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Defining the Reference Range for Oxygen Saturation for Infants After Birth

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WHAT'S KNOWN ON THIS SUBJECT: Fetal Spo_2 is ~60% and can decrease to 30% during labor. After birth, preductal Spo_2 increases, taking ≥8 minutes to exceed 90%. The fraction of inspired oxygen can be titrated in the DR by using Spo_2 target ranges.

WHAT THIS STUDY ADDS: This study documents 3rd to 97th percentile changes in preductal Spo_2 after birth for term and preterm infants with no medical interventions. These findings can be used to monitor changes in Spo_2 and to titrate oxygen treatment in the DR.

abstract

OBJECTIVE: The goal was to define reference ranges for pulse oxygen saturation (Spo_2) 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 Spo_2 immediately after birth. Infants were excluded if they received supplemental oxygen or any type of assisted ventilation. Spo_2 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 Spo_2 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 Spo_2 value of >90%. Spo_2 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 Spo_2 in the first 10 minutes after birth for preterm and term infants. *Pediatrics* 2010;125:e1340–e1347

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

ABBREVIATIONS
Spo_2—pulse oxygen saturation
IQR—interquartile range
LMS—skewness-median-coefficient of variation
DR—delivery room

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Traditionally, oxygenation levels of newly born infants have been assessed clinically. However, O'Donnell et al[1] 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 (Spo_2) 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 Spo_2 measurements during the first minutes after birth were remarkably similar. The average Spo_2 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 al[3] tabulated the 10th, 25th, 50th, 75th, and 95th percentile values. We aimed to measure Spo_2 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 Spo_2. 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 Spo_2 and heart rate during periods of low perfusion.[21] For the Dawson and Vento data sets, Spo_2 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 al[9] Spo_2 data were collected manually from the oximeter display at each minute after birth until 5 minutes or until the Spo_2 was >90%. The Spo_2 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 (Spo_2 and signal quality) were downloaded to a computer by using the ne02M 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 Spo_2 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 Spo_2 percentiles were calculated by using the skewness-median-coefficient of variation (LMS) method described by Cole and Green[24] 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 Spo_2 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 Spo_2 percentage scale; Spo_2 values of 100 were changed to 99.9, and then all Spo_2 values were logistically transformed as follows: $\text{logit} = \log[Spo_2/(100 - Spo_2)] + 5$. 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 Spo_2 values as follows: $Spo_2 = [100\exp(\text{logit} - 5)]/[1 + \exp(\text{logit} - 5)]$.

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 Spo_2 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 set. There were no statistically significant differences between Spo_2 measurements at each minute from 1 to 10 minutes between the 3 data sets.

TABLE 1 Infant Characteristics

	Kamlin (*N* = 175)	Dawson (*N* = 264)	Vento (*N* = 29)	Total (*N* = 468)
Gestational age, mean (range), wk	37.5 (30–42)	39 (27–42)	29 (25–30)	38 (25–42)
Preterm (<32 wk), *n* (%)	7 (4)	12 (5)	20 (69)	39 (8)
Preterm (32–36 wk), *n* (%)	47 (27)	65 (25)	9 (31)	121 (26)
Term (≥37 wk), *n* (%)	121 (69)	187 (70)	0	308 (66)
Birth weight, mean ± SD, g	2953 ± 867	3092 ± 810	1232 ± 908	2970 ± 918
Labor commenced, *n* (%)	137 (78)	190 (72)	29 (100)	356 (76)
Narcotic during labor, *n* (%)	16 (9)	45 (17)	0 (0)	61 (13)
General anesthetic, *n* (%)	9 (5)	8 (3)	0 (0)	17 (7)
Vaginal birth, *n* (%)	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)

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 Spo_2 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 Spo_2 values of >90%. At all time points, the median Spo_2 was significantly lower for preterm infants than for term infants (Table 2). Table 3 compares the times to reach Spo_2 levels of 70%, 80%, 90%, and 95% for preterm and term infants. Preterm infants took longer than term infants to reach each Spo_2 target. Table 4 illustrates Spo_2 values from 1 to 10 minutes for vaginal versus cesarean births. Figures 1 to 4 show the Spo_2 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 Spo_2 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. Spo_2 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] Spo_2 is <60% in the fetus just before birth[28] 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 Spo_2 is significantly higher than postductal Spo_2 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 Spo_2 Values at 1 to 10 Minutes After Birth for Preterm and Term Births

Time After Birth	Spo_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 Spo_2 Targets of >70%, >80%, >90%, and >95%

Spo_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 Spo_2 Values at 1 to 10 Minutes After Birth for Vaginal and Cesarean Births

Time After Birth	Spo_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 Spo_2 measurements during periods of low perfusion.[30]

One reason given for failure of Spo_2 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" Spo_2 algorithms to calculate Spo_2. Thilo et al[32] simultaneously placed oximeters 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 Spo_2 are likely to be ~2% and therefore not clinically important in this situation.

Our findings are consistent with those of Altuncu et al[3] 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 Spo_2 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 Spo_2 measurements with term infants just after birth but few with preterm infants. The median Spo_2 at 5 minutes for our preterm infants was 86%, compared with 92% for term infants ($P < .001$). Kamlin et al[9] reported that the median Spo_2 at 5 minutes for preterm infants was 87%, which was significantly lower than the value for term infants of 90% ($P < .001$). Nuntnarumit and Rojnueangnit[19] studied infants of <35 weeks who did not receive supplemental oxygen in the DR and reported slightly higher Spo_2 values over the first minutes and a shorter time to reach Spo_2 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 Lindner[31] of 15 infants born at 24 to 29 weeks of gestation, the mean time to reach Spo_2 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 Spo_2 in preterm infants after birth could assist clinicians in reducing the oxygen load[37] when supplemental oxygen treatment is used.

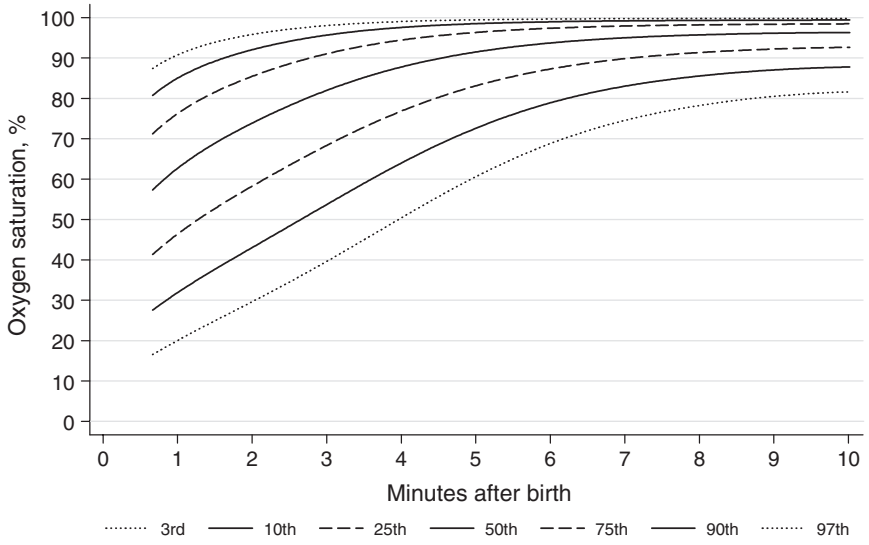

FIGURE 1
Third, 10th, 25th, 50th, 75th, 90th, and 97th Spo_2 percentiles for all infants with no medical intervention after birth.

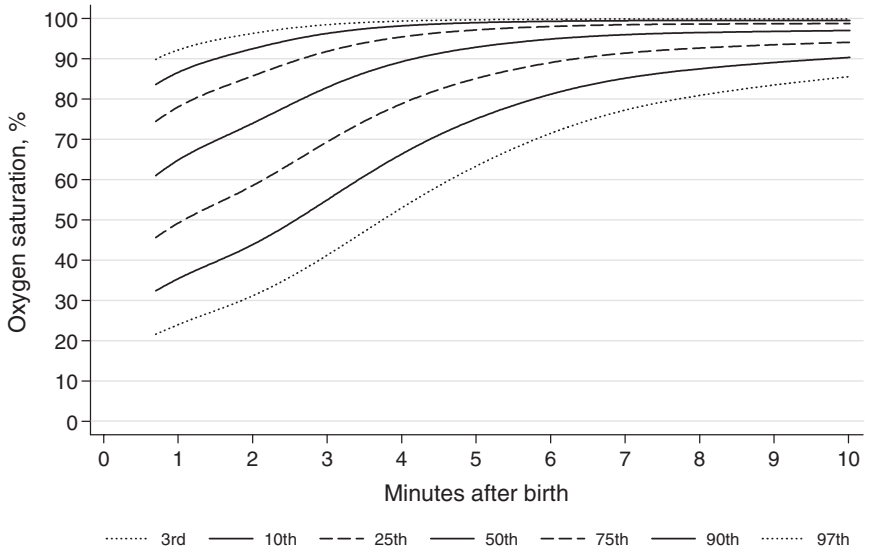

FIGURE 2
Third, 10th, 25th, 50th, 75th, 90th, and 97th Spo_2 percentiles for term infants at ≥37 weeks of gestation with no medical intervention after birth.

In the first 5 minutes after birth, infants born through cesarean section had significantly lower Spo_2 measurements than those delivered vaginally. This is consistent with the findings of Rabi et al[14] 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.

Spo_2 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 Spo_2 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 Spo_2 levels above and below which they do not want the infant's Spo_2 values to go. Some clinicians may want to keep an infant's Spo_2 close to or above the median, others may not want the Spo_2 above the 90th percentile or below the 10th percentile, and others may chose the 25th percentile. Percentile charts allow clinicians to see the dynamic changes in Spo_2 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 Spo_2 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 Spo_2 measurements in the first min-

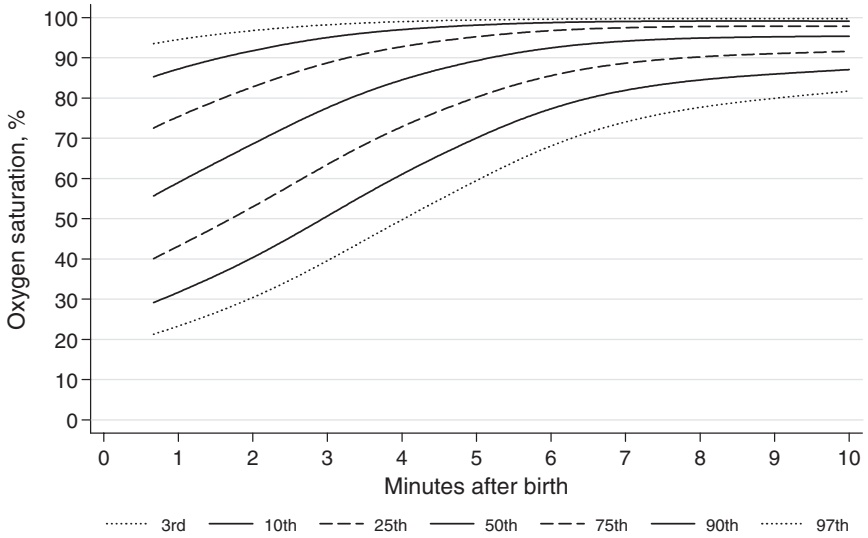

FIGURE 3
Third, 10th, 25th, 50th, 75th, 90th, and 97th Spo_2 percentiles for preterm infants at 32 to 36 weeks of gestation with no medical intervention after birth.

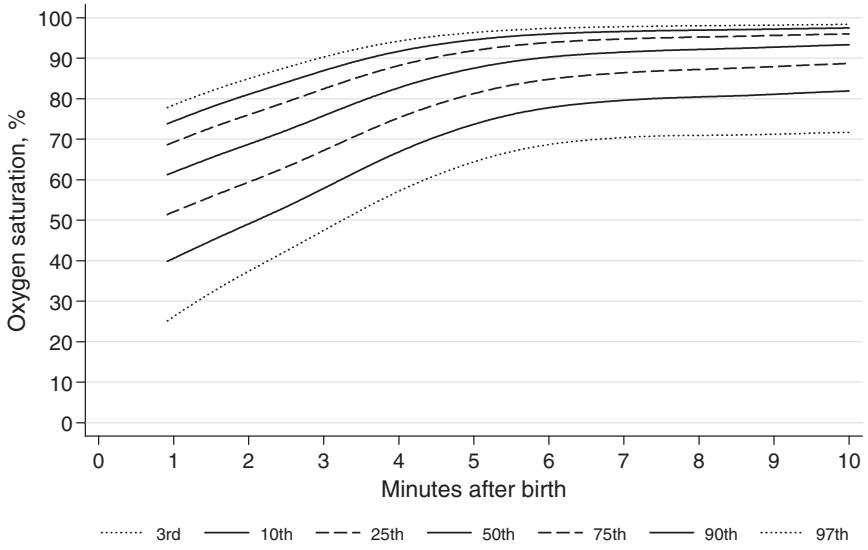

FIGURE 4
Third, 10th, 25th, 50th, 75th, 90th, and 97th Spo_2 percentiles for preterm infants at <32 weeks of gestation with no medical intervention after birth.

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 al[4] and Kopotic and Lindner[31] suggested that using Spo_2 measurements in the DR was valuable in managing resuscitation. Recently, Finer and Leone[39] 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, Kattwinkel[2] 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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