An electronic apparatus for early detection of changes in red cell content of blood during anaesthesia

A preliminary report

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Summary

An electronic apparatus was developed for anaesthetists to use to detect changes in red cell concentration during surgery. The mechanism is based on the relationship between the red cell content and the electrical conductivity of blood. In a pilot study of 170 blood samples, a correlation coefficient of 0,9806 was obtained between haematocrit and the instrument readings. To evaluate the instrument's performance in practice, and factors that might influence its readings, a series of 10 cases of aortic surgery were investigated. It is concluded that, although changes in electrolyte concentration, pH and temperature do affect the instrument's readings, these are insignificant compared with those of red cell content, and that the device can be used to indicate a drop in red cell concentration.

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Observation of changes in a patient's red cell content is fundamental in modern anaesthesia,[1,2] especially if a bleeding tendency exists. Standard techniques for this evaluation include measurement of the haemoglobin and haematocrit values.[3] For these estimations, a blood sample is usually collected and sent to a nearby laboratory for analysis.

A study was undertaken to develop a blood electrometer for the anaesthetist to use in theatre for the speedy determination of blood hydration. Although the instrument was originally developed for this purpose, it has already found valuable applications in other fields of medicine, for instance different intensive care units, paediatric departments and casualty stations.

The mechanism is based on the measurement of the effect a change in red cell concentration exerts on the electrical conductivity of blood. This may be compared with the universally used counter described by Coulter[3] in 1956. His counter is based on the fact that blood is a poor conductor of electricity whereas certain diluents are good conductors.[3] Coulter's method can be performed under standard conditions of pH, temperature and electrolyte composition. In our study, whole blood was used to observe changes in red cell content during any type of surgery and it was necessary to establish the correlation between blood conductivity and haematocrit as well as to what extent other variables in blood affect its conductivity.

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Material and methods

Instrumentation and mode of operation. The equipment consists of a 5 ml syringe with electrodes and an electronic apparatus (Fig. 1*). After collecting a blood sample with the syringe, the contact points of the inner piece are pressed to that of the electrometer and a readout in mVs appears on the display console. After this count has been registered, the blood is injected into a heparin tube for haematocrit value estimation and electrolyte analysis. To maintain sterile conditions, a 5 ml disposable syringe outerpiece is used for every measurement and only the relatively expensive innerpiece is re-used after sterilisation. Blood is not re-infused and only the sterile disposable outerpiece and needle is in direct contact with the patient.

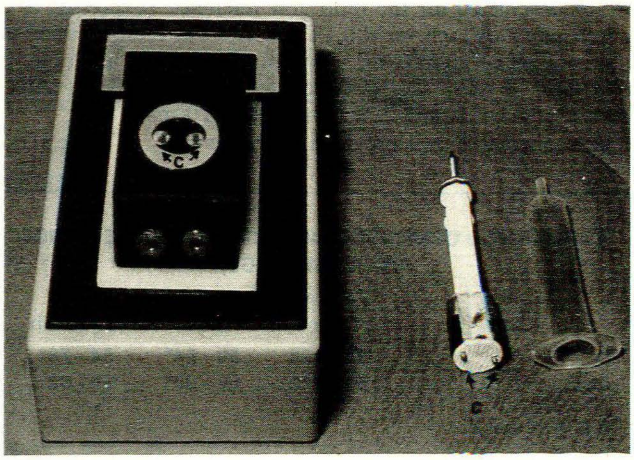

Fig. 1. Electrometer and syringe used for the determination of changes in red cell composition of patients during general anaesthesia.

Apparatus calibration and maintenance. Based on preliminary studies, the apparatus is calibrated to a blood electrometer reading (BEM) of 600 mV when the positive and negative electrodes of the syringe are connected by a 220 mV resistor. The electrometer is equipped with two 9 V rechargeable batteries, which, when fully charged, can be used for up to 6 months.

* Patent pending.

Variation of some blood components during general anaesthesia. Serial blood samples were drawn via the arterial line for the study of variations in concentration of the different blood constituents, and for BEM reading, during 10 cases of aortic surgery. These estimations included electrolyte and plasma protein values performed with a Technicon SMAC II analyser. Haematocrit was obtained by the microhaematocrit method and blood pH was measured on an Radiometer ABL blood gas analyser. The standard deviation of the maximum changes for the different constituents was calculated.

Factors affecting BEM readings. The effects of sodium chloride concentration, percentage of red blood cells, pH, and temperature on BEM readings were investigated. Three sodium chloride solutions of 130 mmol/l, 140 mmol/l and 150 mmol/l were prepared and BEM readings were measured at 37° C. For the percentage red blood cells, readings were obtained at 37°C from a sodium chloride solution of 150 mmol/l containing 0%, 10% and 40% red blood cells respectively. The effect of pH variation on the BEM reading was evaluated on normal blood samples after changing the pH value by acidification with dilute hydrochloric acid to pH values between 7,50 and 5,60. For temperature, three normal blood samples were measured at 36°C, 37°C and 38°C. Mean values were calculated for each relevant point. A series of 20 determinations was done on a blood sample from the same source at 37° C and the standard error calculated.

Correlation between electrometer reading and haematocrit. A total of 170 blood samples was collected on a voluntary basis irrespective of sex, race or age. The greatest number of samples was obtained from a blood donor institution and casualty and trauma units. BEM values were measured according to the described method and haematocrit by centrifugation.

Results

The readings on the BEM were affected by some blood components and also physical factors (Fig. 2). An increase in sodium and hydrogen ion concentrations and in blood temperature causes an elevation, while an increase in red cell content depresses the reading and vice versa. Standard deviations of the different blood constituents during surgery indicated that large variations occur only in haematocrit and BEM values (Table I). Variations in the protein fractions also occurred. A negative correlation between haematocrit and BEM reading is illustrated in Fig. 3 (correlation coefficient 0,9806). The SEM was 2 mV.

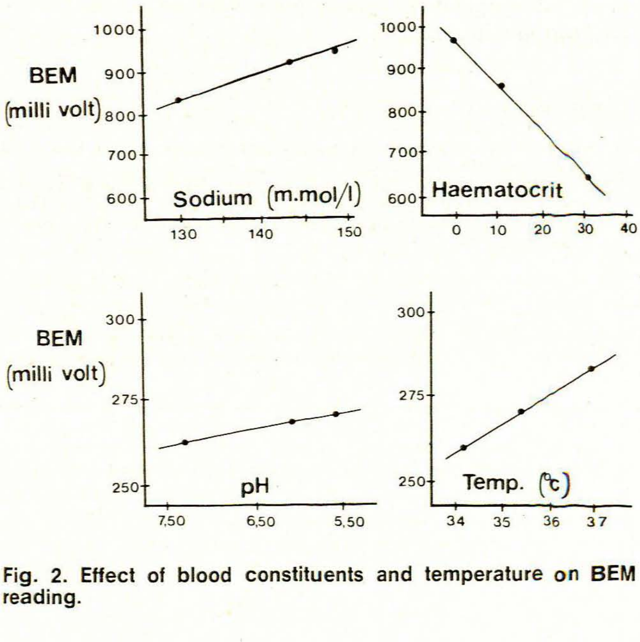

Fig. 2. Effect of blood constituents and temperature on BEM reading.

TABLE I. BODY TEMPERATURE, SERUM ELECTROLYTE AND BEM MEASUREMENTS IN 10 PATIENTS DURING AORTIC SURGERY (MEAN ± SD)

Temperature (°C)	35,20 ± 1,93
Sodium (mmol/l)	136,00 ± 1,79
Chloride (mmol/l)	99,00 ± 1,49
Potassium (mmol/l)	4,10 ± 0,82
Calcium (mmol/l)	2,39 ± 0,12
Magnesium (mmol/l)	0,95 ± 0,08
Phosphorus (mmol/l)	1,38 ± 0,25
Anion gap (mmol/l)	12,00 ± 2,21
Osmolality (mOsmol/kg)	297,00 ± 3,50
Total protein (g/l)	67,00 ± 5,48
Albumin (g/l)	38,40 ± 2,66
pH	7,39 ± 0,0137
Haematocrit	46,00 ± 8,24
BEM (mV)	341 ± 114

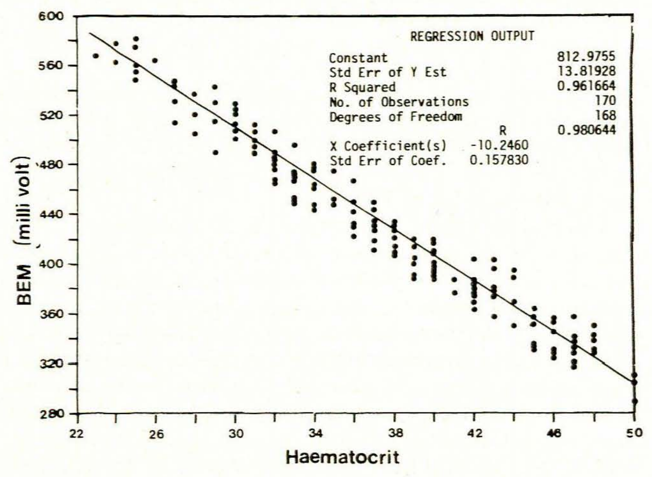

Fig. 3. Correlation between BEM reading and haematocrit from 170 blood samples.

Results of BEM readings, haematocrit and serum sodium concentration during two major surgical operations are shown in Fig. 4. Little variation in serum sodium concentration occurred in either, while the negative correlation between haematocrit and the BEM reading is evident, as well as the sensitive nature of the BEM response to any variation in haematocrit value. In contrast with the first case where only a slight variation in haematocrit occurred, a drastic reduction took place in the second case because of excessive blood loss during surgery. The fast-changing haematocrit was corrected by blood transfusion after 90 minutes. The correlation coefficients between haematocrit and BEM values were 0,9843 and 0,9930 respectively for the two cases.

Discussion

Bleeding is one of the major complications of surgery and results in a drop in the red cell content of blood. Early diagnosis of such a complication is essential for patient care and the apparatus developed fulfils this purpose. In modern

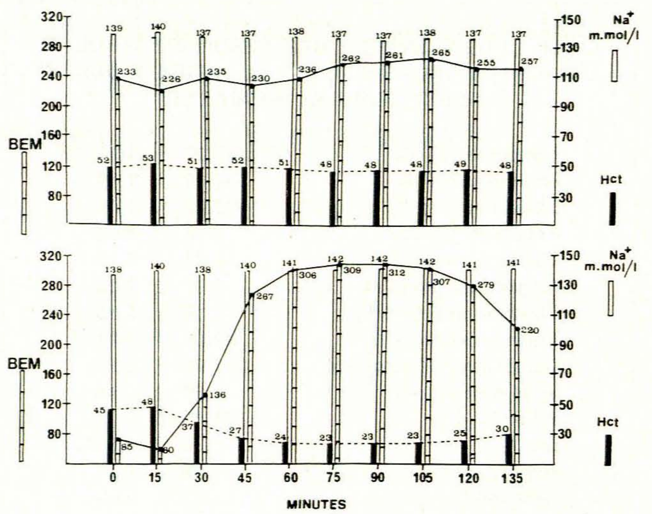

Fig. 4. Variations in BEM reading, haematocrit and plasma sodium concentration in the blood of 2 patients during aortic surgery, which was complicated by excessive blood loss.

surgical practice the drop in haematocrit after haemorrhage is accelerated by the universal practice of replacing volume loss with balanced isotonic crystalloid solutions in the interests of preserving tissue perfusion, haematocrit often being deliberately allowed to fall to 30%.

The biophysical concept involved in the development of this apparatus is the measurement of the effect of red blood cells, with a relatively poor electrical conductivity, on ions such as sodium and chloride in blood with a high capacity for conducting an electrical current between opppositely charged electrodes. For instance, if the electrodes are immersed in a pure saline solution, the electrical flow between the two electrodes is promoted by sodium and chloride ions. If red cells were poured into this solution, some of the sodium chloride ions in the electrical field would be replaced by the relatively inert red blood cells, causing a decrease in electrical conductivity of the solution. The correlation between the decrease in electrical conductivity and the increase in red blood cells can be used as an indication of the alteration of the red cell content of the solution. The high sensitivity of the system for changes in red cell content is explained by large red cell volume in comparison with that of ions.

A prerequisite for the system to be functional is a relatively stable electrolyte-conducting medium since alterations during surgery will contribute to experimental error. Because sodium is quantitatively the most abundant cation present in the extracellular compartment, it is used as an indicator of changes in the non-cellular electrical conducting medium of blood. Sodium, as well the other electrolytes, pH, and temperature affect the BEM reading (Fig. 2) but, because these changes are insignificant in comparison with that of the red cell content (Table I), it is expected that change in red cell concentration is the major variant that affects the BEM reading during surgery. Variation in the protein fractions occurs and as pH represents the hydrogen ion concentration on an antilog scale, the ionisation of ionic groups of the protein molecules — owing to a changing pH — is possible. It is concluded that efficient buffer systems keep the pH value between narrow limits during surgery, such an effect being of a limited extent compared with that of the red blood cells. The close relationship between the haematocrit and the BEM reading is demonstrated by the negative correlation coefficient of $r = 0{,}9806$. This implies that in practice the predicted haematocrit, as determined by the electrometer, does not differ by more than 2 units from the determined value. In clinical practice this difference is often unimportant and can be attributed to differences in electrolyte composition between individuals. During surgery, however, blood is drawn from just one patient and changes in red cell content can in fact be predicted from the BEM reading. This is favoured by the sensitivity of BEM to haematocrit changes and the relatively small SEM.

During pre-anaesthesia investigations, blood samples are routinely drawn from patients to ensure that no abnormality in electrolyte composition exists. Haematological investigations, including haematocrit, can be accurately determined. This investigation ensures that a suitable background for BEM determinations exists during surgery. This technique has already been applied on a routine basis in our vascular unit where more than 150 operations are performed per year. Likewise, results for variations in BEM readings, haematocrit and serum sodium were obtained for the 10 patients used in this study. In clinical practice conclusions were drawn from results obtained from only the patient present in theatre. For illustrative purposes the results of 2 patients are presented in Fig. 4. The excellent correlation between blood conductivity and haematocrit that existed for each patient individually provided a way of detecting a fast-changing haematocrit during surgery and enabled the anaesthetist to take appropriate corrective action.

In conclusion, the BEM proved to be a valuable tool for enabling the anaethetist to increase patient care. Improvements, however, can be obtained by correcting the instrument's reading for variations in temperature to compensate for patients who become hypothermic. The conversion of this value to a 'predicted haematocrit' — a more familiar physical measurement — will further improve its clinical applicability. Fully developed, the apparatus has the potential to be included in an 'inline operating' system in the same way as the ECG is for heart monitoring.

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