

Intermittent on line (vivo) measurement of pO₂, pCO₂, pH and K⁺ by means of automatic sampling of blood and automatic calibration of electrodes and amplifiers

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B 6.5 Mesure intermittente en temps réel, in vivo, de pO_2 , pCO_2 , pH et K^+ par l'échantillonnage automatique des électrodes et des amplificateurs

Intermittent on live (vivo) measurement of pO_2 , pCO_2 , pH and K^+ by means of automatic sampling of blood and automatic calibration of electrodes and amplifiers

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Summary :

For monitoring arterial and/or venous PO_2 , PCO_2 , pH and K^+ of intensive-care patients a prototype apparatus has been developed, named ABGA (Automatic Blood Gas Analyser). ABGA may be connected by means of a sample catheter either to an artery or vein of the patient. At desired intervals ABGA draws a blood sample automatically and performs an analysis. The measuring part of ABGA consists of a special designed cuvet with conventional electrodes. Before a blood sample is drawn the four signal amplifiers are calibrated automatically by means of two calibration solutions equilibrated with gasmixtures of known composition. After completion of the analysis the blood within the cuvet is rinsed away but the blood within the catheter is returned into the patient with the aid of a saline infusion. The measuring cycle time, including calibration is 8 minutes; without calibration 3 minutes. Bloodloss per cycle amounts 2 cc. With electrical grounding the patient current is less than 1 micro amp.

Résumé :

Un appareil prototype nommé ABGA (Automatic Blood Gas Analyser) a été développé pour la surveillance intensive des caractéristiques physicochimiques sanguines suivantes : PO_2 , PCO_2 , pH et (K^+).

Le malade est relié à l'ABGA à l'aide d'un catheter artériel ou veineux. ABGA échantillonne automatiquement le sang et exécute une analyse en temps réel.

La partie de l'appareil qui effectue cet enregistrement consiste en une cuvette spécialement conçue avec des électrodes conventionnelles. Au début du cycle "enregistrement" les quatre amplificateurs sont calibrés automatiquement à l'aide de deux solutions qui se trouvent en équilibre avec un mélange gazeux dont la composition est connue. Après l'analyse la cuvette est vidée du sang et nettoyée. Le sang qui reste dans le cathéter est redonné au malade par transfusion. La durée d'un cycle calibration incluse est de 8 minutes ; sans calibration il dure 3 minutes. La perte de sang d'un cycle est 2cc. Si il y a une prise de terre, le courant traversant le malade est inférieur à 1 micro Amp.

This work has been supported by the Dutch Ministry of Health thanks to a grant to Dr. P.J. van der Schaar. Prof.dr. P.C. Veenstra supervised the technical developments. Ir. H.J.M. Medenblik was the first project leader. Many students contributed to the realisation of ABGA.

Intermittent on live (vivo) measurement of PO_2 , PCO_2 , pH and $[K^+]$ by means of automatic sampling of blood and automatic calibration of electrodes and amplifiers.

Introduction

In principle we distinguish two possibilities for intensive guarding the blood gas and blood ion-status of intensive care patients. These are: 1) continuous recording by means of invasive catheter electrodes and 2) intermittent recording by frequent sampling and analysing the samples by standard laboratory techniques. In case of intermittent methods quantities to be monitored may change abruptly between two samplings. For this reason continuous recording should be preferred. However, at the moment catheter tip electrodes are not available for every parameter of interest. Besides, each quantity to be monitored requires a separate catheter. Further, stability requirements are much more severe for catheter tip electrodes than for electrodes used extra corporeally because frequent calibration of the former is much more complicated than frequent calibration of the latter. Automatic blood sampling and the on-line use of electrodes as applied by us imply the advantage that the number of quantities to be guarded may be extended without great difficulty. The prototype apparatus (ABGA) described below has been designed to measure on-line PO_2 , PCO_2 , pH and $[K^+]$.

Description of ABGA

The most essential part of ABGA is formed by a cuvet containing common commercially available electrodes. This cuvet is continuously connected with the patient, two different calibration fluids and a stock of rinsing solution (saline with heparine) by tubes. The tubes can be closed by electromagnetic clamps; flow through these tubes is effected by small roller pumps. A scheme of the tube circuit is given in figure 1. Pumps and clamps are activated by an electrical switch drum, rotating continuously when a programme cycle is started. A programme cycle is divided into six programme parts: 1) calibration 1, 2) calibration 2, 3) determination of the blood sample, 4) rinsing the cuvet, 5) rinsing the cuvet and patient's line, 6) rinsing the cuvet. Table I shows the status of activation of pumps and clamps at several programme parts.

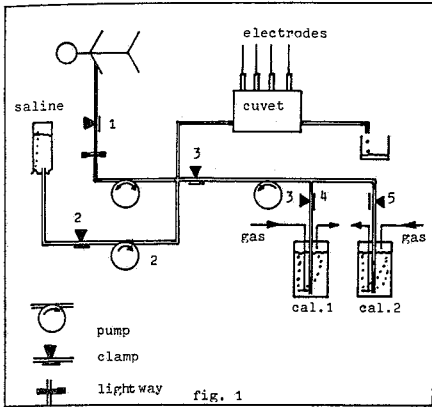


TABLE I
status of pumps and clamps
at several programme parts

programme part	pump			clamp				
	1	2	3	1	2	3	4	5
1 cal.1	0	0	1	0	0	1	1	0
2 cal.2	0	0	1	0	0	1	0	1
3 sampling	1	0	0	1	0	0	0	0
4 rinsing 1	0	1	0	0	1	0	0	0
5 rinsing 2	1	1	0	1	1	0	0	0
6 rinsing 3	0	1	0	0	1	0	0	0

0 = pump halts, clamp in closed position
1 = pump works, clamp in open position

Each electrode is connected with its appropriate amplifier. During parts 1) and 2) of the programme the electrode signal is used for calibration of the amplifiers. The output signals of the amplifiers are successively connected with a digital display. The calibration of the amplifiers is such that the display shows the value of the determined quantity in the correct units.

ABGA makes a type-written report of all measured information on an IBM type-writer. An example of an ABGA-report is given in figure 2. Each cycle the text is generated by a Read Only Memory. The first line of the report gives the Patient's Code (P.C.), the interval time between two successive samplings (I.T.) and serial number (M.Nr.) of the programme cycle. P.C. and I.T. are preset by thumb switches. Line two gives the column heading and line three the units in which the quantities are presented. The haemoglobin content and oxygen saturation are not yet determined by ABGA but also preset by thumb switches. These values are needed for the calculation of "standard bicarbonate" and "base excess" by a specially designed acid-base computer. In lines four and five the calibration values are given. The sixth line gives the values measured in the blood sample. Values which differ too much from expected values are printed in red. The seventh line gives the results calculated from the measured and preset values.

P.C. 040947	I.T. 10 min.	M.Nr. 11						
	Hb	S	Po2	pH	K	Pco2	BE	SB
	g%	%	mmHg		mmol	mmHg	mmol	mmol
cal.1.			113.2	7.601	3.003	21.24		
cal.2.			026.8	7.299	6.024	45.79		
meas.	15.17	91.09	084.2	7.465	4.703	41.32		
calc.							05.45	29.10

figure 2

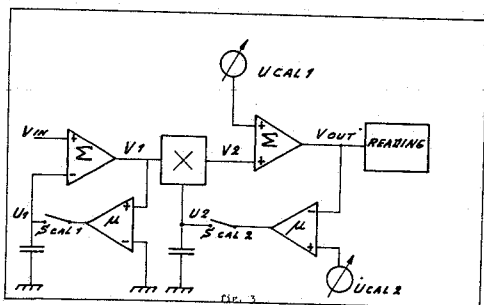
Automatic calibration of the amplifiers

figure 3

whereas V_1 and V_2 remain zero. Now V_{out} only is determined by the preset value of $V_{cal.1}$ that corresponds with the "reading" P_1 . At the second calibration step the electrode is at equilibrium with the second calibration liquid (P_2); then the input voltage of the amplifier is $V_{cal.2}$. After closure of the reed relays $S_{cal.2}$, V_{out} will be adjusted equal to the preset voltage $U_{cal.2}$ which agrees to a "reading" P_2 . This is done by adapting the gain of the amplifier through changing U_2 . When $S_{cal.2}$ opens the calibration is completed. Then the following relation between V_{out} and V_1 will be valid

$$V_{out} = (V_{in} - V_{cal.1}) \times \frac{U_{cal.2} - U_{cal.1}}{V_{cal.2} - V_{cal.1}} + U_{cal.1}$$

Patient's Safety

Many safeguardings are attending to the development of a machine like ABGA. The three most important aspects are the safeguardings from airbubbles returning to the patient, sterility of the fluid returning to the patient and safeguarding from too high an electrical current running through the patient.

The tube connected to the patient passes a bubble detector that reacts only on interfaces between water or blood and air but not on interfaces between blood and saline. When a bubble is detected all clamps will close and all pumps will halt immediately. The machine has to be reset with a key by the operator. The patient's line is pressure-guarded. If the pressure rises above a certain limit the same action is taken as with the detection of a bubble.

The tube circuit is set up completely sterile including the cuvet and electrodes. However, the cuvet is considered being the most probable source for infection because it

Calibration of all amplifiers is effected in two steps with the aid of two calibration liquids having, for a certain quantity (e.g. pH), the calibration values of P_1 and P_2 respectively (see figure 3). At the first calibration step the electrode concerned is at equilibrium with the first calibration liquid (P_1). Then the voltage on the electrode input of the amplifier is $V_{cal.1}$. After closure of the reed-relays $S_{cal.1}$, V_1 will be adjusted in such a way that $V_1 = 0$. After this $S_{cal.1}$ is opened

has one open connection to the outside (waste) and even worse, a lot of small openings to the outside may occur when the sealings of the electrode tips are not perfect. Therefore, the programme has been designed in such a way that fluid in the cuvet only can flow in one direction, viz. out of the cuvet. The length of the tube between bubble detector and patient is twice as long as the length of the tube between the outlet of the cuvet and the bubble detector. If some failure might occur such that fluid flows from the cuvet into the direction of the patient, air will enter the system and will activate the bubble detector before the fluid, which has been in the cuvet, will reach the patient.

Special care is taken with regard to electrical safety. As the sample catheter may be brought into the heart, the requirement of 10 micro amps. (50 hz) maximal patient current has to be taken into account. A maximal current of one micro amp. is obtained if ABGA is well grounded. In case of failure of grounding the maximal current theoretically could become 70 micro amps. This largest possible patient current is obtained by capacitive induction between ABGA cover and bloodlines when the ABGA cover is connected to the mains.

Results

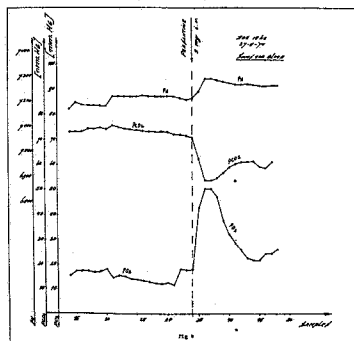


figure 4

Figure 4 shows results of an animal experiment. The patient's line was brought into the coronary sinus. Interval time was 3 minutes (calibration was suppressed). The sharp rise in PO_2 and fall in PCO_2 are the result of the injection of dipyridamole (dose: 10 mg/kg).

Six clinical tests were performed with ABGA connected to post operative patients (open heart surgery) in intensive care. The heparin in the rinsing saline showed to be satisfactory as to preventing clotting of the blood. The accuracy of the on-line measurements which could be attained with the apparatus was somewhat less than that of comparable laboratory instruments.

This is because the electrodes in ABGA are electrically connected to the patient who appears to be a large source for electrical noise. The impression exists that frequent intermittent sampling with interval times varying from 10-30 minutes, is satisfactory for guarding the blood gas and blood ion-status of patients in intensive care.