

PCO₂ AND CALCULATED VALUES FOR HCO₃, TCO₂, BASE EXCESS AND ANION GAP

PCO₂ is measured by direct potentiometry. In the calculation of results for PCO₂, concentration is related to potential through the Nernst equation. Results are measured at 37°C when using cartridges that require thermal control and corrected to 37°C when using cartridges that do not require thermal control.

Calculated Values

When a cartridge includes sensors for both pH and PCO₂, bicarbonate (HCO₃), total carbon dioxide (TCO₂) and base excess (BE) are calculated.¹

$$\log \text{HCO}_3 = \text{pH} + \log \text{PCO}_2 - 7.608$$

$$\text{TCO}_2 = \text{HCO}_3 + 0.03 \text{PCO}_2$$

$$\text{BE}_{\text{ecf}} = \text{HCO}_3 - 24.8 + 16.2 (\text{pH} - 7.4)$$

$$\text{BE}_{\text{b}} = (1 - 0.014 \cdot \text{Hb}) * [\text{HCO}_3 - 24.8 + (1.43 * \text{Hb} + 7.7) * (\text{pH} - 7.4)]$$

When a cartridge includes sensors for sodium, potassium, chloride, pH and PCO₂, anion gap can be calculated.

$$\text{Anion Gap} = (\text{Na} + \text{K}) - (\text{Cl} + \text{HCO}_3)$$

See below for information on factors affecting results. Certain substances, such as drugs, may affect analyte levels *in vivo*.² If results appear inconsistent with the clinical assessment, the patient sample should be retested using another cartridge.

Intended Use

The test for PCO₂, as part of the i-STAT System, is intended for use in the *in vitro* quantification of carbon dioxide partial pressure in arterial, venous, or capillary whole blood.

Contents

Each i-STAT cartridge contains one reference electrode (when potentiometric sensors are included in the cartridge configuration), sensors for the measurement of specific analytes, and a buffered aqueous calibrant solution that contains known concentrations of analytes and preservatives. For cartridges that contain a sensor for the measurement of PCO₂, a list of reactive ingredients is indicated below:

Carbon Dioxide (CO₂)

Metrological Traceability

The i-STAT System test for carbon dioxide partial pressure measures carbon dioxide partial pressure in arterial, venous, or capillary whole blood (dimension kPa) for *in vitro* diagnostic use. PCO₂ values assigned to i-STAT's controls and calibration verification materials are traceable to U.S. National Institute of Standards and Technology (NIST) standard reference materials via commercially available certified specialty medical gas standards. i-STAT System controls and calibration verification materials are validated for use only with the i-STAT System and assigned values may not be commutable with other methods. Further information regarding metrological traceability is available from i-STAT Corporation.

Expected Values

Test/Abbreviation	Units*	Reportable Range	Reference Range	
			(arterial)	(venous)
Partial Pressure Carbon Dioxide/ <i>PCO</i> ₂	mmHg	5 – 130	35 – 45 ³	41 – 51
	kPa	0.67 – 17.33	4.67 – 6.00	5.47 – 6.80
Bicarbonate/ <i>HCO</i> ₃	mmol/L	1 – 85	22 – 26**	23 – 28**
Total Carbon Dioxide/ <i>TCO</i> ₂	mmol/L	1 – 85	23 – 27**	24 – 29**
Base Excess/BE	mmol/L	(-30) – (+30)	(-2) – (+3) ³	(-2) – (+3) ³
Anion Gap/AnGap	mmol/L	(-10) – (+99)	10 – 20 ³	10 – 20 ³

*The i-STAT System can be configured with the preferred units.

**Calculated from Siggaard-Andersen nomogram.⁴

For *TCO*₂, values measured on serum or plasma by chemistry analyzers may be slightly lower than *TCO*₂ calculated from pH and *PCO*₂ due to loss of *CO*₂ during non-anaerobic handling.⁵ Up to 6mmol/L *CO*₂ can be lost per hour by exposure of the sample to air.⁶

To convert *PCO*₂ results from mmHg to kPa, multiply the mmHg value by 0.133.

The reference ranges programmed into the analyzer and shown above are intended to be used as guides for the interpretation of results. Since reference ranges may vary with demographic factors such as age, gender and heritage, it is recommended that reference ranges be determined for the population being tested.

Clinical Significance

*PCO*₂ along with pH is used to assess acid-base balance. *PCO*₂ (partial pressure of carbon dioxide), the respiratory component of acid-base balance, is a measure of the tension or pressure of carbon dioxide dissolved in the blood. *PCO*₂ represents the balance between cellular production of *CO*₂ and ventilatory removal of *CO*₂ and a change in *PCO*₂ indicates an alteration in this balance. Causes of primary respiratory acidosis (increase in *PCO*₂) are airway obstruction, sedatives and anesthetics, respiratory distress syndrome, and chronic obstructive pulmonary disease. Causes of primary respiratory alkalosis (decreased *PCO*₂) are hypoxia (resulting in hyperventilation) due to chronic heart failure, edema and neurologic disorders, and mechanical hyperventilation.

*HCO*₃ (bicarbonate), the most abundant buffer in the blood plasma, is an indicator of the buffering capacity of blood. Regulated primarily by the kidneys, *HCO*₃ is the metabolic component of acid-base balance. Causes of primary metabolic acidosis (decrease in *HCO*₃) are ketoacidosis, lactate acidosis (hypoxia), and diarrhea. Causes of primary metabolic alkalosis (increase in *HCO*₃) are vomiting and antacid treatment.

*TCO*₂ (total carbon dioxide) is either measured on plasma by automated chemistry analyzers or is calculated from pH and *PCO*₂ measured on whole blood gas analyzers. *TCO*₂ is a measure of carbon dioxide which exists in several states: *CO*₂ in physical solution or loosely bound to proteins, *HCO*₃ or *CO*₃ ions, and carbonic acid (*H*₂*CO*₃). Bicarbonate ions make up all but approximately 2 mmol/L of the total carbon dioxide of plasma. Measurement of *TCO*₂ as part of an electrolyte profile is useful chiefly to evaluate *HCO*₃ concentration. *TCO*₂ and *HCO*₃ are useful in the assessment of acid-base imbalance (along with pH and *PCO*₂) and electrolyte imbalance.

Base excess of the extracellular fluid or standard base excess is defined as the concentration of titratable base minus the concentration of titratable acid when titrating the average intracellular fluid (plasma plus interstitial fluid) to an arterial plasma pH of 7.40 at *PCO*₂ of 40 mmHg at 37°C. Excess concentration of base in the average ECF remains virtually constant during acute changes in the *PCO*₂ and reflects only nonrespiratory component of pH-disturbances.

Anion gap is reported as the difference between the commonly measured cations sodium and potassium and the commonly measured anions chloride and bicarbonate. The size of the gap reflects unmeasured cations and anions and is therefore an analytical gap. Physiologically, a deficit of anions cannot exist. While relatively nonspecific, anion gap is useful for the detection of organic acidosis due to an increase in anions that are difficult to measure. Anion gap can be used to classify metabolic acidosis into high and normal anion gap types. Anion gap may be only slightly increased in diarrhea and renal failure, but elevated (often >25) due to an increase in organic anions in lactic acidosis, ketoacidosis (alcoholic, diabetic, starvation) and uremia, an increase in inorganic anions in uremia, and an increase in anions from drugs such as salicylate and carbenicillin or toxins such as methanol and ethanol.

Performance Characteristics

The performance characteristics of the sensors are equivalent in all cartridge configurations.

The typical performance data summarized below was collected in a health care facility by health care professionals trained in the use of the i-STAT System and comparative methods.

Precision data were collected in multiple sites as follows: Duplicates of each control fluid were tested in the morning and in the afternoon on five days for a total of 20 replicates. The averaged statistics are presented below.

Method comparison data were collected using NCCLS guideline EP9-A⁷. Venous blood samples were collected in blood gas syringes. To measure TCO₂, the sample was centrifuged to obtain plasma. All samples were analyzed in duplicate on the i-STAT System and on the comparative methods within 10 minutes of each other. Arterial blood samples were collected from hospital patients in 3cc blood gas syringes and were analyzed in duplicate on the i-STAT System and the comparative method within 5 minutes of each other.

Deming regression analysis⁸ was performed on the first replicate of each sample. In the method comparison table, n is the number of specimens in the data set, Sxx and Syy refer to estimates of imprecision based on the duplicates of the comparative and the i-STAT methods respectively, Sy.x is the standard error of the estimate, and r is the correlation coefficient.*

Method comparisons will vary from site to site due to differences in sample handling, comparative method calibration and other site specific variables.

* The usual warning relating to the use of regression analysis is summarized here as a reminder: For any analyte, "if the data is collected over a narrow range, the estimate of the regression parameters are relatively imprecise and may be biased. Therefore, predictions made from these estimates may be invalid".⁷ The correlation coefficient, r, can be used as a guide to assess the adequacy of the comparative method range in overcoming this problem. As a guide, the range of data can be considered adequate if $r > 0.975$.

Precision Data (mmHg)

Aqueous Control	Mean	SD	%CV
Level 1	63.8	1.57	2.5
Level 3	19.6	0.40	2.0


Method Comparison (mmHg)

	<i>PCO</i> ₂ IL BGE	<i>TCO</i> ₂ IL BGE	<i>TCO</i> ₂ Beckman CX®3	<i>PCO</i> ₂ Radiometer ABL500
n	62	62	51	29
Sxx	0.69	0.40	0.55	0.74
Syy	1.24	0.84	0.55	0.53
Slope	1.003	1.136	1.155	1.016
Int't	-0.8	-4.1	-2.6	1.1
Sy.x	1.65	1.38	1.56	0.32
Xmin	30.4	19.3	18.3	28
Xmax	99.0	43.9	36.1	91
r	0.989	0.965	0.935	0.999

Factors Affecting Results*

Exposing the sample to air allows *CO*₂ to escape which causes *PCO*₂ to decrease and pH to increase and *HCO*₃ and *TCO*₂ to be under-estimated. The use of partial-draw tubes (evacuated tubes that are adjusted to draw less than the tube volume, e.g. a 5 mL tube with enough vacuum to draw only 3 mL) is not recommended for use with the i-STAT System because of the potential for decreased measured *PCO*₂ results and calculated *HCO*₃ and *TCO*₂ values. Under-filling blood collection tubes may also cause decreased *PCO*₂ results. Care must also be taken to eliminate “bubbling” of the sample with a pipette when filling a cartridge to avoid the loss of *CO*₂ in the blood.

Allowing blood to stand (without exposure to air) before testing allows *PCO*₂ to increase and pH to decrease, which will cause *HCO*₃ and *TCO*₂ to be over-estimated, due to metabolic processes.


Caution: When using **Type B** cartridges (cartridges without a  or **CE** on the pouch and box) with either SIMS Portex Dry Line Draw arterial blood gas sampling syringes with dry lithium heparin or SIMS Portex Anaerobic Line Draw arterial blood gas sampling syringes with liquid sodium heparin, ensure that the syringe lot number is 107xxx or higher. Syringe lots below 107xxx have a potential for causing sporadic, artificially low *PCO*₂ results. SIMS Portex Pro-Vent® syringes and Pulsator® syringes have always been compatible with the i-STAT System. For questions regarding the use of SIMS syringes with the i-STAT System, contact SIMS Portex, Inc., at the USA phone number 603-352-3812 (country code 1) and identify yourself as an i-STAT System user.

Interferent

Effect

Propofol (Diprivan®)

The effect of propofol is dependent upon the generation of cartridge, as indicated below:



Type A. For cartridges labeled with either  or **CE** on the pouch and box, there is no interference from propofol.

Type B. For cartridges without these labels, the following cautions apply:

Procedures that involve sustained (>1hour) administration of propofol at rates in excess of 50 µg/kg/min (3 mg/kg/hour) may result in significant errors in i-STAT *PCO*₂ results (see Note 1 below). Alternately, such administration may result in the automated suppression of *PCO*₂ and pH values (***) displayed by the analyzer's quality system. Use cartridges of **type A** (see above) to measure *PCO*₂ when administering propofol at rates in excess of this level. Consider using cartridges of **type A** (see above) when administering propofol at any sustained rate to patients with renal impairment.

Thiopental Sodium

The effect of Thiopental Sodium is dependent upon the generation of cartridge, as indicated below:

Type A. For cartridges labeled with either  or  on the pouch and box, there is no interference from Thiopental Sodium.

Type B. For cartridges without these labels, the following cautions apply:

Sustained administration (over more than a few minutes) of thiopental sodium, either by continuous or intermittent drips, may result in plasma concentrations of thiopental sodium that yield significant errors in i-STAT PCO_2 results (see Note 2 below). Alternately, such administration may result in the automated suppression of PCO_2 and pH values (***) displayed) by the analyzer's quality system. Use cartridges of **type A** (see above) to measure PCO_2 when administering thiopental sodium on a sustained basis.

* It is possible that other interfering substances may be encountered. These results are representative and your results may differ somewhat due to test-to-test variation. The degree of interference at concentrations other than those listed might not be predictable.

Notes:

- 1) Propofol is an intravenous sedative-hypnotic agent. Among its applications are the induction and maintenance of anesthesia and the sedation of intubated, mechanically ventilated patients. Although propofol itself does not directly interfere with the measurement of PCO_2 on the i-STAT System, decreases in PCO_2 of > 5 mmHg (0.67 kPa) have been observed on some patients due to metabolic byproducts of propofol, as a result of sustained (>1hr) administration at rates in excess of 50 $\mu\text{g}/\text{kg}/\text{min}$ (3 mg/kg/hour). At doses of 50-100 $\mu\text{g}/\text{kg}/\text{min}$ (3-6mg/kg/hour) some errors as large as 10 mmHg or 1.33 kPa.(below 40 mmHg or 5.33 kPa) or 25% (above 40 mmHg or 5.33 kPa) were observed. At doses significantly above 100 $\mu\text{g}/\text{kg}/\text{min}$ (6 mg/kg/hour) we have observed errors as large as 40% for administration in excess of 5 hours, although more typically results were suppressed by the analyzer (***)displayed). Below 50 $\mu\text{g}/\text{kg}/\text{min}$, decreases are typically less than 3 mmHg but sometimes as large as 5 mmHg (0.67 kPa). We have observed no decreases when a single dose of propofol is administered to induce anesthesia. We advise caution, however, when administering propofol to any patient with renal impairment as this may affect the clearance rate of metabolic byproducts.
- 2) Thiopental Sodium (*syn.* thiomebumal sodium, penthiobarbital sodium, thiopentone sodium, thionembutal, Pentothal Sodium[®], Nesdonal Sodium[®], IntraVal Sodium[®], Trapanal[®], and Thiothal Sodium⁹) is an ultra-short-acting, intravenous anesthetic. It is used as an induction agent for general anesthesia, to control status epilepticus, in the treatment of intracranial hypertension, and in narcoanalysis of psychiatric disorders. Sustained administration (over more than a few minutes) of thiopental sodium may lead to >5 mmHg (0.67 kPa) decreases in PCO_2 results. Errors observed on patient samples have been as large as 20 mmHg (2.67 kPa). For single dose administration of thiopental given over a few minutes, such as in the induction of anesthesia, interference on the i-STAT PCO_2 is modest (<10% at 40 mmHg or 5.33 kPa, <15% at 70 mmHg or 9.33 kPa) approximately 15 minutes after administration of typical doses, since thiopental is rapidly absorbed from the bloodstream, falling below 10 $\mu\text{g}/\text{mL}$ within 15 minutes¹⁰. The interference will continue to diminish as the drug continues to be absorbed.

References

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