted in the usual way (equivalent degrees of freedom for median: 17; coefficient of variation: 3; skewness: 2; transformed age power: 0.5). The logit percentile values were then back-transformed to Sp_o₂ values as follows: $\text{Sp}_{\text{o}_2} = [100\exp(\text{logit} - 5)]/[1 + \exp(\text{logit} - 5)]$.

The infant characteristics are presented as numbers and proportions for categorical variables, means and SDs for normally distributed continuous variables, and medians and IQRs for variables with skewed distribution. The 2-tailed Mann-Whitney *U* test was used to compare the term (≥ 37 weeks) and preterm (< 37 weeks) subgroups.

RESULTS

A total of 813 births were attended, and 345 infants were excluded. Infants were excluded for the following reasons: 27 infants had congenital anomalies, 11 infants received free-flow oxygen, 290 infants received respiratory support, including continuous positive airway pressure therapy and/or intermittent positive pressure ventilation, and we were unable to obtain or download data for 17 infants. The final data set included 61 650 Sp_o₂ measurements from 468 infants who did not receive any interventions other than warmth and stimulation. The Kamlin, Dawson, and Vento data sets contributed 762, 52 777, and 8611 measurements, respectively, to the final data

TABLE 1 Infant Characteristics

	Kamlin (<i>N</i> = 175)	Dawson (<i>N</i> = 264)	Vento (<i>N</i> = 29)	Total (<i>N</i> = 468)
Gestational age, mean (range), wk	37.5 (30–42)	39 (27–42)	29 (25–30)	38 (25–42)
Preterm (< 32 wk), <i>n</i> (%)	7 (4)	12 (5)	20 (69)	39 (8)
Preterm (32–36 wk), <i>n</i> (%)	47 (27)	65 (25)	9 (31)	121 (26)
Term (≥ 37 wk), <i>n</i> (%)	121 (69)	187 (70)	0	308 (66)
Birth weight, mean \pm SD, g	2953 \pm 867	3092 \pm 810	1232 \pm 908	2970 \pm 918
Labor commenced, <i>n</i> (%)	137 (78)	190 (72)	29 (100)	356 (76)
Narcotic during labor, <i>n</i> (%)	16 (9)	45 (17)	0 (0)	61 (13)
General anesthetic, <i>n</i> (%)	9 (5)	8 (3)	0 (0)	17 (7)
Vaginal birth, <i>n</i> (%)	68 (39)	158 (60)	20 (70)	246 (52)
Apgar score at 1 min, median (IQR)	8 (7–9)	8 (8–9)	6 (5–7)	8 (8–9)
Apgar score at 5 min, median (IQR)	9 (9–9)	9 (9–9)	7 (6–8)	9 (9–9)
Time from birth to first data, median (IQR), s	70 (60–84)	60 (54–74)	99 (85–130)	65 (58–85)

set. There were no statistically significant differences between Sp_o₂ measurements at each minute from 1 to 10 minutes between the 3 data sets.

The median gestational ages of the 306 term infants (≥ 37 weeks) and the 160 preterm infants (< 37 weeks) were 40 weeks (range: 37–42 weeks) and 33 weeks (range: 25–36 weeks), respectively. The characteristics of the infants are presented in Table 1. There were 174, 248, 270, 281, 292, 252, 249, 231, 223, and 215 individual infant Sp_o₂ observations at each minute from 1 to 10 minutes. At 1 minute, the 3rd, 10th, 50th, 90th, and 97th percentiles were 29%, 39%, 66%, 87%, and 92%, respectively; at 2 minutes, 34%, 46%, 73%, 91%, and 95%; and at 5 minutes, 59%, 73%, 89%, 97%, and 98%.

It required a median of 7.9 minutes (IQR: 5.0–10.0 minutes) to reach Sp_o₂ values of $> 90\%$. At all time points, the median Sp_o₂ was significantly lower for preterm infants than for term infants (Table 2). Table 3 compares the times to reach Sp_o₂ levels of 70%, 80%, 90%, and 95% for preterm and term infants. Preterm infants took longer than term infants to reach each Sp_o₂ target. Table 4 illustrates Sp_o₂ values from 1 to 10 minutes for vaginal versus cesarean births. Figures 1 to 4 show the Sp_o₂ 3rd, 10th, 25th, 50th, 75th, 90th, and 97th percentiles for all infants (Fig 1), term infants of ≥ 37

weeks (Fig 2), preterm infants of 32 to 36 weeks (Fig 3), and extremely preterm infants of < 32 weeks (Fig 4).

DISCUSSION

This study reports how Sp_o₂ values changed in a large number of infants in the first 10 minutes after birth. We used a new-generation oximeter to reduce movement artifacts and studied only infants who received no DR interventions. Sp_o₂ increased steadily over time, requiring 8 minutes to exceed 90% in term infants. These data are comparable to those from other studies.^{3,5–10,12,17,25–27} Sp_o₂ is $< 60\%$ in the fetus just before birth²⁸ and can decrease to 30% during labor.²⁹ For comparison, the 3rd percentile values at 1 minute and 5 minutes for all infants were 29% and 59%, respectively. It is important to use the best technique to obtain a signal in the shortest possible time after birth. We used the method described by O'Donnell et al,²⁰ who showed that readings were obtained most quickly when the Masimo sensor was applied to the infant before being connected to the oximeter. We placed the sensor on the right hand or wrist of the infant because preductal Sp_o₂ is significantly higher than postductal Sp_o₂ soon after birth.^{5,10,12,16} We used a Masimo pulse oximeter with 2-second averaging, set at maximal sensitivity, following the recommenda-

TABLE 2 Comparison of Sp_o₂ Values at 1 to 10 Minutes After Birth for Preterm and Term Births

Time After Birth	Sp _o ₂ , Median (IQR), %			P
	Preterm Infants	Term Infants	All Infants	
1 min	62 (47–72)	68 (60–77)	66 (55–75)	<.001
2 min	68 (58–78)	76 (65–84)	73 (63–82)	<.001
3 min	76 (67–83)	81 (71–90)	78 (69–88)	<.001
4 min	81 (72–88)	88 (78–94)	85 (76–93)	<.001
5 min	86 (80–92)	92 (83–96)	89 (82–95)	<.001
6 min	90 (81–95)	94 (86–97)	92 (85–96)	<.001
7 min	92 (85–95)	95 (90–97)	94 (88–97)	<.001
8 min	92 (87–96)	96 (92–98)	95 (90–98)	<.001
9 min	93 (87–96)	97 (94–98)	95 (92–98)	<.001
10 min	94 (91–97)	97 (94–98)	96 (92–98)	<.001

Preterm infants were born at <37 weeks and term infants at ≥37 weeks.

TABLE 3 Time for Infants to Reach Sp_o₂ Targets of >70%, >80%, >90%, and >95%

Sp _o ₂ Target	Time to Reach Target, Median (IQR), min			P
	Preterm Infants	Term Infants	All Infants	
>70%	6.2 (3.6–9.0)	5.0 (3.0–8.8)	5.4 (3.1–8.8)	.08
>80%	7.3 (4.6–10.0)	6.1 (4.0–9.1)	6.6 (4.0–9.4)	.06
>90%	8.1 (6.7–10.5)	7.6 (5.0–9.4)	7.9 (5.0–10.0)	.09
>95%	8.5 (7.0–10.5)	8.8 (6.3–10.1)	8.8 (6.8–10.2)	.61

Preterm infants were born at <37 weeks and term infants at ≥37 weeks.

TABLE 4 Comparison of Sp_o₂ Values at 1 to 10 Minutes After Birth for Vaginal and Cesarean Births

Time After Birth	Sp _o ₂ , Median (IQR), %		P
	Vaginal Birth	Cesarean Birth	
1 min	67 (62–76)	54 (40–70)	.003
2 min	71 (60–78)	62 (41–76)	.002
3 min	80 (68–89)	67 (43–83)	.001
4 min	86 (78–94)	75 (53–91)	<.001
5 min	92 (83–96)	85 (60–94)	<.001
6 min	94 (87–97)	92 (84–96)	.09
7 min	95 (90–97)	94 (83–97)	.2
8 min	96 (92–98)	94 (86–98)	.1
9 min	96 (93–97)	94 (89–97)	.03
10 min	96 (93–98)	94 (91–98)	.2

tion of Leone and Finer.²¹ This combination of settings improves Sp_o₂ measurements during periods of low perfusion.³⁰

One reason given for failure of Sp_o₂ measurements in the DR is motion artifacts.^{4,5,8,9,13,15} This is less when Masimo signal extraction technology is used.^{9,31} We analyzed data only when there was a good plethysmographic wave and good signal quality. Therefore, our results are unlikely to be affected by artifacts. Different manufacturers use “fractional” or “functional” Sp_o₂ algorithms to calculate Sp_o₂. Thilo et al³² simultaneously placed oxime-

ters with either a functional or fractional algorithm on 30 infants and found that the Nellcor oximeter (Nellcor Inc, Hayward, CA) (functional) read higher than the Ohmeda Biox 3700 oximeter (Ohmeda, Louisville, CO) (fractional) by a mean ± SD of 1.61 ± 2.69% (*P* < .001). There are no studies comparing oximeters in the DR. However, the differences between the Masimo oximeter (functional) and other oximeters that measure fractional Sp_o₂ are likely to be ~2% and therefore not clinically important in this situation.

Our findings are consistent with those of Altuncu et al³ who, using a Nellcor

oximeter, described the 10th, 25th, 50th, 75th, and 95th percentile ranges from 1 to 10 minutes for 200 newly born infants at >36 weeks of gestation. The median Sp_o₂ values at each minute were as follows: 1 minute, 71%; 2 minutes, 77%; 3 minutes, 83%; 4 minutes, 90%; 5 minutes, 92%; 6 minutes, 95%; 7 minutes, 96%; 8 minutes, 96%; 9 minutes, 97%; 10 minutes, 98%.³ The small differences with respect to our study could be explained by the slightly different techniques and different oximeters used.

There are reports of Sp_o₂ measurements with term infants just after birth but few with preterm infants. The median Sp_o₂ at 5 minutes for our preterm infants was 86%, compared with 92% for term infants (*P* < .001). Kamlin et al⁹ reported that the median Sp_o₂ at 5 minutes for preterm infants was 87%, which was significantly lower than the value for term infants of 90% (*P* < .001). Nuntnarumit and Rojnueangnit¹⁹ studied infants of <35 weeks who did not receive supplemental oxygen in the DR and reported slightly higher Sp_o₂ values over the first minutes and a shorter time to reach Sp_o₂ of 90% than we found in our study. The lower gestational age of the preterm infants in our study may explain the differences. In the observational study by Kopotic and Lindner³¹ of 15 infants born at 24 to 29 weeks of gestation, the mean time to reach Sp_o₂ of ≥80% was 4.4 minutes; however, their infants might have received oxygen therapy or other interventions.

Preterm infants are at most risk of harm from oxygen toxicity,^{33–35} with the American Heart Association “cautioning the clinician about the use of excessive oxygen, especially in the premature infant.”³⁶ Our percentile values for Sp_o₂ in preterm infants after birth could assist clinicians in reducing the oxygen load³⁷ when supplemental oxygen treatment is used.

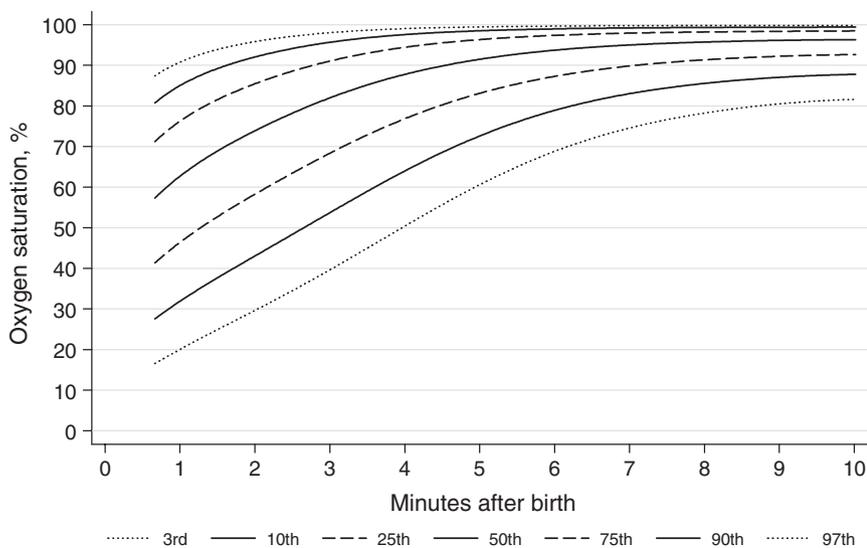


FIGURE 1 Third, 10th, 25th, 50th, 75th, 90th, and 97th Sp_o₂ percentiles for all infants with no medical intervention after birth.

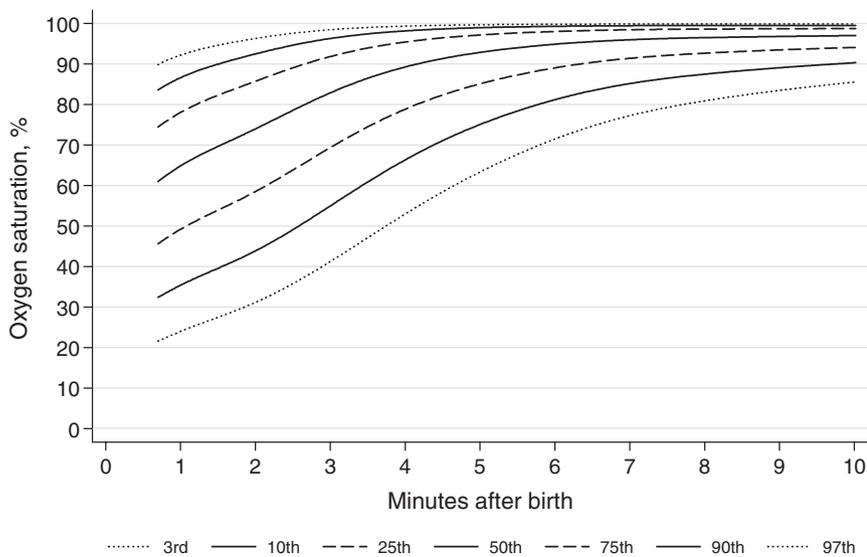


FIGURE 2 Third, 10th, 25th, 50th, 75th, 90th, and 97th Sp_o₂ percentiles for term infants at ≥ 37 weeks of gestation with no medical intervention after birth.

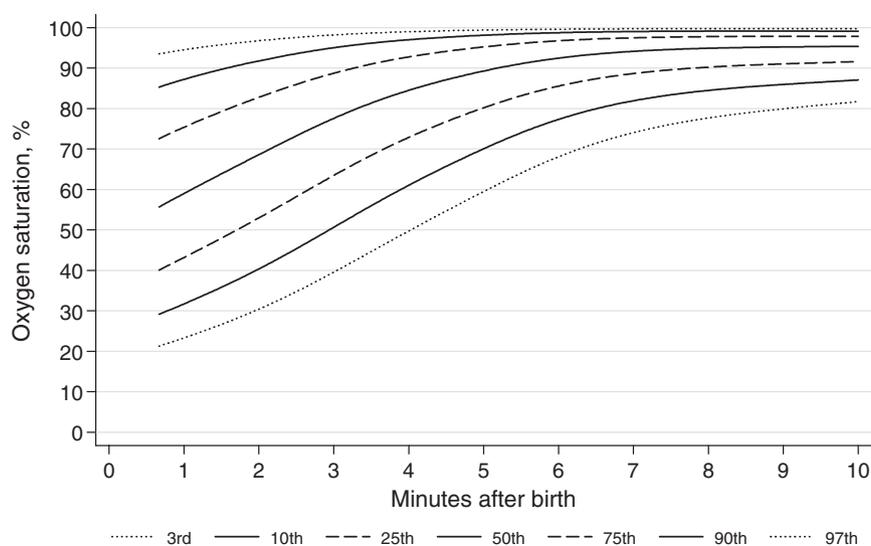
In the first 5 minutes after birth, infants born through cesarean section had significantly lower Sp_o₂ measurements than those delivered vaginally. This is consistent with the findings of Rabi et al¹⁴ and Harris et al.⁸ In contrast, other researchers found no significant differences between infants delivered vaginally or through cesarean section.^{5,13,25} The latter studies had smaller samples and used older-

generation pulse oximeters, which might explain their findings.

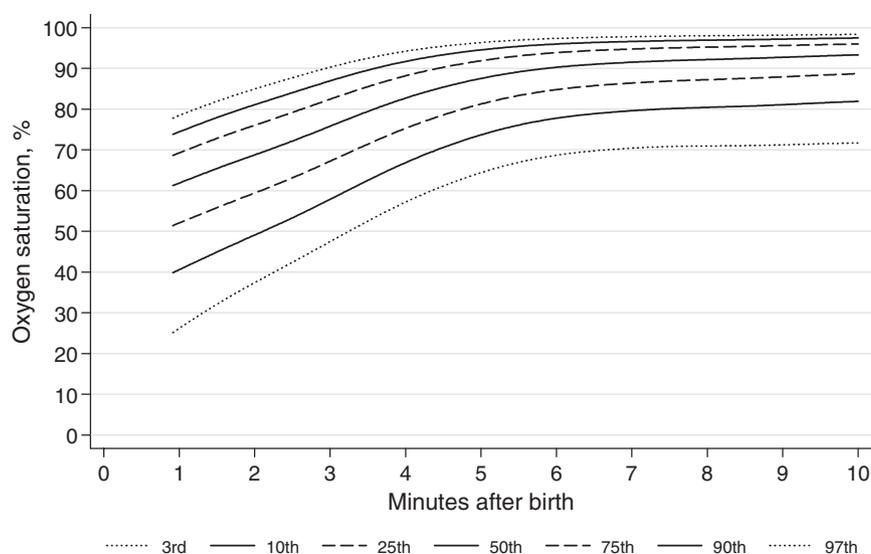
Sp_o₂ decreases with increasing altitude,⁷ and these percentile values might not apply to infants born at a high altitude. However, the magnitude of the changes with time is likely to be similar.

We have presented the data as smoothed percentile curves. These are

used to show the distribution of measurements as they change according to some covariate, often age,²⁴ and are commonly used with anthropometric measurements to assess growth. The benefit of this method was that it allowed us to “capture” every measurement (61 650 Sp_o₂ data points), rather than “snapshots” of the data at each minute after birth. The use of percentiles to describe these data enables us to include all of the data collected every 2 seconds, rather than just values at each minute. If data were plotted at each minute, then an infant without data at that time would not be included in the chart; collecting data every 2 second enables more-accurate charting at each minute and for the 60 seconds between minute points. The use of medians, IQRs, and ranges does not give the same detail, with little information on one-half of the data in the upper and lower quartiles. Percentiles show the whole range of values. Percentile charts allow clinicians to choose Sp_o₂ levels above and below which they do not want the infant’s Sp_o₂ values to go. Some clinicians may want to keep an infant’s Sp_o₂ close to or above the median, others may not want the Sp_o₂ above the 90th percentile or below the 10th percentile, and others may choose the 25th percentile. Percentile charts allow clinicians to see the dynamic changes in Sp_o₂ values as they cross the percentiles. Pediatricians are very familiar with the concepts of percentile charts for growth and how they should be used and interpreted. We have presented percentile charts for all of the infants and for 3 gestational subgroups, that is, ≥ 37 weeks, 32 to 36 weeks, and < 32 weeks. The difference in Sp_o₂ values between the preterm (< 37 weeks) and term (≥ 37 weeks) infants is statistically significant; however, it is not likely to be clinically significant. There is a wide range of Sp_o₂ measurements in the first min-

**FIGURE 3**

Third, 10th, 25th, 50th, 75th, 90th, and 97th SpO_2 percentiles for preterm infants at 32 to 36 weeks of gestation with no medical intervention after birth.

**FIGURE 4**

Third, 10th, 25th, 50th, 75th, 90th, and 97th SpO_2 percentiles for preterm infants at <32 weeks of gestation with no medical intervention after birth.

utes after birth, and we recommend that clinicians consider using one of the charts when monitoring SpO_2 values during transition.

Infants in our study did not receive supplemental oxygen or respiratory support in the first 10 minutes after birth. In other locations, similar infants might have received supplemental oxygen or prophylactic continuous positive airway pressure

therapy or intermittent positive pressure ventilation. At both hospitals during the study period, however, clinicians and not research team members were responsible for deciding whether to provide supplemental oxygen or respiratory support.

The aim of this study was to provide reference charts for SpO_2 measurements that clinicians could use during

stabilization and resuscitation. This is especially important when treating extremely preterm infants at risk of hyperoxia.³⁸ The observational studies by Deckardt et al⁴ and Kopotic and Lindner³¹ suggested that using SpO_2 measurements in the DR was valuable in managing resuscitation. Recently, Finer and Leone³⁹ advocated use of a targeted SpO_2 protocol in the DR. Three randomized trials showed that it was possible to titrate the fraction of inspired oxygen in the DR by using SpO_2 target ranges.^{27,37,40}

In response to the debate on room air versus 100% oxygen, Kattwinkel² suggested that “we should be aiming to restore normoxia quickly and to achieve normal levels of blood oxygen throughout and beyond the resuscitation process. More aggressive use of the pulse oximeter in the delivery setting may facilitate achieving this goal.” The best definition of “normoxia” is that which leads to the best short- and long-term outcomes after resuscitation. There is currently insufficient evidence to specify the optimal concentration of oxygen to be used at the initiation of resuscitation, and studies to compare different ranges of normoxia will take many years. Until then, our percentile charts provide our best estimates of the appropriate SpO_2 targets during resuscitation. Once adequate ventilation has been established, these charts may help guide clinicians in titrating oxygen concentrations to specific targets at different times after birth.

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