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

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ABSTRACT
Oxygen saturation, measured by pulse oximetry (SpO2), is a vital clinical measure. Our descriptive, cross-sectional study describes SpO2 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, SpO2 decreased, especially at altitudes above 2500 m. The increase in altitude had a significant impact on SpO2 measurements from sea level to the highest city in the world.

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. 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. 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 SpO2 and subjects with painted nails or deformities in measurement locations were also excluded. Informed consent was obtained from all subjects or their guardians.

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 SpO2 measurements at each altitude was: 96.7 (95–98) at 85 m; 99.5 (97–99) at 2000 m; 98 (97–99) at 3600 m; 97.5 (96–98) at 3950 m; 97 (96–97) at 4100 m; 87.5 (85–90) at 4500 m; 87 (85–89) at 5100 m; 95 (92–96) at 5625 m; 92 (89–93) at 6250 m; 90 (88–91) at 7000 m; 87 (85–89) at 8500 m; 85 (83–87) at 9200 m; 85 (83–87) at 10000 m; and 70 (60–70) at 11000 m.

CONCLUSION
SpO2 measurements at different altitudes are lower at altitude compared with those at sea level. However, the expected SpO2 at a given altitude is unclear and has been suggested as a range of values rather than a specific number.

REFERENCE
1. Pulse oximetry measurements of oxygen saturation (SpO2) are lower at altitude compared with those at sea level. However, the expected SpO2 at a given altitude is unclear and has been suggested as a range of values rather than a specific number.

Figure 1
2.5th, 10th, 25th, 50th, 75th, 90th, and 97.5th SpO2 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).
85 (83–88) at 4715 m; 81 (78–84) at 5100 m.

Oxygen saturation measurements
SpO₂ 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, SpO₂ 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 human habitation located in Peru at 5100 m. This is the first study to provide reference charts for the expected range of SpO₂ measurements by age group and altitude using centiles by the LMS method.

We have shown the expected reduction of SpO₂ with altitude, an effect that is more evident at altitudes over 2500 m. We have also shown increased variability in the range of SpO₂ 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 SpO₂ of 81% could correspond to a PO₂ less than 50 mm Hg according to the oxygen dissociation curve. This is less than half of the normal PO₂ 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. Having a reference value for SpO₂ 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 SpO₂ 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 and might have different SpO₂ measurements at the same altitude as our subjects.

In conclusion, our data provide a reference range for SpO₂ in people from 1 to 80 years from sea level to the highest city in the world, contributing to global knowledge of expected SpO₂ 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.

Competing interests None declared.

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

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