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Prehospital point of care testing of blood gases and electrolytes — an evaluation of IRMA

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Abstract

Background: This study evaluated the feasibility of blood gas analysis and electrolyte measurements during emergency transport prior to hospital admission.

Results: A portable, battery-powered blood analyzer was used on patients in life threatening conditions to determine pH, pCO_2, pO_2, sodium, potassium and ionized calcium. Arterial blood was used for blood gas analysis and electrolyte measurements. Venous blood was used for electrolyte measurement alone. During the observation period of 4 months, 32 analyses were attempted on 25 patients. Eleven measurements (34%) could not be performed due to technical failure. Overall, 25 samples taken from 21 patients were evaluated. The emergency physicians (all anesthesiologists) considered the knowledge of blood gases and/or electrolytes to be helpful in 72% of cases. This knowledge led to immediate therapeutic consequences in 52% of all cases. After a short training and familiarization session the handling of the device was found to be problem free.

Conclusions: We concluded that knowledge of the patients' pH, pCO_2 and pO_2 in life threatening situations yields more objective information about oxygenation, carbon dioxide and acid-base regulation than pulse oximetry and/or capnometry alone. Additionally, it enables physicians to correct severe hypokalemia or hypocalcemia in cases of cardiac failure or malignant arrhythmia.

blood analysis emergency, prehospital care

Introduction

Oxygenation and ventilation are important factors in the treatment of emergency patients. A number of studies have shown that the severity of hypoxemia is frequently underestimated, even by experienced emergency physicians. With noninvasive methods such as pulse oximetry and capnometry, the ability to obtain reliable measurements assessing oxygenation and ventilation can be limited by abnormal physiologic states commonly seen in emergency patients. In emergency situations (eg shock, bleeding, during cardiac massage, etc) an abnormal ventilation/perfusion (V/Q) relationship affects end tidal CO_2 ($EtCO_2$) measurements, and the absence of an adequate pulse signal can result in the failure of pulse oximetry to measure arterial hemoglobin saturation (SpO_2).

In addition, optimization of the electrolyte status, specifically potassium (K) and ionized calcium (Ca^{2+}), is important in the treatment of a developing or manifested cardiac failure [1].

The purpose of this study was to describe our first experiences with the IRMA Blood Analysis System (DIAMETRICS, ChemoMedica-Austria, Vienna, Austria), a portable, battery-powered blood analyzer which has been available since April 1996 as part of a prehospital emergency physician system.

Methods

The emergency system at the University of Graz is a combination of stationary and rendezvous components. The stationary component is an emergency patient transport vehicle, operated by four emergency technicians of the Austrian Red Cross. One of these individuals, similar to American paramedics, is a young physician or medical student, at the end of their training, who specialised in emergency medicine. The second component is a small emergency car, carrying the emergency physician and an emergency technician, which transports the doctor to the site of the accident, but

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which cannot transport the patient. Consequently, six well educated emergency staff members attend the patient at the site of the accident.

Firstly, six indications for prehospital blood analysis were defined:

1. cardiopulmonary resuscitation (CPR; blood gases and electrolytes);
2. all forms of dyspnea or hypoxia (blood gases);
3. suspected acidosis (blood gases and electrolytes);
4. cardiogenic shock resistant to therapy (blood gases and electrolytes);
5. control of mechanical ventilation (blood gases), and
6. cardiac arrhythmias and tachycardia (electrolytes).

The device was carried in the rendezvous car to the site of the emergency. Samples for tests which included blood gas analysis were taken from an artery with a 26G needle and a heparinized syringe; samples for electrolytes alone were taken from an artery or vein. Additionally, a form was completed by the emergency physician which included the following two questions:

1. Was knowledge of the measured parameters helpful to your diagnosis or treatment?
2. Did you change your therapy due to the prehospital tests?

The emergency physician obtained and interpreted the measurements, and performed the resulting therapeutic interventions at the site of the emergency. All emergency doctors were anesthesiologists at the Department of Anesthesiology and Critical Care Medicine with more than 2 years' experience in prehospital care.

All data were recorded and evaluated after completion of the study. A retrospective investigation of the outcome of the patients and the accuracy of the tentative diagnosis was not performed. The study aimed to evaluate the management and usefulness of a new transportable blood analyzer at the site of an emergency, and the immediate therapeutic consequences.

A prerequisite of the study was not to disturb the essential treatment of emergency patients. The study was approved by the ethics review board of the University.

Technical description

The IRMA Blood Analysis System is one of a new class of instruments which are used for what is termed 'point-of-care testing' (POCT) [2], indicating that it can be used wherever the patient may be to measure blood gases and pH, as well as the electrolytes sodium (Na), K and Ca^{2+}.

The device consists of the analyzer and two types of cartridge, one labeled 'blood gases' and the other 'electrolytes'. Each cartridge is prepackaged with a calibration gel covering the sensors, and with a short fluid filled pouch which stabilizes the humidity. The calibration of the sensors takes place automatically when the cartridge is inserted into the IRMA blood analyzer; there is no need for calibration gases or fluids. Quality control calibration is performed with delivered control reagents. The instrument can only be filled using a syringe, and the blood sample (minimum = 0.2 ml, maximum = 3.0 ml, recommended amount = 1.5 ml) must be injected with dosed power into the filling gap of the cartridge. The instrument measures barometric pressure and determines pH, pO_2, and pCO_2 by analyzing the sample in the blood gas analysis (BGA) cartridge; additional parameters are also calculated (see Table 1). Using the electrolyte cartridge, Na, K and Ca^{2+} are determined. The accuracy of the measurements from the IRMA blood analyzer have been validated in previous studies [2,3]. The device has the size (29.2 × 24.1 × 12.7 cm) and weight (1.35 kg) of a small laptop computer, and each cartridge weighs 19 g and is 9.9 × 5.6 × 1.3 cm in size. The exchangeable batteries operate for 2–3 h and are recharged by an external charger.

Data entry into the analyzer is performed through a back-lit interactive touch screen. The menus guide the user through the operation process with directly labeled buttons. An on-board printer provides a hard copy of results either automatically or on demand. An RS232 port on the back of the unit allows the downloading of data to a personal computer or other data collection system.

The price of the IRMA Blood Analysis System is approximately ATS100,000 ($10,000). Each cartridge (used for one measurement, blood gases or electrolytes) costs about ATS100 ($10). The single-use disposable cartridges can be stored for 12 weeks in normal ambient temperature (12–30°C). The device is Food and Drug Administration (FDA) approved.

Table 1 Measured and calculated parameters

Measured	Range
pH	6.00-8.00
pO_2 (mmHg)	20-700
pCO_2 (mmHg)	4-200
Barometric pressure (mmHg)	350-900
Sodium (mmol/l)	80-200
Potassium (mmol/l)	1.0-20.0
Ionized calcium (mmol/l)	0.2-5
Calculated	
Bicarbonate (mmol/l)	1-99.9
Standard bicarbonate (mmol/l)	1-99.9
Base excess (mmol/l)	-99.9-99.9
Base excess ecf (mmol/l)	-99.9-99.9
Total CO_2 (mmol/l)	1-99.9
Oxygen saturation (%)	0-100

The system is maintained in stand-by mode, with the power automatically switching on when a cartridge is inserted. The calibration code must be observed and if necessary corrected. After confirmation of this code on the touch screen, the calibration procedure starts automatically. Depending on whether an electrolyte or blood gas cartridge is being used the system requires 10 or 90 s to warm up, respectively. The end of the calibration procedure is announced by a beep, after which the user has 120 s to inject the blood sample. Finally, the results are shown on the display and can be printed on demand. The entire measurement takes approximately 70 s for electrolytes and 160 s for blood gases. Correction of the calibration code, if necessary, requires an additional 25 s.

In cases of hypothermia, the blood temperature can be corrected after the measurement and the results recalculated.

Results

During the observation period (April to September 1996) 32 analyses were attempted on 25 patients. Eleven of these samples could not be measured due to problems with the individual cartridges – two were damaged, and nine had to be replaced and the procedure repeated due to the analyzer indicating a 'Cartridge - Error'. Overall, 25 samples obtained from 21 patients were analyzed. The indications for blood analysis, the measured parameters, and the diagnostic and therapeutic consequences are listed in Table 2. In 18 of the 25 cases the measurements were helpful for diagnosis, and resulted in therapeutic consequences in 13 patients. In many cases knowledge of electrolyte or blood gas parameters was helpful, but indicated that no therapy was needed.

After a short training session the operation of the device was problem free, and the results seemed reliable.

Because the data collection period was during the summer the effect of low ambient temperature could not be evaluated.

Discussion

This new transportable blood analyzer, the IRMA Blood Analysis System, opens up important opportunities in prehospital emergency care. Many therapeutic strategies in the treatment of severe life threatening situations depend on the knowledge of blood parameters [1,2,4-7].

Table 2 List of patients, diagnoses, results and the therapeutic consequences

				Blood gases			Electrolytes			Assessment	
No	Age	Sex	Indication	pH	pCO_2	pO_2	Na	K	Ca^{2+}	Helpful?	Therapeutic consequences
1	74	M	Syncope	7.39	37	255	148	4.2	1.2	No	None
2	16	F	Hyperventilation tetany	-	-	-	147	4.1	1.16	No	None
3	83	F	Syncope	-	-	-	141	3.7	0.96	Yes	Substitution
4	35	M	Traumatic shock	-	-	-	150	3.3	1.03	Yes	Substitution
5	26	M	Head injury	7.49	31	322	147	3.4	1.07	Yes	Correction of ventilation
6	78	F	Coma	-	-	-	139	5.6	1.41	Yes	None
7	67	M	CPR	-	-	-	151	4.4	1.6	Yes	None
8	77	F	Dyspnoea	7.32	41	187	-	-	-	No	None
9	84	M	Lung edema	7.34	24	65	145	4.1	1.27	Yes	None
10	60	M	CPR	6.97	61	63	-	-	-	Yes	Buffering, correction of ventilation
				7.01	52	91	-	-	-		
				6.96	59	83	141	5.1	1.18		
11	90	F	CPR	7.02	65	88	148	4.9	1.2	Yes	Buffering, correction of ventilation
				7.12	57	101	-	-	-		
12	42	F	Intoxication	7.36	38	234	147	4.4	0.89	Yes	None
13	86	F	Cardiac failure	7.35	33	91	144	4.0	0.99	Yes	None
14	83	F	Dyspnea	7.38	42	78	140	4.3	1.1	No	None
15	19	M	Intoxication	7.35	39	211	132	3.5	0.9	Yes	Correction of electrolytes
16	71	F	Tachycardia	-	-	-	142	4.4	1.1	Yes	None
17	76	M	Syncope, somnolence	-	-	-	134	3.5	1.4	Yes	Correction of electrolytes
18	74	M	Arrhythmia	-	-	-	145	4.5	0.98	Yes	None
19	90	F	Lung edema	7.35	48	58	142	3.8	1.2	Yes	Intubation
20	52	M	Cardiac failure, tachycardia	7.38	42	88	-	-	-	Yes	None
21	60	M	Coma	-	-	-	145	4.4	1.01	Yes	None

M = male; F = female; CPR = cardiopulmonary resuscitation.

In 'Standards and Guidelines for Emergency Care' the American Heart Association recommends the following application of sodium bicarbonate during CPR, based on blood gas concentrations or levels of serum potassium: class I in the presence of hyperkalemia; class IIa with metabolic acidosis; class IIb in cases of a long arrest interval or after return of spontaneous circulation, and class III with hypoxic lactate acidosis [1]. According to these recommendations we were able to apply sodium bicarbonate exactly on demand. An analysis of the therapeutic benefits and patient outcomes was not possible because we had only three patients requiring CPR and only two of them needed buffering.

Without prehospital measurements the determination of the potential benefits or risks of the application of Ca^{2+} [8] would not have been possible in these patient care situations. Although Ca^{2+} is essential for myocardial contraction, its blind application during cardiac failure is not recommended because of the inherent risk of hypercalcemia which could result in an irreversible myocardial contraction (class III) [1]. Based on our findings this blood analyzer allows much better prehospital management of cardiac failure or CPR by providing the necessary data in a rapid, reliable and easy to use manner. During the observation period we did not encounter a patient with prehospital hypocalcemia.

The IRMA blood analyzer used in this study provides additional measurements to the OPTI 1 (AVL, Graz, Austria), an alternative prehospital system which at present only determines blood gases [9]. The third available system, i-STAT (Hewlett Packard, Vienna, Austria) [10], measures blood gases, electrolytes, and also the hematokrit.

Techniques are already in use which are somewhat helpful in detecting hypoxia or breathing status – transcutaneous pO_2 measurement and pulse oximetry. In the prehospital setting only pulse oximetry is commonly utilized. Pulse oximetry measures oxygen saturation noninvasively at the finger or earlobe and, therefore, requires a sufficient pulse wave. This means that the technique fails under the condition of severe shock. Furthermore, acute carbon monoxide (CO) poisoning constitutes a particular problem as, in this situation, many pulse oximeters report overestimated oxygenation results which wrongly indicate adequate oxygen saturation and are, therefore, useless. Carbon monoxide-induced hypoxemia is caused by the presence of CO bound to hemoglobin. However, arterial pO_2 may still be within normal limits. Therefore, the patient may suffer from severe hypoxia while pulse oximetry and arterial pO_2 measurements fail to reflect the critical situation [11]. Since the IRMA blood analyzer does not detect partial oxygen saturation, CO poisoning does not cause it to overestimate oxygen content. Additionally, severe peripheral hypoxia also leads to lactate production and reduces pH, a parameter which can be determined by blood gas analysis.

Recent studies have described the importance of meticulously performed mild hyperventilation in severe head injury [12,13]. Capnometry measures $EtCO_2$ and is a valuable instrument for the estimation of patients' breathing or ventilation status if V/Q is not severely deranged [14]. In situations of severe cardiovascular insufficiency and CPR, capnometry can either fail or significantly underestimate arterial pCO_2. Lung contusions or aspiration result in atelectasis and an altered V/Q ratio. Cardiovascular insufficiency, like shock or CPR, leads to dead space ventilation; the lungs are ventilated, but insufficiently perfused [4-6,15-17]. In the critically ill patient, optimal oxygenation, mild hyperventilation and adequate therapy cannot be performed without blood gas analysis [18].

However, the routine use of the IRMA system revealed several problems:

1. The system showed a high failure rate (34%), mainly due to problems with cartridge calibration. It may be possible that, due to the difficult storage procedures, the calibration gel spoiled, although the storage time had not been exceeded. Another cause of problems was a batch of inoperable cartridges; these cartridges were changed by the company within a few days.

2. Application of the blood sample also presented problems. The system can only be filled with a syringe and a dosed pressure has to be applied. This means that, for blood gas analysis, arterial puncture or arterial access is necessary as the system has not yet been designed for withdrawal of blood from capillaries. In cases of insufficient blood quantity or excessive application pressure, air bubbles develop and the sample must be rejected. Contrary to the manufacturer's specification of a minimum sample amount of 0.2 ml, our experiences suggest that at least 1.5 ml of blood are required to obtain a valid measurement.

3. For emergency systems with lower numbers of calls, the limited life span (12 weeks) of the cartridges could result in wastage. An on-demand controlled ordering system would be an easy solution to this potential problem.

4. The touch screen is arranged in alphabetical order rather than as a common keyboard and, therefore, requires familiarization by users. Entering the calibration code is, therefore, too time consuming (25 s per attempt).

Conclusions

There are several indications for the use of prehospital blood analysis in emergency situations. In cases of critically ill or severely traumatized patients the widely used monitoring techniques like pulse oximetry and

capnometry are limited and not acceptable alternatives to blood gas analysis. The IRMA transportable blood analyzer, which has been available since April 1996, can deliver these valuable blood gas measurements. The system has been found to be very useful; it is easily transportable and after some corrections performs reliably. We believe that in the future prehospital blood analysis will become an important part of a well organized emergency system.

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