Technical Note

Modification of the Radiometer BMS-3 Electrode System to Improve Thermal Stability

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ACCURATE BLOOD-GAS MEASUREMENTS can be achieved only if the temperatures of electrodes, water bath and blood sample all remain constant. The magnitude of error as a result of thermal change is well established.[1] Temperature changes change blood P_{O_2} and P_{CO_2} 7 per cent/degree C and 4 per cent/degree, respectively, but in addition cooling the electrodes alters the electrical output directly. With a polyethylene membrane the oxygen electrode output decreases about 3 per cent/degree C measured as a decrease in expected P_{O_2}. Example: If the P_{O_2} expected is 100 mm Hg, the P_{O_2} observed will be 97 mm Hg when the water bath has cooled from 37 to 36 C, the calibrating gas remaining constant. If blood with P_{O_2} 100 mm Hg is now added to the cuvette, it will read 90 mm Hg, the sum of blood and electrode errors of 10 per cent/degree C. The CO_2 electrode output increases when cooled, 1.5 per cent/degree C, as measured in this study. Example: If the P_{CO_2} expected is 40 mm Hg, the P_{CO_2} observed will be 40.6 mm Hg when the water bath is cooled from 37 to 36 C, the calibrating gas remaining constant. If blood with P_{CO_2} 40 mm Hg is now introduced into the cuvette it will read 39 mm Hg since positive electrode and negative blood errors in part cancel.

Because of the need for stable blood and electrode temperatures, materials with optimal heat transfer characteristics are imperative in the design of cuvettes for blood-gas electrodes. Thermal transfer values for stainless steel and glass are 94 and 8 compared with plexiglas, which has a relative value of 1. For this reason plexiglas has been considered unsatisfactory for this purpose. Yet manufacturers occasionally introduce new apparatus containing plastic cuvettes without regard for their thermal regulating characteristics. The new Radiometer BMS-3 unit is constructed of plexiglas and consequently may introduce serious errors in blood-gas analysis from thermal disequilibrium, which may persist for as long as 12 minutes after injection of 1 ml of ice-cold blood. We rebuilt the unit using a stainless steel cuvette that fits the same electrodes and water bath (fig. 1) and compared the thermal characteristics of the plastic and steel cuvettes.

Temperature of the liquid in the cuvette was measured with a type 511 polyethylene-covered thermistor probe (Yellow Springs Instrument Co.) inserted from the top outlet into the middle of the cuvette. We first demonstrated that heating and cooling the proxi-

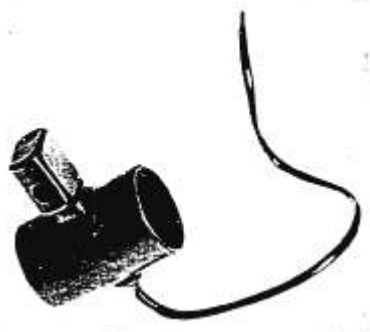

FIG. 1. Stainless steel sample chamber.

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TABLE 1. Thermal Characteristics of Original and Modified BMS-3 Cuvettes*

	Original BMS-3 (Plastic) Cuvette (n = 10) Time to return of temperature to		Modified BMS-3 (Stainless Steel) Cuvette (n = 10) Time to return of temperature to	
	36.9 C	37.0 C	36.9 C	37.0 C
Volume and temperature of water injected into cuvette to duplicate volume of "wash water" injected				
2 ml, 35.5 C	4 min 17 sec	6 min 10 sec	27 sec	55 sec
2 ml, 22.0 C	6 min 07 sec	8 min 20 sec	49 sec	1 min 50 sec
Volume and temperature of water injected into cuvette to duplicate volume of blood which might be injected				
0.2 ml, 0 C	4 min 25 sec	7 min 14 sec	6 sec	21 sec
0.4 ml, 0 C	7 min 01 sec	9 min 57 sec	20 sec	50 sec
1.0 ml, 0 C	9 min 57 sec	12 min 29 sec	38 sec	1 min 29 sec

* Water bath maintained at 37.0 C.

mal catheter lead above the cuvette had no effect on the temperature reading. A variety of injection volumes, flow rates and temperatures of injectate (a few of which are listed in table 1) were tested with the plastic and stainless steel cuvettes. With the stainless steel cuvette, blood at 25 C may be injected continuously at 2 ml/min without change in cuvette temperature.

Internal dimensions and thread of the stainless steel cuvette duplicate those of the original plastic cuvette. A stainless steel T connector (fig. 2) was silver-soldered to its top. The consequences of these modifications are: 1) The volume needed to fill the sample chamber is increased from 0.10 to 0.20 ml, of which 0.10 ml is contained in an inlet tubing (I.D. 1.5 mm). This change eliminates the problem of pressure artifacts during gas calibration when this tubing is used as an outlet. 2) The cuvette, being no longer transparent, cannot be inspected for bubbles. 3) The *p*H electrode cannot be filled by aspirating from the sample chamber. We have found that filling the *p*H needle by injection in the horizontal position avoids backflow of KCl and gives greater reproducibility in any case.

A number of other modifications, although not essential, are helpful (fig. 3). These are: 1) Replacement of the gas delivery tubing with 1.5 mm o.d. nylon tubing to reduce transwall diffusion loss. 2) Replacement of the 15-ml plastic humidifier chambers with 2-ml glass test tubes to permit rapid changes in calibrating gases. 3) Installation of a glass three-way stopcock (9802B, per drawing 042028, Kontes of California, 2809 10th Street, Berkeley, California) to permit connection of the outlet with either of two calibrating gases or the waste port. This stopcock, mounted in a polycarbonate block, was clamped to the cuvette assembly (fig. 2) by a split polycarbonate cylinder. An inlet port on the cylinder permitted thermostated water to be perfused directly around the cuvette. 4) Replacement of the stainless steel bath top, holes being appropriately relocated for the thermistor, stopcock, waste port, and wash water. 5) Replacement of the plastic chamber designated "wash water" with a glass 100-ml beaker, since the temperature in the plastic chamber was found to

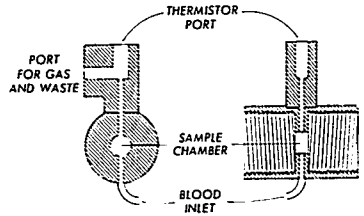

FIG. 2. Diagrammatic cross-sectional views of stainless steel sample chamber. Internal dimensions are the same as those of the original plexiglas chamber. o.d. of the stainless steel cylinder is 17.5 mm. i.d. of the narrow vertical hole is 1.1 mm.

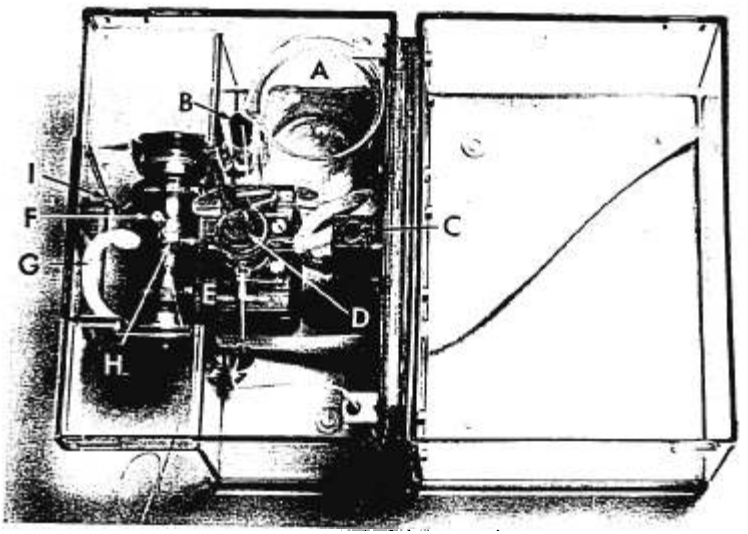

FIG. 3. Complete modification of Radiometer BMS-3 system. *A*, beaker for wash water. *B*, glass humidifier. *C*, waste collector. *D*, four-way stopcock for introduction of two calibrating gases and exit of blood sample. *E*, four-piece polycarbonate stopcock holder fixed rigidly to sample chamber. *F*, thermistor lead wire. *G*, tubing for delivery of thermostated water directly around sample chamber. *H*, stainless steel sample chamber. *I*, stainless steel inlet tube.

be 1.5 C below the temperature of the water bath.

As mentioned, the electrode errors caused by the changing water bath temperature are −3 per cent/degree C for O_2 and +1.5 per cent/degree C for CO_2. As this system is used, however, differential cooling occurs, with the tip of the electrode cold and the rest of the electrode unchanged in temperature. With the modified BMS-3 system it was possible to evaluate differential cooling in the following way. Sterile 0.2 N saline solution was equilibrated at room temperature with 5 per cent CO_2 in air, then transferred to a large syringe without a gas phase. The solution was injected into the cuvette, which had been presterilized with a quaternary ammonium compound and alcohol, until a stable reading was obtained with the liquid at 37 C. The saline was then injected continuously at a rate which reduced its temperature in the cuvette to 36.5, 36.0, and then 35.0 C. The readings at each (constant) temperature stabilized within a minute in both electrodes. Each observed reading was compared with the P_{O_2} and P_{CO_2} calculated for the saline solution at that temperature from known solubility temperature coefficients and measured 37 C values. The electrode error (excluding the actual gas tension changes) was −2 per cent/degree C for oxygen at each temperature, while the errors for P_{CO_2} were +2.4 per cent at 36 C and 0.0 per cent at 35 C, apparently due to cancellation by several opposing changes. The complex nature of these errors re-emphasizes the need for strict thermal stability.

Reference

1. Severinghaus JW: Bioelectrodes. Ann NY Acad Sci 148:115, 1968