

pH-Stat Ventilation Management: A Simple Method of Achieving this Regimen

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Abstract: Since the advent of extracorporeal circulation for life support during cardiac surgery, there have been varied opinions as to the best method of ventilating an oxygenator to achieve the optimum arterial blood gas. With respect to the optimum $p\text{CO}_2$, clinical investigators have focused primarily on the pros and cons of the alpha-stat and pH-stat ventilation schemes. pH-stat is a ventilation scheme that attempts to maintain the temperature corrected pH of the arterial blood at 7.40, no matter what the actual temperature of the blood. This paper does not attempt to elucidate the benefits of one scheme over the other, but is of-

fered to provide perfusionists with a simple method of achieving pH-stat ventilation, using a CO_2 source and materials readily available in any operating room. Strict adherence to a few cautionary notes should enable any perfusionist to safely deliver pH-stat ventilation when indicated. This technique of providing pH-stat ventilation has been used at our institution for over three years. It has proven to be easy to accomplish, adjust and maintain. **Keywords:** cardiopulmonary bypass, oxygenator, alpha stat, ventilation schemes, hypothermia, congenital heart surgery. JECT. 2003;35:287–289

pH-stat is a ventilation scheme that attempts to maintain the temperature-corrected pH of the arterial blood at 7.40, no matter what the actual temperature of the blood (1). The solubility of CO_2 increases, and molecular movement decreases as the temperature falls; therefore, maintenance of the temperature-corrected arterial pH at 7.40 requires that the total CO_2 content of the blood increase to maintain a $p\text{CO}_2$ of 40 mmHg. The nontemperature-corrected arterial blood gas (ABG) reflects increasing respiratory acidosis as the temperature of the blood decreases when maintaining pH-stat ventilation.

Investigators have shown that the use of pH-stat ventilation leads to a decrease in cerebral vascular resistance (CVR) and uncoupling of cerebral autoregulation for oxygen delivery (2). Blood flow to the brain becomes pressure dependent in a linear fashion. In human and animal studies there is mounting evidence that the use of pH-stat ventilation during cardiopulmonary bypass for surgeries requiring low flow or circulatory arrest is associated with better neurological outcomes (3–6).

Because membrane oxygenators are so efficient in removing carbon dioxide at gas flows necessary for oxygen-

ation, endogenous CO_2 production is usually inadequate to maintain pH-stat. This is especially true at the low temperatures targeted for circulatory arrest, which result in decreased CO_2 production (7). To achieve pH-stat ventilation, exogenous CO_2 must usually be blended into the ventilating gas of the oxygenator to maintain the temperature corrected $p\text{CO}_2$ at 40 mmHg.

The percentage of CO_2 in the ventilating gas that is necessary to maintain the $p\text{CO}_2$ at 40 mmHg is found by dividing 40 mmHg by the atmospheric pressure. At sea level this is 40/760 or approximately 5%. This means that for every 100 mL of gas flow to the oxygenator per minute, approximately 5 mL per minute of CO_2 should be blended in to the ventilating gas to maintain a $p\text{CO}_2$ of 40 mmHg in the arterial blood. Because most perfusionists have moved away from the use of bubble oxygenators, carbogen (95% O_2 , 5% CO_2) is not commonly carried in hospitals. A finely calibrated flow meter is usually needed to deliver accurately the small volumes of CO_2 required to achieve pH-stat. This type of flow meter is expensive and often not readily available. For these reasons an alternative method of blending carbon dioxide into the ventilating gas line of the oxygenator may be useful.

MATERIALS AND METHODS

The equipment used includes a room air and oxygen blender and flow meter (Sechrist Industries, Inc., Ane-

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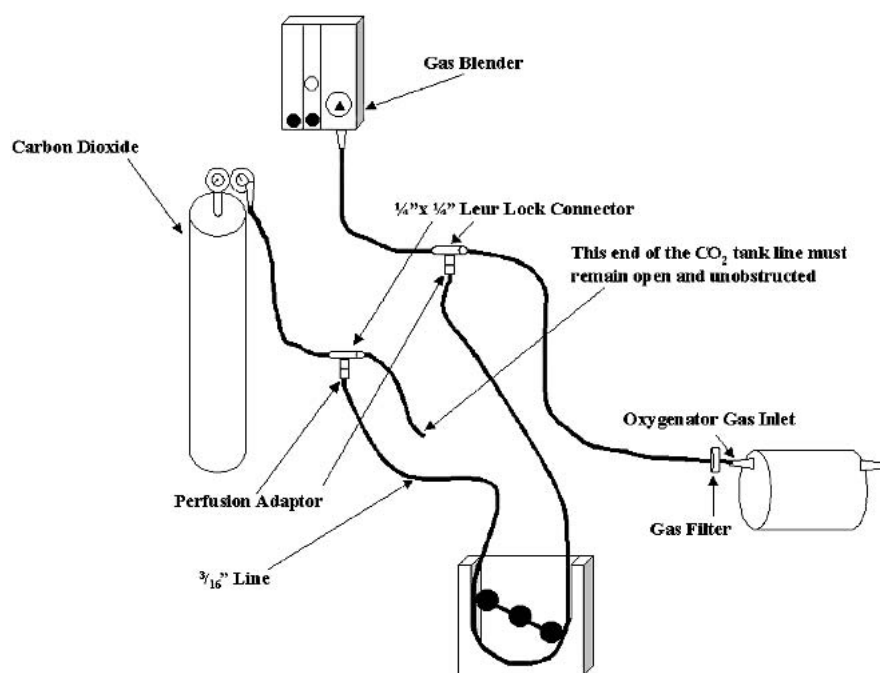


Figure 1. Circuit modifications for pH-stat ventilation.

heim, CA), CDI-500 blood gas monitor (Terumo Cardiovascular, Tustin, CA), $\frac{1}{4}$ " gas delivery line between the blender and the oxygenator, oxygen sensor, two $\frac{1}{4} \times \frac{1}{4}$ " luer lock connectors, two $\frac{1}{4}$ " perfusion adaptors, one 5-foot length of $\frac{3}{16}$ " tubing, Stockert Shiley roller pump fitted with shims to accommodate $\frac{3}{16}$ " tubing (Cobe Cardiovascular, Arvada, CO), CO_2 source with a standard flow meter (Western Medica, Avon Lake, OH).

Before bypass, the circuit is adapted as follows (Figure 1). A $\frac{1}{4} \times \frac{1}{4}$ luer lock connector is placed in the gas delivery line between the blender and the oxygenator. A $\frac{1}{4} \times \frac{1}{4}$ luer lock connector is also placed in a length of $\frac{1}{4}$ " tubing connected to the flow meter of a carbon dioxide source. A 6-foot length of $\frac{3}{16}$ " tubing is prepared by placing $\frac{1}{4}$ " perfusion adaptors in each end. One end is connected to the $\frac{1}{4} \times \frac{1}{4}$ luer in the gas line attached to the carbon dioxide flow meter and the other on the $\frac{1}{4} \times \frac{1}{4}$ luer on the gas delivery line to the oxygenator. The $\frac{3}{16}$ " line is placed in the roller pump so that the rotation of the pump head will deliver gas from the carbon dioxide line into the oxygenator gas delivery line. It is very important that the roller head is adjusted to be totally occlusive on the CO_2 delivery line, to ensure that all ventilating gasses are delivered to the oxygenator, and there is no leak of ventilating gasses back into the CO_2 source line. The open end of the CO_2 tank line must remain unobstructed to prevent pressurization and possible excessive delivery of CO_2 to the oxygenator. A gas filter must be placed in the gas delivery line proximal to the oxygenator and distal to the CO_2 line.

Bypass is initiated in the usual fashion. When pH-stat ventilation is desired, the carbon dioxide source is turned

on to a gas flow of approximately one half to one liter per minute, and the CO_2 delivery roller head is adjusted to approximately one revolution per minute (rpm) for every 100 mL per minute of oxygenator gas delivery flow. For example, if you are ventilating the oxygenator with a gas flow of 500 mL per minute, adjust the CO_2 delivery roller head to 5 rpm. The exact rpm necessary will vary by the stroke length of the roller head used. We monitor the temperature corrected pCO_2 with the CDI-500 system. A capnograph, sampling the gas exiting the oxygenator, may also be used to monitor the approximate pCO_2 in the arterial blood (8). Small adjustments to the CO_2 delivery rate and/or the ventilating gas delivery rate are used to bring the temperature-corrected arterial pCO_2 to 40 mmHg. When alpha-stat ventilation is desired, the CO_2 tank is turned off, and the oxygenator ventilating gas flow is increased to facilitate the removal of carbon dioxide until the nontemperature-corrected pCO_2 is 40 mmHg or until the temperature corrected pCO_2 is approximately equal to the arterial blood temperature.

Table 1. pH-stat values for eleven pediatric and neonate patients undergoing repair of congenital cardiac defects.

Temperature	Parameter	pH-Stat
Cooling data		
32	pCO_2	32.4 ± 4.6
25	pCO_2	36.6 ± 6.1
18	pCO_2	38.2 ± 3.3
Warming Data		
25	pCO_2	30.5 ± 5.9
32	pCO_2	35.8 ± 5.6
37	pCO_2	36.5 ± 4.1

DISCUSSION

As a cautionary note, it is our practice to discontinue any gas flow through the oxygenator and to circulate the prime through the arterial filter purge and recirculation line during periods of circulatory arrest. When using this technique, the perfusionist must remember to turn off the carbon dioxide delivery roller head any time that the ventilating gas flow is turned off. Failure to do so results in ventilating the oxygenator with 100% carbon dioxide and will lead to $p\text{CO}_2$ levels approaching atmospheric pressure in the circuit. This could cause deleterious effects to the patient when bypass is resumed.

This technique of providing pH-stat ventilation has been used at our institution for over 3 years. It has proved easy to accomplish, adjust, and maintain. This method of attaining pH-stat ventilation was used in a study looking at the effect of carbon dioxide on cerebral oxygen saturation (9). The collected data demonstrate that this technique achieves the desired $p\text{CO}_2$ to achieve pH-stat (see Table 1). Our current protocol calls for pH-stat ventilation on all pediatric cases where we cool the patient to 25°C or lower. This accounts for approximately 120 cases each year.

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