THE DIAGNOSIS AND TREATMENT OF POSTOPERATIVE RESPIRATORY AND METABOLIC ACIDOSIS AND ALKALOSIS

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Although this subject is theoretically a complicated one, reaching out, as it does, into the realms of biochemistry and physical chemistry and requiring the knowledge of involved formulae and some applied mathematics — we are fortunate that today's masters of this science, e.g. Astrup, Severinghaus, Wynn, Davenport, etc., have brought it down to earth for the benefit of the clinician, and reduced it to simple terms for his purpose, so that any doctor, without being a biochemist, can reap these benefits for himself and for his patients in his practice.

Dr. V. Wynn, of the Surgical Unit at St. Mary's Hospital, London, and expert in this field, said:

'I should like to draw attention to the fact that a great deal of knowledge about the metabolic aspects of respiratory failure and acid-base disorders was established by physiologists more than 30 years ago. It is now our task to see that, without further delay, this knowledge is applied to the care and treatment of patients.'

The subject is old, but most clinicians fight shy of it because it is too complicated for them. All that is new is their new awareness of the problem.[1]

DIAGNOSIS

In a case of postoperative coma, or suspected imbalance of the metabolic or respiratory acid-base relationship, all that is necessary is to take an arterial (or arterialized) blood sample — or even a venous one in case of emergency — and request the following figures from the laboratory: (1) pH, (2) HCO_3 in mM/l., and (3) pCO_2 in mm.Hg.

The pH gives the overall acid-base relationship, the pCO_2 the respiratory acid-base relationship, and the HCO_3 the metabolic acid-base relationship.

That is all. For this particular purpose we are *not interested* in sodium, potassium or other electrolytes, nor in oxymetry, and the whole determination can be done in less than 20 minutes. All that is needed is a good pH meter and a simplified van Slyke apparatus.

From these the pCO_2 is evaluated by a nomogram. The doctor will then be able to plot these figures on routine charts and he will *at once,* without having to do any calculations, be able to say *not only*:

A. *Which of the Following Conditions has the Patient?*

pH	*pCO_2*	
Low	High	*1. Metabolic acidosis plus pulmonary acidosis
Low	Low	2. Metabolic acidosis plus pulmonary alkalosis
Low	Normal	3. Metabolic acidosis plus pulmonary neutrality
High	Low	4. Metabolic alkalosis plus pulmonary alkalosis
High	High	5. Metabolic alkalosis plus pulmonary acidosis
High	Normal	6. Metabolic alkalosis plus pulmonary neutrality
Normal	High	7. Pulmonary acidosis plus metabolic neutrality
Normal	Low	8. Pulmonary alkalosis plus metabolic neutrality.
Normal	Normal	9. Normal pulmonary and metabolic balance

* For significance of numbers see Fig. 1. which gives approximate values modified by the buffer line.

but also:

B. *What is the treatment?*

(*a*) *Metabolic*

1. Acidosis. *How much* sodium bicarbonate is to be given?
2. Alkalosis. *How much* ammonium chloride or intravenous acid equivalent is to be given?

(*b*) *Pulmonary*

1. Acidosis. Should the patient inhale pure O_2 or O_2 + air?
2. Alkalosis. Should the patient inhale $CO_2 + O_2$ or $O_2 + CO_2$ + air?
3. Is a tracheotomy indicated?

Is the intermittent positive-pressure respirator (IPPR) indicated?

and

C. *What is the Progress?*

Charts are supplied to the wards, on which the *effect* of the treatment will be plotted hourly or as often as is necessary, so that the progress of the pH, the HCO_3 and the pCO_2 can be graphically represented until normal balance has been established — and the treatment can be increased, decreased or varied accordingly, hour by hour.

In this way it will be apparent whether and how quickly the patient's condition is approaching normality. It is necessary to point out that it is dangerous to swing the pH too fast, since this will precipitate cardiac arrhythmias and even cardiac failure. As in most things — slowly does it. Pure O_2 too can be dangerous when the patient is underventilating — it can kill instead of help.

As regards blood sampling — arterial blood is best for absolute accuracy. The next best is 'arterialized' blood, i.e. keeping the arm and hand on an electric hot-pad for ¼ hour and taking blood from the dorsum of the hand, avoiding stasis. Blood must be taken without air-bubbles and not left lying around at room temperature. If it cannot be rushed to the laboratory at once, the syringe must be packed in ice. Use only a minimum of anticoagulant. Venous blood taken even without compression or stasis should not be used, except in an emergency, since the results will not be very accurate, although they will show gross changes if they are present. Venous blood taken under stasis is quite useless.

It has been shown that all the clinician needs to know from the laboratory technician in order to be fully equipped to diagnose and treat these conditions is: (1) pH, (2) pCO_2, and (3) HCO_3.

These, as stated before, must be obtained from arterial or 'arterialized' blood, using a couple of drops of heparin, 1 : 5,000, as the anticoagulant. If possible the estimation should be done at once on the fresh blood. Remember to draw the blood without air bubbles. Do not use a paraffined syringe. Do not preserve the blood under liquid paraffin. Traces of liquid paraffin will 'poison' the pH electrode, so do not spin the blood under liquid paraffin. In short: Do not use liquid paraffin, and please do not use venous blood — otherwise one will have to report: 'subject to clinical confirmation, the patient is dead'.

All that has to be done now, is to plot the results on the charts — and there is your answer! But the clinician will say:

'Surely there is more to it than that — what about all those highly complicated books on acid-base chemistry, and the Henderson-Hasselbalch equation:

$$pH = 6 \cdot 10 + \log. \frac{(\text{total } CO_2)\text{p-}0 \cdot 030 \ pCO_2}{0 \cdot 0301 \ pCO_2}$$

and what about the CO_2 dissociation curve, and CO_2 carriage in the blood, and the alkali reserve, and the CO_2 combining power, and the equilibration of separated plasma with standard gas mixtures of a partial pressure of 40 mm.Hg of CO_2, and the plasma electrolytes. Surely all this, and much more, has got something to do with it too?'

My advice to the clinician is:

'My friend — it has — but just forget it for the time being! You don't need it in actual practice! I am just about to give away to you a few trade secrets of the professional physiologists and some specialist physicians, who pride themselves on having mastered such an awfully difficult subject as acid-base physiology, and fill their books, articles and conversation with equations and logarithms and curves and double-ended reversible arrows — because they would like you to think how terribly difficult this all is, and don't want that superstition rudely dissipated. Their final trump card will be: "But you have only presented the easy parts and left out the things that are really difficult!" And the ghastly fact about this accusation is that *it is true*! That is indeed the whole purpose of this article, which is to explain to the practical doctor that anybody can diagnose and treat these conditions without being compelled to toil through the intricate out-of-the-way (and mostly theoretical and irrelevant) mathematical and chemical gymnastics so dear to the

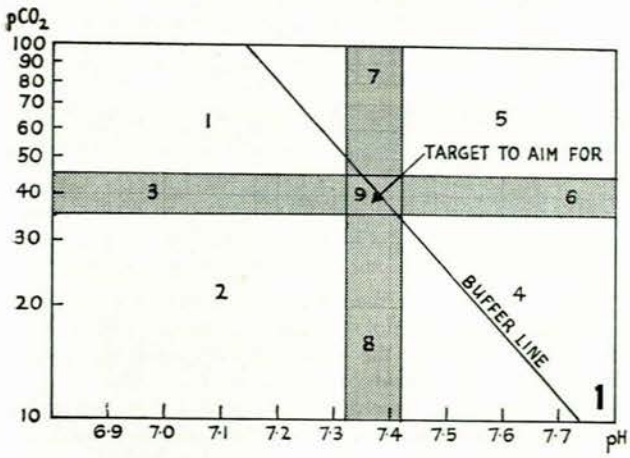

Fig. 1. Acid-base diagram (after Astrup). For explanation see text.

unpractical academically minded specialist or professor. '*And here is how to do it,* my clinician friend:

'Take a pencil, pipe, lipstick, comb or whatever is handy and on Fig. 1 point with it to where the pH and the pCO_2 intersect. This immediately tells you — according to which of the 9 squares or sectors you are in — whether the patient has a metabolic acidosis plus a respiratory acidosis or a pure respiratory alkalosis or whatever the case may be.'

TREATMENT

After you have recovered from the perfectly stunning bit of deduction mentioned above, your thoughts will inevitably turn to *what to do about it*. Well, again, nothing could be simpler.

Metabolic Acid-base Balance

You again take up one of the 'special diagnostic instruments' and make a stab at Fig. 2, aiming for the intersection of your pH and HCO_3. Again you can tell *at once* and *exactly* how many milliequivalents per litre *excess base or acid* the patient has got — and thus not only whether he requires ammonium chloride or sodium bicarbonate, but exactly *how much* he requires. If your point falls anywhere near the normal buffer line, then *he requires neither* — even if his pH is as low as 6·9 or as high as 7·7.

Do please remember this and don't put up a bicarbonate drip on speculation just because your patient is deeply comatose with a highly acid pH of 6·9. He may be suffering from acute pulmonary acidosis or CO_2 poisoning with a pCO_2 of over 160, and your bicarbonate will merely

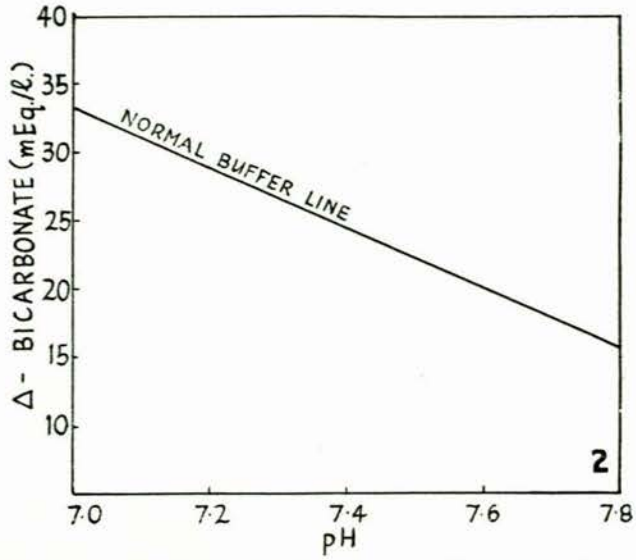

Fig. 2. pH-bicarbonate diagram (after Davenport). For explanation see text.

add insult to injury, giving him a quite unnecessary metabolic alkalosis on top of his other troubles. I think we have all done this at one time or another. Do not give oxygen either! I wonder how many doctors and nurses realize that oxygen or an oxygen tent can kill as surely as prussic acid in such a case. 'And he looked so nice and pink too when he died, what a shame!' The oxygen merely depresses the urge to get rid of the excess CO_2, and lends a false colour of health to an otherwise cyanosed face.

Nobody would steer a ship full-speed ahead in dark uncharted waters without a compass to act as a guide or without taking soundings every so often, but nobody thinks twice about putting up drips with all sorts of things in them, and giving patients oxygen for hours without having the faintest idea which way the wind — and the CO_2 — is blowing. On the rocks, my friend, until the point of no return is passed.

And yet the navigable channel is clearly marked: 6·9 to port and 7·7 to starboard — keep nicely in the middle, with a pCO_2 of about 40 and you will make the harbour, but you must take bearings (pH) and soundings (pCO_2) all the time, in case you run aground.

And here is another tip. During *hypothermia* the circulation is sluggish and any curare, 'flaxedil', etc. which is given, will be released during re-warming. These can inhibit breathing action and lead to an extreme respiratory acidosis owing to CO_2 retention. The pCO_2 will soar to dizzy figures in keeping with the patient's feelings.

Respiratory Acid-base Balance

Right — what do we do now? We have corrected the patient's *metabolic* acid-base balance by means of Fig. 2, and we now turn to his *respiratory* acid-base balance — each of which has to be corrected separately. The metabolic imbalance is corrected by giving a base or an acid by mouth (or intravenously), and the respiratory imbalance is corrected by using the positive-pressure respirator, for forced ventilation.

We can dismiss *pulmonary alkalosis* very briefly. Either you are yourself the culprit by over-ventilating the patient with the respirator — you didn't know you could do that, I suppose — or it usually corrects itself on its own owing to CO_2 accumulation, if no respirator is used at all. If the patient is unconscious, procure a cylinder of carbogen (5% CO_2 with oxygen) and let him breathe this by mask or respirator.

Pulmonary acidosis is more common and more dangerous and requires good forced ventilation with the respirator to wash out the excess CO_2. A mixture of air + oxygen is best, and a button is provided on the machine which will deliver this at will. It may take several days in patients with emphysema, etc., to correct the imbalance.

While on the subject of the respirator itself, please observe the following: An *incorrectly* used respirator can *itself* cause hyperventilation (respiratory alkalosis) or hypoventilation (respiratory acidosis). It can also cause cardiac embarrassment by preventing good venous return to the heart.

The watchword is: *Primum non nocere!* If you do not know how to use the respirator correctly, make enquiries. The mask *must* make a perfectly *airtight* joint round the mouth and nose. This cannot be done if gastric suction tubes are in position, and also cannot be achieved in a small child.

What about a Tracheotomy?

If the pulmonary acidosis is very high, say 100 - 180, and the face mask does not give satisfactory airtight closure or is contraindicated or not tolerated, or if there is much bronchial secretion to be aspirated, a tracheotomy is indicated. It is often delayed too long. The respirator then works through the tracheotomy.

Additional Therapy

Naturally, there are other important matters that must not be forgotten, and each must be attended to on its own merits — treat anaemia and hypotension, watch the fluid intake and output to provide a reasonable fluid balance and urinary excretion so that Nature can help to correct the acid-base balance, which it is trying hard to do. Replace electrolytes lost owing to vomiting, diarrhoea, sweating, and kidney dysfunction. Check on the haematocrit to detect haemoconcentration and dehydration, i.e. loss of fluid volume.

Comments on Treatment

Otherwise, here we go: We drive a car using the accelerator, clutch and brake (pH, pCO_2 and HCO_3). We correct our progress as we go and steer towards the target (Fig. 1), and we don't worry about carburation, combustion, entropy and the laws of thermodynamics — although all these are terribly necessary to make the car go (as any professor of mechanical engineering will tell you); in fact, it will not go at all without them. If you were to listen to *him*, you'd have no business driving at all.

Naturally we do not drive blindly, but now and again we look at the signposts to check that we are not getting lost; similarly, when using the respirator, or giving oxygen, or a bicarbonate drip or an acid drip, we check the pH, the HCO_3 and the pCO_2 at suitable intervals — maybe every hour or maybe every 4 hours according to the severity of the condition, to see whether we are on the right road or not, and whether everything is going nicely.

At this the physiological purist will throw up his hands in horror — if he is still with us — and exclaim:

'But all this is most unscientific, and you have left out all the difficult bits and some of the corrections and you haven't allowed for all sorts of things, which will make a difference in the third decimal place!'

And my answer to him will be:

'My friend — it's all right — what you say is quite true, but don't let's get bogged down with scientific niceties. We are not now dealing with the primary examination for the Fellowship, nor with a precise and inert laboratory experiment, but with an ill human being, who lives and sweats and passes urine and wants to get better. Instead of being academic let's do something practical. Let us correct his respiratory and his metabolic acid-base balance to two places of decimals as near as doesn't matter — and Providence will help to look after the third decimal place.

THE USE IN PRACTICE OF INTRAVENOUS INFUSIONS FOR WATER, SALT AND ELECTROLYTE REPLACEMENT AND FOR THE CORRECTION OF UNBALANCED ACID-BASE METABOLISM

It might appear from theoretical considerations and from the biochemical physiology books that it will first be necessary to calculate the exact amount in milliequivalents per litre of excess acid or excess base, or deficiency of sodium, potassium, calcium, chlorides, lactate, ammonia, bicarbonate and what have you, before you can set about putting up a drip.

This is just to make it sound difficult, and it really is amazing how many people are going about all the time making things sound difficult, when in reality they are quite easy.

Nothing is further from the truth, because one must realize that chemical changes are going on in the body all the time as a result of breathing, sweating, renal activity, liver function, etc., and things are never the same for five minutes running — and have even changed since you took the blood sample and since you received the report and worked out the so-important 'milliequivalents'.

This shows once more the futility of becoming lost in the niceties of theoretical calculations to the 3rd place of decimals because 'the formula says so'. In other words the 'formula' must be satisfied and becomes an end in itself. One does not measure the length and width of one's foot to the nearest millimetre before one goes to buy shoes! In any case, it swells a bit and spreads a bit and is never the same. No — one takes either an 8 or a 9 and that is the end of it. Similarly, the average egg cup for 10c at the bazaar fits most eggs, and one does not require a scientifically designed set of 12, in ascending diameters.

Imagine working out all the exact milliequivalents and titrating a special concoction for each patient which is already incorrect before it is put up. This is a very nice physiological text-book exercise, but not much use in practice.

What Drip shall we Put Up and How Much shall we Give?

As explained before, we do not work out to the nearest milliequivalent what to put into the drip. All we need to know in the first instance is what we are aiming at.

Are we trying to correct an acidosis or an alkalosis or an ionic imbalance? Once we know what we are after, we pick out the nearest standard solution commercially obtainable and put it up. Home-made brews, e.g. of sodium bicarbonate, are discouraged. We can estimate how many bottles we are likely to need from Fig. 2 by Astrup's formula: Total surplus acid or base = $\triangle$ acid-base per litre × 0·30 × body weight in kg.

For *practical purposes* we are only interested in three types of drip:

1. To correct metabolic acidosis.
2. To correct metabolic alkalosis.
3. To correct electrolyte and water deficiency.

As you will have realized by now, we do not neutralize a pulmonary acidosis with an antacid drip, but with the respirator, to get rid of the CO_2 which causes it.

The following then are our stock-in-trade:

1. *1/6 Molar sodium r-lactate.* 1,000 ml. cost R0.60 For the correction of metabolic acidosis of whatever kind including diabetic acidosis.

1,000 ml. contain: sodium 167 mEq., and lactate 167 mEq.

Usual dose: 40 ml. per kg. body weight.

2. *Travert 10% electrolyte No. 3.* 1,000 ml. cost R0.60. For the correction of metabolic alkalosis usually due to vomiting and acid loss.

1,000 ml. contain: ammonium 150 mEq., sodium 63 mEq., chloride 70 mEq., invert sugar 100 G., and potassium 17·5 mEq. (rate of infusion not to exceed 1 litre in 3 hours).

3. *Polyionic solution No. 1.* 1,000 ml. cost R0.60. For the correction of electrolyte and water loss in all postoperative cases for routine use. It combats dehydration and the lactate copes with a mild acidosis.

1,000 ml. contain: potassium 15 mEq., chloride 22 mEq., phosphate 3 mEq., sodium 30 mEq., lactate 20 mEq., and invert sugar 50 G.

N.B.—This contains potassium and hence must not be given until urinary output is adequate. In such a case give normal saline first (the rate of infusion is not to exceed 1 litre in 3 hours).

By comparison normal saline, which contains sodium 154 mEq., and chloride 154 mEq., costs R0.45 per 1,000 ml. vacolitre, and hence the three special drips cost only R0.15 more per bottle.

SUMMARY

1. I claim little or no credit for original research in these matters.

2. I was most diffident and apprehensive in presenting these facts, in case I appeared to be talking down to my eminent colleagues, the clinicians.

3. I need not have worried, since one or two were kind enough to assure me that they had never really understood acid-base chemistry themselves before, and that for the first time these problems had been explained and *interpreted so simply* that they felt confident they could themselves diagnose and correctly treat a post-operative comatose patient within 20 minutes of seeing him and getting the pink slip from the laboratory technician. Until now they had taken part in many discussions on the subject, but everything seemed to be so technical and full of chemistry and mathematics and involved and nebulous, that they didn't even know where to start. All the experts always seemed *to talk* high theory and to scribble formulae on bits of paper, but nobody had shown them in a practical way *what to do.*

4. One told me I had just cribbed a whole lot of stuff from well-known decent books on biochemistry, like the *Handbook of Biochemistry* and *Davenport* and the *Symposium on Acid-Base Balance*, etc.

5. I have.

My thanks are due to Dr. H. R. J. Wannenburg, Superintendent of Wentworth Hospital, Durban, for permission to publish this paper and for access to the patients, and to Dr. H. D. Tonking, Chief Pathologist of the Natal Provincial Administration, for providing suitable facilities in his laboratories.

1. Van die Redaksie (1962): S.Afr. T. Geneesk., **36**, 383.