Chapter 13 / Capítulo 13

Electrolyte and Internal Environment Imbalances in Emergencies (English Edition)
ISBN: 978-9915-9680-3-2
DOI: 10.62486/978-9915-9680-3-2.Ch13

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Arterial Blood Gas Analysis in High-Altitude Residents

Gasometría arterial en residentes a gran altura

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ARTERIAL BLOOD GAS AT ALTITUDE

Table 13.1. Arterial Blood Gas Values at Very High Altitude

Variable/Value	Average	SD	Lower limit	Upper limit	Women	Men
pH	7,431	0,04	7,39	7,47	7,429	7,434
PaO2	58,69	8,55	50,14	67,24	58,93	58,01
PaCO2	26,14	2,89	23,25	29,03	26,74	24,51
HCO3	20,14	1,95	18,19	22,09	20,34	18,59
SaO2%	91,70	2,85	88,86	94,55	91,50	92,26
ctHb (g/dl)	16,25	1,98	14,27	18,23	16,35	15,99
p50c (mmHg)	28,68	3,28	25,40	31,95	29,33	26,88
ctO2c (Vol%)	20,43	2,74	17,69	23,17	20,19	19,84
Lactate (mmol/L)	1,82	0,82	1,04	2,68	1,69	1,84
FO2HB (%)	90,73	3,07	87,65	93,80	90,49	91,39
FCOHB (%)	0,63	0,70	0,08	1,33	0,50	0,96
FHHb (%)	7,05	3,64	3,42	10,69	7,48	5,88
FMetHB (%)	1,32	0,26	1,06	1,58	1,38	1,15
Sodium (mEq/L)	139	5,70	133,20	144,60	140	137
Potassium (mEq/L)	3,9	0,68	3,19	4,55	3,6	4,6
Chloride (mEq/L)	111	5,92	105,12	116,95	111	110
iCa (mmol/L)	0,98	0,22	0,76	1,21	1,02	0,88
Glucose (mg/dL)	106,47	12,64	93,82	119,11	106,95	105,13
Anion gap (mmol/L)	11,6	2,16	9,44	13,76	11,6	11,5
Anion gap w/o K (mmol/L)	7,7	2,17	5,56	9,90	8,0	6,9
mOsm (mmol/Kg)	283,7	11,52	272,20	295,23	285,4	279,1
SaO2/FiO2	436,7	13,56	423,13	450,24	435,7	439,3
PaO2/FiO2	279,5	40,71	236,79	320,21	283,2	278,9
cBase (mmol/L)	-5,1	1,82	-6,96	-3,32	--5,0	-6,5

SD: Standard deviation, SaO_2%: Arterial oxygen saturation, ctHb: Calculated total hemoglobin, p50c: Partial pressure of oxygen required to reach 50% hemoglobin saturation, ctO_2c: Calculated arterial oxygen content, FO_2Hb: Fraction of oxyhemoglobin, FCOHb: Fraction of carboxyhemoglobin, FHHb: Fraction of dysfunctional hemoglobin (dyshemoglobin), FMetHb: Fraction of methemoglobin, iCa: Ionized calcium, Anion gap w/o K: Anion gap without potassium, cBase: Base excess or deficit.

The arterial blood gas values considered "normal" for cities located between 3500 and 5800 meters above sea level (at Very High Altitude), which should be taken into account, are shown in table 13.1.

The arterial partial pressure values of oxygen and carbon dioxide are lower than those reported at sea level, as is serum bicarbonate, which is also decreased as compensation for the reduction in $PaCO_2$, since for an acid-base balance "every respiratory compensation entails a metabolic response." Arterial blood gas analysis is one of the most commonly used tests in Acute Medicine, as well as in Emergency Medicine, Internal Medicine, Pulmonology, Cardiology, and other specialties. The difference between $SatpO_2$% from blood gas analysis and pulse oximetry is no greater than 5%; however, if the latter exceeds 5%, consider severe anemia, methemoglobinemia, carboxyhemoglobinemia, or elevated glycosylated hemoglobin (HbA1c). Excess heparin is associated with low PCO_2 and bicarbonate values. If the sample remains in the syringe, oxygen consumption (for example, in patients with leukemia) and CO_2 production continue; however, the presence of bubbles in the sample is associated with an increase in PaO_2 and a decrease in $PaCO_2$. For all these reasons, ideally, a blood gas analyzer should be available in the same Critical Care unit.

Central Venous Blood Gas at High Altitude

The respective values of central venous blood gas at Very High Altitude are shown in table 13.2.

Table 13.2. Differences between arterial and central venous blood gas values at very high altitude

Variable	Arterial Sample	Central Venous Sample	Mean Difference
Oxyhemoglobin Saturation (%)	91,7	62,25 (61,5-63)	(-) 29,45
pH	7,431	7,44 (7,37-7,46)	(+) 0,009
pO2 (mmHg)	58,69	41,92 (39-48)	(-) 16,77
pCO2 (mmHg)	26,14	29,5 (25-32)	(+) 3,36
HCO3 (mmol/L)	20,14	21,17 (19-23)	(+) 1,03
Sodium (mEq/L)	139	138 (135-143)	(-) 1
Potassium (mEq/L)	3,9	4,1 (3,4-5)	(+) 0,2
Chloride (mEq/L)	111	113 (98-116)	(+) 2
Ionized calcium (mmol/L)	0,98	0,97 (0,7-1,14)	(-) 0,01

At sea level, a normal value for central venous oxygen saturation ($SvcO_2$) is considered to be between 65–75% (average 70%), which is 5% lower than mixed venous oxygen saturation ($SvmO_2$ or SvO_2). This, evidently, does not correspond to Very High Altitude, where the $SvcO_2$ value is 62,25 %, thus inferring an $SvmO_2$ of 67,25 %. A low $SvcO_2$ may be associated with low cardiac output (hypodynamic state), anemia, hypoxia, or hypermetabolism (hyperthyroidism, fever, seizures). For practical purposes, in addition to being useful for calculating variables derived from oxygen metabolism in our body (oxygen extraction, lactate clearance, and others), a central venous blood gas analysis is also useful for interpreting acid-base balance, taking into account as fundamental principles pH, pCO_2, and HCO_3.

Peripheral Venous Blood Gas at High Altitude

Although arterial blood gas analysis is the most frequently performed test in the Intensive Care Unit (ICU) because it is essential for managing critically ill patients, it has two main objectives: the first one is to assess the acid-base status through pH (bicarbonate and pCO_2),

and the second one is to evaluate the respiratory status (through pO_2 and pCO_2). However, it carries risks of nerve injury, arterial hemorrhage, hematoma, dissection, arterial fistula, pseudoaneurysm, thrombosis, and is also more painful; therefore, it is suggested to consider peripheral venous blood (PVB) gas analysis, which involves lower risk of complications and is less painful, and could provide guidance on these values, especially in Acute Medicine (Emergency, Anesthesiology, and Critical Care), except when an arterial blood gas is required to evaluate respiratory status or a central venous blood gas for assessing the PCO_2 Delta (ΔPCO_2), tissue oxygen extraction (EO_2), and others. Thus, PVB can be useful for estimating acid-base status in relation to arterial blood gas, highlighting pH (with a correlation coefficient r = 0,92 and an average difference of 0,04), serum bicarbonate, and lactate. Table 13.3 shows the reference values for peripheral venous blood gas at Very High Altitude.

Table 13.3. Peripheral Venous Blood Gas Values at Very High Altitude

Variable/Blood Gas	Arterial	Central Venous	Peripheral Venous
pH	7,43	7,44	7,37
pO2 (mmHg)	58,69	41,92	36,15
pCO2 (mmHg)	26,14	29,5	35,78
HCO3 (mmol/L)	20,14	21,17	20,11
SatO2 (%)	92	62,25	59
Sodium (mEq/L)	139	138	138
Potassium (mEq/L)	3,9	4,1	4,14
Chloride (mEq/L)	111	113	104
Calcium (mmol/L)	0,98	0,97	0,97

Where: pO_2: Partial pressure of oxygen; pCO_2: Partial pressure of carbon dioxide; HCO_3: Serum bicarbonate; $SatO_2$: Peripheral oxyhemoglobin saturation.

This information is very useful as it helps guide the management of patients living at high altitude, recognizing that peripheral venous blood gas in healthy permanent adult residents shows a lower pH level related to the transport of carbon dioxide from the tissues as a product of metabolism. However, serum bicarbonate is similar to the arterial sample. As expected, oxygenation values are very low since it is venous blood.

Arterial Blood Gas in Normal Pregnancy at Very High Altitude

In cities located between 3500 and 5800 meters above sea level, the normal values shown in table 13.4 should be considered.

Table 13.4. Normal Arterial Blood Gas Values in Normal Pregnancy at Very High Altitude

Variable/Value	Total	SD	Lower limit	Upper limit
pH	7,452	0,02	7,432	7,472
PaO2	65,22	7,22	58,0	72,40
PaCO2	24,35	2,51	21,8	26,9
HCO3	20,13	1,14	18,99	21,27
SaO2%	90,41	2,56	87,85	92,97
ctHb (g/dl)	14,39	3,0	11,39	17,40

p50c (mmHg)	29,11	0,90	28,21	30,0
ctO2c (Vol%)	18,01	3,7	14,31	21,71
Lactate (mmol/L)	1,32	0,4	0,92	1,72
FO2Hb (%)	89,23	2,46	86,77	91,69
FCOHb (%)	0,01	0,24	0,23	0,25
FHHb (%)	9,47	2,54	6,93	12,01
FMetHB (%)	1,28	0,27	1,01	1,55
Sodium (mEq/L)	139	4	135	143
Potassium (mEq/L)	3,84	0,43	3,41	4,27
Chloride (mEq/L)	112	3	109	115
iCa (mmol/L)	1,12	0,16	0,96	1,28
Glucose (mg/dL)	90,13	14,47	75,66	104,6
Anion gap (mmol/L)	11,01	3,71	7,30	14,72
Anion gap w/o K (mmol/L)	7,17	3,71	3,46	10,88
mOsm (mmol/Kg)	283,07	8,79	274,28	291,86
SaO2/FiO2	430,51	12,18	418,33	442,69
PaO2/FiO2	310,59	34,28	276,31	344,87
cBase (mmol/L)	-6,37	1,48	-7,85	-4,89

Where: SD: Standard deviation; SaO_2%: Arterial oxygen saturation; ctHb: Calculated total hemoglobin; p50c: Partial pressure of oxygen required to reach 50 % hemoglobin saturation; ctO_2c: Calculated arterial oxygen content; FO_2Hb: Fraction of oxyhemoglobin; FCOHb: Fraction of carboxyhemoglobin; FHHb: Fraction of dysfunctional hemoglobin (dyshemoglobin); FMetHb: Fraction of methemoglobin; iCa: Ionized calcium; Anion gap w/o K: Anion gap without potassium; cBase: Base excess or deficit.

Peripheral Venous Blood Gas in Normal Pregnancy at High Altitude

The peripheral venous blood gas values in normal pregnancy at Very High Altitude, compared to other groups, are shown in table 13.5.

Table 13.5. Peripheral Venous Blood Gas Values in Normal Pregnancy at Very High Altitude

Variable/Blood Gas	Arterial (Non-pregnant)	Central Venous (Non-pregnant)	Peripheral Venous (Non-pregnant)	Arterial in Normal Pregnancy	Peripheral Venous in Normal Pregnancy
pH	7,43	7,44	7,37	7,45	7,41
pO2 (mmHg)	58,69	41,92	36,15	65,22	40,09
pCO2 (mmHg)	26,14	29,5	35,78	24,35	26,25
HCO3 (mmol/L)	20,14	21,17	20,11	20,13	18,24
Sat (%)	92	62	59	90	62

This information is very useful for pregnant women in critical condition, as it helps guide the management of patients living at high altitude, recognizing that peripheral venous blood gas in healthy permanent resident pregnant women shows a higher pH level related to the gestational state (progesterone acting as a respiratory stimulant at the bulbar level and the pregnant uterus), with a compensatory decrease in serum bicarbonate also observed. As expected, oxygenation values are very low since it is venous blood.

BIBLIOGRAPHY

1. Viruez-Soto JA, Gutiérrez-Beltrán J, Prieto-Jemio JL, Auza-Santivañez JC, Briones-Garduño JC, Díaz de León-Ponce MA Manual de Medicina Aguda a Muy Alta Altitud. La Paz (Bolivia): Nexo Editores; 2024.