Reference values for oxygen saturation from sea level to the highest human habitation in the Andes in acclimatised persons

ABSTRACT

Oxygen saturation, measured by pulse oximetry (SpO_2), is a vital clinical measure. Our descriptive, cross-sectional study describes SpO_2 measurements from 6289 healthy subjects from age 1 to 80 years at 15 locations from sea level up to the highest permanent human habitation. Oxygen saturation measurements are illustrated as percentiles. As altitude increased, SpO_2 decreased, especially at altitudes above 2500 m. The increase in altitude had a significant impact on SpO_2 measurements for all age groups. Our data provide a reference range for expected SpO_2 measurements in people from 1 to 80 years from sea level to the highest city in the world.

BACKGROUND

Pulse oximetry has led to a great advancement in patient management offering non-invasive estimation of arterial oxygen saturation. It is routinely used in emergency departments, wards, intensive care and other medical situations. At high altitudes, physiological ventilation parameters like plasma bicarbonate are different.[1] Pulse oximetry measurements of oxygen saturation (SpO_2) are lower at altitude compared with those at sea level. However, the expected SpO_2 at a given altitude is unclear and has been suggested as a range of values rather than a specific number.[2]

METHODS

Subjects

Data were collected from 15 locations at different altitudes from sea level to the highest permanent human habitation located in a remote area at 5100 m in Puno, Peru, a city named La Rinconada.[3]

We recruited subjects between 1 and 80 years with a minimum of 2 months residence at the place of evaluation because alveolar gas composition is different after acclimatisation.[4] Exclusion criteria were based on history and clinical examination. Subjects with a history of the following were excluded: habitual smoker (≥1 cigarette day), ongoing pregnancy, chronic cardiorespiratory disease, anaemia, polycythaemia or having received a blood transfusion in the last 6 months and with abnormal findings in physical examination. Children who were asleep at the time of measurement of SpO_2 and subjects with painted nails or deformities in measurement locations were also excluded. Informed consent was obtained from all subjects or their guardians.

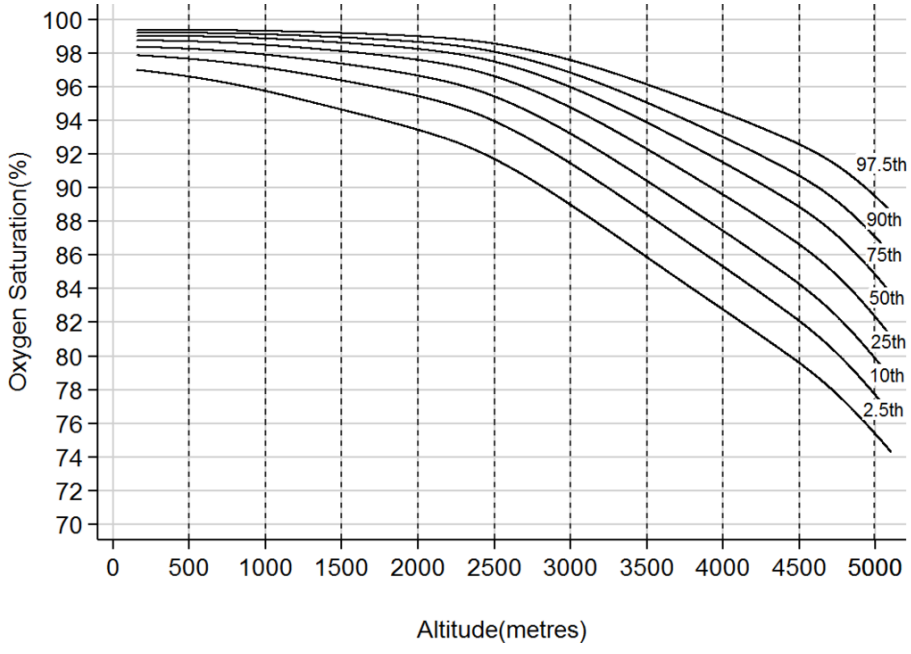

Figure 1 2.5th, 10th, 25th, 50th, 75th, 90th, and 97.5th SpO_2 percentiles for all subjects according to altitude. (n=6289) distributed by the following altitudes: 154 m (n=709), 562 m (n=405), 1400 m (n=315), 2000 m (n=209), 2335 m (n=522), 2500 m (n=416), 2880 m (n=404), 3250 m (n=422), 3600 m (n=361), 3950 m (n=350), 4100 m (n=644), 4338 m (n=457), 4500 m (n=525), 4715 m (n=251), 5100 m (n=299).

Measurement of SpO_2

SpO_2 was measured using a pulse oximeter (Nellcor 560, Hayward, California, USA), with sensors appropriate to the weight of the subject. SpO_2 measurements were recorded every 10 s for a total of six measurements and the average was used to determine SpO_2 for each study subject, as described in previous studies.[5]

At the end of the study, we compared SpO_2 measurements against simultaneous measurements of arterial oxygen saturation (SaO_2) by arterial blood gases in 10 hospitalised patients, at sea level. The average of (SaO_2 –SpO_2) was 1.48%. This was within the expected value of ±2% for a range of SpO_2 measurements between 70% and 100% reported by the manufacturer.[6]

To assess the reproducibility of our data, at 5100 m, we measured SpO_2 twice in 23 subjects waiting 30 min before taking the second measurement. For this test, we used the Fingertip Pulse Oximeter MD300C1. The average difference between SpO_2 measured by the two devices (Nellcor-MD300C1) was −0.8%.

STATISTICAL ANALYSIS

Descriptive statistics were used to summarise characteristics of the subjects.

Constructing oxygen centile charts

SpO_2 data were entered into Microsoft Excel and were analysed and charted using Stata (Intercooled 10, Stata Corp, College Station, Texas, USA). The SpO_2 centiles were calculated using the LMS method of Cole and Green[7 8] and fitted using the LMSChartMaker Light V.2.3 (Institute of Child Health, London, England). These values were then used to illustrate the 2.5th, 10th, 25th, 50th, 75th, 90th and 97.5th centile for SpO_2 for each age group according to residential altitude (see online supplement).

RESULTS

We studied subjects residing at 15 specific altitudes. We initially evaluated 6601 subjects. Three hundred and twelve met exclusion criteria. A total of 6289 subjects were studied: 47.2% (n=2967) males and 52.8% females (n=3322). The median (IQR) for all SpO_2 measurements at each altitude (metre) were respectively: 99 (98–99) at 154 m; 99 (98–99) at 562 m; 98 (97–99) at 1400 m; 97 (96–98) at 2000 m; 97 (96–99) at 2335 m; 96 (95–97) at 2500 m; 95 (94–96) at 2880 m; (92–95) at 3250 m; 92 (90–93) at 3600 m; 90 (88–91) at 3950 m; 87 (85–89) at 4100 m; 87 (85–89) at 4338 m; 87 (85–89) at 4500 m;

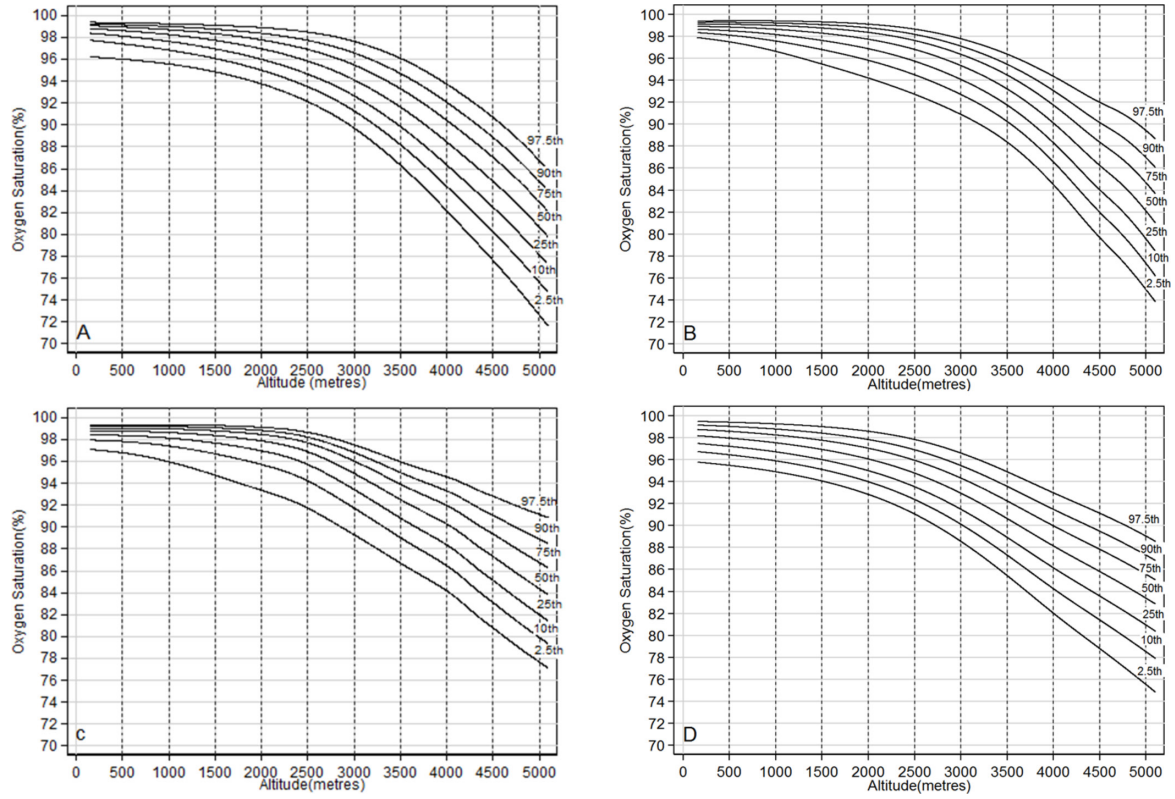

Figure 2 2.5th, 10th, 25th, 50th, 75th, 90th, and 97.5th SpO_2 percentiles for children. (A) Represents children 1–5 years (n=994) with N for specific altitude in the same order as figure 1 (n=64, 91, 69, 26, 70, 87, 95, 140, 30, 46, 91, 47, 36, 28, 74). (B) Represents children 6–17 years (n=2379) (n=281, 144, 146, 116, 171, 234, 122, 181, 117, 202, 117, 126, 121, 133, 168). Adults 18–50 (C) (n=2195) (n=310, 120, 28, 40, 239, 70, 134, 56, 136, 45, 297, 247, 353, 68, 52) and 51–80 years (D) (n=721) (n=54, 50, 72, 27, 42, 25, 53, 45, 78, 57, 139, 37, 15, 22, 5), adults according to altitude.

85(83–88) at 4715 m; 81 (78–84) at 5100 m.

Oxygen saturation measurements

SpO_2 measurements illustrated as percentiles are shown for all subjects in figure 1, and by age group (1–5, 6–17, 18–50 and 51–80 years) in figure 2. The figures show that for all age groups, as altitude increased, SpO_2 decreased, especially at altitudes above 2500 m (see online supplement tables).

DISCUSSION

We obtained measurements from over 6000 subjects, from 1 to 80 years old, from sea level to the highest permanent human habitation located in Peru at 5100 m.[3] This is the first study to provide reference charts for the expected range of SpO_2 measurements by age group and altitude using centiles by the LMS method.

We have shown the expected reduction of SpO_2 with altitude, an effect that is more evident at altitudes over 2500 m. We have also shown increased variability in the range of SpO_2 measurements at higher altitudes. Our observation could be explained by a genetic variability in the hypoxic ventilatory response. It is noteworthy that at 5100 m, the median SpO_2 of 81% could correspond to a PO_2 less than 50 mm Hg according to the oxygen dissociation curve. This is less than half of the normal PO_2 at sea level.

Pulse oximetry utility in clinical care outside the operating theatre has been supported by studies at sea level and at high altitude.[9] Having a reference value for SpO_2 is needed in clinical management at high altitude locations.

There are some limitations to our findings and analysis. We did not enrol subjects over 80 years or children less than 1 year. Our study does not apply to non-acclimatised individuals. We did take a clinical history and conducted a physical examination of all subjects. However, we did not conduct further testing, such as chest radiography, spirometry or haemoglobin measurement, to rule out pathology not evidenced by clinical examination. Therefore, in evaluating patients at high altitude, their history and clinical presentation must be incorporated into deciding whether an individual SpO_2 measurement should raise concern for a patient at their usual residential altitude.

All our subjects were Andean Natives and Hispanics and care should therefore be taken in applying these results to other ethnicities and to other parts of the world. For example, Tibetans have different physiological traits for the oxygen delivery process[10] and might have different SpO_2 measurements at the same altitude as our subjects.

In conclusion, our data provide a reference range for SpO_2 in people from 1 to 80 years from sea level to the highest city in the world, contributing to global knowledge of expected SpO_2 measurements at any given habitable altitude.

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Contributors All authors were involved in the design of the study and collection of clinical data. JAD, JRC and CRM performed the data analysis. JRC, CRM, DC, JAD, MP, VYL and RS drafted the final manuscript and all authors reviewed and made amendments.

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Patient consent Obtained.

Ethics approval Ethics Committee at Hospital Nacional Docente Madre Niño San Bartolomé, Lima-Peru.

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