Clinical use of a portable electronic device to measure haematocrit

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Abstract **A small portable device called the blood electrometer (BEM) was developed to assist clinicians to distinguish patients with extreme blood loss from those with normal packed cell volumes. Blood was collected in 5 ml lithium heparin tubes from 80 normal controls and 24 patients in an intensive care unit. BEM and accurate microcentrifugal techniques were compared. Intraclass correlation coefficients between the techniques of $r = 0,96$ and $r = 0,93$ were found in the normal controls and patients respectively. Because the BEM operates on the principle of conductivity, changes in some of the biochemical variables which could influence conductivity were investigated in the patients. Mean plasma total protein and albumin concentrations were lower compared with normal reference ranges. Six of the 24 patients were acidotic and 4 alkalotic. Leucocyte counts obtained randomly from 13 patients were elevated. Changes in measurements which could influence conductivity did not affect the BEM reading. We conclude that the portable BEM could be of great value in circumstances where a fixed power source is not available and rapid haematocrit measurements in a large number of patients are required.**

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Most patients under intensive care experience acute blood loss. Some of these patients suffer from acute internal bleeding, which is normally difficult to detect. The fast and reliable measurement of haematocrit (Hct) is of paramount importance in the treatment of patients with acute blood loss.

A small portable device, the blood electrometer (BEM), was developed to assist clinicians to distinguish patients with extreme blood loss from those with normal packed cell volumes. The BEM operates on the principle that blood cells do not conduct a low-frequency alternating current while plasma conducts electricity. Early detection of changes in packed cell volume by means of the BEM has already been investigated in patients during anaesthesia[1] and horses participating in endurance trail rides.[2]

The purpose of this study was to investigate the ability of the BEM to measure Hct accurately. Changes in other biochemical variables which could have an influence on conductivity were also investigated.

Patients and methods

Blood samples were drawn randomly from 80 normal controls and 24 patients, the latter in the intensive care unit of Universitas Hospital. Some of these patients had suffered severe blood loss, due to an operation or internal bleeding. Blood was collected in 5 ml lithium heparin tubes. After venepuncture, the blood was mixed with anticoagulant and left until it reached room temperature (23°C ± 1°C). The tube was then decapped and inserted in the sample holder of the BEM (Fig. 1). A BEM reading, which is related to packed cell volume, could then be obtained immediately. These results were

compared with Hct measurements obtained by means of the microcentrifugal (microfuge) technique,[3] done in duplicate on the same samples.

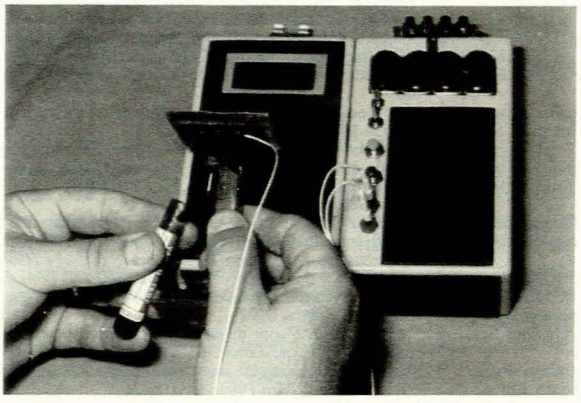

FIG. 1.
Blood electrometer with sample holder and electrode.

Measurements which could have an influence on conductivity, such as those of total protein and albumin, were investigated in serum from the 24 patients by means of a Technicon SMAC analyser. The acid-base state of each patient was evaluated on heparin blood with an ABL 500 blood gas analyser. Leucocyte counts were done on a Technicon H1 analyser.

Ninety-five per cent confidence intervals (CIs) were calculated for the mean differences between the BEM and microfuge measurements, to assess the magnitude of differences. Intraclass correlation coefficients[4] were calculated to measure intertechnique reliability.

Results

The differences in Hct values determined by means of the BEM and microfuge methods in the 80 normal controls and in the 24 patients were close to zero and statistically insignificant (Table I). The intraclass correlation coefficients between the two methods were $r = 0,96$ and $r = 0,93$ in the normal controls and patients respectively (Fig. 2). Fig. 3 shows the distribution histograms of the differences in Hct values as measured by both methods (Microfuge Hct values subtracted from BEM Hct ones) for the controls and patients.

TABLE I.
Differences in Hct values determined by the BEM and microfuge methods

	No.	Mean difference	SD	95% CI for mean difference
Patients	24	0,04	1,47	–0,58 - 0,66
Controls	80	0,00	1,09	–0,24 - 0,24
Total	104	–0,01	1,18	–0,24 - 0,22

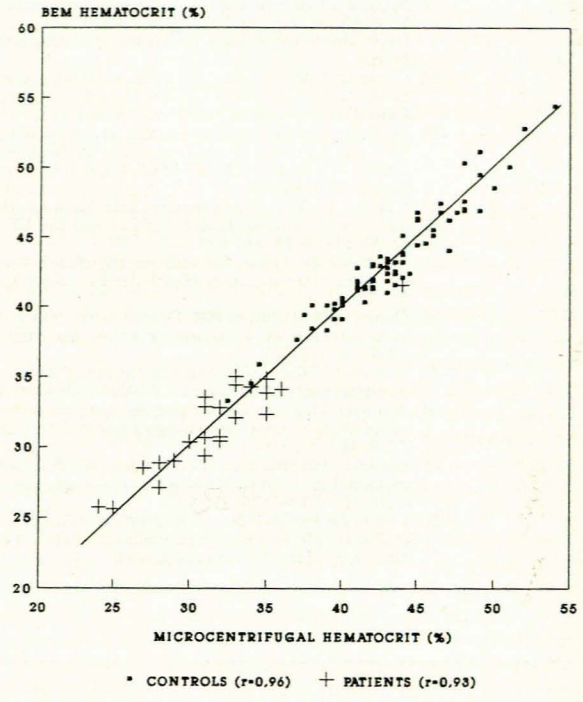

FIG. 2.
Intraclass correlation of Hct as measured by the blood electrometer and microcentrifugal techniques.

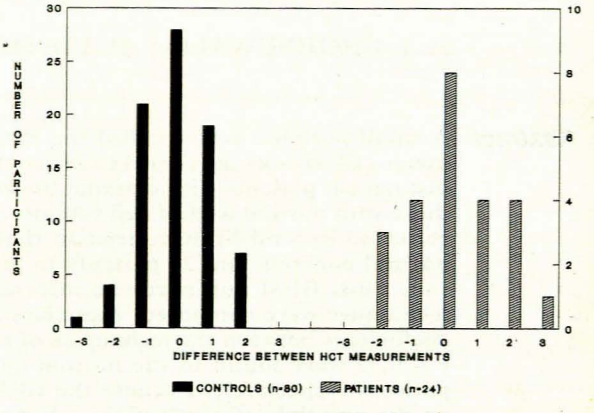

FIG. 3.
The distribution of differences in Hct as measured by means of the blood electrometer and microcentrifugal techniques.

Mean plasma total protein and albumin concentrations were lower than normal reference ranges in the 24 patients. Leucocyte counts, which were only done on 13 of the 24 patients, were higher than normal. Six of the 24 patients were acidotic and 4 alkalotic (pH group). The results are summarised in Table II.

TABLE II.
Summary of results obtained from patients

Group	No.	Result	SD	Range	Reference range	Intraclass correlation coefficient for Hct (BEM/microfuge)	*P*-value
pH (units)	10	7,37	0,10	7,21 - 7,51	7,35 - 7,45	0,82	< 0,01
Leucocyte count (x 10^9/l)	13	17,58	6,88	8,30 - 30,90	4 - 11	0,88	< 0,01
Albumin (g/l)	24	28,54	7,65	9 - 39	38 - 52	0,93	< 0,01
Total protein (g/l)	24	52,86	7,57	30 - 73	65 - 80	0,93	< 0,01

Discussion

In the normal controls as well as the patients, Hct values obtained with the BEM agreed well with those obtained via the microfuge technique (Table I, Fig. 2). The high intraclass correlation coefficients in the normal controls and patients respectively confirm the findings of unpublished experiments that the BEM can measure Hct accurately between a range of 17% and 72% Hct. The differences in Hct as measured by the two different techniques (Fig. 3) were very small, considering all the factors which could have influenced both techniques: (*i*) the BEM operates on the principle of conductivity and could therefore be vulnerable to changes in temperature, extreme changes in concentrations of electrolytes and protein, and changes in the white cell count; and (*ii*) the microfuge technique is subject to error if the white cell or platelet counts are elevated, plasma is trapped or the technique is poorly applied.

Some of the patients were acutely ill and changes in their blood values occurred which could have an effect on conductivity (Table II). *In vitro* experiments with another electronic Hct meter have shown that every 1 g/l change in albumin concentration causes an error of approximately 0,186% Hct units.[5] In that experiment, saline and various concentrations of albumin were substituted for plasma. In our study the total protein and albumin concentrations of the patients were far below their normal ranges. No difference was found in Hct values measured by both the BEM and microfuge techniques in these groups.

Complex changes in ion composition also take place in patients under critical care.[6] Despite the possibility of these changes, the BEM measurement was not significantly affected (high *r*-value, no significant difference from control *r*) in the 10 patients with abnormal changes in blood pH. The changes in pH as well as protein concentrations are therefore probably too small to have any effect on the BEM reading.

In leukaemia patients studied by Rosenthal *et al.*,[7] the conductivity technique overestimated the Hct by 5,7% compared with the centrifugal technique. This may be as a result of the poor conductivity of the white cells. The mean white cell count of their leukaemia patients was $96{,}2 \times 10^9$/l. Therefore an increase of $16{,}88 \times 10^9$/l in white cells is needed for a 1% unit change in the Hct, measured by means of the conductivity technique. A mean leucocyte count of $17{,}58 \times 10^9$/l was measured in 13 of our 24 patients (Table II). This should result in a mean overestimation of the Hct by about 1,04% if the BEM is used. In our study, however, the increase in white cell count was probably too small to affect the BEM measurement significantly. This is supported by both the insignificant difference and the good correlation observed between the BEM and microfuge Hct measurements. This correlation coefficient also did not differ from the correlation coefficient obtained in the normal control group.

The margin of error between the measurements of BEM and microcentrifugal Hct is reflected in the standard deviation (SD) of the difference between the two measurements (Table I). The 95% CI, calculated from Table I for the difference between centrifugal Hct and BEM Hct in both patients and controls, is –2,3 - 2,3 Hct units. This means that in 95% of paired measurements, the centrifugal Hct will differ by between –2,3 and +2,3 Hct units from the BEM measurement. The variation reflects the sum of instrument error and biological variation that could reasonably be expected. This is also regarded as both statistically and clinically insignificant (Table I) especially if the inherent accuracy of the centrifugal method (±2 Hct units) is taken into account.[3]

We conclude that the BEM is sensitive to changes, especially in red cell content. Changes in biochemical measurements observed in this study did not influence the ability of the BEM to measure Hct accurately. The BEM is a small portable device and could therefore be of great value in circumstances requiring rapid Hct determinations, where a fixed electric power source is not available and a large number of traumatised patients must be handled simultaneously.

The principle of the device has already been used by others[5,8-10] but the electrode was originally developed by us (S.A. patent). Although the device is not commercially available, it can easily be made. Details of the features and electronic circuit will be published in due course.

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