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Oxygen saturation in adolescent high-altitude residents, implications for clinical decision-making

Saturación de oxígeno en adolescentes residentes de gran altitud, implicancias para la toma de decisiones clínicas

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Abstract

In high-altitude cities such as El Alto (4150 meters above sea level), reference values established at sea level are still applied, which can lead to misdiagnosis, overestimation of respiratory pathologies and clinical decisions with direct repercussions on nursing care. A quantitative, descriptive and cross-sectional study was carried out in 94 adolescents living permanently in El Alto, selected under inclusion and exclusion criteria (absence of acute respiratory infection, anemia, lung disease, pregnancy and tobacco use). Oxygen saturation was measured by non-invasive digital pulse oximetry, after three minutes of rest and with three consecutive readings, registering the most stable value. 71 % were 14 years old; 60 % male, 40 % female. The saturations at rest were; 47 % between 91-95 %, 42 % between 86-90 %, 7% between 80-85 % and 2 % between 96-100 %. The average was 88.2 % in 14-year-olds, 91.3 % in 15-year-olds, and 95% in 16-17-year-olds. The heart rate was between 91-100 bpm in 21 % of cases, and only 2 % reported a respiratory history. Most of them had saturations between 88 and 95 %, values compatible with a physiological adaptation to chronic hypobaric hypoxia typical of extreme altitude. These evaluations show the need to have contextualized reference values for populations living at high altitudes, avoiding inappropriate clinical interpretations and optimizing care decision-making.

Keywords: Oxygen saturation, pulse oximetry, adolescent, environmental hypoxia, altitude, reference values.

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Resumen

En ciudades de gran altitud como El Alto (4150 msnm) se siguen aplicando valores de referencia establecidos a nivel del mar, lo que puede inducir diagnósticos erróneos, sobreestimación de patologías respiratorias y decisiones clínicas con repercusiones directas en los cuidados de enfermería. Se realizó un estudio cuantitativo, descriptivo y transversal en 94 adolescentes residentes permanentes de El Alto, seleccionados bajo criterios de inclusión y exclusión (ausencia de infección respiratoria aguda, anemia, enfermedad pulmonar, embarazo y consumo de tabaco). La saturación de oxígeno se midió mediante oximetría de pulso digital no invasiva, tras tres minutos de reposo y con tres lecturas consecutivas, registrándose el valor más estable. El 71 % tenían 14 años; 60 % del género masculino, 40 % al femenino. Las saturaciones en reposo fueron; 47 % entre 91-95 %, 42 % entre 86-90 %, 7 % entre 80-85 % y 2 % entre 96-100 %. El promedio fue 88.2 % en adolescentes de 14 años, 91.3 % en los de 15 años y 95 % en los de 16-17 años. La frecuencia cardíaca se ubicó entre 91-100 lpm en el 21 % de los casos, y solo el 2 % refirió antecedentes respiratorios. La mayoría presentó saturaciones entre 88 y 95 %, valores compatibles con una adaptación fisiológica a la hipoxia hipobárica crónica propia de la altitud extrema. Estas evaluaciones evidencian la necesidad de disponer de valores de referencia contextualizados para poblaciones residentes en gran altitud, evitando interpretaciones clínicas inapropiadas y optimizando la toma de decisiones asistenciales.

Palabras clave: Saturación de oxígeno, oximetría de pulso, adolescente, hipoxia ambiental, altitud, valores de referencia.

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Introduction

Peripheral oxygen saturation (SpO_2), measured by pulse oximetry, is a widely used clinical parameter for assessing the body's oxygenation status. Its non-invasive nature, accessibility, and ease of application have made it an essential component of routine evaluation across different levels of care, supporting clinical decision-making related to the respiratory and cardiovascular systems[1-3].

Reference values for SpO_2 are derived primarily from populations residing at sea level, where readings between 95 and 100% are considered normal. However, in populations living at high altitude, the reduction in barometric pressure lowers the partial pressure of inspired oxygen, resulting in chronic hypobaric hypoxia. This phenomenon induces physiological adaptations that translate into baseline oxygen saturation values lower than those observed in low-altitude populations[4-6].

SpO_2 has been recognized as the "fifth vital sign" due to its utility in the early detection of hypoxemia and the monitoring of patients with respiratory compromise. In pediatric and adolescent populations, its relevance is even greater owing to their susceptibility to hypoxemia and rapid decompensation in the face of respiratory alterations[4-6].

The City of El Alto, Bolivia, located at more than 4000 masl, constitutes an ideal setting for the study of human oxygenation, given that its population is permanently exposed to environmental hypoxia. In this context, applying sea-level reference values can lead to erroneous clinical interpretations and misguided healthcare decisions[7-9].

Available evidence on oxygen saturation in adolescents residing at high altitude is scarce, as most studies have focused on young children or adults. Factors such as age, nutritional status, anemia, respiratory diseases, and environmental conditions (pollution, tobacco smoke) also influence SpO_2 values[9-12]. Andean populations, moreover, exhibit ventilatory, hematological, and cardiovascular adaptations that allow them to maintain tissue oxygenation under chronic hypoxia[13,11].

Given the limited specific information on adolescents, there is a need to generate local evidence that allows for contextualizing the interpretation of pulse oximetry and strengthening clinical practice based on parameters adjusted for altitude.

In this context, the objective was to determine SpO_2 ranges in permanent adolescent residents of the City of El Alto, Bolivia (4150 masl), and to analyze their implications for clinical interpretation and decision-making in high-altitude settings.

Material and methods

A quantitative, observational, cross-sectional study with a descriptive scope was conducted, aimed at evaluating oxygen saturation in adolescents residing at high altitude.

The target population consisted of students aged 14 to 17 years enrolled at the Mariscal José Ballivián Educational Unit, located in the Ballivián Zone, District 6 of the City of El Alto (≈4150 masl), Department of La Paz, Bolivia. The study period ran from February to June 2025.

The total population included 101 students from the third year of secondary school. After applying inclusion and exclusion criteria, only apparently healthy adolescents who were permanent residents and had no history of respiratory disease, anemia, pregnancy, or tobacco use were selected. The final sample comprised 94 participants.

Data collection was carried out using a structured clinical form, previously validated by experts. SpO_2 measurement was performed at rest using a portable, non-invasive digital pulse oximeter (Edan® brand, model H100B, made in China). Before the start of fieldwork, the equipment's functionality was verified through repeated measurements on the principal investigator and on two Biology teachers from the educational unit, who knew their usual oxygen saturation values as permanent high-altitude residents. The readings obtained were consistent with the expected ranges for healthy residents of the city of El Alto, demonstrating stability and consistency in the device's performance.

Prior to measurement, students received information about the study objectives and procedures and completed the data collection form. They then remained under usual resting conditions within the classroom for approximately 30 min, avoiding intense physical activity. Measurements were taken in an enclosed environment with stable environmental conditions. Each recording was obtained after 3 min of rest and through three consecutive readings, selecting the most stable value.

Ethical considerations. The study received approval from the corresponding educational authority. Informed consent was obtained from parents or guardians, and assent was obtained from the students. Confidentiality was guaranteed through anonymous codes. In cases of persistently low SpO_2 (<88-90 %) or the presence of compatible symptoms, immediate referral to the health center was coordinated with the responsible teacher.

Products and transfer. A report was prepared for the educational unit's administration, including recommendations applicable to the school setting; improvement of ventilation and occupancy capacity, implementation of active breaks, and establishment of annual screening through pulse oximetry.

Results

Table 1 Oxygen saturation levels by age and gender City of El Alto, 2025

Age (years)	Gender	N° Students	%	Saturation Level (%)	Medium saturation (%)
14	Male	44	46	80 – 94	88.2
14	Female	23	24	84 – 97	
15	Male	11	11	85 – 97	91.3
15	Female	13	13	87 – 98	
16	Male	1	1	98	95
16	Female	1	1	94	
17	Female	1	1	97	95
Total		**94**	**100**		

Discussion

The results of this research broaden the understanding of SpO_2 levels in adolescents at the Mariscal José Ballivián Educational Unit in El Alto (over 4000 masl). The majority presented values consistent with those described in healthy populartions residing at high altitude, indicating that the relative decrease in saturation reflects a physiological adaptation to chronic hypobaric hypoxia and not necessarily a pathological condition[7,14]. The mean of 88.2 % coincides with national and international evidence reporting values between 88 and 92 % as an expression of reduced barometric pressure and partial pressure of oxygen, generating compensatory mechanisms aimed at maintaining tissue oxygenation.

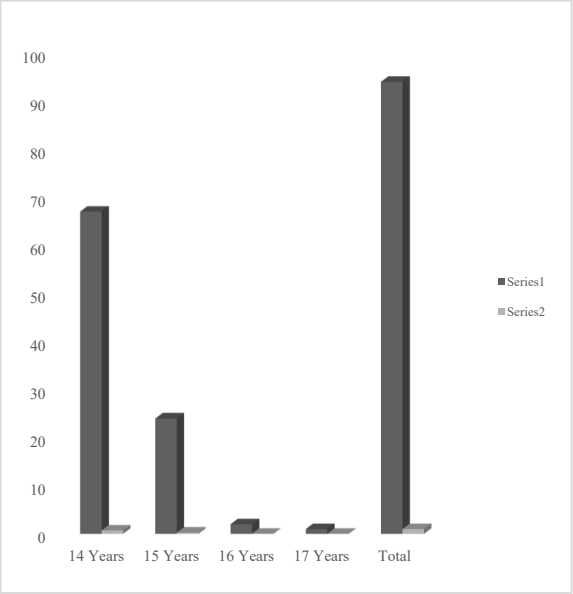


Figure 1 Age of students, City of El Alto, 2025

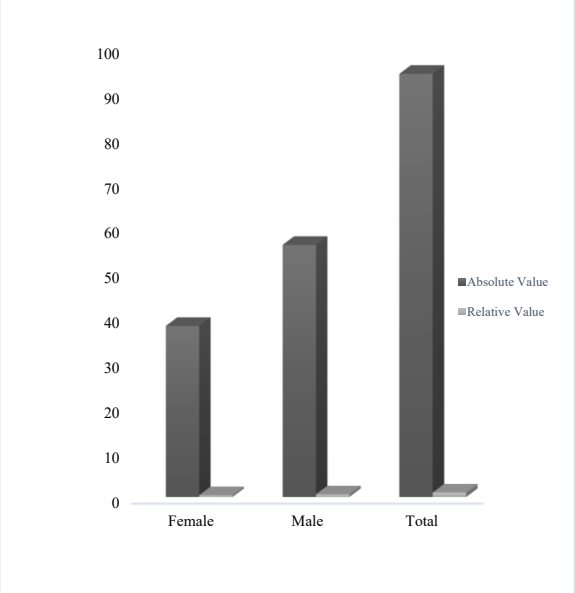


Figure 2 Gender of students, City of El Alto, 2025

These findings are consistent with studies in Andean populations, which describe mean values of 89-92 % in the absence of clinical hypoxemia, lower than those observed at sea level[14,15]. Therefore, the clinical interpretation of pulse oximetry at high altitude must consider the geographic and physiological context, avoiding the indiscriminate application of parameters designed for low-altitude populations[7].

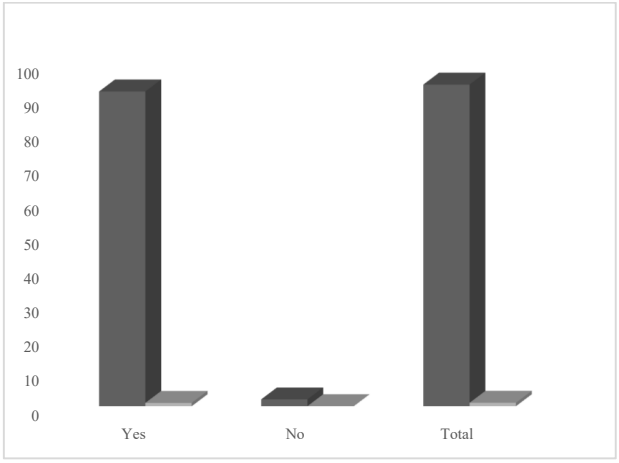


Figure 3 Condition for peripheral oxygen saturation measurement: resting state, City of El Alto, 2025

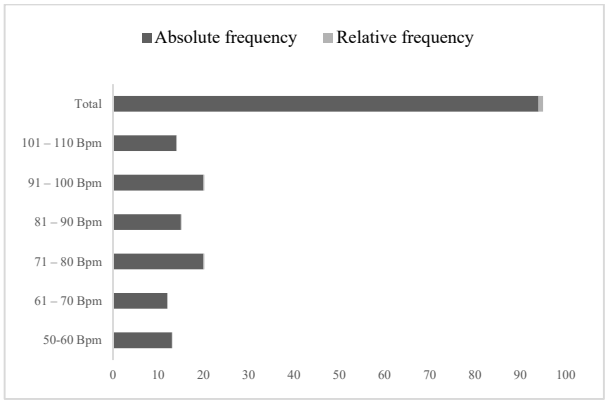


Figure 4 Heart rate levels of students, City of El Alto, 2025

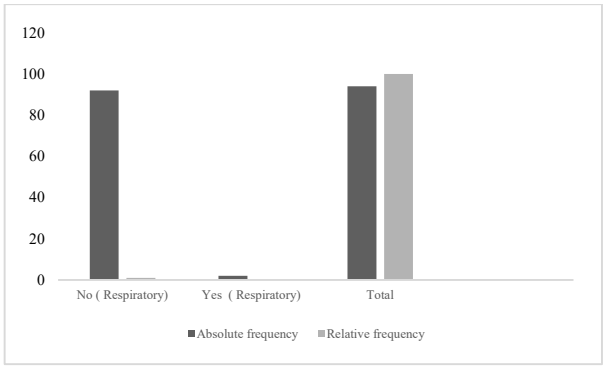


Figure 6 Respiratory history of students, City of El Alto, 2025

A relevant finding was the upward trend in saturation according to age; 88.2 % in 14-year-old adolescents, 91.3 % in 15-year-olds, and values close to 95 % in 16-17-year-olds. This pattern could be related to

pulmonary, cardiovascular, and hematological maturation characteristic of adolescence. The identification of lower values requires a comprehensive clinical assessment, considering respiratory symptoms and the degree of adaptation. Regarding heart rate, the 91-100 bpm range predominated in 21 % of participants, which may be interpreted as a compensatory mechanism to optimize oxygen transport, as described by Mortola[15].

Although only 2 % reported a history of respiratory conditions, the literature indicates that children and adolescents at high altitude may present physiological variations and desaturation episodes, especially during sleep[16-18]. These findings reinforce the need to contextualize the clinical interpretation of SpO_2 and to have reference values adjusted for altitude.

The main contribution of this study lies in generating specific evidence for adolescents, a group underrepresented in the international literature. The available information has focused on young children, adults, or populations at moderate altitude[15-18]. Limitations include the single educational unit setting and the cross-sectional design, which precludes the assessment of longitudinal changes. Nevertheless, the results constitute an initial and relevant approximation for future research.

Chronic high-altitude hypoxia generates complex physiological adaptations that condition SpO_2 values in adolescents. The generation of local evidence-based parameters is a necessity to strengthen clinical and nursing practice in high-altitude regions. This study represents an initial contribution and underscores the importance of expanding research to different age groups and more representative samples, in order to consolidate reference ranges applicable to the high-altitude reality and improve safety in clinical decision-making.

It is recommended to extend research to different age groups and larger populations, incorporating complementary measurements of hemoglobin, pulmonary function, and arterial blood gases. The consolidation of altitude-adjusted reference values will enable the development of evidence-based clinical guidelines adapted to the high-altitude reality, and will contribute to safe, accurate, and culturally appropriate care.

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Authors' own resources.

Conflicts of interest

This research does not generate conflicts of interest.

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Ethical considerations

The approval of the research by the Ethics Committee of the Department of Research and Projects of the Peasant Academic Unit of Pucarani (DIP-UACP). This has also been guided respecting the authors as a source of scientific information. The corresponding permits were requested from the Educational Unit, the principal and the Biology Teacher, and the consent of the parents was collected.

Authors' contribution

Quenta Quispe Loreley Mijaela, *Mamani Mamani Yhissel*, were in charge of the collection and analysis of the data, in addition to the bibliographic review for the preparation of the article. *Quispe Apaza Soledad Etelvina* was responsible for coordinating the activeities to obtain the information, as well as supervising the revision and correction of the writing of the scientific article.

Limitations in research

Scarce literature at the local level which did not allow for contextualized comparison.

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