

Pulse oximetry curves in healthy children living at moderate altitude: a cross-sectional study from the Ecuadorian Andes

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Abstract

Background

In populations above 3000 meters above sea level (m a.s.l.) normal values of oxygen saturation (SpO₂) above 90% have been reported. Few studies have been conducted in cities of moderate altitude (between 2500 and 3000 m a.s.l.) We set out to describe the range of SpO₂ values measured with a pulse oximeter in healthy children between 1 month and 12 years of age living in an Ecuadorian Andean city.

Methods

A cross-sectional study was carried out in Quito, Ecuador, located at 2800 m a.s.l. SpO₂ measurement in healthy children of ages ranging from 1 month to 12 years of age living in the city were recorded by pulse oximetry. Age and gender were recorded, and 2.5th and 5th percentile were drawn. Nonparametric tests were used to compare differences in SpO₂ values by age and gender.

Results

1378 healthy children were eligible for the study, 719 (52.2%) males. Average SpO₂ for the entire population was 94.5% (SD 1.70; 95%CI 94.41–94.59). No differences were observed between SpO₂ values by age and gender. The SpO₂ 2.5 percentile value in the whole was 90%, in children under 5 years of age was 91% and it was 90% in children older than 7.

Conclusions

In cities of moderate altitude, the SpO₂ percentile measures developed in healthy children may contribute to an improved decision-making process, especially in cases where resource availability is limited.

Background

Oxygen saturation is an indirect index of global oxygen supply-to-demand balance [1, 2]. Pulse oximetry provides information about patient's oxygenation status and is a reliable, simple, safe, accurate, and cheap method to monitor the patient as compared to expensive and labor-intensive methods [3, 4]. Patient's oxygenation status can show a reduced partial pressure of oxygen and / or decreased oxygen saturation in arterial blood and in this case, it should be called hypoxemia [5]. Hypoxemia in children has been associated with increased mortality and is a frequent complication in cases of pneumonia, bronchiolitis, asthma and other severe diseases such as sepsis [6]. The identification of hypoxemia in children with pneumonia contributes to diagnosis, is crucial in patient management, and aids in determining prognosis [6–8].

The World Health Organization (WHO) recommends an oxygen saturation threshold value of 90% measured by pulse oximetry, as the cut-off point for oxygen administration in populations living at 2500 m a.s.l. or less [7]. In clinical practice, the “normal” pulse oximetry value at sea level has been estimated to be between 95% and 100%, however, several authors consider that values of 95% and 96% were abnormal [3]. In altitudes above 3000 m a.s.l., where oxygen saturation values are lower than at sea level, the 90% cut-off point could be less useful [9].

There are few studies about pulse oximetry values performed in cities between 2000 and 3000 m a.s.l. [10, 11]. In order to contribute to the best comprehension about SpO₂ values in healthy children living at moderate altitude, our study was devised to describe the values range of SpO₂ measured with a pulse oximeter in healthy children between 1 month and 12 years of age living at 2800 m a.s.l.

Methods

Subjects and methods

This cross-sectional study included 1378 children residing in Quito, aged between 1 month and 12 years, who sought preventive medical attention at three primary health-care centers (Lucha de los Pobres Health-care Center, Cotacollao Health-care Center and Clínica Pichincha), three elementary schools (Escuela Francisco Salazar, Centro del Muchacho Trabajador Cotacollao and Centro del Muchacho Trabajador La Marín) and nine kindergarten municipal schools (Abdón Calderón, Andalucía, Carapungo, Colibrí, Cotacollao, Empleados Municipales, Ipiales, La Carolina and Santa Clara). Non-probabilistic and convenience sampling were used because age and gender distribution at the schools and health-care centers was unknown. The centers are located at an altitude between 2740 and 2901 m a.s.l. (average 2810 m a.s.l., 9219.16 ft.). Ambient temperature throughout the study was, on average, 14.4 Celsius degrees and humidity was 72.2% as reported by Ecuador’s National Institute of Meteorology and Hydrology [12]. Exclusion criteria included a registered axillary temperature > 37.5 C° at the time of evaluation, history of respiratory symptoms in the two weeks prior to evaluation, any abnormal cardio-respiratory signs during physical examination, history of chronic cardio-respiratory disease, history of neonatal respiratory disease, history of blood component transfusion in the six months prior to evaluation, and the presence of malnutrition, defined as a Z-score less than - 2SD for either height for age or weight for height [10, 11].

Fifteen students from fourth year of a school of medicine were rigorously trained in anthropometric measurements and pulse oximetry assessment by the standardization method of the Central America and Panama Institute of Nutrition (INCAP) [13]. To manage measurement bias, the students’ measurements were compared against a pediatrician’s reference pattern, establishing a maximum margin of error of 0.2 kg for weight and 0.5 cm for length and height [13].

Variable Definition

Weight and height were measured using high fidelity equipment (Health-o-Meter 498KL and 593KL), regulated and previously calibrated by the Ecuadorian Institute of Normalization. Respiratory frequency was obtained through observation in calm and alert patients, visually counting thoracic and abdominal movements over one minute. Temperature was assessed with a digital thermometer, placed in patient's armpit until a reading signal was obtained. Heart rate and SpO₂ were evaluated using automatically calibrated non-invasive pulse oximeters (Huntleigh MP1R Smartsigns® MiniPulse), which show continuous measurements with a precision range of $\pm 2\%$. Pulse oximetry was assessed in calm and alert patients, proper sensors were used depending on the patient's age and placed either on right hand's index finger or the big toe for nursing babies. Nail polish removal was provided for students who had nail polish present at the time of the test. A time of at least ten seconds was defined to obtain the correct measurement of heart rate and oxygen saturation values [8, 14]. These variables were assessed three times in each patient and the average was calculated and recorded [15, 16].

Statistical Analysis

Descriptive statistical tests were run for all variables. The Kruskal-Wallis test was used to compare differences in SpO₂ mean values by age groups, Mann-Whitney U test was used to compare mean differences between males and females. Statistical significance was accepted with $p < 0.05$. Smooth lines were designed for percentiles 2.5th and 5th for SpO₂ using the Spline method (*smooth.spline* function in R, with a 7 degree freedom range). All data was registered in the digital survey platform SurveyMonkey®, and analyses were performed using SPSS®, version 24 and R, open source. Graphics were designed using R.

Results

1516 children were invited to participate. 138 patients were excluded, 50% of whom were men. 74% of the excluded children declared respiratory symptoms in the two weeks prior to the examination and the rest had other exclusion criteria.

A total of 1378 (90.9%) children were included in the study, of whom 719 (52.2%) were men. Measurements characteristics are listed in Table 1.

Table 1
Measurements characteristics (mean and standard deviation) by age group

Age (years)	Frequency (%)	HR (bpm)	RR (bpm)	BMI (Kg/m ²)	Height (m)	Temp (°C)
< 1	167.0 (12.1)	132.8 (14.3)	43.6 (9.2)	16.6 (1.8)	0.64 (0.1)	36.8 (0.2)
1–2	58.0 (4.2)	125.4 (12.0)	33.8 (5.4)	16.4 (1.4)	0.78 (0.1)	36.7 (0.4)
2–3	149.0 (10.8)	113.4 (10.9)	30.1 (4.4)	16.27 (1.4)	0.87 (0.0)	36.6 (0.4)
3–4	154.0 (11.2)	105.9 (11.2)	27.1 (3.6)	16.0 (1.3)	0.95 (0.1)	36.6 (0.4)
4–5	155.0 (11.2)	100.6 (11.2)	26.0 (3.3)	16.0 (1.4)	1.00 (0.0)	36.6 (1.9)
5–6	111.0 (8.1)	98.4 (11.9)	25.9 (3.1)	16.0 (1.3)	1.06 (0.1)	36.6 (0.4)
6–7	74.0 (5.4)	88.8 (12.6)	24.5 (3.8)	16.1 (2.4)	1.13 (0.1)	36.72 (0.4)
7–8	101.0 (7.3)	91.7 (12.4)	26.1 (3.5)	16.3 (1.9)	1.19 (0.6)	36.6 (0.4)
8–9	93.0 (6.7)	88.0 (11.1)	25.9 (3.9)	17.0 (2.3)	1.24 (0.1)	36.7 (0.4)
9–10	96.0 (7.0)	87.9 (12.6)	25.2 (4.3)	17.0 (1.9)	1.28 (0.6)	36.6 (0.4)
10–11	85.0 (6.2)	84.0 (11.4)	24.8 (3.9)	17.5 (2.1)	1.33 (0.1)	36.5 (0.4)
11–12	100.0 (7.3)	82.2 (11.1)	24.1 (3.9)	18.1 (2.4)	1.38 (0.1)	36.6 (0.4)
12–13	35.0 (2.5)	83.0 (11.3)	24.0 (2.7)	18.1 (1.9)	1.41 (0.1)	36.5 (0.4)
^a Heart Rate (HR) defined as beats per minute (bpm). Respiratory Rate (RR) defined as breaths per minute (<i>bpm</i>). Body Mass Index (BMI). Height measured in meters (m) and Body temperature measured in Celsius degrees (°C)						

The overall SpO₂ mean value was 94.5% (SD 1.70; 95%CI 94.10-94.59), lowest and highest values were 87% and 99%. Mean and standard deviation values for SpO₂ by age are listed in Table 2.

Table 2
Distribution of oxygen saturation measured by pulse oximetry by age

Age (years)	Mean	Standard deviation	Median	Q ₁ -Q ₃
< 1	94.9	2.2	95.0	93.7–96.7
1–2	95.1	1.4	95.3	94.2–96.0
2–3	94.8	1.6	95.0	93.7–96.0
3–4	94.9	1.4	95.0	94.0–96.0
4–5	94.7	1.7	95.0	94.0–95.7
5–6	94.4	1.6	94.3	93.3–95.3
6–7	94.4	1.8	94.5	93.3–95.7
7–8	94.2	1.7	94.3	93.3–95.7
8–9	94.1	1.6	94.3	93.3–95.3
9–10	94.1	1.8	94.3	93.0–95.3
10–11	94.2	1.6	94.3	93.3–95.3
11–12	94.0	1.5	94.0	93.0–95.0
12–13	93.9	1.3	93.7	92.7–94.2

SpO₂ at 12 years of age was the lowest median value (93.9%), and the highest median value was observed in children aged 1 year (95.07%), no significant differences in SpO₂ median values were found between age (K-W Chi square test = 7.94, df = 11, p = 0.72).

Figure 1 shows the smooth percentile lines for SpO₂ corresponding to percentiles 5.0th and 2.5th in all participants by age. It is noteworthy that in children between the ages of 7 and 9 the SpO₂ value for percentile 2.5 was between 89 and 90%, while in other age groups the values recorded were between 90 and 91%.

Figure 2 represents SpO₂ percentile lines for male population, value percentile 2.5th for SpO₂ was between 89% and 90% for children younger than 1 year and of 8 and 9 years of age, respectively. Figure 3 represents the same data for females. Values 2.5th percentile for SpO₂ were between 89% and 90% from 4 to 11 years of age. No differences were observed by gender (Mann-Whitney U test = 243.18, p = 0.40).

Discussion

The use of pulse oximetry is advised in order to increase detection of hypoxemia considering normal SpO₂ range values at higher altitudes [6, 9]. The average SpO₂ value is close to 99% at sea level and appears to decrease to 97% after 1500 to 1600 m a.s.l. [16–18]. Furthermore, at 3000 m a.s.l., mean

SpO₂ values of 89.6% [19] or even 85.7% have been reported [20]. We have found an SpO₂ mean value of 94.5% (SD 1.07) at 2800 meters, similar to those reported in studies in altitudes, *e. g.* Rojas-Camayo *et al.* at 2830 m a.s.l. with an SpO₂ mean value of 95% (SD 1) [21], or slightly higher than that reported by Lozano *et al.* at Bogotá-Colombia (2600 m a.s.l.) of 93.3% (SD 2.05) [11] or by Nicholas *et al.* at Colorado (2800 m a.s.l.) of 91.7% (SD 2.1) [10].

Pulse oximetry is the standard of care to assess hypoxemia. It is highly cost-effective and identifies between 20 and 30% more cases than clinical signs alone [22–25]. Some studies have previously used average SpO₂ values – 2SD to define hypoxemia [9]; however, for many of them the SpO₂ value distribution is negatively biased rather than normally distributed [9]. If 2SD are added to the mean, values higher than the theoretical maximum 100% can be obtained, a circumstance observed mainly in studies at places under 2000 m a. s. l. [9, 17, 26]. This result suggests that this definition of hypoxemia might not identify the lowest 2.5% values in moderate altitude accurately [9]. In contrast, data expression as percentile measures can show the complete range of values and allows pediatricians to accurately assess dynamic changes in SpO₂ values.

In this study, no differences in SpO₂ values were observed between girls and boys neither by age, as it has been previously reported [20, 27].

Unreal SpO₂ values could increase hospital admissions and hospital stays with subsequent iatrogenic risks and misuse of resources [24, 25]. Without pulse oximetry, the management of pediatric patients depends on precise identification of the clinical signs of hypoxemia, which are not always easy to assess in all patients. Clinical signs alone are unreliable for the detection of hypoxemia [28].

Pulse oximetry is a non-invasive and low-cost assessment method able to reduce child mortality by accurately diagnosing hypoxemia, increasing the possibilities of early and effective treatment [24]. Our results suggest a SpO₂ value > 90% (> percentile 2.5th) as the cut-off point to define “normality” in “children at community settings without respiratory symptoms and not fever living at moderate altitude”.

There are some limitations to the study. 1. Measurements were carried out in children between 1 month and 12 years of age living in Quito, so the results obtained cannot apply to patients who have not adapted. 2. All patients in the sample had their medical records and physical examination taken but did not undergo laboratory testing for parameters such as serum hemoglobin, arterial blood gas testing or chest X-rays to discard other pathologies not found on clinical evaluation. 3. In this study we did not set out to compare the SpO₂ results between the group that met the inclusion criteria with the excluded group; however, this comparison could provide additional information.

Conclusion

This is the first known study to describe the reference range of oxygen saturation among healthy school-aged children at Ecuadorian Andes (2800 meters). Our results suggest a SpO₂ value > 90% (> 2.5 percentile) as the cut-off point to define “normal”. Percentile lines may contribute to an adequate

decision-making process and improved and individualized management patient in cities located at this altitude.

Abbreviations

SpO₂

Oxygen Saturation

WHO

World Health Organization

m a.s.l.

meters above sea level

UIDE

Universidad Internacional del Ecuador

Declarations

Ethics approval and consent to participate

The study was approved by the Universidad Internacional del Ecuador ethics committee and by the health committee at each center participating in the study. Information on the study was provided to the directive councils and medical teams at each institution.

Consent for publication

Patients were enrolled in the study after written informed consent obtained from their parents. No other personal identifiable information will be shared outside of the study.

Availability of data and materials

Non-identified individual participant data (including data dictionaries) will be made available, in addition to study protocols, the statistical analysis plan, and the informed consent form. The data will be made available upon publication to researchers who provide a methodologically sound proposal for use in achieving the goals of the approved proposal. Proposals should be submitted to vinanmay@gmail.com.

Competing interests

The other authors have indicated they have no potential conflicts of interest to disclose.

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Authors' contributions

MD Andrade and Prof Romero-Sandoval conceptualized and designed the study, drafted the initial manuscript, and reviewed and revised the manuscript. MD. Riofrío and Mr. Andrade designed the data collection instruments and collected data. Drs. Martin and Nedel carried out the initial analyses and reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Figures

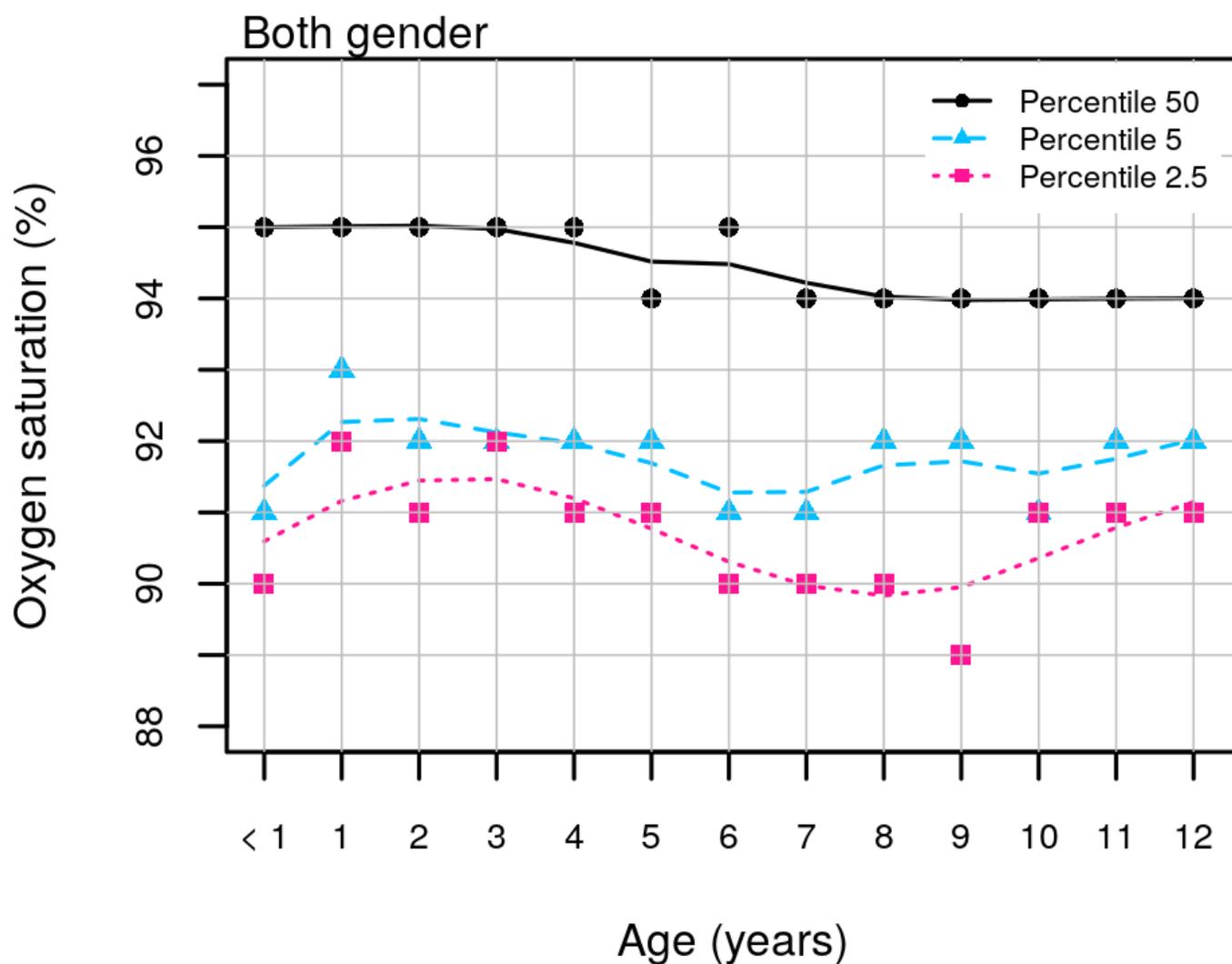


Figure 1

SpO2-for-age ALL (percentiles)

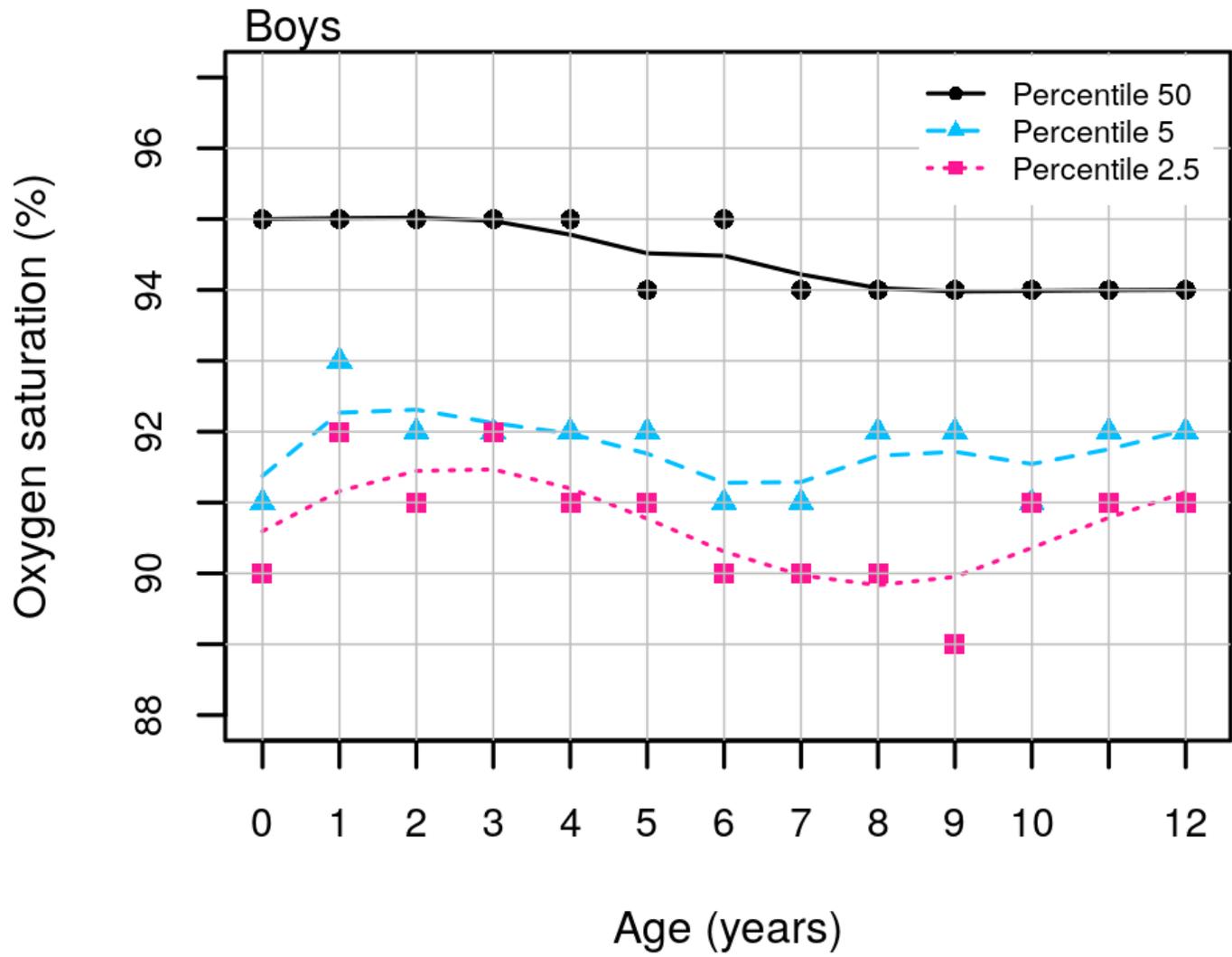


Figure 2

SpO2-for-age BOYS (percentiles)

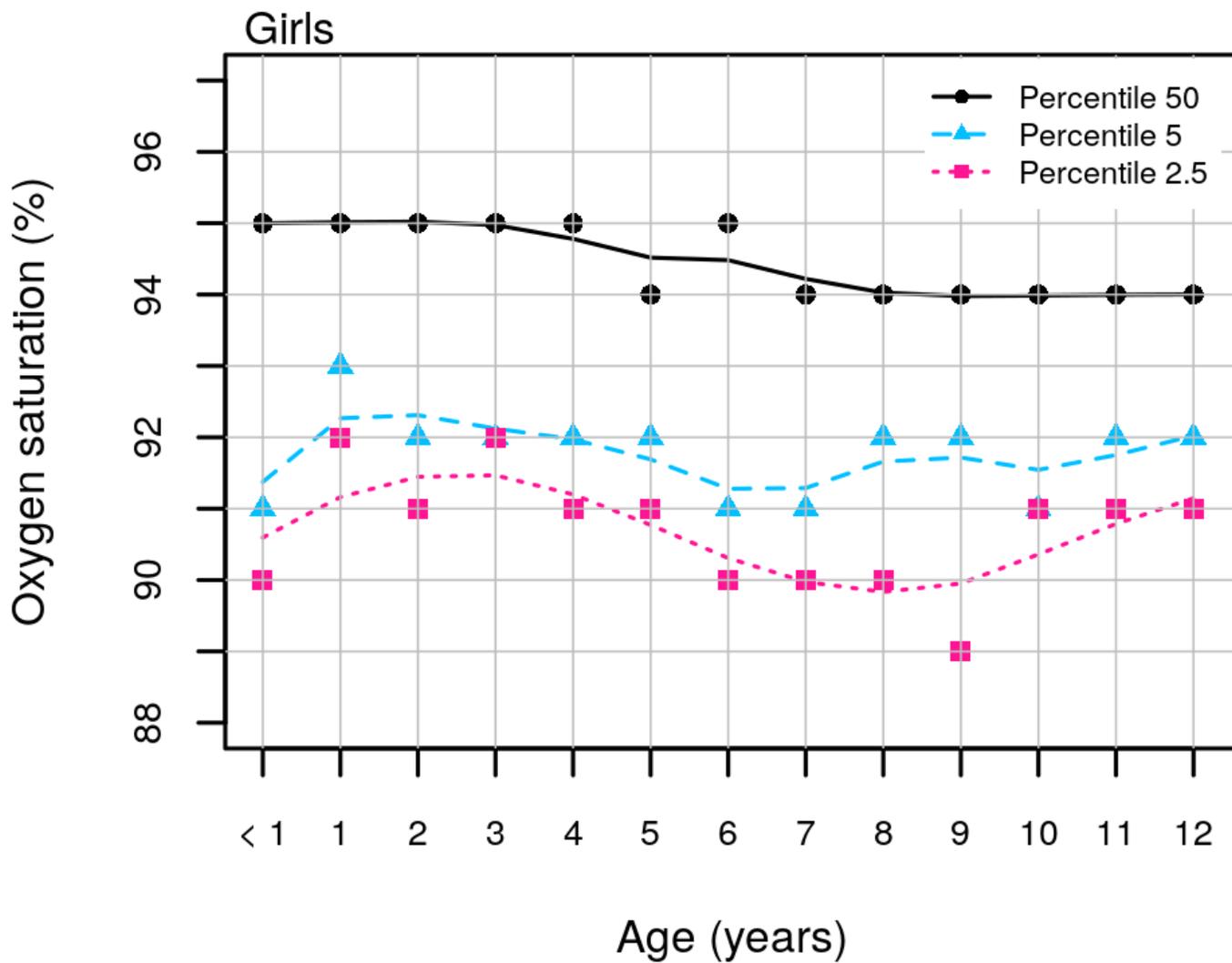


Figure 3

SpO2-for-age GIRLS (percentiles)