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The Reliability and Accuracy of

The Beckman Blood Chemistry Monitor

The Beckman Blood Chemistry Monitor Model 400 (BCM) is a continuous gas analyzer which measures *in vivo* as well as *in vitro* blood flows and is automatically temperature compensated for the other three blood chemistry parameters (PO_2 , PCO_2 , pH). The temperature compensation referred to here is concerned only with the effects of temperature on the sensors themselves and has no relationship to the effects of temperatures on the values of PO_2 , PCO_2 and pH in the blood.

It gives actual readings at any temperature of the sensor Teflon block instantaneously on the four meters as well as on a chart recorder. The chart recorder records each parameter every four seconds. The blood flowing through the Teflon block comes into contact only with Teflon, silicone rubber, and dialysis cellophane.

An important feature of this system

is that the glass surface of the pH electrode does not come into contact with the blood proteins because of the cellophane membrane barrier. This feature is a major factor which allows blood chemistry to be measured continuously for long periods of time on whole blood, since the glass electrode exposed directly to blood becomes coated with serum proteins within a short period of time.

Two different size Teflon blocks were tested. The large bore block had a cell volume of 8.5 ml. and could be used at flow rates of up to 400 ml. per minute. The small bore Teflon block had a cell volume of 0.5 ml., and could be used at flow rates from 1 ml. to 50 ml. per minute. The large bore Teflon block was used with the heart-lung machine.

Purpose of Testing

The purpose of testing the BCM was to determine its reliability and

accuracy under actual surgical procedure, i.e., total body perfusion. The testing was divided into three major divisions. The first division utilized a known synthetic blood solution, which was composed of: 0.0250 M. sodium bicarbonate saline solution and a known carbon dioxide and oxygen gas mixture. The gas mixture was analyzed for percentage composition and purity. This solution was used for measuring the accuracy and reliability of the BCM for long periods of operation and for determining how rapidly the four parameters change when a different gas mixture is substituted.

The second division utilized Arterio-Venous loops on dogs. The testing rationale of the A.V. loops was to determine how easily and accurately this system could be used to measure continuous blood chemistry, i.e., post-operative patients. The third division utilized total body perfusion on dogs

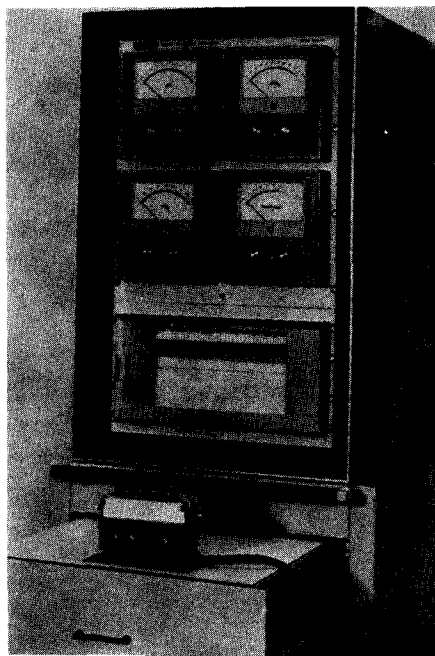
to determine how accurately blood chemistry could be measured on the BCM. The main criteria that were taken into consideration were, whether or not the BCM could be satisfactorily utilized during total body perfusion and how rapidly it would monitor induced changes in the blood, i.e., reduced oxygen perfusion and sodium bicarbonate injections.

Methods of Calibration

Two methods were used to calibrate the BCM. Each method had certain advantages. The first method had the advantage of being the most accurate and reproducible. This type of calibration made use of the previously mentioned solution (known synthetic blood solution). This solution was heated to a constant 37°C., and circulated by a Harvard Peristaltic pump through the Teflon block. Theoretical data was computed from this solution beforehand, by using the Hasselbach Equation.¹ Therefore, the pH, PCO₂, PO₂ and temperature of this solution was known. It was then a simple matter to adjust the dials on the BCM monitor to read the exact theoretical values for PO₂, pH and PCO₂.

The second method of calibration makes use of another blood gas analyzer as a reference. This method has the advantage of speed in calibration. However, by doing this, one incorporates any errors in the reference analyzer, as well as any error in the adjustment of the BCM. Other errors involved in this type of calibration are: changes in blood chemistry while analyzing the samples in the laboratories; obtaining a representative blood sample; and all the implied summation of errors of the additional equipment and procedural steps.

This calibration consists of taking a representative blood sample from a continuously flowing blood loop of



Blood Chemistry Monitor and Flow Assembly

some type, i.e., total body perfusion, A.V. loop. This sample is taken to be analyzed on a reference blood chemistry analyzer. At the time the blood sample is taken the four parameters on the BCM monitor are recorded. When the results of the analysis by the reference analyzer become known, the four parameters on the BCM monitor are again recorded. Then the change from the first BCM reading to the second BCM reading is recorded. This change is then added or subtracted (depending whether there was an increase or decrease on each of the four parameters) from the first reference analyzer readings. The BCM was then adjusted separately for each of the four parameters and locked into position.

Arterio-Venous loops

The A.V. loops employed the use of a number 10 French, 22 inch plastic catheter, which was inserted into the left femoral artery and advanced up into the left iliac artery, tying and securing it in place. The venous catheter (same as above) was placed in the left femoral vein and pushed up into the left external iliac vein, tied and secured. The two catheters were filled with saline and attached to the Teflon block. This established a circulating A.V. loop. During the course of the experiments, 5 cc. syringes were connected to a stopcock on the arterial catheter for reference analysis.

The dogs were anesthetized with Diabulal (sodium pentobarbital, 60 mg./1 cc.) and were administered 1 cc./5 lbs. body weight. Then the dogs were heparinized with heparin sodium (1000 u.s.p. units/1 cc.) at 2 mg./1 k.g. body weight.

All the studies on the A.V. loops were precalibrated by using another blood gas analyzer. The BCM was checked and calibrated against the I.L. pH/Gas Analyzer, Model 113. Recordings were then made at certain intervals of all parameters, and compared with the I.L. Analyzer. After the recordings, the stopcocks were closed, the A.V. loop was interrupted, and the circuit disassembled.

A consistency was noted on all parameters in all the tests. The first two A.V. loop experiments produced no PCO₂ readings. This was attributed to a faulty PCO₂ electrode from the factory. It was discovered in the second A.V. loop experiment that the blood circuit was disrupted. This was probably caused by a blood clot in the tubing leading from the BCM Teflon block; also several folds in the venous return tubing from the Teflon block were noticed. From this second A.V. loop we concluded that the A.V. circuit should be flushed with heparinized saline every hour as a safeguard, and/or another type of catheter should be used. In addition, a small pump might be used to attain a constant blood flow through the A.V. loop.

Since the Teflon block is at or below ambient temperature, all the I.L. Analyzer figures had to be compensated for changes in temperature in order to compare to changes in BCM figures as caused by changes in temperature. After comparing the temperature compensated reference figures to the BCM figures in all the A.V. loops, it was concluded that a high degree of correlation existed.

Total Body Perfusion

The total body bypass employed the use of an Olson heart-lung pump (Model 601-36) which was used in conjunction with a Temptrol Disposable Blood Oxygenator. All tubing used in the total body perfusion was standard Tygon Surgical Tubing used in most perfusion procedures. A Y-connector (1/4 inch inside diameter) was connected directly from one of the four ends to the intake end of the BCM

¹ For a given PCO₂, (for example 19.5) and a known bicarbonate Molarity, which in this case is 0.0250 M., the pH can be determined by use of the Hasselbach equation as follows:

$$\text{pH} = \text{pK}^1 + \log \frac{(\text{HCO}_3^-)}{(\text{CO}_2)}$$

$$\frac{(\text{HCO}_3^-) + 0.0250}{(\text{CO}_2)} = \text{PCO}_2 \times .03 = 0.585$$

$$\text{pK}^1 \quad 6.1 \text{ for all normal ranges of temperature}$$

$$\text{pH} = 6.1 + \log \frac{(0.0250)}{(0.585)}$$

$$\text{pH} = 7.71$$

large bore Teflon block. The output end of the block had a tube (1/4 inch inside diameter) leading directly to the oxygenator.

The technique for total body bypass used in the perfusions was as follows: The femoral artery was used for perfusion. The inferior vena cava was cannulated for all lower extremity drainage, and the right atrium for all upper extremity and coronary sinus drainage. The azygous vein was ligated. The main pulmonary artery was occluded.

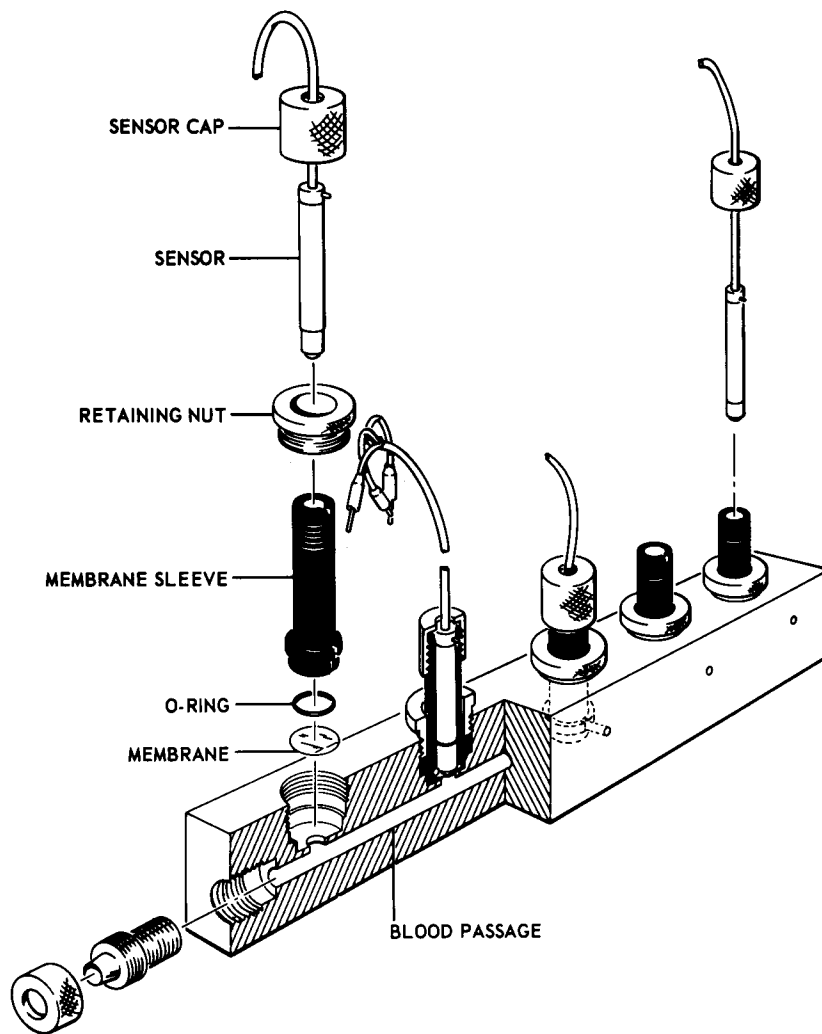
In the perfusion procedures the BCM large bore Teflon block was gas sterilized (ethylene oxide) the night before with the various membranes installed. The BCM was calibrated several hours before the perfusion took place by using the known synthetic blood solution method under sterile conditions.

In the total body perfusion experiments the oxygen flow to the oxygenator was reduced by 2 L./min. Two ampules of sodium bicarbonate were also added. Both of these were done to check corresponding changes in the four parameters. Several interesting observations were noted on graph 1, after the oxygen flow was reduced from 7 L./min. to 5 L./min. for 6 minutes.

Point 1, of the pH recording, represents a .03 of a pH unit decrease within the first 12 seconds. Point 2 represents the lowest trend in the pH caused by the reduced oxygen flow, and the starting point for the upward trend in response to the addition of sodium bicarbonate. Point 2 to point 3 represents a .07 of a pH unit increase within the first 12 seconds, caused by the addition of the first ampule of sodium bicarbonate.

Midway between point 3 and point 4, a second 50 cc. ampule of sodium bicarbonate was added. Point 4 to point 5 represents .035 of a pH unit increase in response to the addition of the second ampule of sodium bicarbonate. Point 5 to point 6 represents a .04 of a pH unit increase within 12 seconds. The trend from this point onward is towards the normal pH range.

In addition to these observations, a similar response in the opposite direction was observed on the PCO₂ recording when the oxygen flow was reduced



Sketch of Flow Assembly

from 7 L./min. to 5 L./min. for the second time. Point 1 of the PCO₂ recording represents the point where the first 50 cc. ampule of sodium bicarbonate was added. The effect of this ampule is not noticed until point 3, which is approximately 30 seconds later.

Between points 3 and 4 a second 50 cc. ampule of sodium bicarbonate was added. Point 4 represents the turning point of the first sodium bicarbonate effect. Point 5 represents a reversal of CO₂ buildup, caused by the second 50 cc. ampule. Point 5 also represents 5.4 mm.Hg PO₂. Shortly after point 5, the normal oxygen flow was resumed to the oxygenator. On the PO₂ recording,

point 1 represents the point where the normal oxygen flow was resumed. The rest of the PO₂ recording is relatively stable with minor variations.

On the PO₂ recording, the O₂ trend is slightly to the left. Point 1 of the PO₂ recording represents the low point of the PO₂ just prior to the resumption of the normal oxygen flow. Point 1 of the PO₂ recording represents a PO₂ reading of 22 mm.Hg. The total body bypass was concluded with the following readings: pH 7.45; PCO₂ 26 mm. Hg.; and PO₂ 25 mm.Hg.

Discussion

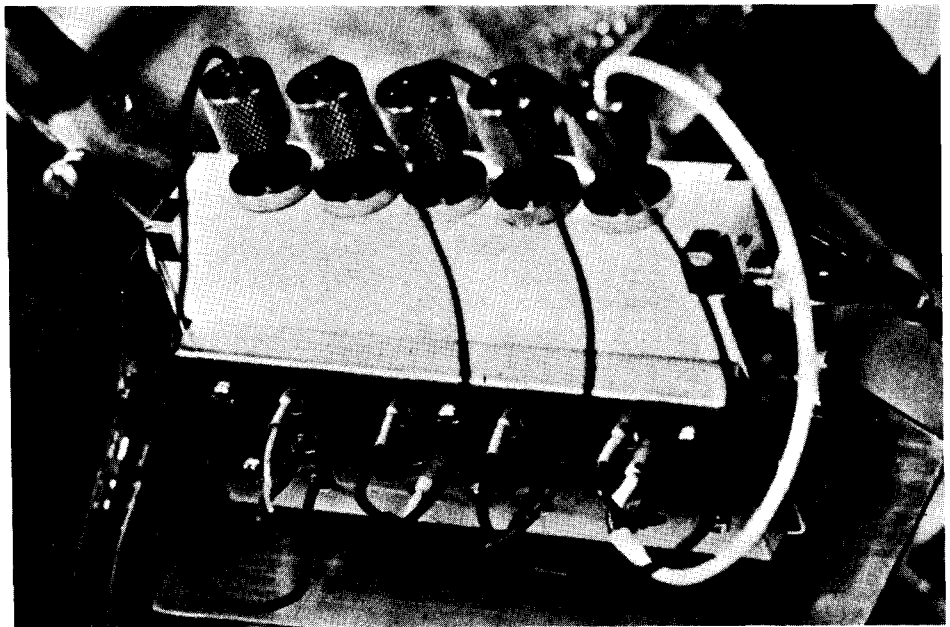
After testing the Beckman Blood Chemistry Monitor, Model 400 (BCM)

on Arterial Venous loops, total body bypasses, and a known synthetic variable blood solution, we found the BCM to respond instantaneously to changes in the four parameters. This would indicate that an abrupt change in a patient's blood chemistry can be monitored as it is happening. On the other hand, measurement by the conventional methods would take between five and ten minutes to observe what had already happened.

From the information from A.V. loops, we learned that it is quite feasible to monitor blood chemistry for long periods of time. We also learned that the A.V. loop system should be flushed every hour to prevent any stagnation of blood. The accuracy of the A.V. loops can only be as accurate as the reference analyzers with the incorporation of errors in the reference analyzer, as well as any error in the adjustment of the BCM.

A second method of calibration can be utilized. This method uses a sodium bicarbonate solution of known molarity and a gas of known concentration. This method eliminates the errors involved in transferring the blood sample to a reference analyzer, as well as the summation of errors of the additional equipment and procedural steps. By using this method of calibration a high degree of accuracy and reliability can be obtained. In most cases, we found the insignificant errors incorporated into our readings, when using this method of calibration, were caused by a minute maladjustment of the calibration knobs.

From the results of the total body



bypasses, we discovered that accurate readings could be obtained at the time they are happening. We found that induced changes such as reduction of oxygen flow and the addition of sodium bicarbonate ampules cause corresponding changes on the BCM recordings in real time. We also discovered that the greater the gradient in all four parameters, the quicker the response time.

It was also concluded that sterilization of the Teflon block with the membranes installed, was easy and did not lose accuracy or reliability because of it. It was also concluded that the BCM unit was quite portable and could be placed at a distance from the sterile field by means of a 30 foot cable.

In conclusion, we feel that the BCM is extremely accurate and reliable; can

be utilized in open-heart surgery with no apparent technicalities; and can be used to measure blood chemistry via an A.V. loop.

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"A large segment of the medical community views the invasion of technology into medical practice with concern if not with alarm. Some of this reaction reasonably stems from instruments or equipment which have proved unreliable or ineffectual in the past. But current trends should receive a warmer welcome since they show real promise

of being able to free physicians from certain types of routine activity which do not require their extensive training. If new diagnostic tools in the hands of *well-trained* technicians can provide consistently reliable data, displayed to physicians with greater clarity and less redundancy, then all participants in the health care delivery system, including the patient, must benefit."