The management of acid–base balance in children with diabetic acidosis

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Summary

Acid–base changes in eleven diabetic children admitted to hospital with keto-acidosis are described. Six children required intravenous sodium bicarbonate to correct the metabolic acidosis. It is concluded that immediate use of bicarbonate in these children was efficient, rapid and safe.

Introduction

Metabolic acidosis is one of the many biochemical complications which occur in uncontrolled diabetes mellitus; it is one of the most serious, and it may lead to death (Joslin & Wilson, 1950; Klein & Laron, 1956; Larson, Sterky & Christianson, 1961). Early recognition and treatment of severe keto-acidosis is of paramount importance if the patient is to survive.

We discuss this problem in eleven children with diabetic ketosis and the management of the more severe episodes with intravenous bicarbonate solution.

Methods

PCO_2 , pH, standard bicarbonate and base deficits (in mEq/l) were determined by micro-Astrup apparatus (Astrup *et al.*, 1960). Electrolytes, blood sugars and haematological values were performed by routine laboratory methods employing micro-techniques.

Each child was weighed on admission and the bicarbonate dose (mEq) was calculated as recommended by Astrup *et al.* (1960) (base deficit $\times 0.3 \times$ body weight in kg). Molar bicarbonate (8.4% w/v; 1 mEq/ml) was used intravenously.

Case reports

Case 1

J.P., a 9-year-old girl, diagnosed as having diabetes mellitus in May 1966, remained well on

32 units Insulin Zinc Suspension (Lente) and a 'free' diet up to June 1967, when she developed an upper respiratory tract infection which did not improve over 2 weeks. She progressively deteriorated; 2 days before admission she complained of abdominal pains, started to vomit and rapidly became drowsy. Urine testing over 48 hr preceding admission to hospital revealed heavy glycosuria and acetonuria.

On examination, she was unconscious and moderately dehydrated; the respirations were gasping and her breath smelled strongly of acetone. Axillary temperature 94°F, weight 26 kg. Extremities cold. Pulse was rapid and thready and blood pressure barely recordable. Pupils were equal and gave a sluggish reaction to light; fundi were normal. Examination was otherwise negative. No obvious focus of infection was detected.

Investigations: Urine—trace of albumin; glycosuria 4+; acetone 3+. Blood sugar 1250 mg/100 ml, sodium 126, potassium 5.5, chloride 90 mEq/l, urea 130 mg/100 ml, Hb 14.45 g/100 ml, PCV 44%, WBC 23,000/mm³, 83% neutrophils, 17% lymphocytes.

Initial treatment consisted of normal saline, 50 units of soluble insulin and 100 mEq of sodium bicarbonate intravenously. Penicillin and streptomycin were given by intramuscular injection. The response to bicarbonate therapy was extremely good and after 30 min she was semiconscious, although her blood sugar at the time was still 1300 mg/100 ml and although only 300 ml of normal saline were infused. Acid–base changes and blood sugar levels during the first 24 hr are recorded in Table 1.

In all she received 4 litres of normal saline and 160 units of soluble insulin during the first 24 hr. Further progress was uneventful and she was discharged home 14 days after admission on a 2000 calorie diet containing 200 g of carbohydrate and 40 units of Insulin Zinc Suspension (Lente) daily.

TABLE 1. Biochemical changes and insulin given in Case 1

Time	pH	PCO ₂ (mmHg)	Standard bicarbonate (mEq/l)	Base deficit (mEq/l)	Bicarbonate given (mEq)	Blood sugar (mg/100 ml)	Soluble insulin units
10.30 hours	7.02	23	8	27	100	1250	100
11.00 hours	7.29	11	11.1	20	50	1300	
14.00 hours	7.30	23	14.5	13.5	50	670	50
17.00 hours	7.48	16	19.7	6			
22.00 hours	7.42	25	21.2	4		400	10
21.00 hours	7.43	32.5	22.5	1.5		210	

TABLE 2. Biochemical changes and insulin given in Case 2

Time	pH	PCO ₂ (mmHg)	Standard bicarbonate (mEq/l)	Base deficit (mEq/l)	Bicarbonate given (mEq)	Blood sugar (mg/100 ml)	Soluble insulin units
05.30 hours	7.04	25	7.4	21	45	640	30
12.00 hours	7.27	27	18	13	10	320	
17.00 hours	7.27	45	20	2		115	

TABLE 3. Biochemical changes and insulin given in Case 3

Time	pH	PCO ₂ (mmHg)	Standard bicarbonate (mEq/l)	Base deficit (mEq/l)	Bicarbonate given (mEq)	Blood sugar (mg/100 ml)	Soluble insulin units
15.00 hours	7.12	17	9.8	23		765	50
19.00 hours	7.20	20	14	17		800	50
23.00 hours	7.25	24	15	15.5	20	560	25
03.00 hours							25
09.00 hours	7.40	31	21	3.5		128	
13.30 hours	7.35	42	22.5	2		153	

Case 2

A.McG. A 5-year-old boy was admitted to hospital in 1965 with vomiting of 24 hr duration and polyuria and polydipsia of 3 days' duration. He was the second child of healthy parents; there was no family history of diabetes mellitus.

On examination he was moderately dehydrated and semi-conscious. Respirations were gasping, pulse 140/min; BP 100/70. His throat was inflamed. Weight, 15.5 kg.

Investigations: blood sugar 640 mg/100 ml, Hb 14 g/100 ml, WBC 21,000/mm³ (90% neutrophils, 10% lymphocytes). Blood urea 32 mg/100 ml, sodium 126, potassium 3.6, chloride 100 mEq/l. Acid-base changes and blood sugar levels are given in Table 2.

He was treated with normal saline and soluble insulin; sodium bicarbonate solution was given twice, on admission and 6 hr later. There was rapid improvement following bicarbonate infusion. Further

progress was satisfactory. He was discharged home on a 'free' diet and 14 units of Insulin Zinc Suspension (Lente) daily.

Case 3

R.B. An 8-year-old boy was admitted to hospital in July 1966 with a 3-day history of thirst, polyuria and glycosuria. No family history of diabetes mellitus.

On examination he was very dehydrated; pulse rapid; BP 80/50. No other abnormal findings. No focus of infection found. Weight 26 kg.

Investigations: Blood sugar 765 mg/100 ml. Hb 13.5 g/100 ml, WBC 16,000/mm³ (67% neutrophils, 21% lymphocytes, 2% monocytes). Urine: trace of protein, sugar 3+, acetone 4+. Sodium 138, potassium 2.1, chloride 101 mEq/l. Blood urea 153 mg/100 ml. Acid-base changes and blood sugar levels are shown in Table 3.

TABLE 4. Biochemical changes and insulin given in Case 4

Time	pH	PCO ₂ (mmHg)	Standard bicarbonate (mEq/l)	Base deficit (mEq/l)	Bicarbonate given (mEq)	Blood sugar (mg/100 ml)	Soluble insulin units
21.30 hours	7.12	21	9.5	22	40	560	25
24.00 hours	7.10	18.5	8.8	23	40		
09.30 hours	7.29	31	15	10.5		225	16
22.00 hours	7.51	38.5	20	+7.5		142	

TABLE 5. Biochemical changes and insulin given in Case 5

Time	pH	PCO ₂ (mmHg)	Standard bicarbonate (mEq/l)	Base deficit (mEq/l)	Bicarbonate given (mEq)	Blood sugar (mg/100 ml)	Soluble insulin units
17.00 hours	7.07	12	7.5	24	50	750	50
20.30 hours	7.31	16	12	15.5	25	250	
23.00 hours	7.44	28	22	2.5		108	14
09.30 hours	7.44	25	+1.0			175	

He was treated with normal saline, 500 ml being given every 3 hr with 1 g of potassium chloride in alternate 500 ml bottles. One hundred and fifty units of soluble insulin were required to stabilize him during the first 24 hr of treatment. Further progress: satisfactory. Discharged home on a free diet and 20 units Insulin Zinc Suspension (Lente) daily.

Comment: This child remained clinically acidotic for much longer than the children who were given sodium bicarbonate early, but once acidosis was partially corrected with intravenous bicarbonate his improvement was rapid. In this particular instance bicarbonate was given 8 hr after admission.

Case 4

C.H. A 7-year-old boy admitted to hospital in 1965 with symptoms suggestive of diabetes mellitus. No family history of diabetes.

On examination, weight 20 kg. Wasted and lethargic child. Sighing respirations. Pulse rate 120/min. BP 120/70. Reflexes uniformly sluggish. Pupils and fundi normal.

Investigations: Urine—glucose 3+, acetone 2+, albumin 1+. Blood sugar 560 mg/100 ml. Haemoglobin 13.9 g/100 ml, WBC 16,000/mm³ (81% neutrophils, 19% lymphocytes). Blood urea 42 mg/100 ml, sodium 112, potassium 4.6, chloride 98 mEq/l. Acid-base changes and blood sugar levels are shown in Table 4.

He was treated with normal saline, soluble insulin (25 units initially) and sodium bicarbonate. His total

base deficit was estimated at about 130 mEq hence 40 mEq of sodium bicarbonate were given on admission and repeated 2½ hr later. Further progress was uneventful. He was discharged home on a 'free' diet and 20 units of Lente insulin daily.

Case 5

C.S. A 9-year-old boy originally diagnosed as having diabetes mellitus in 1961 at the age of 4 years. Progress satisfactory up to the end of 1966 when he required 18 units of Lente insulin daily. He was then admitted to hospital with a 24-hr history of polyuria, polydipsia, vomiting and drowsiness.

On examination, weight 28.2 kg. He was drowsy, his respirations were gasping; there was some dehydration but no wasting. Pulse 110; systolic blood pressure 70/mmHg. Bilateral otitis media was present.

Investigations: Blood sugar 750 mg/100 ml, Hb 14 g/100 ml, WBC 35,000/mm³ (neutrophils 74%, lymphocytes 36%), blood urea 80 mg/100 ml; sodium 136, potassium 5.5, chloride 100 mEq/l. Acid-base changes and blood sugar levels are shown in Table 5. He was given normal saline and 50 mEq of sodium bicarbonate on admission and 25 mEq were given 3½ hr later before his acid-base changes reverted to normal. Again it was noted that there was rapid improvement in his clinical state with correction of metabolic acidosis. Subsequent progress was uneventful and he was discharged home on Lente insulin 20 units daily and a 'free' diet.

TABLE 6. Biochemical changes and insulin given in Case 6

Time	pH	PCO ₂ (mmHg)	Standard bicarbonate (mEq/l)	Base deficit (mEq/l)	Bicarbonate given (mEq)	Blood sugar (mg/100 ml)	Soluble insulin units
(a) First day							
06.00 hours							68 (Lente)
12.00 hours	6.9	20	6	> 22	200	346	
14.00 hours	7.15	21	10	20.5	200	570	16 (soluble)
16.30 hours	7.28	34	16	9.5	150	640	16 (soluble)
(b) Second day							
06.30 hours							72 (Lente)
11.30 hours	6.9	19	6	> 22	300	510	
14.30 hours	7.16	20	10	21	250	460	16 (soluble)

Case 6

J.O. A 10-year-old girl diagnosed as having diabetes mellitus in October 1966 and initially stabilized on 68 units Lente insulin and a diet containing 200 g carbohydrate each day. She was admitted to hospital seven times in the next 12 months with ketosis resulting from dietary indiscretions, minor infections or emotional disturbances. In December 1967 she was again admitted with sore throat, nausea, vomiting and abdominal pain.

On examination there was little to find except mild dehydration; her weight was 30 kg. She was afebrile and there was no obvious source of infection, nor any hyperpnoea. The urine showed heavy glycosuria and acetonuria. Pulse, blood pressure and peripheral circulation were normal.

Investigations: Blood sugar 400 mg/100 ml; sodium 131, potassium 4.5, chloride 103, alkali reserve 10.5 mEq/l, urea 25 mg/100 ml, Hb 14 g/100 ml, WBC 10,000/mm³. Throat swab—no pathogens; urine—no evidence of infection.

Treatment consisted of intravenous normal saline 1000 ml followed by 500 ml N/2 saline with 5% dextrose. No additional insulin was given on the day of admission, nor any sodium bicarbonate. Within 3 hr of starting intravenous therapy the blood sugar fell to 140 mg/100 ml, nausea and vomiting had subsided and she was sitting up in bed asking for food and drink. Intravenous therapy was, therefore, discontinued, although the urine still showed glycosuria and moderate acetonuria.

The following morning profuse vomiting recurred followed by dehydration, hyperpnoea and minimal peripheral circulatory failure. She had been given her normal dose of Lente insulin earlier because of the apparent recovery the previous day. Clinically she was drowsy, pulse rate 140/min, BP 85/60, tongue brown and dry.

Investigations: Urea 25 mg/100 ml; sodium 131, potassium 4.8, chloride 102, alkali reserve 3 mEq/l.

Acid-base balance and blood sugar levels are shown in Table 6(a).

Intravenous therapy was restarted and ampicillin commenced. 200 ml of 8.4% sodium bicarbonate were given rapidly and followed by a marked improvement in pulse, blood pressure, peripheral circulation and respirations. Intravenous therapy was continued with normal saline.

Two hours later there was further improvement, blood sugar and acid-base findings as in Table 6(a). Soluble insulin (16 units) was given and a further 200 ml 8.4% sodium bicarbonate, followed in a further 2 hr by 150 ml, and in a further 2 hr by 150 ml and more soluble insulin (16 units). Improvement again quickly followed the administration of bicarbonate.

On the 3rd day her general condition was good although the blood sugar was still high (490, 250 and 270 mg/100 ml). Other investigations: sodium 145, chloride 115, potassium 3.3, alkali reserve 23 mEq/l, urea 22 mg/100 ml. Nausea and vomiting were no longer a feature of the illness, she was drinking well and acetonuria was decreasing. Twenty-four hours later the improvement had been maintained and all therapy, except Lente insulin (72 units) and ampicillin was discontinued.

She remained well for 2 days then again relapsed, the same clinical and biochemical events recurring, i.e. acetonuria, nausea, vomiting, drowsiness and peripheral circulatory failure. Acid-base changes were as severe as before and are summarized in Table 6(b).

Similar therapy was given. A total of 550 ml 8.4% sodium bicarbonate was again required before the acid-base balance approximated to normal. Rapid improvement occurred and within 18 hr biochemical and clinical states were excellent. (Blood sugars 225 and 175 mg/100 ml.)

A stable diabetic condition is now maintained with a mixture of protamine zinc and soluble

TABLE 7. Biochemical state of patients not requiring bicarbonate

Case No.	pH	Pco ₂ (mmHg)	Standard bicarbonate (mEq/l)	Base deficit (mEq/l)	Blood sugar (mg/100 ml)
7	7.35	31	20.5	1	500
8	7.35	18	17.5	10	325
9	7.34	35	19.5	6	720
10	7.22	34	14.5	7	575
11 after 24 hr	7.34	24	16	11	500
	7.34	41	20.5	3	260

TABLE 8. Biochemical state of patients requiring bicarbonate

Case No.	pH	Pco ₂ (mmHg)	Standard bicarbonate (mEq/l)	Base deficit (mEq/l)	Blood sugar (mg/100 ml)
1. J.P.	7.02	23	8	27	1,250
2. A.McG.	7.04	25	7.4	21	640
3. R.B.	7.12	17	9.8	23	765
4. L.H.	7.12	21	9.5	22	560
5. C.S.	7.07	12	7.5	24	750
6. J.O.					
(a)	6.9	20	6	>22	346
(b)	6.9	19	6	>22	510

insulins (36 and 32 units, respectively) combined with a diet containing 220 g carbohydrate/day.

Five other children were admitted to hospital with diabetic keto-acidosis, but in these the metabolic acidosis was not severe enough to require correction with sodium bicarbonate. The initial acid-base state and blood sugar levels are summarized in Table 7.

Discussion

Although most children with diabetic keto-acidosis will respond well when fluid and electrolyte losses are replaced and insulin given, there are some who need rapid correction of the metabolic acidosis. Few patients survive prolonged depression of the blood pH below 7.0 (Siggaard-Anderson, 1963). Thrower, Darby & Aldinger (1961) showed that if acidosis persists a stage may be reached when death will ensue despite correction of the underlying metabolic disturbance. Enzyme activity may be impaired by a drop in pH (Barness, 1959). Addis, Thomson & Welch (1964) accept a pH of 7.2 as the lowest 'safe' level in an adult diabetic.

It is desirable to correct rapidly, even though only partially, the metabolic acidosis present in diabetic ketosis. For many years a M/6 solution of sodium lactate has been used for this purpose, and this treatment is still recommended in some textbooks.

Unfortunately some diabetics when ketotic have a high blood lactate level (Walker, Linton & Thomson, 1960; Anderson, Thomas & Tomlinson, 1966), and furthermore oxygen may not be readily available for conversion of lactate to bicarbonate which is the chief buffer of plasma. For efficient and safe administration of intravenous sodium bicarbonate use must be made of the Astrup apparatus for rapid estimations of pH and Pco₂ and calculation of the base deficit (Astrup *et al.*, 1960). The technique is not difficult to learn and the test may sometimes be regarded as a bedside rather than a laboratory procedure. In the first instance the calculation of bicarbonate required should aim at half or three-quarter correction in order to prevent a secondary alkalosis. The intention is to help the natural processes of repair and to avoid over-correction.

Case 6 was probably in greater danger than the others as shown by the blood pH and base deficit. Estimation of blood sugar in her case gave little help in planning treatment and indeed the blood sugar rose while the base deficit fell and while her clinical state improved (Table 6a).

Some of the initial biochemical estimations in the six children who received sodium bicarbonate are shown in Table 8. According to the criteria of Addis *et al.* (1964) the pH of all was at a dangerously low level. Tables 1-6 show the rapid correction in pH obtained. Excellent clinical improvement always

followed even when the blood sugar level remained high. This feature has been commented on by others (Phear, 1963; Cunningham & Hilton, 1964; Addis *et al.*, 1964). It is probable that with this treatment the insulin requirement will sometimes be lower than with other regimens, and it becomes even more essential to watch for evidence of dangerous hypoglycaemia during the stage of recovery.

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