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SCIENTIFIC LETTER

Gasometry and altitude: investigation of normal ranges in Quito, Ecuador (2,850 m above sea level)

Gasometría y altitud: investigación de los rangos de normalidad en Quito, Ecuador (2.850 m sobre el nivel del mar)

Dear Editor:

Hypobaric hypoxia associated with altitude decreases partial pressure of arterial oxygen (PaO_2).[1] Arterial blood gas measurements are essential for diagnosing acute respiratory failure (ARF), and are part of the SOFA severity score and the APACHE II scale, together with hematocrit. Acute respiratory failure is considered to be present when the patient is resting, awake and breathing at an atmospheric pressure (AP)close to 760 mmHg, PaO_2 < 60 mmHg, and arterial oxygen saturation (SpO_2) < 90%.

Quito (Ecuador) is located at an altitude of 2,850 m, and its intensive care units treat patients with ARF. Despite this, reports of blood gas values that should be considered normal at these altitudes are nonexistent or very rare, evidencing PaO_2 levels close to or below 60 mmHg.[2,3] Based on the limited data available, a recent publication in the journal *Medicina Intensiva* has commented on the need there is to investigate which blood gas values are considered normal at different altitudes.[4]

This study aimed to determine the normal values of arterial blood gases, especially PaO_2 and hematocrit, in a population living at an altitude of 2,850 m above sea level.

This is a proof-of-concept conducted through an observational, descriptive and cross-sectional study in healthy volunteers during the first semester of the year 2024 at the *Centro de Investigación Clínica* Hospital Pablo Arturo Suárez, in Quito-Ecuador (2,850 m, AP 547 mmHg).

The inclusion criteria were: a) subjects aged between 25 and 50 years; (b) permanent residence in Quito for more than a year; (c) voluntary acceptance to participate in the study; and (d) healthy subjects, i.e., non-smoker adults, without any medication, and with no cardiovascular, pulmonary or hematological diseases. The exclusion criteria were: (a) non-healthy subjects; and (b) an occupational history with respiratory repercussions, respiratory symptoms, body mass index (BMI) >30 kg/m^2, anatomical deformities of the chest, and/or treatments that alter alveolar ventilation or affect the pH or bicarbonate (HCO_3^-) values.

The radial artery blood sample was obtained from the non-dominant arm according to the hospital protocol. The analysis was performed on a GEM Premiere 5000 gasometer with an Intelligent Quality Management (iQM2) system, calibrated at an atmospheric (barometric) pressure of 547 mmHg (AP of Quito). This analyzer also determines hematocrit. Extraction was performed by expert personnel, and the sample was processed immediately.

The variables studied were: age, gender (male or female), hematocrit, lactate, pH, PaO_2, arterial partial pressure of CO_2 ($PaCO_2$), SpO_2 and HCO_3^-. The Kolmogorov–Smirnov test was used to test the data distribution. Estimators of central tendency and dispersion were the median and interquartile range (IQR), respectively. The mean with standard deviation (SD) and 95% confidence interval (95%CI) were calculated. In the presence of important differences in median values and interquartile ranges, nonparametric tests of median difference and hypothesis testing were used, with statistical significance being considered for $p < 0.05$. The SPSS version 23 statistical package was used throughout.

Written approval was obtained from the hospital Ethics Committee before the study began. Once approval was obtained, the study participants were given information regarding the study granting all of them their consent. Illiterate subjects gave verbal consent to participation.

A total of 66 patients were enrolled (50% men and 50% women).

Tables 1 and 2 report the mean ± SD, median with interquartile range and 95%CI. The largest differences in the range were found for the variables PaO_2, SpO_2 and hematocrit. These variables were contrasted to assess possible associations with gender as a cause of the observed variability. The p-value proved significant for PaO_2 ($p = 0.027$) and hematocrit ($p = 0.000$).

The results obtained are consistent with those of other studies carried out at similar altitudes, but not with those conducted at different altitudes.[3,4] A special comment should be made on the unexpected and exceptional significance found in relation to gender.

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Table 1 Medians of each studied variable with their interquartile ranges.

Variable	Mean ± SD	Median	Interquartile range (IQR)	95%CI
Total age (years)	32.6 ± 6.6	34	29.2–36.7	27–46
Age - Men	33.6 ± 6.8	31	29–36	27–46
Age - Women	32 ± 6.1	30	28–34	26–42
pH	7.43 ± 0.03	7.43	7.41–7.45	7.37–7.49
PaO_2 (mmHg)	74.27 ± 8.58	75	67.9–80	57.11–91.43
$PaCO_2$ (mmHg)	30.29 ± 3.48	30.6	27.7–32.4	23.33–37.35
HCO_3 (mmHg)	20.33 ± 1.83	20.2	18.8–21.7	16.67–23.99
$SatO_2$ (%)	94.40 ± 2.32	95	93–96	89.76–98.04
Lactate (mmol/L)	1.06 ± 0.68	1	0.57–1.4	0.9–1.24
Hematocrit	44.09 ± 6.6	45.4	37.2–50	32–54

Abbreviations: SD: standard deviation; pH: hydrogen potential; PaO_2: arterial oxygen pressure; $PaCO_2$: arterial carbon dioxide pressure; HCO_3: bicarbonate; $SatO_2$: arterial oxygen saturation; mmHg: millimeters of mercury; mmol/L: millimoles per liter; 95%CI: 95% confidence interval.

Table 2 Median difference between PaO_2 and hematocrit.

	Sex		
Variable	Male	Female	P value
PaO_2 (mmHg)	72.27	76.24	0.027
Hematocrit (%)	48.40	39.80	0.000

Abbreviations: PaO_2: arterial oxygen pressure.

In effect, PaO_2 was significantly higher in the female gender. In a study conducted in Mexico City (altitude 2,240 m) with 217 healthy subjects (48% women),[5] this significance was not found. An association between ovarian hormones and altitude has been described. In premenopause, oxygenation is better and the hemoglobin levels are lower.[6] This could be a possible explanation since the mean age of the women in the Mexican study was 43.5 ± 14.4 years.[5] Another study,[7] conducted at 2,640 m in 374 healthy adults, 55% of whom were women, obtained similar results to ours. In the mentioned study, the group of women aged between 18 and 30 years had higher PaO_2 levels than the men, followed by a decrease with age.

The hematocrit was significantly lower in women. A study conducted in Quito with 2,613 hematological samples, in which 46.4% of the subjects were female, already found this difference.[8] The underlying explanation may also be endocrine. Ovarian hormones attenuate hemoglobin production at high altitude.[9] A study of hematological parameters at altitude showed that postmenopausal Tibetan women had higher hemoglobin levels than premenopausal women.[10] The median age of the patients in our sample excludes postmenopausal women.

Being a proof-of-concept, the main limitation of this study is its sample size. The greatest strength and originality lie in the study group, which was balanced in terms of gender and age. However, although reference intervals have been established in a smaller number of subjects,[9] a larger study that will serve to validate these results is planned.

In conclusion, the PaO_2 values observed at the altitude studied are consistent with those reported in the literature at similar altitudes, and differ from those described at lower or higher altitudes. The observed significance in terms of gender was an unexpected result, and as such should be considered with caution until further research is conducted.

CRediT authorship contribution statement

Jorge Luis Vélez-Páez: conception, design, data collection, analysis and interpretation of the data and drafting of the article, and final approval of the submitted version.

Christian Castro-Bustamante: data collection, revision of the article and final approval of the submitted version.

Manuel Luis Avellanas-Chavala: conception, design, analysis and interpretation of the data and drafting of the article, and final approval of the submitted version.

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Declaration of competing interest

The authors declare that they have no conflicts of interest.

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