THE INVESTIGATION AND INTERPRETATION OF ACID-BASE DISTURBANCES IN THE PAEDIATRIC AGE-GROUP

H. DE V. HEESE, M.D., B.Sc., M.R.C.P. (EDIN.), D.C.H.; A. F. MALAN,* M.B., CH.B., M.MED. (PAED.), D.MID. C.O. & G. (S.A.); V. C. HARRISON,† M.B., CH.B., M.MED. (PAED.), D.C.H.; AND A. EVANS, B.Sc.; *Department of Paediatrics, Groote Schuur Hospital and Department of Child Health, University of Cape Town*

The development of the Astrup micromethod for the determination of pH, carbon-dioxide tension, base excess, standard bicarbonate and actual bicarbonate in capillary blood[1] has resulted in a new interest being taken in acid-base disturbances in the paediatric age-group, i.e. premature babies, newborns, infants and older children. The method has opened up a wide field for research[2] but, more important, permits the paediatrician to treat and manage acid-base disturbances on a rational basis. This can be regarded as perhaps one of the most important recent advances in paediatrics, as so many life-threatening illnesses affecting the paediatric age-group are associated with severe disturbances of acid-base metabolism.

Many clinicians still regard the interpretation and application of acid-base investigations as being beyond the scope of the 'ordinary mortal'. This negative attitude has been brought about mainly by the lack of uniformity in acid-base terminology; heated discussions of the latter by the *pundits* in the medical literature; the difficulty in the past of collecting suitable blood (usually arterial) in order to carry out the necessary determinations for the assessment of the acid-base status of the patient; the difficulty of the interpretation of results; and the practical application of the results in the management of a given case.

These can be largely overcome by:

1. Accepting the terminology and classification for acid-base disturbances employed in this paper, until final agreement is reached in this matter.
2. Employing micromethods.
3. Making use of the various methods which give a graphic representation of the acid-base status of a patient.
4. Managing or correcting acid-base disturbances in a given disease:
   (*i*) by equations to determine the amount of acid or base required for the correction of a particular non-respiratory disturbance in a given patient; and
   (*ii*) by making use of the results obtained from acid-base studies to control any severe respiratory acidosis with augmented or intermittent positive-pressure respiration.

TERMINOLOGY AND CLASSIFICATION

The terminology and classification for acid-base disturbances employed in our laboratory are as follows:

1. A reduced pH and an increased pH are described as acidosis and alkalosis respectively.
2. Respiratory acidosis is defined as an excess of carbonic acid due to a rise in the PCO_2.
3. Respiratory alkalosis is defined as a deficit of carbonic acid due to a lowered PCO_2.
4. Metabolic acidosis is defined as an excess of non-volatile acid or a deficit of base.
5. Metabolic alkalosis is defined as an excess of base or deficit of non-volatile acid.
6. Base excess (BE) is defined as the titrable base on titration of blood (or plasma), with a PCO_2 of 40 mm.Hg and a temperature of 38°C, to a normal pH of 7·40. It is regarded as a measure of metabolic alkalosis or metabolic acidosis. A positive value of BE signifies a metabolic alkalosis with a base excess or deficit of non-volatile acid, whereas a negative value of BE signifies a metabolic acidosis with a base deficit or excess of non-volatile acid.
7. The standard bicarbonate is the bicarbonate in plasma measured under the following standardized conditions: the haemoglobin must be fully oxygenated; the PCO_2 must be 40 mm.Hg and the temperature 38°C. It is regarded as an expression of the metabolic aspect of acid-base metabolism.
8. The actual bicarbonate is the concentration of bicarbonate in plasma that is separated from the cells at the actual PCO_2 and at a temperature of 38°C.
9. The buffer base is the total available buffer, which includes bicarbonate, proteins, haemoglobin and phosphates.

METHODS

The determination of the acid-base equilibrium of a patient can be made either on arterial blood or arterialized capillary blood.[3] Arterial blood is collected either from the umbilical, temporal, femoral or brachial artery, in a syringe in which the dead space is filled with concentrated heparin solution. Arterialized capillary blood can be collected from the warmed lobe of the ear in older children or from the warmed heel in infants, in heparinized capillary tubes. In the latter instance the foot must be thoroughly warmed for at least 10 - 15 minutes to promote the free flow of blood following a clean stab of the heel with a blade.[3,4] Care must be taken:

(i) to avoid crying before and during the procedure as this would lower the PCO_2;
(ii) not to squeeze the heel in order to avoid a possible admixture of tissue fluid or obstruction of the circulation;
(iii) to collect the blood anaerobically in the heparinized capillary tubes from quickly-forming unbroken drops of blood;
(iv) to mix the blood with the specially supplied stirring rods and magnet before clotting takes place;

*CSIR Senior Bursar.
†Wellcome Trust Fellow

(v) to exclude air and seal the ends of the capillary tubes with plasticine;
(vi) to store the capillary tubes in iced water unless estimations are carried out immediately;
(vii) to record the body temperature at the time the sample is taken in order to allow for corrections to be made in determining the actual pH of the patient. This latter measurement is extremely important in the paediatric age-group, especially in premature and newborn infants in whom hypothermia occurs both easily and rapidly.

In the present studies arterial blood is usually collected from the umbilical artery in premature and full-term newborns during the first 48 - 72 hours of life; from the temporal artery in premature[5] or full-term infants and from the femoral artery in older infants and children. Arterialized capillary blood is collected in premature babies, infants and older children with good peripheral circulations. Blood is analysed either (*i*) within minutes after collection, or (*ii*) after storage for a period of less than 1 hour in ice water. Temperature corrections are made for the actual pH measurements by adding a factor of 0·015 for every 1°C that the patient is below 38°C to the pH value measured at 38°C. When the patient's temperature is over 38°C this factor is subtracted.[6,7]

NORMAL VALUES

Normal values for the acid-base status of premature and full-term infants during the first 72 hours of life[8] (Table I) and premature infants during the first 5 weeks of life[9] (Table II) have been established in our laboratory. Values of arterial blood, arterialized capillary blood and venous blood have not been clearly established in the literature for infants and children belonging to older age-groups. It is stated that the acid-base status alters with age, so that a wholly or partly compensated metabolic acidosis is found in children, which gradually decreases with growth, disappearing before the age of 17.[10] At 2 - 3 years of age the BE in the blood is approximately 2 mEq./l. lower and the PCO_2 is approximately 4 mm. lower than in adults.[11] Children over 6 years of age are regarded in our laboratory as having normal acid-base values within the range reported by Siggaard-Andersen for adults.[12]

TABLE II. ACID-BASE VALUES IN 52 PREMATURE INFANTS[9] DURING FIRST 5 WEEKS OF LIFE

	2–4 *days*	5–8 *days*	9–12 *days*	3rd *week*	4–6 *weeks*
Number of determinations	9	14	27	40	58
pH	7·30	7·32	7·30	7·30	7·31
S.D.	±0·13	±0·03	±0·04	±0·02	±0·03
PCO_2 (mm./Hg)	34·6	39·4	40·4	39·9	42·1
S.D.	±12·3	±10·2	±6·3	±9·7	±5·3
BE (mEq./l.)	−4·8	−6·8	−6·4	−6·6	−5·7
S.D.	±2·2	±2·4	±2·9	±2·8	±5·3
Actual HCO_3	19·9	19·5	19·3	18·4	20·4
S.D.	±3·0	±4·8	±3·4	±4·4	±2·3

For practical purposes, however, we regard this difference between the age-groups to be only of importance in the immediate newborn period and in premature infants during the first 6 weeks of life. The assessment of acid-base disturbances in the former is of importance in cases of the respiratory distress syndrome, and in the latter in the management of cases of late metabolic acidosis of prematurity.

Graphic Presentation of the Acid-Base Status

The assessment of the acid-base status cannot be determined from one parameter alone and it is therefore necessary to know:

(*i*) the pH to decide whether an acidosis or alkalosis is present;
(*ii*) the PCO_2 to evaluate the respiratory component of acid-base metabolism; and

TABLE I. SUMMARY OF BLOOD VALUES AT VARIOUS AGES[8] IN PREMATURE AND FULL-TERM INFANTS

		Premature			*Full-term*		
	Hours	*Mean*	*Standard deviation*	*Range*	*Mean*	*Standard deviation*	*Range*
pH	4	7·35	0·04	7·28–7·42	7·38	0·04	7·33–7·46
	24	7·39	0·04	7·33–7·48	7·41	0·04	7·32–7·48
	48	7·37	0·05	7·29–7·46	7·42	0·05	7·31–7·50
	72	7·37	0·05	7·28–7·45	7·42	0·04	7·32–7·48
PCO_2 (mm.Hg)	4	43·4	8·2	31·7–58·5	36·7	5·3	24·3–45·7
	24	35·8	4·0	27·6–43·0	34·9	4·0	28·5–43·0
	48	39·5	6·1	33·0–57·0	34·0	4·5	27·0–41·5
	72	36·8	5·2	29·0–45·0	35·5	5·4	25·0–46·0
Base excess (mEq./l.)	4	−2·3	2·6	−6·6+2·9	−2·5	1·6	−5·9+0·9
	24	−2·6	1·8	−7·4–0	−1·4	1·8	−4·3+3·7
	48	−2·7	1·2	−7·5+0·6	−1·2	1·7	−5·3+2·0
	72	−3·3	2·9	−9·6–0·5	−0·8	2·4	−4·8+3·1
Buffer base (mEq./l.)	4	47·8	3·0	44·0–53·2	47·5	1·8	45·0–51·2
	24	46·6	2·7	40·8–50·3	47·6	2·7	43·8–55·3
	48	46·2	2·8	41·8–51·0	47·8	3·2	39·6–51·5
	72	46·5	3·3	40·6–50·2	49·0	3·3	42·5–54·0
Standard HCO_3^- (mEq./l.)	4	22·2	2·2	19·2–26·2	22·0	1·3	19·7–24·6
	24	21·9	1·6	18·4–24·0	22·8	1·6	20·5–26·8
	48	21·9	1·7	18·4–24·4	23·0	1·6	19·9–25·5
	72	21·4	2·0	17·1–23·5	23·3	2·1	20·0–26·0
Actual HCO_3^- (mEq./l.)	4	22·9	3·7	17·0–30·5	21·4	1·4	18·0–23·4
	24	20·8	1·9	16·2–24·6	21·7	1·9	18·1–26·4
	48	21·6	1·6	17·6–24·6	21·3	2·0	19 4–26·0
	72	20·6	2·7	14·4–23·6	22·2	3·1	17 0–28·0

(*iii*) the base excess or standard bicarbonate or actual bicarbonate to assess the metabolic component of acid-base metabolism.

Thus, for instance, it may be completely misleading to evaluate the acid-base status of a patient from the BE or standard bicarbonate or actual bicarbonate values alone. An elevated value for any of these measurements can be the result of a metabolic alkalosis, but can also be the result of a compensatory rise in the presence of a respiratory acidosis. A correct assessment can only be made if the PCO_2 value is known.

To simplify the interpretation by the clinician of acid-base disturbances, methods for the graphic representation of the latter have been developed. These methods are also of great help in the management of such cases.

The pH, HCO_3^- coordinate system proposed by Van Slyke[13] has been popularized in recent years by Davenport[14] and Siggaard-Andersen.[15] Siggaard-Andersen's system is shown in Fig. 1. The addition of a table next to the graph introduces a time factor and permits the recording of serial

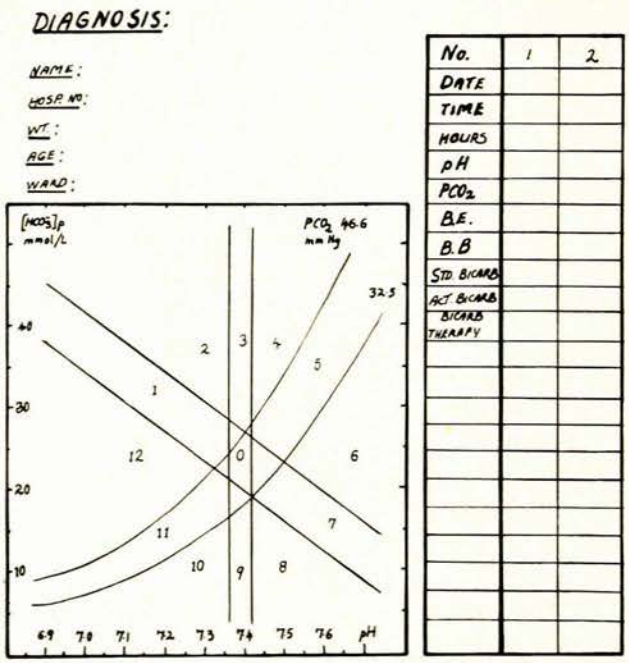

Fig. 1. Example of graphic representation of acid-base status.

acid-base and other data, treatment given to the patient, etc. By plotting a point on the graph, the acid-base status of the patient can be determined immediately by noting the area in the diagram in which the point falls. Each area represents a specific state of acid-base disturbances. The following indicate zones on the graph:

0. Normal
1. Uncompensated respiratory acidosis
2. Partly compensated respiratory acidosis
3. Fully compensated respiratory acidosis
4. Partly compensated metabolic alkalosis
5. Uncompensated metabolic alkalosis
6. Combined metabolic alkalosis and respiratory alkalosis
7. Uncompensated respiratory alkalosis
8. Partly compensated respiratory alkalosis
9. Fully compensated respiratory alkalosis
10. Partly compensated metabolic acidosis
11. Uncompensated metabolic acidosis
12. Combined metabolic and respiratory acidosis

AETIOLOGY OF ACID-BASE DISTURBANCES IN THE PAEDIATRIC AGE-GROUP

Over the last 2 years approximately 7,000 acid-base determinations were carried out in premature infants, full-term newborns, neonates, infants and children suffering from a wide spectrum of disease processes.

The following conditions were found to be associated with significant acid-base disturbances in many cases:

Newborns

Metabolic acidosis—infectious and septicaemic conditions; congenital heart disease; diarrhoea; acute haemorrhagic shock.

Respiratory acidosis—Asphyxia neonatorum; neonatal pneumonia; pneumothorax; meconium aspiration; clinical hyaline membrane disease; neonatal disseminated atelectasis.

Combined acidosis—Clinical hyaline membrane disease; neonatal disseminated atelectasis; post-exchange transfusion; cerebral birth trauma; meconium aspiration; neonatal tetanus; neonatal surgical conditions.

Prematures

As above; and late metabolic acidosis of prematurity.

Infants

Metabolic acidosis—Gastroenteritis; overwhelming infections; renal disease; surgical conditions; salicylate intoxication.

Respiratory acidosis—Pneumonia; bronchiolitis; laryngo-tracheo-bronchitis; foreign body; asthma; CNS depression secondary to poisons.

Metabolic alkalosis—Pyloric stenosis; iatrogenic, e.g. over-treatment with sodium bicarbonate.

Respiratory alkalosis—Encephalitis.

Older Children

Metabolic acidosis—Renal disease; late salicylate poisoning; diabetic pre-coma.

Respiratory acidosis—Ascending myelitis; Guillain-Barré syndrome; poliomyelitis; tetanus; asthma.

Metabolic alkalosis—Excessive vomiting; associated with intestinal obstruction.

Respiratory alkalosis—Hyperventilation:

(i) Iatrogenic—IPPR
(ii) Encephalitis
(iii) Asthma
(iv) Early salicylate poisoning

Acidosis, either metabolic, respiratory, or a combination of both, was the commonest significant disturbance encountered. Severe metabolic acidosis was especially common during periods of stress during the first year of life.

Significant metabolic alkalosis was rare and mainly seen in conditions associated with severe and prolonged vomiting such as pyloric stenosis.

SUMMARY

The development of micromethods for acid-base determinations is of particular interest to the paediatrician, as many life-threatening illnesses affecting the paediatric age-group are associated with severe disturbances of acid-base metabolism.

The interpretation and application of acid-base investigations can be simplified by understanding the terminology used, knowing the normal values for the different acid-base parameters at various age-groups, and by making use of methods which give a graphic representation of the acid-base status of the patient.

In a survey of acid-base disturbances in premature infants, full-term newborns, neonates, infants and older children

suffering from a wide spectrum of disease processes, acidosis which was either metabolic, respiratory or a combination of both was the commonest significant disturbance encountered. Severe metabolic acidosis was especially common during periods of stress in premature infants, full-term newborns and infants up to the age of 1 year.

The management of metabolic acidosis and respiratory acidosis will be discussed in further articles.

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