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CONTENTS

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Abbreviations

TBK	Total body potassium
TBW	Total body water
ECFV	Extracellular fluid volume
FFBW	Fat free body weight (or lean body mass)
PCM	Protein-calorie malnutrition
GTT	Glucose tolerance test
W	Weight
H	Height
kg	Kilogram (cf. Kg, the glucose disappearance rate constant)
cm	Centimetre
Kg	The glucose disappearance rate constant (Please see page A41)
I/G	Insulin-Glucose ratio (Please see page A41)
mEq	Milliequivalents
Na	Sodium
K	Potassium
Cl	Chloride
pCO_2	Partial pressure of carbon dioxide in millimetres of mercury (Hg)
BE	Base excess (mEq/l)

INTRODUCTION

Potassium is one of the major constituents of the human body but its role in metabolism is not clearly defined. One reason for this is the predominant intracellular distribution of the ion and the attendant difficulties in the detection of deficiency states. Serum potassium levels are of little value as over 95% of the potassium in the body is intracellular. Balance studies[120,121,194] and the analysis of biopsy material[87,242] have been used. However, they are so time-consuming that they are only of use in establishing the diagnosis retrospectively and give very little indication of the severity of the deficit.

Exchangeable potassium measurements do give an indication of the severity of the deficit[225,233]. However, they involve the administration of an isotope which is not always available because of its short half-life. The development of the whole body counter has overcome most of these problems.

The accuracy of the method is established[17,18,19,46,64,84,95,131,241] but the interpretation of the results is difficult.[42] The normal method of expressing the results, mEq or mEq/kg, does not allow for individual differences in body composition. The first part of this study was devoted to finding a method for predicting the normal TBK of an individual and so provide a reference value for the observed TBK. This method and the conventional expressions of TBK were used to compare the results of the control series and children suffering from acute dehydrating gastroenteritis and acute pulmonary infections. By using both methods it was possible to establish the frequency of abnormal TBK values in each group and to compare the three groups. Children suffering from PCM (kwashiorkor) were also studied. It

was not possible to calculate reference values for these children and when comparing this group with the other groups only the conventional method of expression was used.

Children admitted with PCM and gastroenteritis were studied during recovery to investigate the time required for the return of TBK to normal levels and to assess the effect of potassium supplementation. This part of the study was extended in a few children suffering from PCM to include the effect of potassium supplementation on extracellular fluid volume and total body water, and on glucose tolerance and serum insulin levels.

The serum electrolyte concentrations (sodium, potassium and chloride) of the children suffering from PCM, gastroenteritis and pneumonia were examined to see if there was any relationship between TBK and serum electrolyte disturbances. In the children suffering from gastroenteritis the study was extended to include acid-base status. The aims of the study can, therefore, be summarised as:

1. To solve the problem of interpretation of TBK results;
2. To investigate the changes, if any, taking place in TBK in acute gastroenteritis and pulmonary infections and to compare these changes with the changes known to occur in PCM; and
3. To try to relate functional changes possibly due to, or resulting in, potassium depletion, to changes in TBK.

The work done is presented in seven chapters with three appendices.

Chapter 1: "Review of the literature: Some effects of potassium depletion".

Only those aspects which are important in discussing the work done have been covered. Where contradictory views are present, the preferred studies are human to animal, whole body to isolated

organ and in vivo to in vitro.

Chapter 2: "Interpretation of TBK results".

The effect on TBK of changes in body composition is illustrated. Various methods of predicting TBK are investigated. The results of the control series are compared with those from other centres.

Chapter 3: "TBK in PCM, acute gastroenteritis and acute pulmonary infections".

The results of the three groups of children are compared using the conventional methods of expression. In the last two groups the prediction method is used to compare the groups and to establish the frequency of abnormal results. The relationship between TBK and nutritional status as judged by percentage expected weight for age and serum albumin levels is examined in each group and the effect of potassium supplementation in PCM and gastroenteritis is shown. The meaning of low TBK values and the need for a reassessment of the current concept of potassium capacity is discussed.

Chapter 4: "The relationship between TBK and serum electrolyte concentrations".

The TBK values and the serum sodium, potassium and chloride concentrations of children suffering from PCM and gastroenteritis and acute pulmonary infections are examined. In the case of children suffering from gastroenteritis the blood pH and pCO_2 and base excess are also considered.

Chapter 5: "The effect of potassium supplementation on extracellular fluid volume and total body water in PCM".

The effect of potassium supplementation on extracellular fluid volume is shown and attempts are made to relate the changes found to changes in TBK and serum potassium levels. The changes found in total body water are reported.

Chapter 6: "The effect of potassium supplementation on glucose tolerance and serum insulin levels".

The results of the potassium supplemented and non-supplemented groups are compared. Attempts were also made to relate the changes in glucose tolerance and serum insulin levels to changes in TBK, serum sodium and potassium concentrations, total serum protein and serum albumin levels.

Chapter 7: Summary and Conclusions.

Appendix A: Laboratory methods.

Appendix B: Statistical methods.

Appendix C: Detailed results.

In this appendix the results of the individual cases investigated are given, together with one table considered to be too large to be placed in the text.

Chapter 1

REVIEW OF THE LITERATURE

SOME EFFECTS OF POTASSIUM DEPLETION

Interest in the function of potassium in metabolism arises from the predominant intracellular localization of the ion. The normal distribution of sodium and potassium ions across the cell membrane is maintained by two adenosine triphosphatases (ATPases) which require the presence of both sodium and potassium ions. One of the ATPases is also magnesium dependent. The presence of phosphatidyl serine, a normal constituent of the cell membrane, is necessary for optimal function of these enzymes which are very sensitive to changes in pH, the concentrations of the activating electrolytes and infections[34,44,77,130,212,250]. While the proportions of the ATPases vary, they have been either demonstrated in, or isolated from brain[128,226], intestinal mucosa[205], skeletal muscle[115], heart muscle[123], kidney[45,57,167] and erythrocytes [193,206,213].

Normal intracellular concentrations of sodium and potassium are probably essential for normal cellular function. Many enzymes are activated by these cations. The principal reactions involved are phosphorylation and elimination[231].

Effect of potassium depletion on protein synthesis

While this thesis is not directly concerned with protein synthesis, the influence of potassium on protein synthesis is important when considering potassium capacity[219].

Potassium ions influence ribosomal structure and activity and the transfer of aminoacids to growing polypeptide chains[6,82, 161,179]. The factor(s)[214] involved in the elongation of the polypeptide chain may be abnormal in potassium depletion[6].

These disturbances may impair protein synthesis in vivo.

The effect of potassium depletion on blood glucose and plasma insulin levels

Potassium depletion in patients undergoing peritoneal and haemodialysis results in an abnormal glucose tolerance test (GTT) and a delayed, low response of endogenous insulin to a glucose load. After potassium repletion the GTT returns towards normal and there is a prompter, higher response of endogenous insulin[221]. In hypertensives, cirrhotics and other patients who become potassium depleted following diuretic therapy, and who then receive potassium supplements similar patterns have been found[52,53,105,200]. Anderson et al[21] studied obese patients. They found that those pateints who received a potassium supplement during the fast had more normal GTT and plasma insulin responses than prior to fasting, while those who did not receive potassium supplement showed no change in GTT and a more delayed sustained insulin response. Abikar and Katims[3] studied normal subjects, maturity onset diabetics, hypertensives and diabetic hypertensives and found that some patients in each group showed an improvement in the GTT and a rise in immunoreactive insulin levels (IRI). They concluded that in man potassium loading had a small insulin-releasing effect.

The original evidence that potassium affected insulin release was provided by in vitro studies of the rat and rabbit pancreas. Grodsky and Bennett[110] perfused isolated rat pancreases and found that the concentration of potassium in the perfusate affected insulin secretion. When the concentration was increased from 4 - 8 mEq/l there was a direct stimulation of insulin release in the complete absence of glucose. The omission of calcium completely inhibited insulin release stimulated

by glucose. A high extracellular magnesium concentration also inhibited insulin secretion. Hales and Milner[116] incubated pieces of rabbit pancreas and investigated insulin secretion in media of different ionic compositions and in response to various stimuli and inhibitors. They concluded that the sodium pump played a role in insulin secretion as inhibition of the pump by ouabain, or by the omission of potassium from the medium, resulted in a sustained rise in insulin secretion. A rise in extracellular potassium concentration stimulated initial insulin secretion independently of changes in the osmolarity or sodium or chloride concentration of the incubation medium. The degree of stimulation was maximal at an extracellular potassium concentration of 55.5 mEq/l. Extracellular sodium was a prerequisite for the maintenance of insulin secretion stimulated by glucose, glucagon, L-leucine, tolbutamide, potassium or ouabain. They inferred that a trans-membrane sodium flux probably in the beta cell was a fundamental event in the stimulation of insulin secretion by diverse stimuli.

In these in vitro studies the insulin accumulating in the perfusate and incubation medium arises from the secretion of stored insulin rather than synthesis of the hormone. Insulin secretion requires the viability of a series of membranes including that around the intracellular granule and the plasma membrane. It is possible that the sodium-calcium-potassium effects are at the membrane level. ATPase has been demonstrated in rabbit and rat beta cells and is in high concentration in the membrane surrounding insulin granules. The ATPase levels may, or may not, correlate with functional activity. The membranes contain glyco- and lipoproteins[111].

Potassium may also affect insulin secretion and/or

glucose tolerance by altering the rate of glycolysis. Several of the enzymes involved in this glycolysis are potassium-dependent[231]. Cell membrane transport of potassium stimulates the rate of glycolysis in Erlich ascites tumour cells under anaerobic and aerobic conditions[101].

From these facts it can be appreciated that although the mechanism of the action is not clear, potassium is intimately related to insulin secretion and glycolysis.

The effect of potassium depletion on acid base, water and electrolyte balance[1,117,159,188,203,209,216]

In the body, as in any other "system" the laws of ionic and osmotic equilibria must be obeyed. In view of the first, it is impossible for potassium ions to be lost from the body or cells without one or both of the following taking place. (1) The loss of an anion (or anions) and (2) the gain of a cation (or cations). As potassium ions are responsible for much of the intracellular osmotic pressure, a decrease in the intracellular concentration must be accompanied by one or more of the following changes:

1. a loss of intracellular water,
2. the excretion of extracellular ions and/or the retention of water,
3. the dissociation of polar covalant compounds.

Because of these laws it is impossible for potassium depletion to occur spontaneously or be induced experimentally without associated ionic or water disorders; eg. experimental potassium depletion is frequently accompanied by chloride depletion especially when it is induced by the administration of thiazide diuretics, sodium nitrate or corticosteroids.

pH is controlled initially by the buffering systems of the body. However, only the kidney has a capacity for selective excretion and so ultimate control of acid-base balance by the excretion of appropriate amounts of hydrogen and bicarbonate ion depends on renal function. Water and electrolytes are lost extra-renally eg. sweat and faeces but these are not "controlled" losses. Selective excretion by the kidney is again essential for normal balance. Hence potassium depletion by interfering with normal renal function has marked effect on acid-base, water and electrolyte balance. There are three basic mechanisms by which potassium depletion may do this: (i) in man and in rats potassium depletion consistently lowers the arterial pressure, resulting in reduced renal blood flow and a lowered glomerular filtration pressure[232]; (ii) potassium deficiency is frequently associated with protein deficiency which might cause alterations in renal function[39,177]; (iii) a direct effect on renal cellular activity.

Intracellular and extracellular acid-base balance

In experimental animals potassium depletion is almost always accompanied by an extracellular alkalosis. In acute spontaneous potassium depletion in man alkalosis is very common but it is an infrequent finding in chronic depletion. The reason for these differences probably lies in the cause of potassium depletion, eg. in dogs given deoxicorticosterone potassium depletion and extracellular alkalosis are invariably present. However, if dogs are potassium depleted by diet alone, there is no alkalosis until deoxicorticosterone is administered. It is possible that some of the causes of potassium depletion, particularly acute depletion, stimulate adrenals and the alkalosis

is due to the "excess" corticosteroids rather than the potassium depletion. However, in chronic potassium depletion from extra-renal causes, the corticosteroids are low even when there is a concomitant sodium loss and hypovolaemia[112,132,140,223,227,235].

Apart from hormones secreted by the adrenal cortex, there are several possible reasons for an extracellular alkalosis in potassium depletion. There is a very attractive hypothesis, which is probably partly true, that there is no change in acid-base balance in the body as a whole but there is a redistribution of hydrogen and bicarbonate ions between the intra- and extracellular compartments. Hydrogen ions are said to move into the cell to replace as much as a third of the lost potassium ions and so leave a relative excess of bicarbonate ions extracellularly. According to this theory, sodium ions replace the remainder of the potassium[32,55]. There have been many attempts to confirm or refute this theory but there are many technical difficulties in the measurement of tissue pH[58,71,93,104,123,129,136,137,210,211]. Another theory is that free aminoacids, in particular lysine and arginine, fill the cation gap rather than sodium and hydrogen ions. According to this theory, the slight extracellular acidosis observed when potassium is replaced, is due to the passage out of the cell of acid metabolites of these aminoacids[69,70]. Both these theories are supported by the fact that when potassium is given (not as the chloride) to a depleted subject with an extracellular alkalosis there is an improvement in acid-base balance with little or no change in external balance of hydrogen and bicarbonate ions. There is also a definite movement of sodium out of the cells. When chloride is given (not as potassium chloride) there is also improvement in acid-base balance which

is accompanied by bicarbonate diuresis[145].

Perhaps the best study for differentiating the effect of potassium and chloride ions on acid-base balance is that by Wilson and Simmons[256]. They induced potassium and chloride depletion in dogs by repeated injections of sodium nitrate and then repaired the chloride deficit by infusing hydrochloric acid or sodium chloride. Their findings may be summarised as follows.

(A) potassium and chloride depletion

(i) a reduced extracellular fluid volume (ECFV)

(ii) a 20% reduction in total body potassium (TBK)

(iii) a 50% reduction in total body chloride ($TBCl^-$)

(iv) an unchanged total body sodium (TBNa) but a markedly increased intracellular sodium concentration

(v) an unchanged total body bicarbonate ($TBHCO_3$), but the extracellular bicarbonate concentration was increased and the intracellular concentration decreased, i.e. an extracellular alkalosis and intracellular acidosis.

(vi) a marked hypochloraemia and hypokalaemia

(vii) a mild hyponatraemia and hypocapnoea.

(B) potassium depletion and normal extracellular fluid chloride concentrations.

(a) When hydrochloric acid was infused until the extracellular alkalosis was corrected there was no change in intracellular pH until potassium was administered.

(b) When sodium chloride was infused until the extracellular chloride concentration was normal.

(i) a rise in ECFV almost to control values and a reduction in total body solids.

(ii) TBK unchanged

(iii) TBCl 92% of normal

(iv) a rise in TBNa. Both extracellular and intracellular sodium concentrations increased, TBNa being approximately 10% higher than normal.

(v) A reduction in $TBHCO_3$; the extracellular concentration decreased and the intracellular concentration fell even further than in the potassium and chloride depleted group. There was a mild extracellular acidosis.

(vi) serum potassium returned towards, but did not reach, normal values.

(vii) extracellular sodium almost reached normal values and there was still hypocapnoea.

(C) potassium depletion and hyperchloraemia (after continuation of the sodium chloride infusion).

(i) the ECFV increased

(ii) a normal extracellular sodium concentration, and a further rise in extracellular potassium concentration but this was still below normal.

(iii) the extracellular acidosis was more marked but the pCO_2 was unchanged.

(D) All concentrations returned to normal after potassium chloride administration.

In this study, it is interesting to note that during potassium and chloride depletion, the sum of the extracellular sodium and potassium concentrations was lower than in the control while the sum of the intracellular concentrations was higher. It is probable that electrical neutrality was maintained by the binding of proteins.

Some of the findings of Wilson and Simmons appear to contradict other reports. The following are particularly important.

(i) an extracellular acidosis in the presence of potassium depletion (Bv and Ciii)

(ii) a rise in ECFV (Bi and Ci)

The differences found are probably due to the fact that chloride depletion was not excluded in many of the other studies[113].

Hydrogen and bicarbonate ion excretion by the potassium deficient kidney[25,217,234]

The potassium deficient kidney loses its ability to regulate acid-base balance. The urinary pH is remarkably stable at about 6 and never moves into the alkaline range. The normal nocturnal aciduria and inverse changes in urinary potassium disappear while rapid large changes in blood pH result in minimal changes in urinary pH. In fact, in potassium depletion the ingestion of a very small amount of alkali results in a marked rise in blood pH with no correction by the kidney. Thus the extracellular alkalosis may arise "accidentally" and then persist because of the paradoxical aciduria. In a normal subject almost all the bicarbonate in the glomerular filtrate is reabsorbed up to a threshold value approximately equal to the normal plasma bicarbonate level. In potassium depletion this threshold is elevated and excessive amounts of bicarbonate are reabsorbed, even when there is no disturbance of blood pH. The mechanism of the changes are unclear but it may be related to one or more of the following.

(i) altered glomerular filtration

(ii) the release of bicarbonate ion reabsorption by the proximal tubule from normal controlling mechanisms. This may be due

to potassium depletion per se or to changes in ECFV. In potassium depletion bicarbonate reabsorption is enhanced by a reduction in, and partly diminished by, an expansion of the ECFV[154,155,156].

(iii) the relative concentrations of sodium and chloride in the glomerular filtrate.

Even in the presence of changes in the blood pH, the titrateable acidity of the urine formed when a potassium deficit exists is practically constant as is the urinary ammonium ion concentration. The inability to acidify to an appreciable extent is found in moderate depletion and the greater the depletion, the less the ability to excrete hydrogen ions[258]. In potassium deficiency, the percentage of hydrogen ions excreted as ammonium ions is higher than normal and may account for 80% of the total acidity. The relative increase in the urinary ammonium ion excretion is explained by the accelerated formation of ammonia in the tubular cells due to the increased activity of glutaminase II and amino oxidase. It is possible that the ammonium ion plays the part of available cation and so assists in the conservation of potassium[11,12,46,133,134,178,202,215].

Excretion of potassium by the potassium deficient kidney[257]

Disturbances in acid-base balance and electrolyte balance may result in the urinary loss of potassium. These factors are probably responsible for many of the reports than potassium conservation is relatively inefficient. However, if the potassium deficit is not great and there is no major disturbance of electrolyte or acid-base balance, there is good potassium conservation. Potassium excretion is always less than 10 mEq/day and can be as low as 2 mEq/day. Sodium restriction

tends to enhance potassium conservation[20,75,85,86,227] while chloride depletion results in an inability to conserve potassium[63,94,162,163,230,235,238,239].

During progressive potassium repletion by regular intake, potassium excretion remains at low levels until repletion is complete. There is then a sudden increase in excretion. However, if a sharp rise in serum potassium to a level greater than 4.5 mEq/l is induced, there is a rise in urinary potassium excretion which becomes massive when the serum level exceeds 5 mEq/l. There is also a sharp rise in urinary pH and a diminution in the excretion of free hydrogen ions although the total titrateable acidity remains the same. During rapid potassium administration there is increased aldosterone secretion which is in contrast to the very low levels usually found in potassium deficiency. If the serum potassium is allowed to fall below 3 mEq/l before repletion is complete the urinary potassium concentration falls to the original low potassium conserving levels[117].

An extracellular acidosis results in marked initial potassium excretion. If the acidosis persists, there is a fall in the urinary potassium concentration and a rise in ammonia production but potassium conservation is not efficient[191]. An extracellular alkalosis always results in marked potassium losses.

Osmolar clearance in potassium depletion

One of the most consistent and striking findings in natural and experimental potassium depletion is a considerable reduction in osmolar clearance which is often fixed[107,108]. These findings appear to be more closely related to the serum

potassium level than to the degree of total body depletion. However, the principal determinants of the serum potassium concentration are the pH of the intra- and extracellular compartments and the mass of exchangeable potassium.

Polyuria is also a frequent finding, but it is more closely related to the pathology causing potassium depletion. If the loss is gastrointestinal, polyuria is inconstant while it is rarely absent in primary hypoaldosteronism.

The mechanism for the impairment in concentrating ability is not known. It may be a tubular defect, i.e. a diminution of the selective permeability of the collecting tubules to water[166][207] or to a defect in the countercurrent mechanisms for establishing a steep concentration gradient in the renal medulla[24,30,102]. The defect in concentrating ability is not corrected by the administration of exogenous vasopressin[187,202].

Extracellular fluid volume and sodium and water excretion in potassium deficiency[48,78,146]

There are a number of papers on the effect of potassium depletion on ECFV, some reporting a decrease, some no change, and others an increase. The differences are probably due to:

(1) the mechanism of inducing potassium depletion (diuretic induced potassium depletion is accompanied by a decrease in ECFV while corticosteroid-induced depletion results in an increase in ECFV),

(2) the severity of the potassium depletion,

(3) the presence or absence of other electrolyte abnormalities (eg. chloride depletion)[94,162,163,230,256],

(4) the availability of water and sodium ions[32,86,158].

The reabsorption of sodium and water by the kidney are intimately related and with antidiuretic hormone, control the ECFV. The failure of the kidney to respond to exogenous vasopressin[187,202] indicates that antidiuretic hormone does not play an important role in controlling ECFV in potassium depletion. A rise in ECFV decreases sodium reabsorption and a decrease in ECFV results in a rise in sodium reabsorption[61]. Potassium depletion increases proximal tubular sodium reabsorption even in the presence of an increased ECFV[24,142,158]. This may be due to a direct effect on the proximal tubular cells[47]. Aldosterone does not appear to be involved as there is a marked inhibition of aldosterone secretion in potassium depletion even in the presence of sodium depletion. There is a definite relationship between sodium and potassium balance and aldosterone and renin secretion although the mechanism is not clear[2,40,43,62,76,91,140,157,220]. Potassium depletion may result in impaired function of 11-beta-hydroxylase, so reducing aldosterone synthesis and resulting in an excess of corticosterone[28,247,255]. Potassium depletion results in an increase in plasma renin even in the presence of a degree of sodium retention which would normally inhibit renin secretion. The rise in plasma renin is modified by changes in sodium balance. Aldosterone secretion is directly influenced by potassium ion. The administration of potassium increases and depletion decreases secretion. This effect of potassium can supersede the normal stimulation of aldosterone secretion by sodium losses just as a high potassium intake abolishes the usual renin response to sodium deprivation.

It seems possible that a rise in plasma renin in the presence of low plasma aldosterone levels is a mechanism for

potassium conservation while rises in plasma renin and aldosterone concentrations result in potassium excretion. In potassium depletion sodium conservation does not appear to require aldosterone, and an increased ECFV in potassium depletion is probably due to sodium retention with secondary water retention.

Oedema is a common finding in potassium depletion. It may only appear after potassium repletion has commenced and a negative sodium balance established.[32,86,158] The fact that some subjects become oedematous and others do not in apparently identical circumstances seems to exclude a simple increase in ECFV from being the cause of the oedema.

Summary of functional effects of potassium depletion

Potassium depletion has widespread effects. It interferes with protein and glucose metabolism. This is important when considering the concept of potassium capacity. The effects of potassium depletion on the distribution of hydrogen, bicarbonate, sodium and potassium ions are not clearly understood. Any disturbances which may arise tend to persist and to result in further losses of potassium. There is a redistribution of ions between the intracellular and extracellular compartments and the kidney is unable to secrete selectively in response to changes in plasma levels. Disturbances in water balance are complex. As with many of the other changes occurring in potassium depletion, the presence or absence of associated disturbances in other ions is extremely important. In "pure" potassium depletion the ECFV is probably increased.

Chapter 2 INTERPRETATION OF TOTAL BODY POTASSIUM RESULTS

Theoretical considerations

Any method for predicting TBK is, in effect, a method predicting the weight of the fat-free body tissue (FFBW) or lean body mass, as it is often called. The relationship between TBK and FFBW arises from the distribution of potassium in the body. Fat contains very little potassium and liver, brain, muscle and similar tissues contain much potassium. Extracellular fluid which forms part of the FFBW can also have a marked effect on TBK because of the low potassium concentration of this tissue[254], eg. Table 1 gives the proportions of fat, ECFV and "remaining tissues" in three theoretical children (a) (b) and (c), aged 12 months and weighing 10 kg. The potassium content of the various compartments and the TBK in mEq, and in mEq/kg are also given.

Table 1 Effect of body composition on TBK

		(a)	(b)	(c)
Proportions	Fat	20%	10%	10%
	ECFV	25%	25%	55%
	Remaining tissues	55%	65%	55%
Potassium Content	Fat	0	0	0
	ECFV	10	10	14
	Remaining tissues	454	522	454
TBK mEq		464	532	468
TBK mEq/kg		46.4	53.2	46.8

In the calculations of the potassium content shown in this table the following assumptions have been made:

1. fat contains no potassium
2. FFBW contains 58 mEq potassium/kg when the ECFV is 25% of body weight

3. ECFV contains 4 mEq potassium per litre.

The composition of the FFBW varies with age. Garrow et al[97] have compiled "ratios" of the potassium content (in mEq) per kilogram FFBW from foetal age to 60 years of age. The "ratio" of 58 mEq/kg is given for children aged one year. The effects of the changes with age are shown in Table 2 and contrasted with the effects of the change in the proportion of fat. The children (d) and (e) are assumed to contain 58 mEq potassium/kg FFBW and the children (f) and (g) 50.8 mEq/kg (the value given by Garrow et al[97] for neonates).

Table 2 Effect of age and total body fat on TBK

		1 year		neonate	
		(d)	(e)	(f)	(g)
Proportions	Fat	20%	10%	20%	10%
	ECFV	25%	25%	25%	25%
	Remaining tissue	55%	65%	55%	65%
Potassium Content	Fat	0	0	0	0
	ECFV	10	10	10	10
	Remaining tissue	454	522	394.4	447.2
TBK mEq		464	532	406.4	457.2
TBK mEq/kg		46.4	53.2	40.64	45.72

The change in the potassium content of the FFBW is due to changes in total body water, ECFV and composition of the tissues. The effect of a change in ECFV was demonstrated in Table 1.

It has been shown that the ECFV decreases with age. The values given by Friis-Hansen[88,89,90] for children of the same age as those studied in this investigation are shown in Table 3. (TBW was determined by the deuterium oxide dilution technique and the ECFV was the thiosulphate space).

Table 3 TBW and ECFV as a percentage of body weight (Mean values reported by Friis-Hansen)

Age months	TBW %	ECFV %
1- 3	72.3	32.2
3- 6	70.1	30.1
6-12	60.4	27.4
12-24	58.7	25.6

From this table it would appear that the difference between the ECFV of the youngest and oldest children studied, 1.5 and 27 months was approximately 7% when both values were expressed as percentages of body weight. However, all the children had height ages and weight ages less than 12 months (height age, or weight age being the age of a normal child of the same height or weight). It has been suggested that after recovery from the acute phase of PCM the body composition of a child is the same as that of normal children of the same weight and/or height, i.e. the "body composition for age" range of the children in this study was approximately 1 to 12 months[38].

The fall in TBW reflects an increase in total body solids. Even if the concentration of potassium in the total body solids remained the same, there would be an increase in the potassium content per kg FFBW because of the increased proportion of total body solids. The relative amount of connective tissue in the FFBW is another factor which affects the TBK. As there is no method of measuring the total connective tissue content of the body, little can be done to correct for this compartment. However, on the basis of weight, bone is the most important of connective tissues and Doyle et al[66] suggested that in adults muscle mass is an important determinant

of bone mass. As TBK and muscle mass are closely linked, this would relate TBK and bone mass.

Because of the relationship between body composition and TBK it might be thought that the best method of predicting TBK would be detailed laboratory investigations involving total body water, ECFV and urinary creatinine and hydroxyproline excretion and radiological investigation of muscle mass, skeletal mass and body fat (urinary creatinine would be used as an index of muscle mass and hydroxyproline as an index of total body collagen). In fact, several workers have found good correlations between TBK and TBW, TBCl, ECFV and urinary creatinine in healthy children and adults.

This approach ignores two important facts.

(1) The reason for requiring a method of predicting TBK and

(2) The effects of potassium depletion on body composition.

A method for predicting the normal TBK of an individual is required because at present there is no way that the presence of potassium deficiency can be proved or an indication of the severity given on the basis of a single TBK determination[42]. Comparison of such a determination with previous determinations of normal children is of no use because of the extremely wide normal range. (The TBK values of control cases in this study ranged between 33.3 to 55 mEq/kg). The diagnosis can be made retrospectively on the basis of serial determinations but this is of limited clinical use. There are further objections to detailed laboratory investigation: The time required to collect specimens for analysis, the technical difficulties and the fact that it would not be possible to investigate a sick child in such detail without interfering with treatment. However, it would

be worthwhile performing these investigations in those cases where the presence or absence of potassium depletion is of clinical importance, if these methods were likely to be accurate. The effect of potassium depletion on body composition makesthis unlikely. The finding of Wilson and Simmons summarized on page 11 will be used as an example. They show that the ECFV could be reduced, normal or increased in potassium depletion depending on the associated electrolyte and acid-base disturbances. If the ECFV is used as a predictor, it would underestimate the normal TBK if there was associated chloride deficiency and over-estimate the normal TBK if there was an increased total body chloride. Reba et al[201] investigated the relationship between TBK in mEq and total body water, ECFV, total body chloride and urinary creatinine excretion in children between 5 and 16 years of age. They investigated 18 normal males, 16 normal females and 12 male and 10 female children with cardiac disease. Some of their findings are summarised in Table 4. The differences between the four groups could be due to changes in the potassium content of the tissue or to changes in the predictor, or to other changes in body composition.

Table 4 A prediction of TBK in mEq (from Reba et al)

Predictor	Correlation Coefficient
TBW	
Normal male	0.974
Normal female	0.966
Male cardiac	0.926
Female cardiac	0.887
ECFV	
Normal male	0.964
Normal female	0.966
Male cardiac	0.874
Female cardiac	0.836
Total body chloride mEq	
Normal male	0.950
Normal female	0.953
Male cardiac	0.873
Female cardiac	0.913
Creatinine excretion mEq	
Normal male	0.978
Normal female	0.961
Male cardiac	0.935
Female cardiac	0.783

Analysis of biopsy specimens has been used in the assessment of potassium depletion although there are many disadvantages[87,242]. Four are of particular importance.

1. It takes several days for analysis to be completed
2. The collection of specimens involves surgical procedures
3. In the presence of a potassium-losing state, tissues lose potassium at different rates.
4. Potassium depletion may alter the composition of the tissues by interfering with protein and glycogen synthesis. (This will be discussed further in Chapter 3).

Because of all these difficulties it was decided that the initial attempts to predict TBK should be based on anthropological measurements rather than laboratory investigation.

CLINICAL MATERIAL

The ideal method for predicting TBK is one that would be applicable to underweight and normal weight children. For this reason the samples selected included some children who were severely malnourished and some who were well-nourished. None of the children had any known abnormality which may have resulted in potassium depletion. The children who will be referred to as the control cases fell into three groups:

(i) 30 normal children aged 1½ to 12 months attending a Child Welfare Clinic. They were all regular attenders and had shown a consistent gain in weight from birth. Children who fell below the 3rd percentile were premature infants who had shown "catch-up" growth. The mothers gave no history of any illness. (Physiological, neonatal jaundice was not considered an illness if no treatment had been required and there were no neurological sequelae). The children in this group are cases numbers 1-30 in Table C-1 of Appendix C.

(ii) 16 children aged 1½ to 12 months who had been admitted to the general ward with a variety of acute illnesses. These children are cases numbers 31-46 in Table C-1 of Appendix C.

(iii) 41 children aged 5 to 27 months who had been admitted to the metabolic unit with kwashiorkor. These children are cases numbers 47-87 in Table C-1 of Appendix C and will be termed recovered PCM to distinguish them from children who have not reached this stage.

For at least 2 weeks the children in groups 2 and 3 had shown no radiological, bacteriological or clinical abnormality apart from being underweight for age. The serum albumin had been greater than 3 g/100ml for the same period. Detailed results of the 87 children are given in Table C-1 of Appendix C. Figures 1 and 2 show the weights and heights of the children plotted on percentile charts[139]. In Fig.3 height has been plotted against weight and the lines show 80%, 100% and 120% of expected weight for height[139].

Prediction of TBK from weight and height

TBK is normally expressed in mEq, i.e. the absolute amount or in mEq/kg body weight, i.e. per unit weight. The TBK in mEq is of little use on its own as it largely depends on the size of the child. The TBK in mEq/kg gives a far better indication but as mentioned previously, the range is so wide that in many children it is not possible to detect low TBK values by this means, eg. a child who normally has a TBK of 54 mEq/kg can lose 33% of the potassium in its body and still be above the lowest normal value. Height is even worse as a predictor, i.e. TBK mEq/cm (Table 5).

Table 5 TBK values of control cases

	TBK	
	mEq/kg	mEq/cm
Mean	44.75	4.35
S.D.	4.79	0.88
S.E.M.	0.51	0.09
95% tolerance limits		
lower limit	35.18	2.59
As % of mean	78.61	59.54
upper limit	54.32	6.11
As % of mean	121.39	140.46

Fig.1. The weights of the control cases are plotted on a Boston percentile chart.

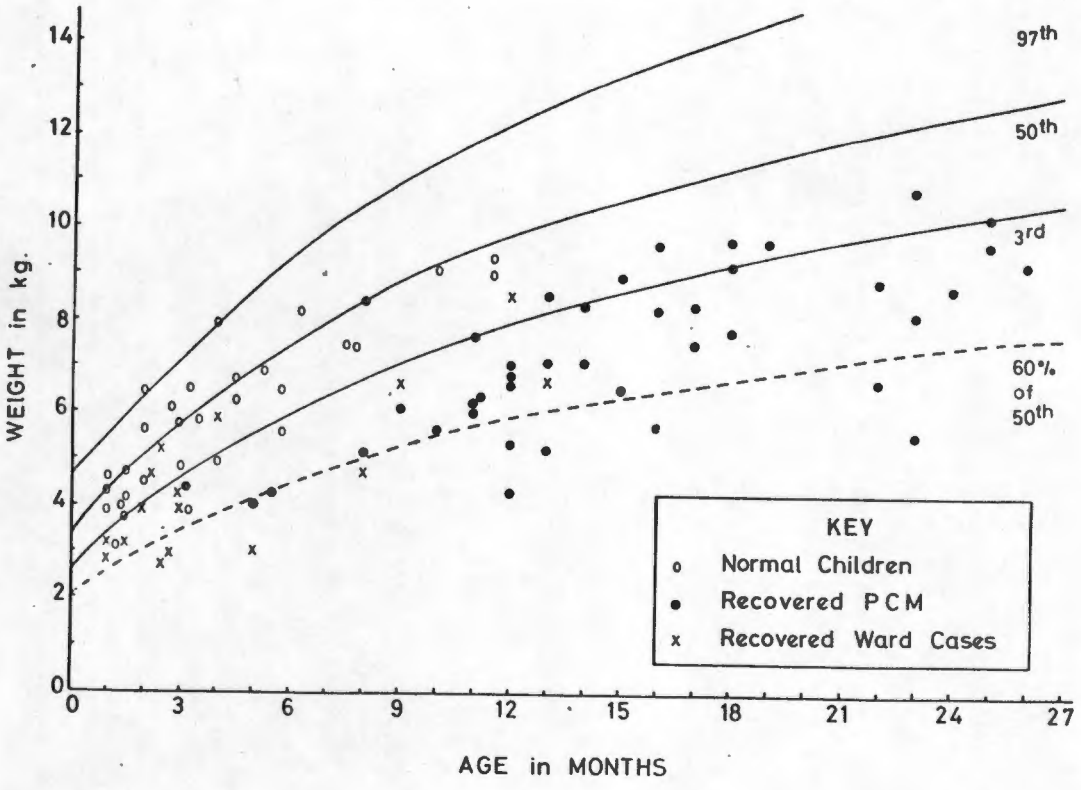


Fig.2. The heights of the control cases are plotted on a Boston percentile chart.

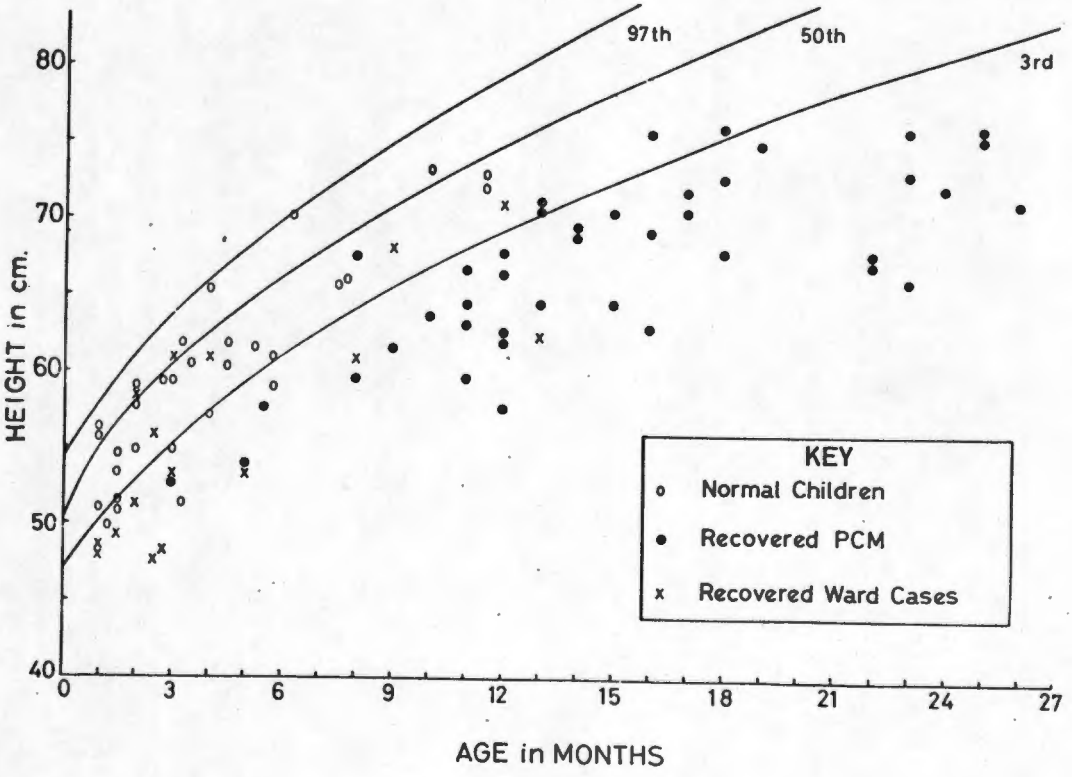
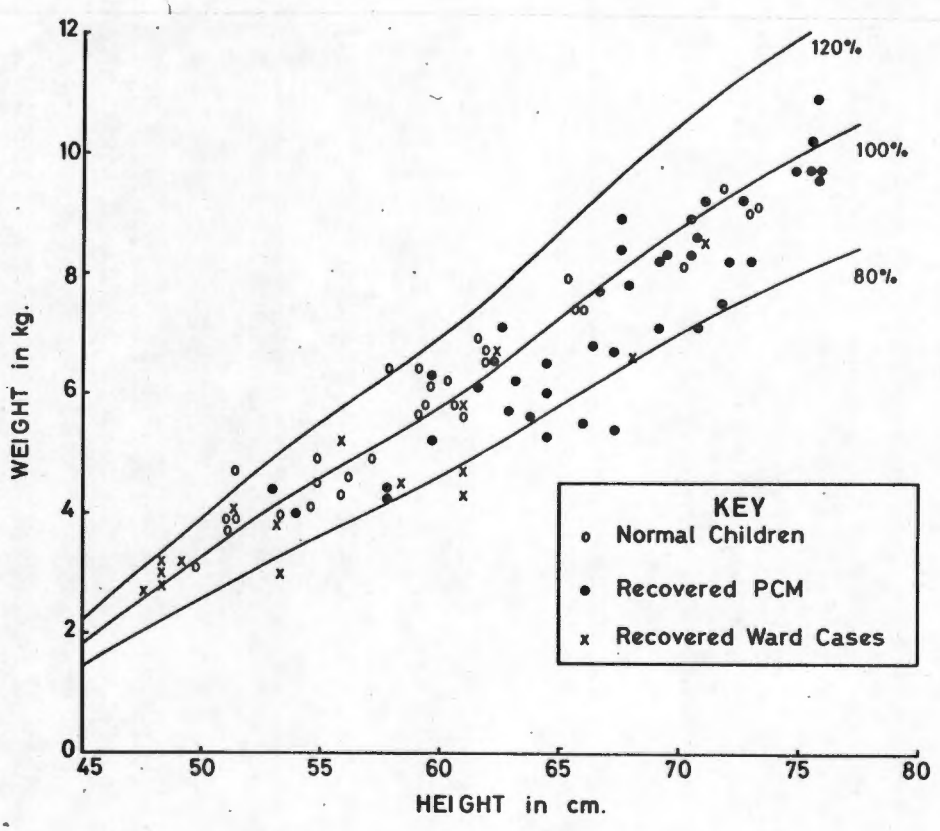


Fig.3.

Control cases; weight plotted against height.



Various functions of weight/height (W/H) have been used as ponderal indices or for correcting for selfabsorption in TBK determinations[49,131]. Donath et al reported a good correlation between TBK and W/H^3 in children aged 5 to 7 years[64]. (The values obtained in this study for TBK (mEq/kg) against W/H, W/H^2 and W/H^3 are shown in Figs. 4, 5, and 6). Several other functions of W/H were investigated as possible predictors of TBK in mEq and mEq/kg. The results are summarised in Table 6.

Fig.4. Control cases; TBK in mEq/kg against W/H.

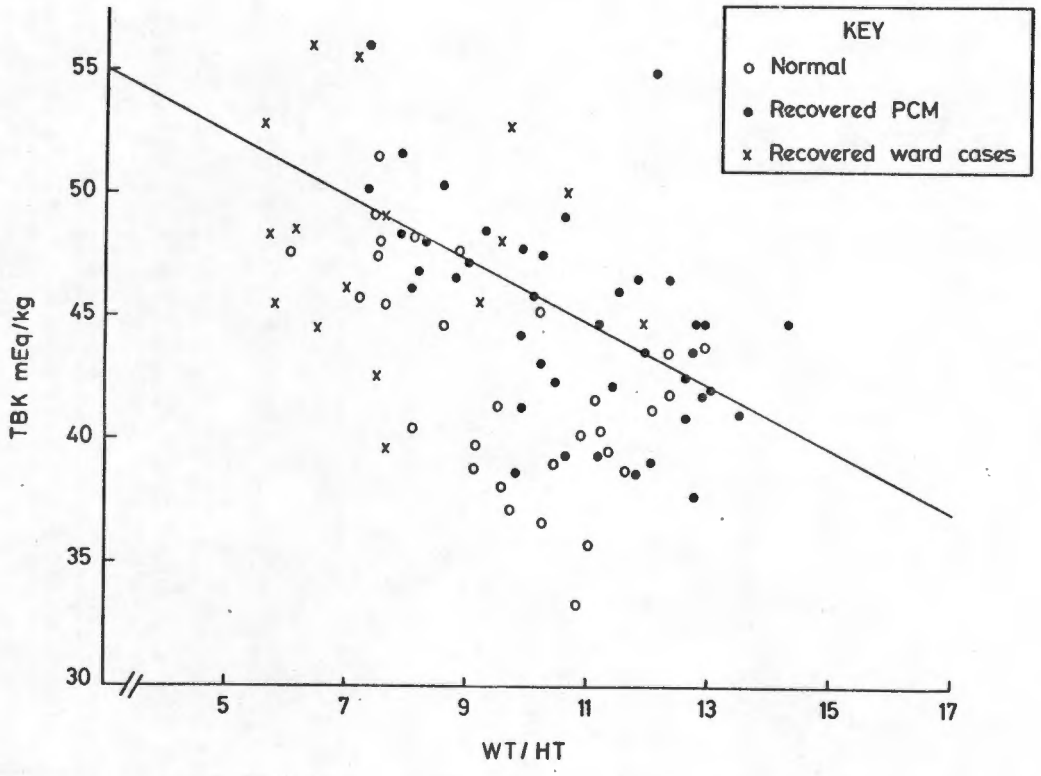


Fig.5. Control cases; TBK in mEq/kg against W/H^2

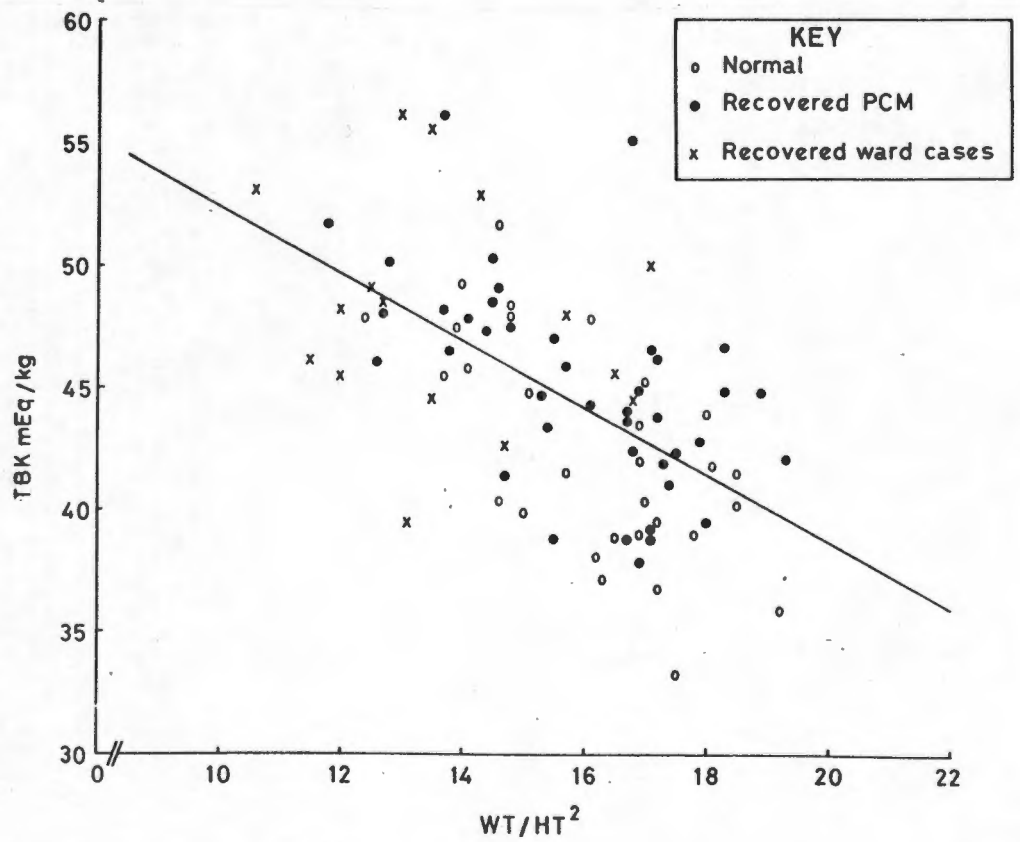


Fig.6. Control cases; TBK in mEq/kg against W/H^3

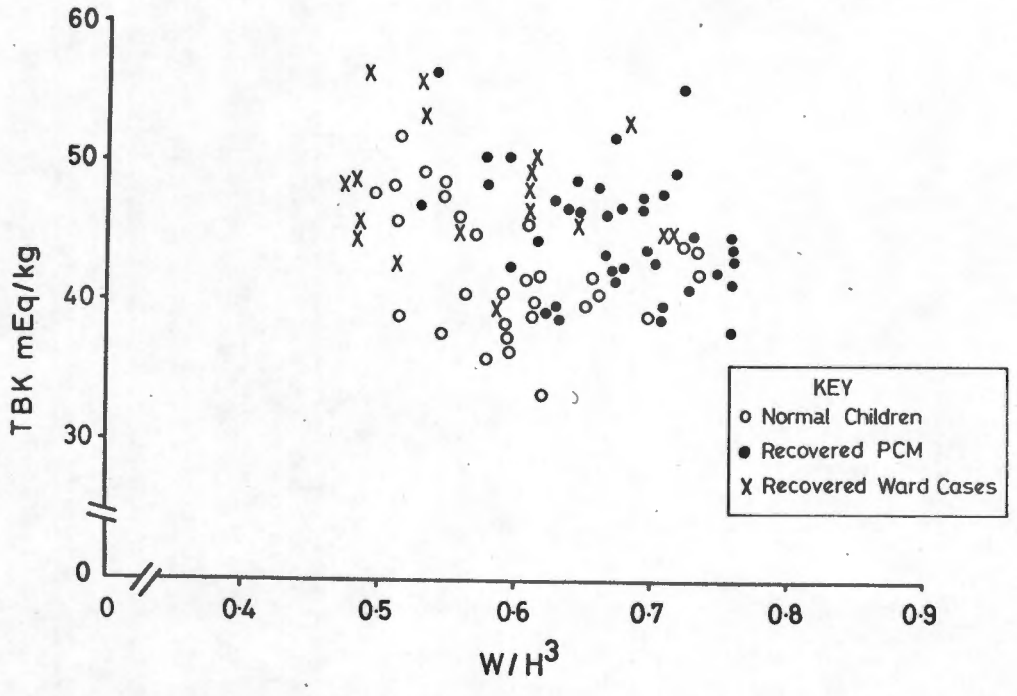


Table 6 Prediction of TBK from $f(W/H)$

$f(W/H)$	mEq r	mEq F_{reg}	mEq/kg r	mEq/kg F_{reg}
W	.942	667.30	-.392	15.43
W^2	.934	582.04	-.349	11.78
W^3	.909	404.30	-.306	8.75
$W^{1/2}$	.936	605.07	-.411	17.24
$W^{1/4}$	.931	552.79	-.419	18.08
$W^{3/2}$	.941	653.67	-.371	13.56
$W^{3/4}$	.940	644.93	-.402	16.35
H	.927	515.39	-.259	6.10
H^2	.930	545.01	-.247	5.52
H^3	.930	544.40	-.235	4.97
$H^{1/2}$	.923	491.09	-.265	6.40
$H^{1/4}$	.921	477.19	-.267	6.54
$H^{3/2}$	.929	433.76	-.253	5.81
$H^{3/4}$	.925	503.89	-.262	6.25
W/H	.896	346.76	-.474	24.60
W^2/H	.928	529.58	.393	15.51
W^3/H	.915	435.17	-.337	10.87
W/H^2	.626	54.67	-.578	42.67
W/H^3	-.273	6.87	-.337	10.89
$(W/H)^{1/2}$	.889	322.07	-.484	25.96
$(W/H)^{1/4}$	.885	307.54	-.488	26.55
$(W/H)^2$	.902	370.74	-.486	21.42
$(W/H)^3$	.899	357.50	-.419	18.07
W^3/H^2	.913	426.13	-.374	13.83
W^2/H^3	.826	183.09	-.517	30.96

The best predictor of TBK in mEqs was weight ($r = 0.942$, $F_{1,85} = 667.30$), and of TBK mEq/kg W/H^2 ($r = -0.578$, $F_{1,85} = 42.67$). The 95% tolerance limits for these predictions at the mean value of the respective f (W/H) are given in Table 7.

Table 7 Prediction of TBK in mEq from W and in mEq/kg from W/H^2

95% tolerance limit	TBK mEq,W.	TBK mEq/kg, W/H^2
Lower limit	219.66	36.88
as % of mean TBK	78.58	82.41
Upper limit	339.40	52.60
as % of mean TBK	121.42	117.54
Mean TBK	279.53	44.75

Prediction of TBK from skinfold thickness

Because these tolerance limits are too wide for these methods of prediction to be of any great practical value the use of various skinfold thicknesses was investigated. A logarithmic transformation of the individual skinfold thicknesses gave a better prediction of TBK in mEq/kg than any of the f (W/H) and it was further improved by taking the mean of the three skinfold thicknesses. The log transformation used is the one given by Edwards et al[73], i.e.

$$100 \log_{10} (10S - 18)$$

Where S is the skinfold (or mean skinfold) thickness

The results are summarised in Table 8.

Table 8 Prediction of TBK in mEq/kg from skinfold thickness

Skinfold thickness	Correlation coefficient	F_{reg}
Midtriceps	-0.889	320.86
Subscapular	-0.898	353.98
Paraumbilical	-0.777	129.70
Mean	-0.944	694.20

The logarithmic transformation of skinfold thicknesses was necessary as the relationship between TBK in mEq/kg and skinfold thickness was not linear (Figs. 7 and 8).

Further examination of the results revealed, that for a given mean skinfold thickness, children who were approximately 100% of expected weight for height tended to have a higher TBK than children who were markedly above or below 100% expected weight for height (Fig.9).

The prediction was not improved by multiplying or dividing the mean skinfold thickness by the percentage expected weight for height before or after log transformation. Addition and subtraction also failed to improve prediction. However, it was improved by multiplying the mean skinfold thickness before log transformation by

$$1 + \left|\frac{100 - P}{100}\right|$$

where P is percentage expected weight for height, i.e. the predictor becomes

$$100 \log_{10} \left[10S \left(1 + \left|\frac{100 - P}{100}\right|\right) - 18\right]$$

This is termed correction A in Table 9.

Fig.7. Control cases; TBK in mEq/kg against mean skinfold thickness.

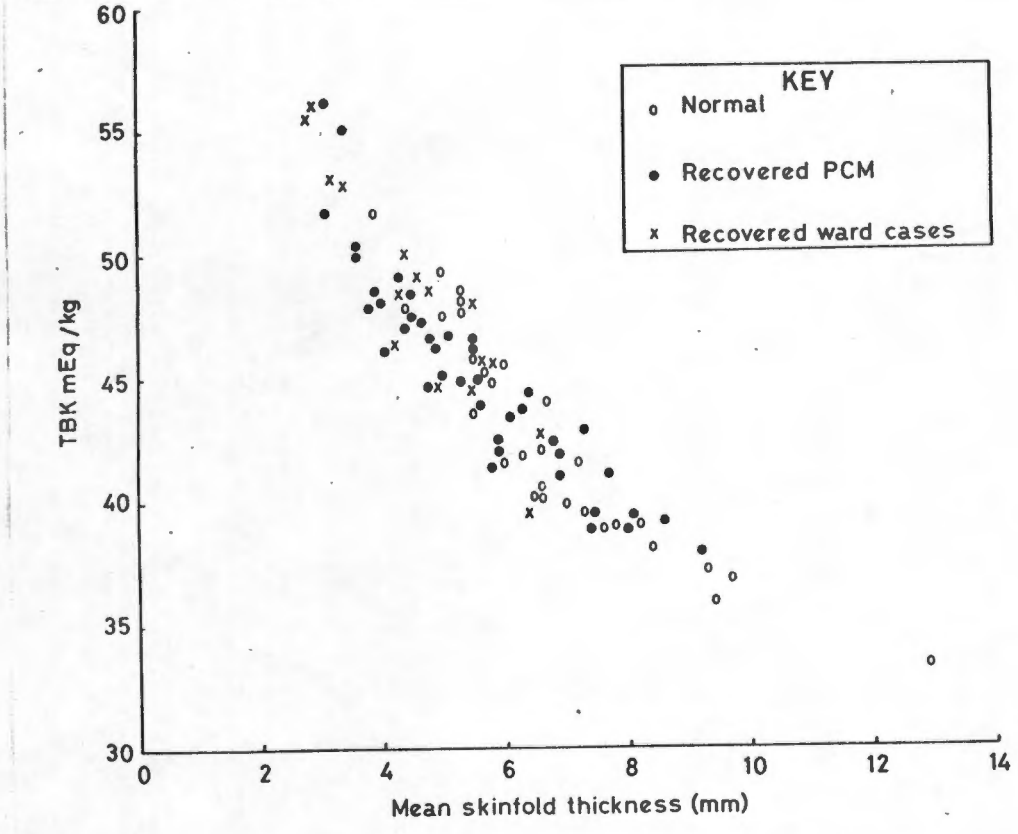


Fig.8. Control cases; TBK in mEq/kg against a log transformation of the mean skinfold thickness

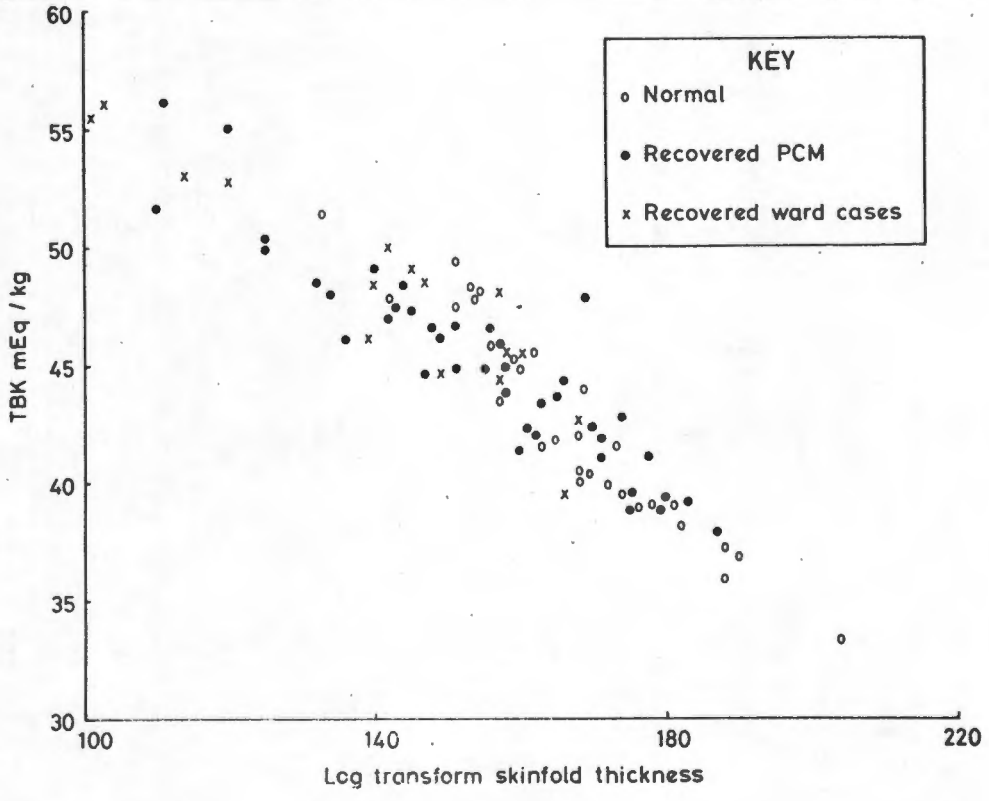
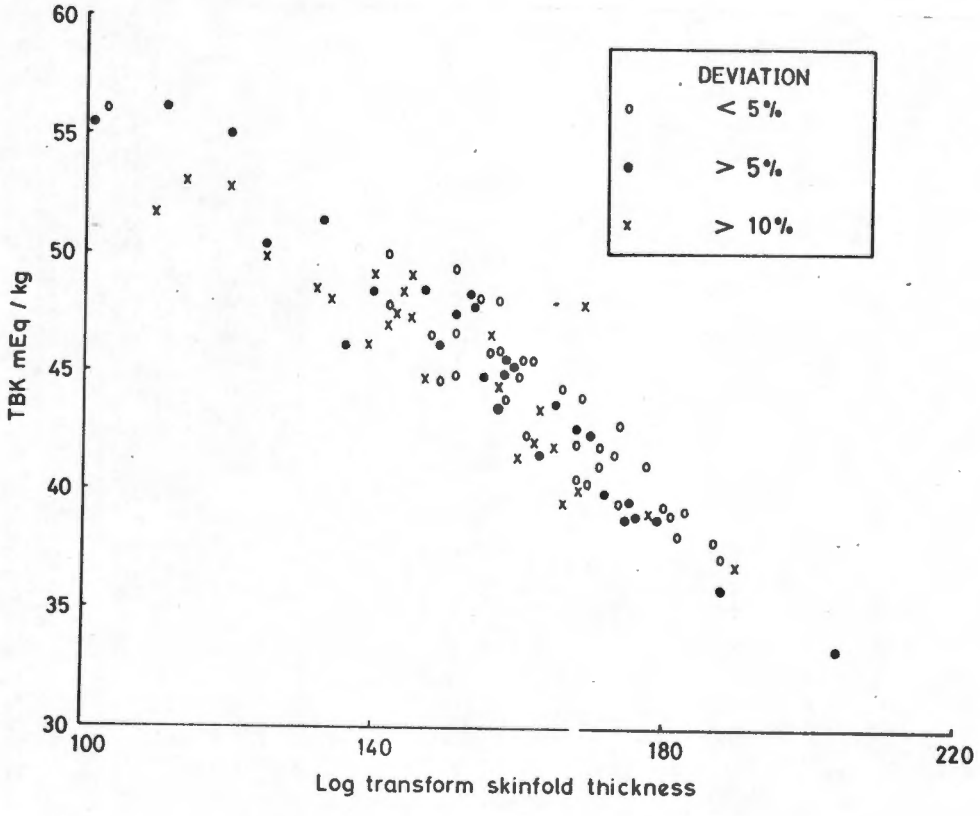


Fig.9. Control cases: TBK in mEq/kg against a log transformation of the mean skinfold thickness showing the effect of deviations from 100% expected weight for height.



The prediction was further improved by altering the constants, the best prediction being given by

$$100 \log_{10} \left[10S \left(1.51 + \left|\frac{100 - P}{100}\right|\right) - 16.5 \right]$$

This correction is termed correction B in Table 9, where the prediction of TBK in mEq/kg from log transformation of mean skinfold thickness, correction A and correction B are compared.

Table 9 Prediction of TBK mEq/kg from a log transformation of a function of skinfold thickness (Mean TBK 44.75 mEq/kg)

f (Skinfold thickness)	95% tolerance limits at mean of f (S)				Correlation coefficient
	mEq/kg		as % of mean TBK		
	lower limit	upper limit	lower limit	upper limit	
Mean skinfold	41.57	47.93	92.89	107.11	-0.944
Correction "A"	41.90	47.60	93.63	106.37	-0.955
Correction "B"	41.99	47.52	93.82	106.18	-0.958

Correction B was the best predictor of TBK in mEq/kg and will be termed the log transformation of the corrected skinfold thickness (LCS).

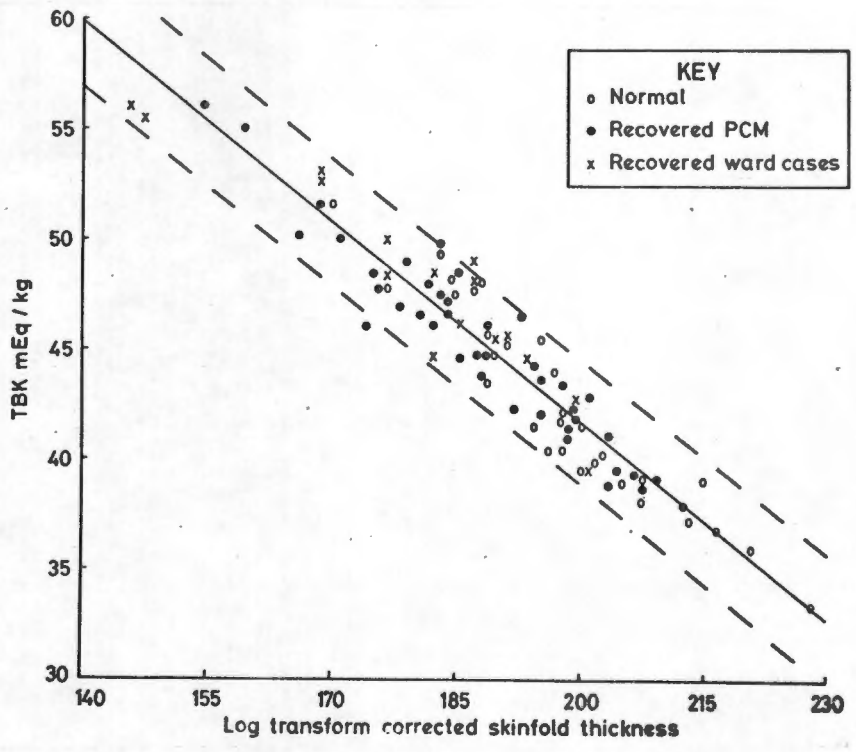
The individual values obtained, the regression line and the 95% tolerance limits for the log transformation of corrected skinfold thickness are shown in Fig.10. The equation for the regression line is

$$\text{TBK mEq/kg} = 98.68 - 0.2912 \text{ LCS}$$

The correlation coefficient was -0.958 and $F_{1,85} = 954.74$.

The predicted TBK calculated from the equation for the regression line can be compared with the observed TBK in two ways. Firstly, the difference between the predicted and

Fig.10. Control cases: TBK in mEq/kg against a log transformation of the corrected skinfold thickness showing the regression line and 95% tolerance limits.



observed TBK gives the deviation in mEq/kg. This method of expressing the results has two main disadvantages:

(a) the "normal range" (width of the tolerance limits) has to be given for each predicted value.

(b) an absolute deviation without reference to the predicted content does not give a completely true picture of the severity of the deviation. For example, a difference of 10 mEq/kg is more important in a child who has a predicted value of 30 mEq/kg than in a child who has a predicted value of 50 mEq/kg.

The second method of comparison is to express the observed TBK as a percentage of the predicted TBK. The advantages of this method are that it gives an indication of the severity of the deviation and the 95% tolerance limits remain the same. The main disadvantage is that it gives no indication of the absolute deviation.

In the control series the normal range is $100 \pm 6.0\%$ when the observed TBK is expressed as a percentage of predicted TBK and the 95% tolerance limits calculated (Fig.11).

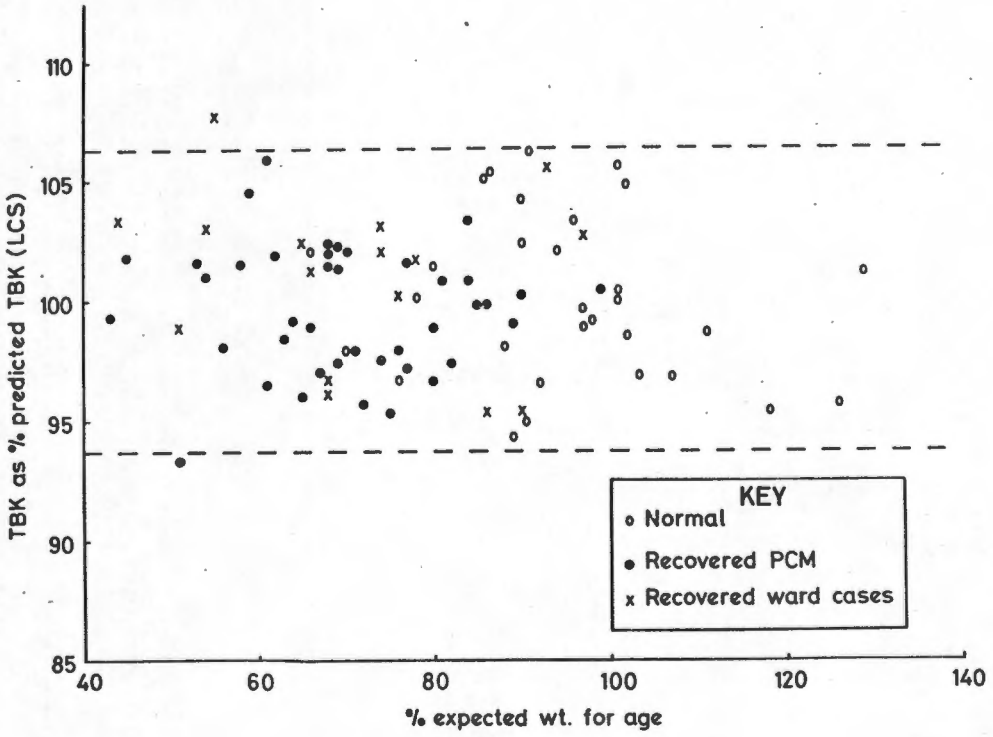
Multivariate prediction of TBK

It is not possible to measure skinfold thickness accurately in oedematous children. For this reason the method of prediction presented is not of any value in children suffering from kwashiorkor and an alternative method had to be found. In an attempt to improve the prediction of TBK in mEq or mEq/kg from *f* (W/H) the use of various combinations was investigated. The *f* (W/H) were those shown in Table 6. The results are shown in Table C-10 of Appendix C. The equation used is

$$y = a + bx1 + cx2$$

where y is the TBK in mEq or mEq/kg and x_1 and x_2 are different *f* (W/H).

Fig.11 Control cases: TBK as a percentage of the value predicted from the corrected skinfold thickness against percentage expected weight for age.



The best prediction of TBK in mEq was given by a combination of $H^{3/4}$ and W^3/H^2 ($R = 0.951$ and $F\ 2,84 = 401.60$; where R is the square root of multiple correlation coefficient). The best prediction of TBK in mEq/kg was a combination of W^2/H^3 and $(W/H)^3$. ($R = 0.602$, $F\ 2,84 = 23.90$).

The predicted values were calculated from the various $f\ (W/H)$ which singly or in combination were the best predictors of TBK in mEq and mEq/kg, from tables 6 and C-10.

The best predictor was a function of W^2/H^3 and $(W/H)^3$. The equation for the regression plane was

$$TBK\ (mEq/kg) = 59.747 - 156659.590\ W^2/H^3 + 885.786\ (W/H)^3$$

However, the 95% tolerance limits, $100.00 \pm 17.11\%$ are too wide for this method to be of use in oedematous children, i.e. those suffering from kwashiorkor. For this reason the observed values will be used in comparing these cases with other children. In discussing the results of children suffering from pneumonia and gastroenteritis both the observed and predicted values will be used.

Four variable predictions of TBK in mEq and mEq/kg from functions of weight, height and skinfold thickness did not result in narrower tolerance limits.

DISCUSSION

The poor prediction of TBK in mEq by the various $f\ (H)$ is disappointing as height would have been an ideal predictor particularly during the early stages of recovery from PCM when rapid changes in body composition occur.

Alleyne found that TBK (in mEq) was more closely correlated with height than with the cube of height ($r = 0.8383$ and 0.7827) in children recovering from PCM[8]. In this study

it was found that the square of height and the cube of height both correlated significantly better with TBK than did height ($r = 0.930$, 0.930 and 0.927) in the control series. The reason is not clear but it was not due to the inclusion of normal children. For the recovered cases of PCM the correlation coefficient for TBK in mEq against height was 0.862, against the square of height 0.866, and against the cube of height 0.868. The correlation between TBK in mEq and weight ($r = 0.942$) was higher in this series than in Alleyne's ($r = 0.901$). The differences are probably due to variations in the stage of recovery.

The negative correlation between TBK in mEq/kg and percentage expected weight for height reported by Alleyne[8] ($r = 0.35$, $p < 0.05$) was confirmed ($r = 0.391$, $p < 0.01$). This is almost certainly due, at least in part, to the less underweight children having a higher total body fat.

The good correlation between TBK in mEq/kg and the log transformation of mean skinfold thickness was not surprising although it was better than expected. Potassium has been used as an estimator of fat content in man and Forbes et al[84] reported a correlation coefficient of 0.80 for fat content against average skinfold thickness in millimetres. The skinfold thicknesses measured were midbiceps, midtriceps, abdominal, subcostal, subscapular and iliac crest. The fat content was calculated as the difference between total weight and lean body weight (LBW) on the basis that the latter has a potassium content of 68.1 mEq/kg.

$$\frac{\text{LBW (kg)} = \text{TBK mEq}}{68.1}$$

The correlation coefficient for TBK against a log transformation of mean skinfold thickness was 0.93 in the present series. The difference between the correlation coefficients

may be due to log transformation, to the relatively narrow range in skinfold thickness in our series, or to small variations in the potassium content of the LBW resulting in inaccuracies in the fat content calculated by Forbes et al[84].

The improvement in the correlation after "correction" for deviations in percentage expected weight for height from 100% can be explained in several ways. The factor may correct for a reduction in muscle bulk and/or an abnormality in muscle composition in children who are below 100% expected weight for height. In the children who have a high percentage expected weight for height there may be an underestimate of body fat by the skinfold thicknesses measured. For example, there may be a disproportionate increase in intra-abdominal and/or thigh fat.

Another possible explanation is that the factor corrects for geometrical losses. For example, selfabsorption losses are related to the thicknesses of the tissue between the "source" and the detector. The fact that functions of weight, height and skinfold thickness did not correlate better with counting efficiency than weight alone does not exclude this possibility. (Appendix A).

The improvement in the correlation brought about by altering the constant may be due to differences between young children and older subjects, eg. the constant 16.5 may bear a closer relationship to the thickness of skin in young children than the constant 18. Theoretically, the intercept should be the potassium concentration in mEq/kg of the FFBW. However, the value obtained is far higher than any of the values given in the literature for the potassium content of the FFBW. It is probable that the relationship between TBK and the log transformation is not linear at more extreme values of skinfold thickness.

Burkinshaw et al[42], studying adults, predicted TBK from weight and height. They found the prediction was improved when measures of fat were included in the regression. The form of the best predictor found in this study differs from that of Burkinshaw et al; their equation is of the multivariate type.

TBK in mEq = a + b (H) + c (W) + d (fat measure)

As stated earlier, no equation of this form was comparable as a predictor to the log transformation of the corrected skinfold thickness.

Kennedy's failure to relate exchangeable potassium levels to creatine, creatinine or skinfold measures is probably due to the wide age range in his series, 3 months to 16 years[147]. Donath has found it necessary to calculate different constants for the predictor he uses, W/H^3, for each 2 year period in the range 5 to 15 years. In the older children the sexes were separated[65].

The results obtained in this study for TBK in mEq/kg are very similar to those reported from other centres (Table 10).

Table 10 Comparison of mean TBK in mEq/kg from Mayo Clinic, Jamaica, Los Alamos and Cape Town

Centre	Children studied	Number of cases	Mean TBK mEq/kg	S.D.
Mayo Clinic[183]	Normal male (1 month)	31	46.0	5.75
	Normal female (1 month)	33	47.1	5.51
Jamaica[8]	Sexes combined			
	Recovering PCM 31-40 days after admission	23	46.5	4.2
	60+ days after admission	11	44.6	3.1
Los Alamos[17]	Normal infants Sexes combined (approx. 1 year)	-	43*	-
Cape Town	Control series	87	44.75	4.79
	Normal infants (6 weeks to 1 year)	30	42.49	4.51
	Recovered PCM	41	45.08	4.25

(* read off graph)

Novak et al[183] at the Mayo Clinic, studied normal children aged 1 month. The sex difference in the mean is not significant. The normal infants in the present study were older and the slightly lower values may be due to the higher total body fat. There was no significant correlation ($p>0.1$) between TBK and age, in the control series ($r = -0.037$) or in the group of normal children ($r = 0.180$). It is possible that there is not a linear increase in potassium concentration per kg body weight between 1.5 and 12 months contrary to Garrow's suggestion[96]. This would not necessarily exclude an increase in the potassium concentration of the FFBW, as this may be masked by other changes in body composition, for example an increase in body fat. The

lack of correlation between TBK and age is fortunate as many children in the age group under study are malnourished and have the body composition of far younger children[38]. It would be impossible to assess the "body composition age" of such children accurately. In fact, the difference between the correlation coefficient of the recovered PCM cases and of the normal children is almost significant, suggesting that the lack of significance between TBK and age in the normal children may only be due to small numbers although the effect of age would be minimal.

There was no sex difference in the control series ($F_{1,85} = 0.496$, $p<0.05$) or in the normal group ($F_{1,28} = 0.149$ $p>0.05$). Anderson and Langham[17] of Los Alamos found that the sex difference only appeared at puberty. However, Reba et al found a sex difference at the age of 5 years[201]. They did not investigate younger children.

The presence of 12 children who had no oedema or who were predominantly marasmic in Alleyne's series in Jamaica, probably accounts for the slightly higher mean TBKs found when compared with the present series. There are many other reports from Jamaica on TBK in PCM[13,14,95,96,180,182]. The values reported are almost identical to those in Alleyne's series.

SUMMARY

Changes in body composition, particularly in the proportion of fat and ECFV have a marked effect on TBK. Theoretically TBK per unit weight should increase with age but this was not found in this series.

A log transformation of the mean of midtriceps,

subscapular and paraumbilical skinfold thicknesses correlated well with TBK in mEq/kg and the correlation was improved by a factor incorporating deviation from 100% expected weight for height.

The regression line for TBK against the log transformation of corrected skinfold thicknesses will be used to predict the "normal" TBK of an individual child and so provide a reference point. In oedematous children it is not possible to measure skinfold thickness accurately and the normal TBK cannot be predicted with sufficient accuracy from a function of weight and height. The sexes will not be separated as no sex difference was found in this series.

Chapter 3 TOTAL BODY POTASSIUM IN PROTEIN-CALORIE MALNUTRITION, ACUTE GASTROENTERITIS AND ACUTE PULMONARY INFECTIONS

The relationship between malnutrition and infection is well-established with gastroenteritis and pulmonary infections being particularly common. Gastroenteritis is known to result in excessive potassium losses, but the role of pneumonia has not been defined. In this chapter the total body potassium results of children suffering from these illnesses will be compared and an assessment made of the effect of potassium supplementation on total body potassium in PCM and gastroenteritis.

CLINICAL MATERIAL

1. PCM

49 children in the metabolic unit had more than 3 TBK determinations during the first 13 days after admission. They all had the stigma of PCM and all were oedematous. None of them had severe diarrhoea or clinical or radiological evidence of a pulmonary infection at the time of admission. Children who became ill during the course of the trial were removed and any results during the previous 7 days excluded. Children who dropped out of the trial did not re-enter it at a later stage. All the children received prophylactic antibiotics, antihelmintics, anti-protozoals and iron and vitamin supplements. They were given 120 ml/kg of ½ strength Darrow's solution with 2.5% dextrose (½ DD) orally until the morning after admission. For the next 4 days they received the same volume of a liquid lactose-free diet supplying 0.5g protein/kg/day and 3 mEq potassium/kg/day. The protein content was then increased to 1g/kg/day for a further 4 days, the potassium content remaining the same. Thereafter solid foods were introduced, the potassium intake depending on

the quantity of solids eaten. Some of the children were also given a potassium supplement of 6 mEq/kg/day commencing immediately after the first TBK determination. Detailed results are given in Table C-2 of Appendix C. Cases 1 to 26 received the potassium supplement.

Figure 12 shows the weight of the children plotted on the standard percentile chart[139] and Fig.13 the weight plotted against height.

2. Gastroenteritis

49 children who had acute gastroenteritis and no evidence of pulmonary infection and who had been referred to the drip room for intravenous rehydration were investigated. They had been ill for less than 48 hours and had had no illnesses for the month prior to admission. In all cases the first TBK measurement was made immediately after admission and second the next day (with the exception of the children who died. They were only counted on the day of admission).

20 children were transferred to the metabolic unit immediately after the first TBK determination. They were rehydrated intravenously with ½ DD with added sodium bicarbonate to fully correct the base deficit. When rehydration was complete, 150 ml/kg/day of the same solution was given orally until the morning of the third day. The children were then fed in the same way as the children suffering from PCM, the only difference being that they received the 0.5 gram protein diet for 3 instead of 4 days. (This brought the two groups into the same time scale as regards feeding).

A stool specimen was sent for bacteriological examination on each of the first 3 days after admission. Antibiotics were only given when the pathogen was isolated. All the

Fig.12 Weights of PCM cases plotted on a Boston percentile chart.

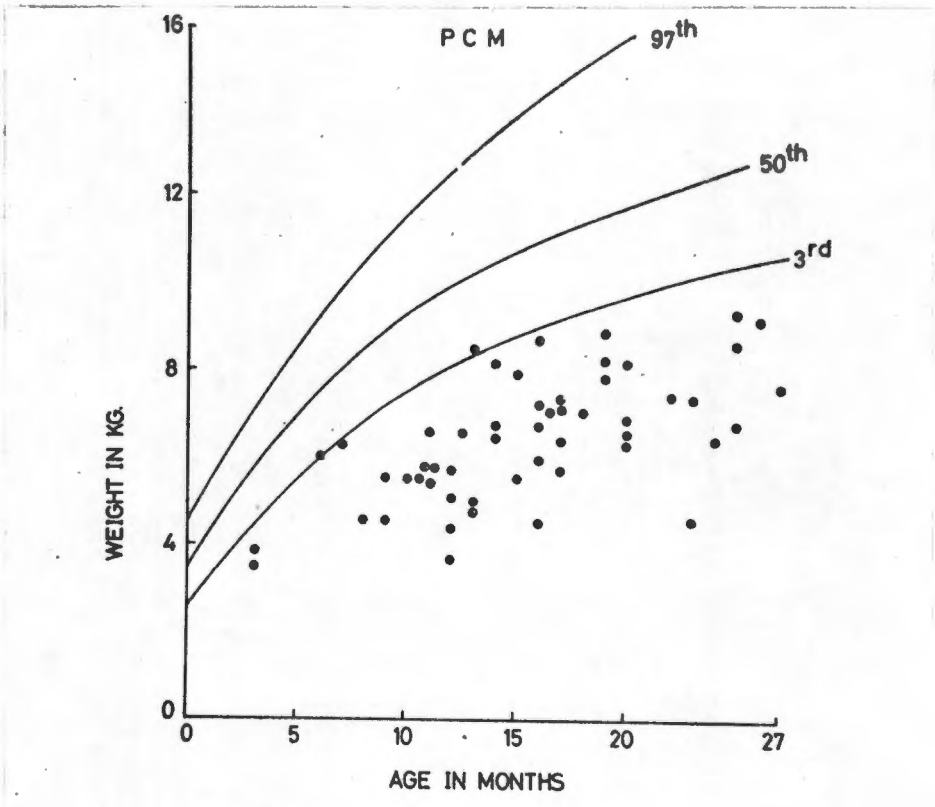
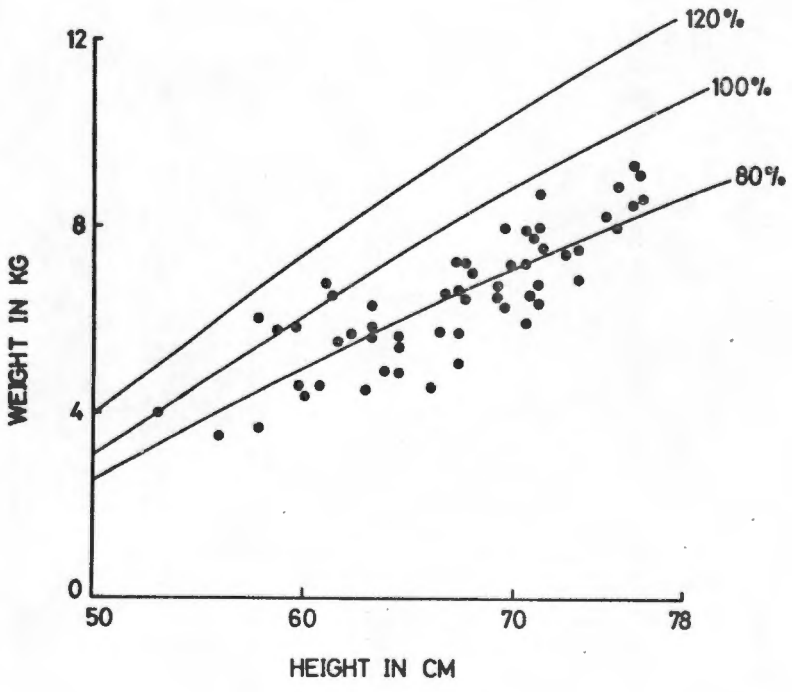


Fig.13 Weights of PCM cases plotted against height.



children received iron and vitamin supplements. Six of them received potassium supplement with 6 mEq/kg/day commencing immediately after the second TBK determination. The children who remained in the drip room were rehydrated with ½ DD. They did not receive potassium supplements. Detailed results are given in Table C-3 of Appendix C. Cases 1 to 29 were treated in the drip room. Of the metabolic unit cases, cases 30 - 39 received potassium supplements and cases 40 - 49 did not. Fig.14 shows the weights of the children plotted on a percentile chart[139] and Fig.15 the weight against height.

3. Pulmonary infection

Initially 42 children in the emergency ward with acute pulmonary infections were investigated. The children were all very ill requiring oxygen. Other treatment consisted of humidity, antibiotics, bronchodilators and if necessary, intravenous fluids. The children suffered from bronchiolitis, or bronchopneumonia with or without bronchospasm. They had been ill for less than 48 hours and had been well for the previous month. Investigations were performed as soon as the children were able to remain out of oxygen without distress for the time required and always within 18 hours of admission. Later, three children were transferred from the emergency ward to the metabolic unit for more detailed study. Treatment was the same. The children were fed in the same way as those suffering from gastroenteritis although one did not require intravenous fluids. They did not receive potassium supplements. The thiosulphate space was measured within 12 hours of admission to hospital and again 3 - 4 weeks later. Detailed results are given in Table C-4 of Appendix C. Cases 43 - 45 were in the metabolic unit.

Figures 16 and 17 show the values for weight against

Fig.14. Weights of gastroenteritis cases plotted on Boston percentile charts.

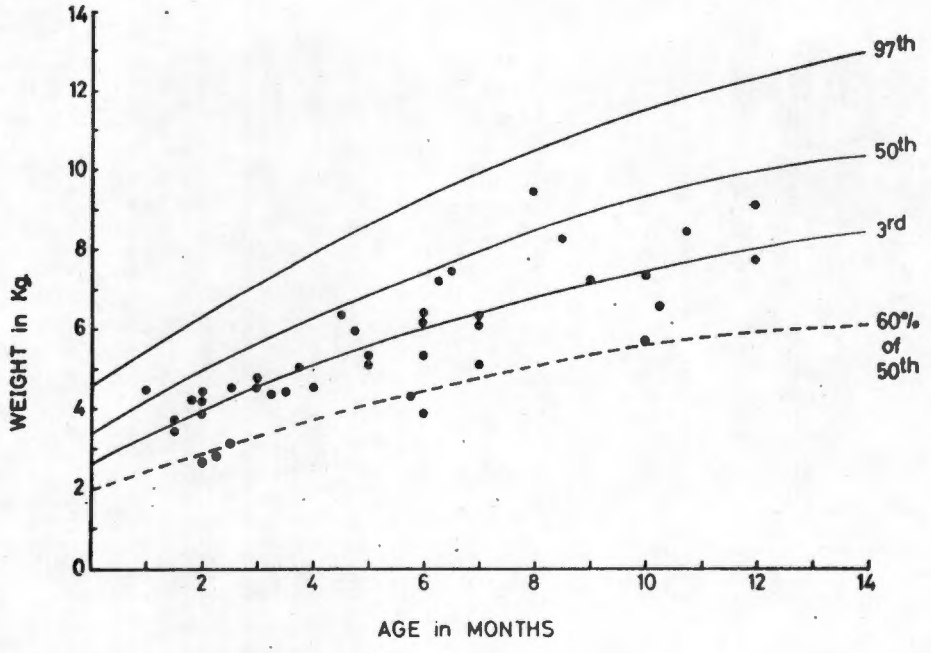


Fig.15. Weights of gastroenteritis cases plotted against height.

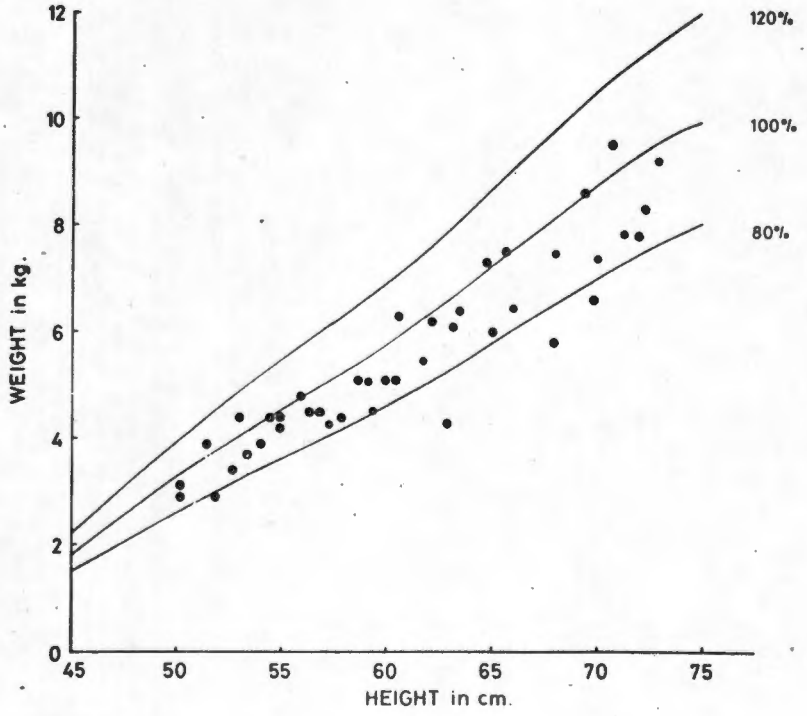


Fig.16. Weights of pulmonary infection cases plotted on a Boston percentile chart.

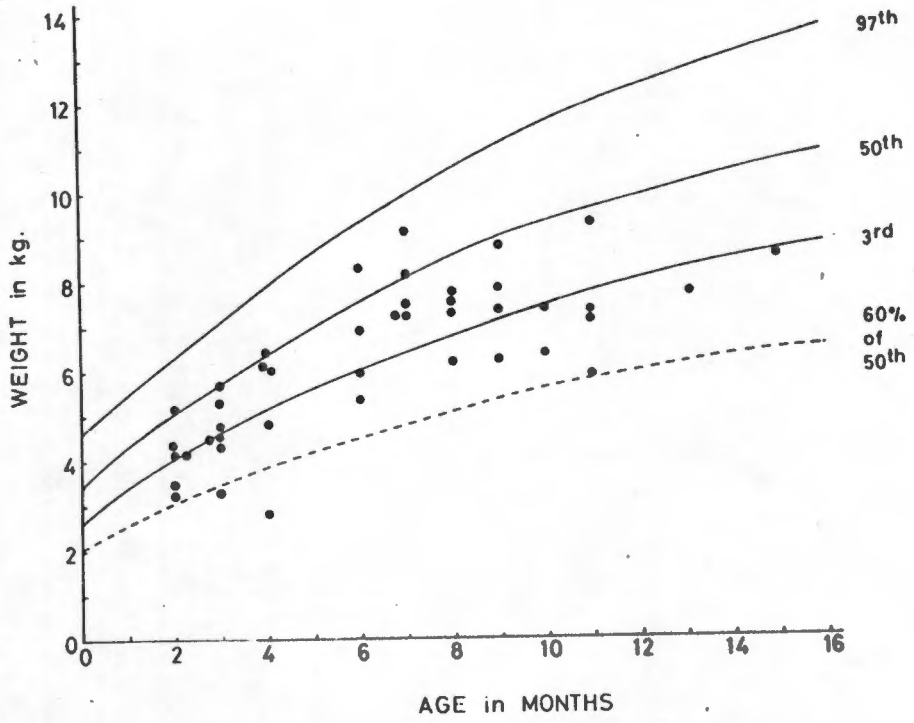
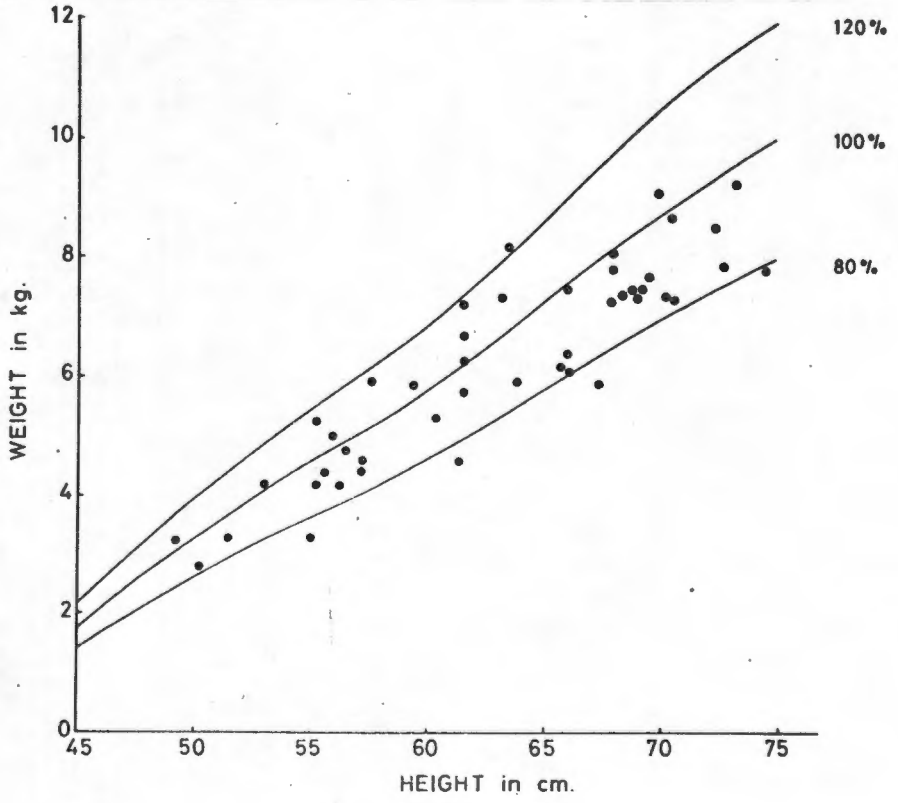


Fig.17. Weight of pulmonary infection cases plotted against height.



age and weight against height[139].

Comparison of the TBK in mEq/kg of the control, PCM, gastroenteritis and pulmonary infection cases on admission

The normal children and the recovered cases of PCM in the control series differed ($p < 0.05$). However, the control children will be treated as a single group as the percentage expected weight for age range is similar to the range in the groups investigated. Further, there is no reason to suspect that any of the children were potassium depleted, and the findings presented in the previous chapter suggest the differences are due to variationsin body fat.

There was a marked difference between the TBKs of the PCM cases and those of the control series, of the gastroenteritis cases (day 1) and of the children with acute pulmonary infections ($p < 0.005$). The last two groups also differed from the control series ($p < 0.005$) but not from each other ($p > 0.1$). If the day 2 results of the gastroenteritis cases were taken as being a truer reflection of their TBK, there was a significant difference between the gastroenteritis and pulmonary infection cases ($p < 0.005$), although the day 1 and day 2 gastroenteritis results did not differ ($p > 0.1$). The differences between the gastroenteritis results and those of the control series and of the PCM cases remained the same ($p < 0.005$). There was no difference between the TBKs of the cases with bronchiolitis and bronchopneumonia with bronchospasm and without bronchospasm ($p > 0.1$).

The mean and S.D. of the TBK and the number of cases in each of the groups compared are given in Table 11.

Table 11 Mean and S.D. of TBK mEq/kg and number of cases (N) in groups

Group	Mean TBK mEq/kg	S.D.	N
Normal infants	42.49	4.52	30
Recovered PCM	45.05	4.25	41
Control series	44.75	4.79	87
PCM	31.76	5.24	56
Gastroenteritis (day 1)	40.95	4.87	49
Gastroenteritis (day 2)	39.50	5.18	46
Pulmonary infections	42.41	5.50	45

The effect of potassium supplementation on the TBK in mEq/kg in PCM

There was no difference between the initial TBKs of the non-supplemented group and either of the supplemented groups ($p>0.1$). There was a difference between the initial TBKs of the supplemented groups ($p<0.05$). (The mean value of the group which subsequently received the smaller supplement was lower than that of the group which received the larger supplement). For this reason the findings in this section must be compared with those on page 57 (i.e. "The effect of potassium supplementation on the increment in TBK").

On day 5 there was no difference between the results of the non-supplemented children and those who had received a supplement of 6 mEq/kg ($p>0.1$). The children receiving a supplement of 12 mEq/kg differed from the non-supplemented cases ($p<0.005$) and those receiving the smaller supplement ($p<0.025$).

On day 9 there was no difference between the two supplemented groups or between those children on the smaller supplemented and those on no supplement ($p>0.1$). The group receiving the larger supplement differed from the non-supplemented cases ($p<0.01$). There was no difference between these groups

on day 13 ($p>0.1$). (The number of children receiving the smaller supplement was too small to enable comparisons to be made at this stage).

The day 5 results of the non-supplemented children did not differ from the results of the PCM group on admission ($p>0.1$), but there was a difference between the admission values and the results of the supplemented cases ($p<0.1$ and <0.005 for the smaller and larger supplements respectively). Similarly, between day 5 and day 9 there was no difference in the non-supplemented group ($p>0.1$), but there was for the group receiving a supplement of 6 mEq/kg/day ($p<0.05$) and 12 mEq/kg/day ($p<0.05$). However there was a difference between the admission PCM results and the non-supplemented children on day 9 (<0.005).

There was no difference between the day 9 and day 13 results of the supplemented group ($p>0.1$) but there was a difference in the non-supplemented cases ($p<0.05$).

When the results of the groups were compared at the four stages, no difference was found between the day 5 results of the 12 mEq/kg/day group and the day 13 non-supplemented cases or between the day 5 6 mEq/kg/day children and the day 9 non-supplemented cases ($p>0.1$).

The mean and S.D. of the TBKs and the number of cases in each of the groups compared are given in Table 12.

Table 12 Mean and S.D. of TBK in mEq/kg and number of cases of supplemented and non-supplemented PCM during recovery

Day	Supplement mEq/kg/day	Mean TBK mEq/kg	S.D.	N
2	-	31.76	5.24	56
5	nil	33.79	5.24	16
	6	34.83	5.10	12
	12	40.09	4.24	14
9	nil	36.15	5.47	15
	6	39.02	3.94	12
	12	41.29	4.31	13
13	nil	40.85	6.09	9
	12	43.30	5.09	10

While a supplement of 12 mEq/kg/day appears to have a marked effect on TBK, the persistence of infections may also be of considerable importance. Both the children described below had no clinical or radiological evidence of infection on admission and received the larger potassium supplement. The first case had a TBK of 33.6 mEq/kg on day 2. Two days later he had right upper lobe consolidation clinically and on x-ray. Klebsiella species were isolated from his sputum on three occasions and on day 20 a course of chloramphenicol was started. At this stage his TBK was 35.2 mEq/kg. In the next 5 days the pneumonia resolved and his TBK rose to 43.1 mEq/kg. The second patient who was extremely thin, had a TBK which rose from 36.3 to 38.7 mEq/kg between day 2 and day 17. He was then found to have pulmonary tuberculosis. His subsequent course is not known.

The effect of potassium supplementation on TBK in mEq/kg in gastroenteritis

There was no difference between the non-supplemented and supplemented (6 mEq/kg/day) cases at any stage, i.e. day 1, day 2, day 5, day 9, day 13 or day 17. The first results to differ from the day 1 results were the day 17 non-supplemented and supplemented values ($p < 0.05$). When the day 2 TBKs were compared with later measurements the day 13 supplemented cases were found to differ ($p < 0.1$). This group also differed from the day 5 supplemented cases ($p < 0.01$). In both supplemented and non-supplemented groups the day 9 and day 17 results differed ($p < 0.05$).

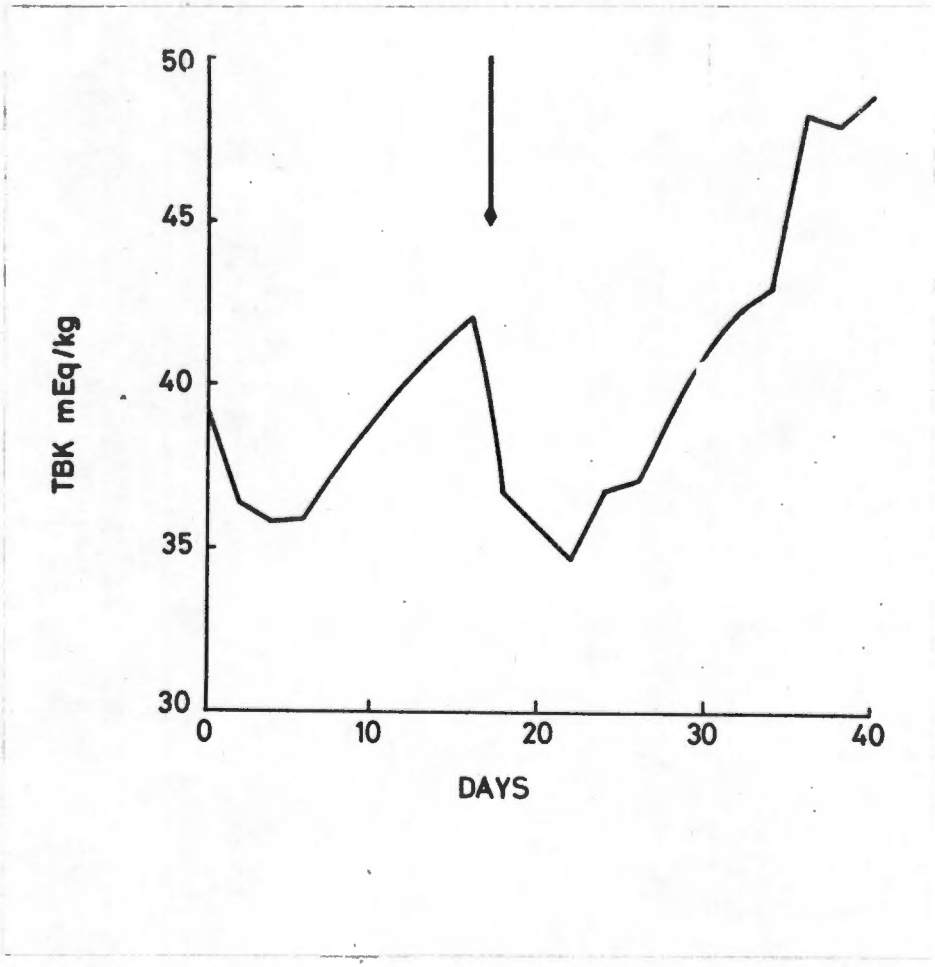
The mean and S.D. of the TBKs and the number of cases in each of the groups are given in Table 13.

Table 13 Mean and S.D. of TBK in mEq/kg and number of cases of supplemented and non-supplemented gastroenteritis during recovery

Day	Supplement mEq/kg/day	Mean TBK mEq/kg	S.D.	N
1	-	40.95	4.87	49
2	-	39.50	5.18	46
5	nil	38.96	4.78	10
	6	38.79	4.50	10
9	nil	39.98	3.38	10
	6	40.62	2.79	10
13	nil	42.12	3.14	10
	6	42.77	3.67	10
17	nil	45.39	2.89	10
	6	44.48	3.41	10

The course of a child who had two different specific (or atypical) E. coli infections is shown in Fig 18. The

Fig.18. Effect of severe diarrhoea on TBK in mEq/kg. The arrow shows the day on which the diarrhoea commenced.



striking feature is the rapid fall in TBK with the onset of the second episode of diarrhoea. (The child became dehydrated within 12 hours of the first loose stool).

Comparison of TBK in mEq/kg of control series, pulmonary infections on admission, and gastroenteritis and PCM cases during recovery

The day 13 TBKs of the PCM cases receiving a supplement of 12 mEq/kg/day did not differ from the control values ($p > 0.1$), but the non-supplemented cases did ($p < 0.025$). Neither the supplemented nor the non-supplemented gastroenteritis cases differed from the control series on day 13 ($p > 0.1$).

The day 5 results of the PCM cases receiving the larger supplement did not differ from the day 2 gastroenteritis cases, while the day 9 results of this PCM group were the same as the day 1 gastroenteritis and the pulmonary infection values ($p > 0.1$). The day 13 TBKs of the non-supplemented PCM cases were the same as results of the gastroenteritis day 1 and day 2 and the respiratory infection groups ($p > 0.1$). The day 9 results of the PCM group receiving the smaller supplement did not differ from the day 1 or the day 2 gastroenteritis cases ($p > 0.1$).

There was no difference between the supplemented and non-supplemented gastroenteritis cases on day 9 and the pulmonary infection group.

The comparisons made in this section are summarised on the following page in Table 14. In Table 15 the information presented in Tables 11, 12 and 13 is combined into a single table.

Table 14 Summary of important comparisons of TBK in mEq/kg where no significant difference was shown ($p > 0.1$)

Groups compared	
Control	PCM, day 13, supplement
	gastroenteritis, day 13, supplement
	gastroenteritis, day 13, no supplement
PCM, day 5, large supplement	PCM, day 13, no supplement
	PCM, day 9, small supplement
	gastroenteritis, day 2
PCM, day 9, large supplement	gastroenteritis, day 1
	pulmonary infections
PCM, day 13, no supplement	gastroenteritis, day 1
	gastroenteritis, day 2
	pulmonary infections
Pulmonary infections	gastroenteritis, day 9, no supplement
	gastroenteritis, day 9, supplement

Table 15 The mean and S.D. of the TBKs in mEq/kg and the number of cases in the groups and sub-groups, compared so far in this chapter

Group	Day	Supplement mEq/kg	Mean	S.D.	N
Control series			44.75	4.79	87
PCM	2	-	31.76	5.24	56
	5	nil	33.79	5.24	16
		6	34.83	5.10	12
		12	40.09	4.24	14
	9	nil	36.15	5.47	15
		6	39.02	3.94	12
		12	41.29	4.31	13
	13	nil	40.85	6.09	9
		12	43.30	5.09	10
Gastroenteritis	1	-	40.95	4.87	49
	2	-	39.50	5.18	46
	5	nil	38.96	4.78	10
		6	38.79	4.50	10
	9	nil	39.98	3.38	10
		6	40.62	2.79	10
	13	nil	42.12	3.14	10
		6	42.77	3.67	10
	17	nil	45.39	2.89	10
		6	44.38	3.41	10
Pulmonary infection			42.41	5.50	45

Comparison of TBK as a percentage of the predicted value of the control, gastroenteritis and pulmonary infection cases on admission

The control cases differed from the cases of gastroenteritis on day 1 and day 2 ($p < 0.005$) and from the children with pulmonary infections ($p < 0.05$). There was no difference between the gastroenteritis cases on day 1 and day 2 ($p > 0.1$). Both these groups differed from the group with respiratory diseases ($p < 0.005$).

The mean and S.D. of these groups and the number of cases is given in Table 16.

Table 16 Mean and S.D. of TBK as a percentage of the predicted value and number of cases in the control, gastroenteritis and pulmonary infection groups

	Mean	S.D.	N
Control cases	100.00	3.02	87
Gastroenteritis cases			
day 1	85.72	11.16	49
day 2	85.35	9.07	46
Pulmonary infection cases	96.88	10.61	45

The effect of potassium supplementation on the percentage predicted TBK in gastroenteritis

The findings when the TBK was expressed as a percentage of the predicted value was almost identical to those found when the TBK was expressed in mEq/kg. There was no difference between the supplemented and non-supplemented cases on day 5, 9, 13 or 17, or between consecutive determinations ($p > 0.1$).

The mean values, S.D. and number of cases are given in Table 17.

Table 17 Mean and S.D. of percentage predicted TBK of the supplemented and non-supplemented cases of gastroenteritis during recovery

Day	Supplement mEq/kg/day	Mean TBK % predicted value	S.D.	N
1	-	85.72	11.16	49
2	-	85.35	9.07	46
5	nil	81.98	5.47	10
	6	85.75	7.57	10
9	nil	86.04	4.85	10
	6	90.35	5.82	10
13	nil	91.25	7.66	10
	6	95.47	4.01	10
17	nil	99.13	4.05	10
	6	99.86	3.06	10

Comparison of the percentage predicted TBK of the control and pulmonary infection cases and of the gastroenteritis cases during recovery

There was no difference between the results of the control series and of the supplemented and non-supplemented gastroenteritis cases on day 17. The pulmonary infection group did not differ from the supplemented gastroenteritis cases on day 13 and the non-supplemented cases on day 17.

The frequency of abnormal results and the relationship between TBK and nutritional status

Whitehead et al have recently reviewed biochemical and other indices of nutritional status[252]. They came to the conclusion that the percentage expected weight for age and the serum albumin concentration were the most reliable.

a. Protein-calorie malnutrition

As it was not possible to find a satisfactory method of prediction for oedematous children, it is difficult to assess the frequency of abnormal TBK results in PCM. When the best

predictor is used, all the observed TBKs fall below the predicted values (Fig. 19). This suggests that all cases of PCM (kwashiorkor) have low TBK values, although several of the percentage predicted TBKs were above the lower tolerance limit.

The admission TBK in mEq/kg correlated with the serum albumin concentration ($r = 0.467$, $p < 0.01$, Fig. 20). There was a negative correlation between the TBK and the percentage expected weight for age ($r = -0.305$, $p < 0.05$, Fig. 21).

b. Gastroenteritis

The number of cases falling below the lower limit of normal, when the TBK is expressed as the percentage predicted values, are given in Table 18.

Table 18 The number of cases of gastroenteritis falling below the lower limit of normal when TBK is expressed as the percentage of the predicted value

Day	Supplement mEq/kg/day	Number of cases below lower limit of normal	Number of cases investigated
1	-	38	49
2	-	39	46
5	nil	10	10
	6	8	10
9	nil	10	10
	6	8	10
13	nil	5	10
	6	4	10
17	nil	1	10
	6	1	10

Fig.19. PCM: Observed TBK in mEq plotted against the TBK predicted from a function of weight and height.

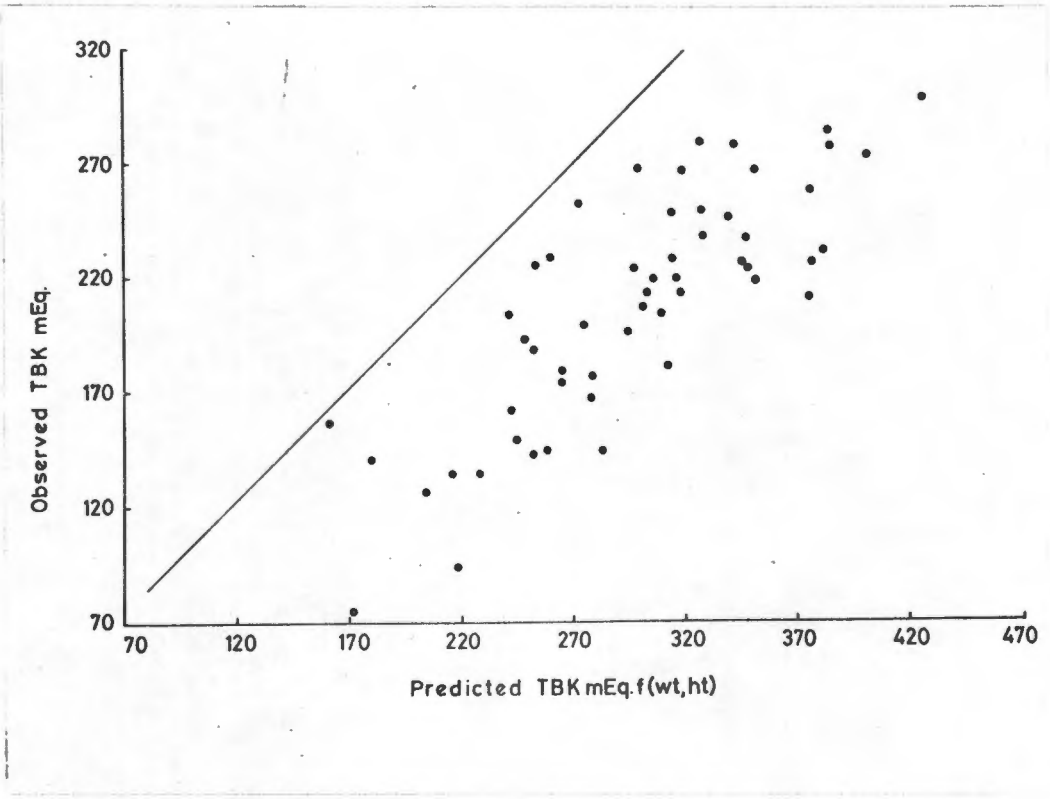


Fig.20. PCM: The relationship between the TBK in mEq/kg and the serum albumin (g/100ml)

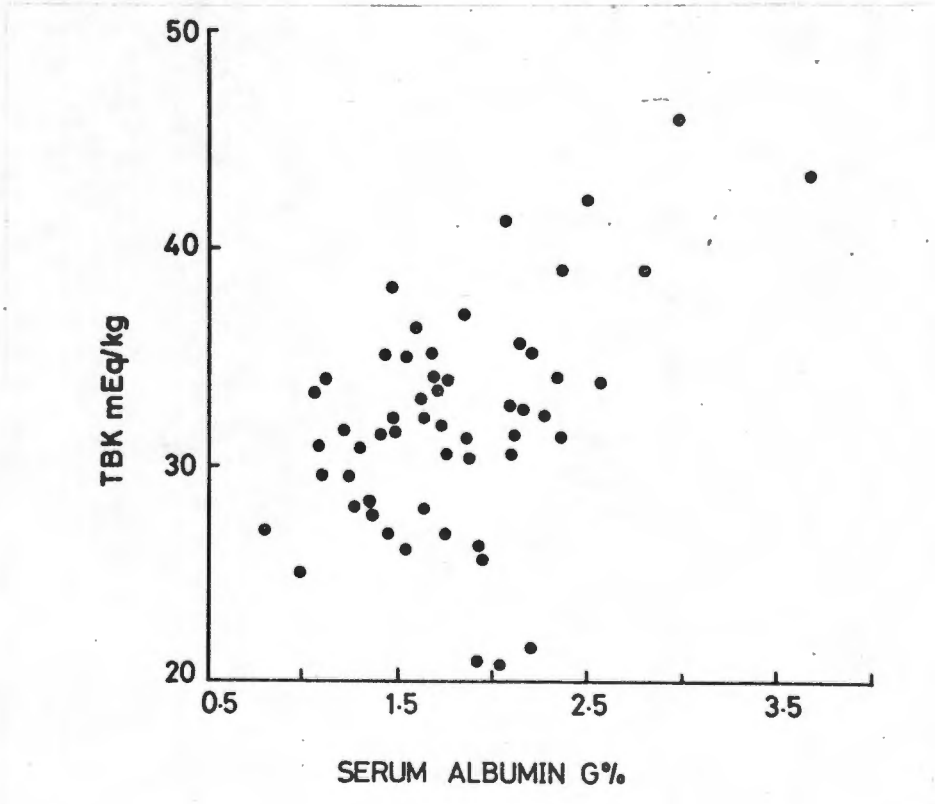
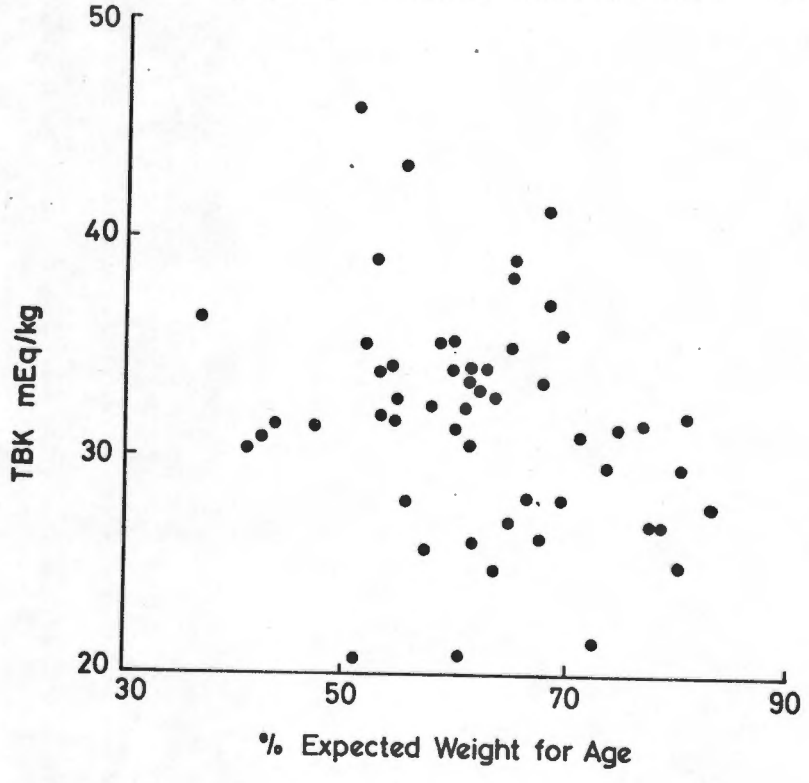


Fig.21. PCM: The relationship between TBK in mEq/kg and percentage expected weight for age.



There was a negative correlation between the TBK in mEq/kg and the percentage expected weight for age on day 1 and day 2 (Fig.22) but no correlation with the serum albumin concentration. The percentage predicted TBK did not correlate with the percentage expected weight for age or the serum albumin concentration. The values of the correlation coefficients and the levels of significance are given in Table 19.

Table 19 Correlations between TBK and percentage expected weight for age and serum albumin in gastroenteritis (45 cases)

Day	Dependent variable	Independent variable	r	p
1	TBK (mEq/kg)	Percentage expected weight for age	-0.436	<0.01
		serum albumin	-0.057	>0.1
	TBK (% predicted)	Percentage expected weight for age	0.099	>0.1
		serum albumin	-0.033	>0.1
2	TBK (mEq/kg)	Percentage expected weight for age	-0.475	<0.001
		serum albumin	-0.046	>0.1
	TBK (% predicted)	Percentage expected weight for age	0.075	>0.1
		serum albumin	-0.026	>0.1

c. Pulmonary infections

Of the 45 children, 17 fell below the lower limit of normal and 8 above the upper limit. There was a negative correlation between the TBK in mEq/kg and the percentage expected weight for age (Fig. 23) but no correlation with the serum albumin. There was a positive correlation between the percentage predicted TBK and the percentage expected weight for age (Fig. 24). The values for the correlation coefficients

Fig.22. Gastroenteritis: The relationship between TBK in mEq/kg and percentage expected weight for age on admission.

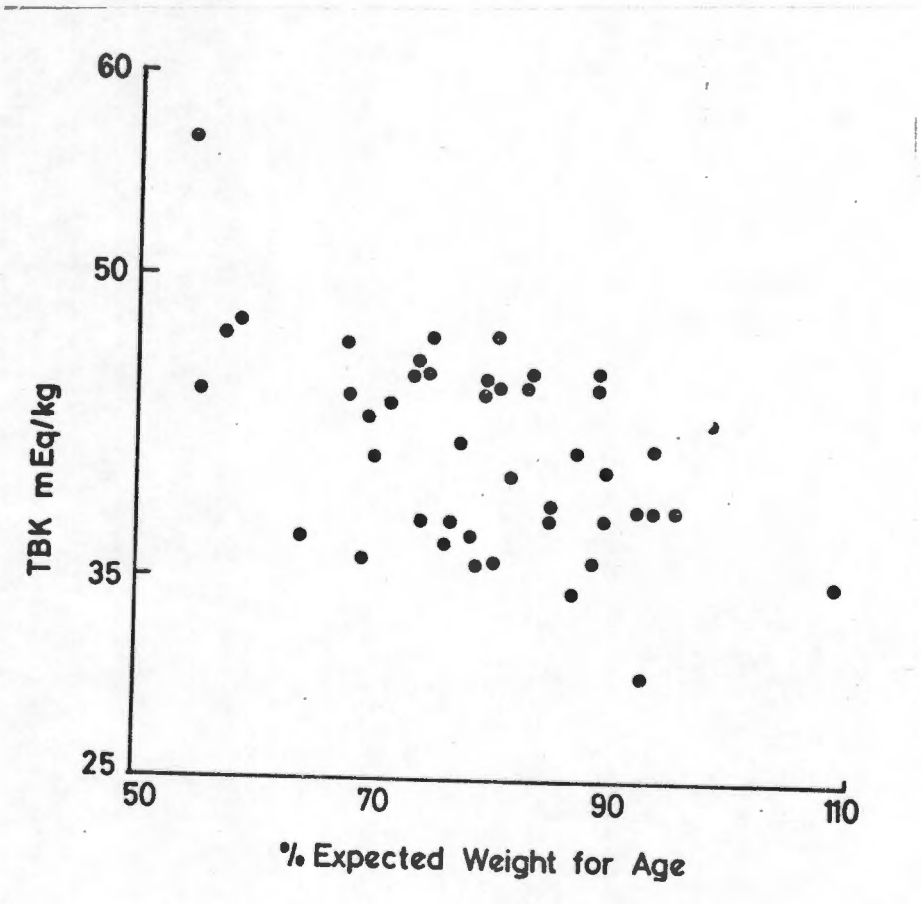


Fig.23. Pneumonia: The relationship between TBK in mEq/kg and percentage expected weight for age.

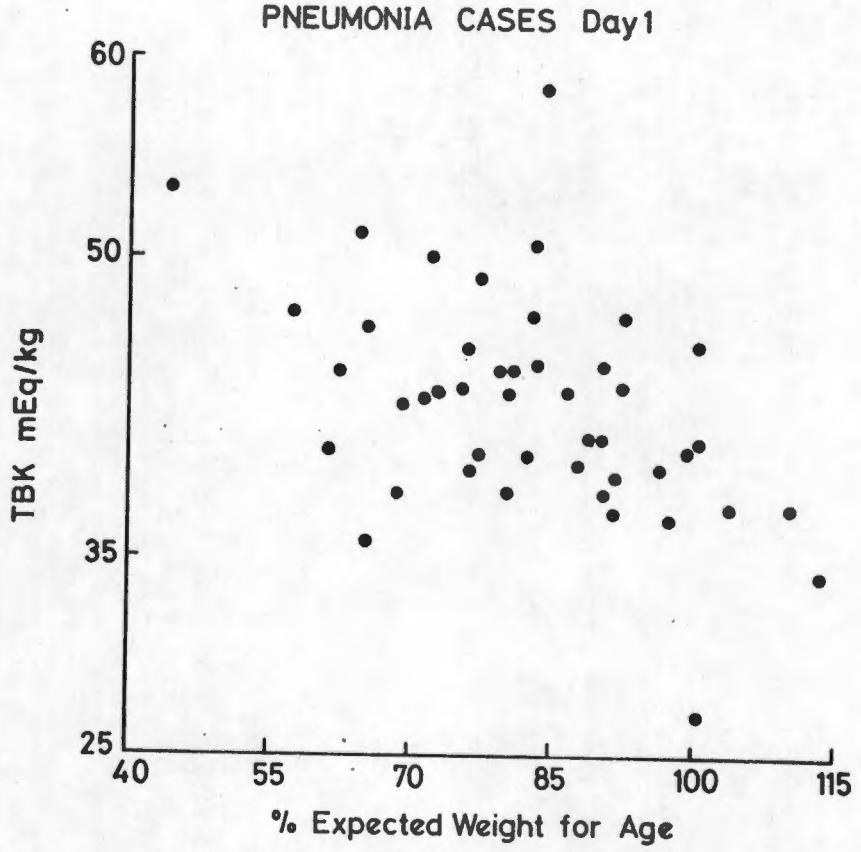
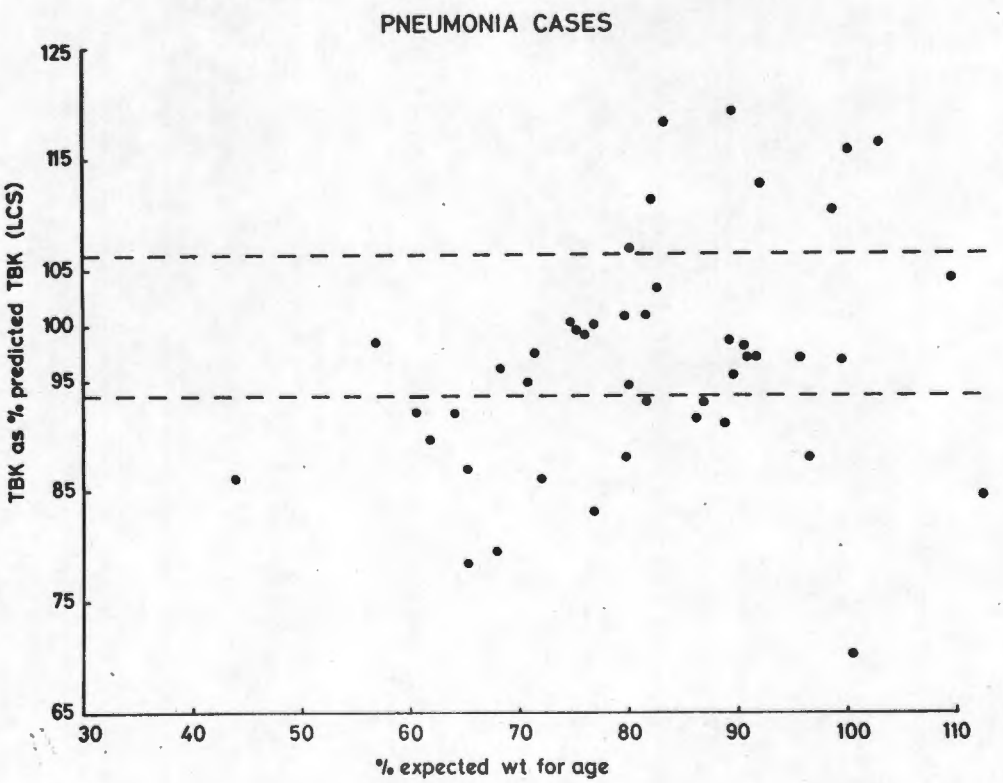


Fig.24. Pneumonia: The relationship between the percentage predicted TBK and the percentage expected weight for age.



and the levels of significance are given in Table 20.

Table 20 Correlations between TBK and percentage expected weight for age and serum albumin in children with severe pulmonary infections (45 cases)

Dependent variable	Independent variable	r	p
TBK mEq/kg	Percentage expected weight for age	-0.479	<0.001
	serum albumin	0.090	>0.1
TBK % predicted	Percentage expected weight for age	0.303	<0.05
	serum albumin	0.201	>0.1

When the children suffering from the pulmonary infections were divided into two groups on the basis of percentage expected weight for age, it was found that those children who were below 80% of expected weight for age had lower percentage predicted TBK than the control children ($p < 0.0025$, one-tailed). The children of normal weight did not differ from the controls ($p > 0.1$). The distribution of the cases in these groups differs ($X^2 = 6.559$, $p < 0.05$); the numbers of cases below normal, within the 95% tolerance limits and above the upper limit are shown in Table 21.

Table 21 Numbers of underweight and normal weight children with pneumonia and who had a TBK below normal, within normal limits and above normal

	Below normal	Normal	Above normal	Total
<80.0% expected weight for age	9	8	0	17
>80.0% expected weight for age	8	12	8	28
Total	17	20	8	45

The reason for the children falling above the upper limit of normal was not clear but it was thought it may have been due to a reduction in total body water and/or extracellular fluid volume. Unfortunately, it was not possible to measure total body water but one of the three children had a reduced thiosulphate space. The results are shown in Table 22. The case numbers are those given in Table C-4.

Table 22 Thiosulphate space in pulmonary infections

Case *	Admission		Recovery	
	litres	ml/kg	litres	ml/kg
43	2.36	256.1	2.42	263.0
44	1.35	155.2	2.26	258.1
45	1.65	219.2	1.57	208.5

* from Table C-4.

Two of the three children fell within the normal range of TBK throughout their stay in hospital. One was below the lower limit of normal until the 9th day.

The effect of potassium supplementation on the increment in TBK

In this section the increment in TBK is the difference between two TBK determinations expressed in mEq.

a. PCM

The initial TBK in mEq/kg of the group receiving a supplement of 6 mEq/kg/day was lower than in the group receiving 12 mEq/kg/day, and may account for the difference found between the two groups on day 5 when the TBK is expressed in mEq/kg. (page 44).

As the weights of the non-supplemented and the two supplemented groups did not differ ($p>0.1$) it was possible to compare the change in TBK in mEq of the 3 groups between day 2 and day 5. The children who received no supplement retained less potassium than the group receiving the larger supplement ($p<0.05$, one tail) and the group receiving the smaller supplement ($p<0.01$, one tail). There was no difference between the two supplemented groups ($p>0.1$). The mean and S.D. of the initial TBK in mEq/kg and increment in mEq are given in Table 23 for each of the groups.

Table 23 Mean and S.D. of initial TBK in mEq/kg and change in TBK in mEq between Day 2 and Day 5 in PCM

Supplement mEq/kg/day	Initial TBK mEq/kg		Increment TBK mEq		Number of cases
	Mean	S.D.	Mean	S.D.	
nil	31.89	4.11	10.54	20.55	16
6	29.99	4.70	29.58	15.16	12
12	35.37	5.65	27.89	23.68	14

In Fig. 25 the two supplemented groups have been combined and the mean TBK on day 2, 5, 9 and 13 compared with the non-supplemented cases.

There was no correlation between the increment in TBK in mEq and the serum albumin, initial TBK in mEq/kg or weight in the non-supplemented group or in the children receiving the smaller supplement ($p>0.1$). In those cases receiving the larger supplement there was a correlation between the increment in TBK and the initial TBK ($p<0.001$).

When the supplemented cases were treated as a single group there was a correlation between the change in TBK and the initial TBK and the serum albumin ($p<0.01$, Figs. 26 and 27).

The correlation coefficients are given in Table 24.

Table 24 Correlation between potassium retained in the first 3 days and initial TBK in mEq/kg and serum albumin (g/100ml) in PCM

Group	Independent variable	r	p
Supplemented	initial TBK	-0.431	<0.01
	serum albumin	-0.415	<0.01
Non-supplemented	initial TBK	-0.153	>0.1
	serum albumin	-0.103	>0.1

Fig.25. The effect on potassium supplementation in protein-calorie malnutrition. (The potassium supplemented groups have been combined).

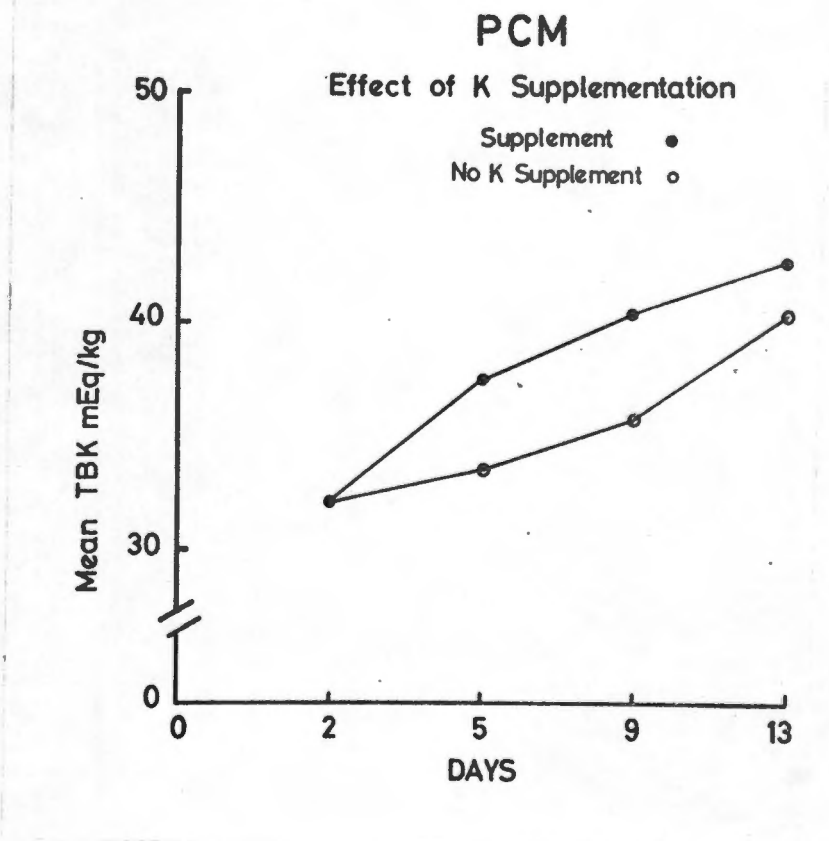


Fig.26. PCM: The relationship between potassium retention and the initial TBK in mEq/kg. (The potassium supplemented children have been treated as a single group).

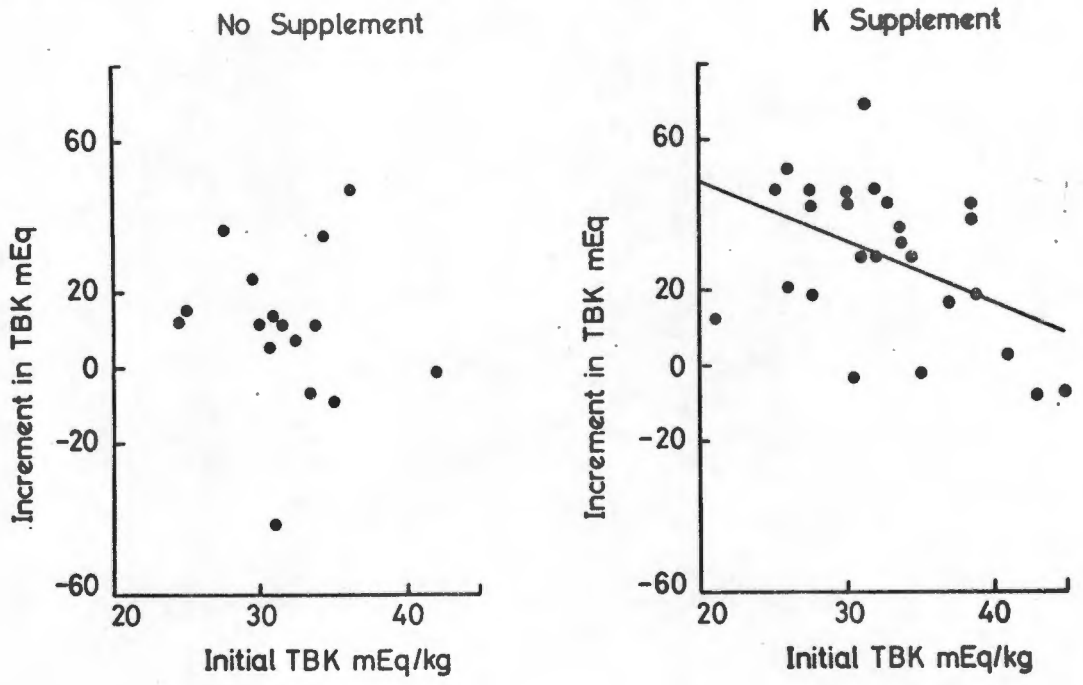
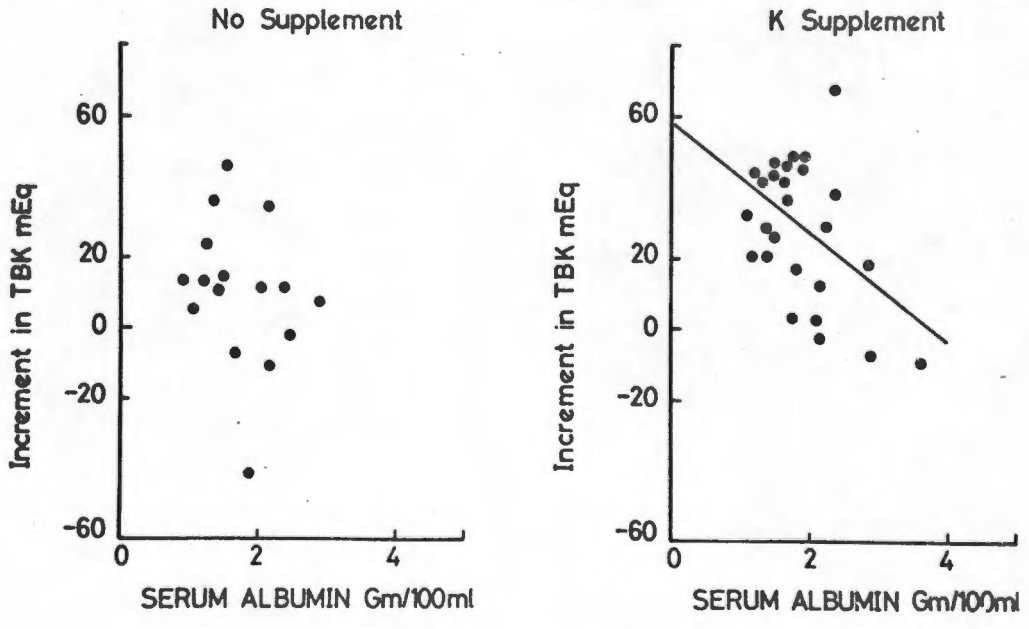


Fig.27. PCM: The relationship between potassium retention and the serum albumin concentration.



b. Gastroenteritis

The day 1 and day 2 TBKs in mEq/kg and weights of the children who were allocated to the supplemented and non-supplemented groups did not differ ($p>0.1$). The increase in TBK in mEq between day 2 and day 5 was greater in the supplemented group than in the non-supplemented group ($p<0.05$). (This is in contrast to the absence of differences between the TBK in mEq/kg on day 2 and 5 in these groups, page 47). The mean and S.D. of the increments are given in Table 25.

Table 25 Mean and S.D. of increase in TBK between day 2 and day 5 in gastroenteritis

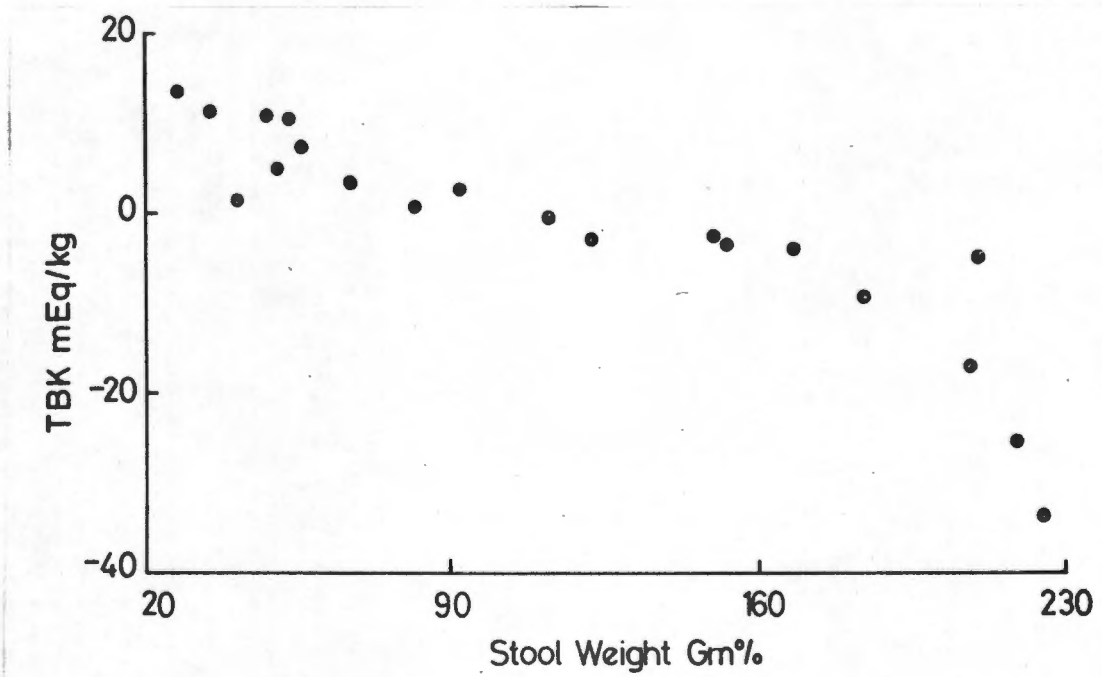
Supplement mEq/kg/day	Mean Increase (mEq)	S.D.	Number of cases
Nil	-13.46	23.60	10
6	0.79	18.05	10

There was no correlation between the change in TBK and initial TBK or serum albumin ($p>0.1$). However, there was a highly significant correlation between stool weight and the change in TBK between day 1 and 2 ($p<0.001$, Fig. 28). The change in TBK between day 2 and day 3 and between day 3 and day 4 also correlated with the stool weight on the corresponding day in the supplemented and the non-supplemented cases ($p<0.05$). The slopes of the regression lines did not differ ($p>0.1$).

c. Comparison of the increment in TBK in gastroenteritis and PCM

There was no difference in the weights of the 5 groups of children; 3 with PCM and 2 with gastroenteritis. The initial TBKs of all the PCM groups were lower than the gastroenteritis cases ($p<0.005$). The non-supplemented PCM cases retained more potassium than the corresponding gastroenteritis

Fig.28. Gastroenteritis: The relationship between potassium retention and stool weight.



cases and both the supplemented PCM groups more than the supplemented gastroenteritis group ($p<0.01$).

DISCUSSION

Compared to the control series, children admitted to hospital with PCM, acute dehydrating gastroenteritis and severe pulmonary infections had low TBK values. The persistence of low results until day 9 or later in PCM and gastroenteritis raises the following questions.

1. Does a low TBK in mEq/kg imply potassium depletion exists?
2. How long does the potassium depletion persist?

The questions would be easier to answer if it were possible to define potassium depletion precisely. The term is frequently used particularly in studies on malnourished children and is usually linked in some way with nitrogen. Hansen[120] found that in children suffering from kwashiorkor, the uptake of potassium was independent of the administration of nitrogen and took place even in the presence of a negative nitrogen balance in cases where nitrogen was withheld. Once nitrogen was introduced into the diet in these cases potassium was retained with nitrogen in a ratio that was close to that in muscle. Nichols et al state that the concentration of potassium in fat-free whole muscle, total muscle water, dry solids and total nitrogen is reduced from the concentration in recovered controls when the TBK is less than 35 mEq/kg. In concentrations based on water content, fat-free whole muscle and muscle water, the decrease was found below a TBK of 40 mEq/kg[180,181,182]. These findings suggest that potassium depletion almost certainly exists at a TBK of less than 35 mEq/kg, and possibly when the

TBK is less than 40 mEq/kg. Alleyne et al[14] based their calculations on the concept of potassium capacity introduced by Scribner and Burnell[219], who define potassium capacity as:

"the sum total of all anions and other chemical groups outside of the extracellular space capable of holding or binding potassium ions".

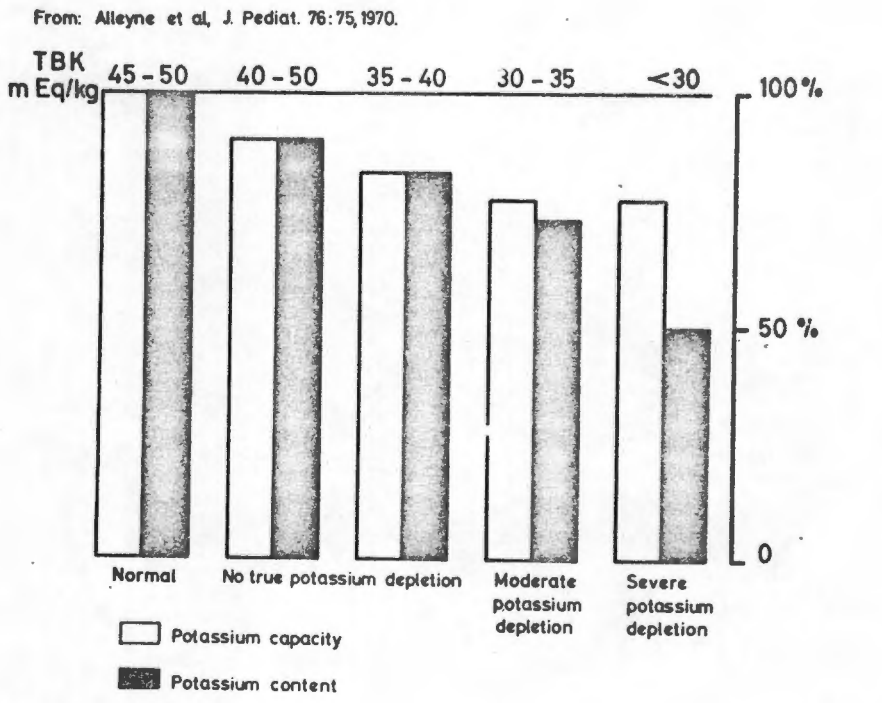
Fig.5 of the paper by Alleyne et al[14] has been reproduced on the following page (Fig.29). They write:

"In infantile malnutrition when the TBK is between 30 and 40 mEq/kg, there is a modest reduction in the concentration of potassium in muscle. If the changes in muscle in this range of TBK are an indication of the state of the other potassium-containing organs, this fall in TBK is a reflection of a reduction mainly of potassium capacity, i.e. there is a reduction in the amount of tissue which can absorb potassium.

Smith and Waterlow did, in fact, consider the possibility that reduction of tissue mass might contribute to the low values for TBK in malnutrition[225]. When total body potassium falls further, below 30 mEq/kg, there is a marked fall of potassium concentration in muscle. There is now, not only a fall of potassium capacity but this capacity is unsaturated. Thus there is true potassium depletion".

This approach assumes that the potassium content has no effect on the potassium capacity. Alexis et al studied the effects of inadequate dietary potassium intake on protein synthesis in skeletal muscle of weanling rats[6]. In vivo uptake of 3H-leucine into mixed muscle proteins were significantly reduced by feeding a deficient potassium diet when compared with

Fig.29. This figure is reproduced from the paper by Alleyne et al(14).



The potassium status of the children investigated in terms of our concept of their body potassium capacity & content.

the incorporation for age control rats given an adequate diet. These findings confirm those of Rinehart et al who suggested that potassium depletion may reduce the incorporation of ^{14}C-leucine into potassium depleted chicks[207]. The relationship between potassium and glucose metabolism has been outlined in Chapter 1. These findings suggest that potassium losses may interfere with protein and glycogen metabolism and so reduce potassium capacity.

If this is the case, it is possible that potassium capacity is, to some extent, potassium dependent, and that capacity may decrease until capacity and content are proportionate. The results of Nichols et al and Alleyne et al may describe such an "end-state" which is partly due to excessive potassium losses. Decreased food intake and increased tissue breakdown almost certainly play an important role in a child with a severe infection, but it is possible that disproportionate potassium losses may lead to inefficient utilization of the available nitrogen and calories. Studies showing increased nitrogen retention and turnover during recovery from PCM[120,121,190] do not exclude the possibility that potassium losses may be an important factor in the development of the disease, as children studied during recovery almost invariably receive potassium supplements. In fact, the response to potassium supplementation in this study suggests that potassium may influence metabolism during recovery. Alleyne's finding of a negative correlation between potassium retention and initial TBK was confirmed[14] but the amount of potassium retained between day 2 and day 5 was the same in the two supplemented groups in spite of the higher initial TBKs of the group receiving the larger supplement.

If potassium capacity is related to potassium content

and the response to excessive potassium losses is to reduce capacity, Alleyne's finding of "moderate or no depletion" when the TBK is above 30 mEq/kg is easily explained. The "severe depletion" occurring below 30 mEq/kg may be due to a minimum potassium capacity, i.e. lower protein and glycogen levels are not compatible with life but potassium levels can fall slightly lower. (The lowest levels reported from Jamaica and found in this study are approximately 20 mEq/kg).

If potassium capacity is potassium dependent, the current concept of potassium capacity cannot be used in the definition of potassium depletion. The problem is to find a suitable denominator as definitions which do not relate potassium content to tissue mass are unlikely to be satisfactory, e.g. potassium depletion exists when potassium losses exceed potassium intake. As the effect of potassium depletion on potassium capacity would be a change in rates of synthesis and catabolism the best definition may be in terms of the relative reaction rates. It would not be possible to investigate every child who may be potassium depleted in this way. The solution may be to investigate the reaction rates of some children with a particular disease and to relate the changes to body or tissue composition. Measurements of TBK or analysis of biopsy material could then be used as a guide to the presence or absence of potassium depletion.

Thus a low TBK value suggests that potassium depletion exists. The values of 30 and 40 mEq/kg mentioned by Alleyne[14] may underestimate the frequency, severity and duration of the potassium depletion which occurs in PCM. Similarly, relating potassium and nitrogen retention[120] would underestimate the time that potassium depletion persists, while the time required for TBK to return to normal may overestimate the duration of the

depletion.

The low TBK found in most children with gastroenteritis and many with severe pulmonary infections, and the persistently low values in children with chronic infections, suggest that the low TBK found in PCM may be the result of repeated and/or chronic infections. In fact, individual cases of gastroenteritis and pneumonia had TBKs which were as low as most of the PCM cases. When the results of the groups are compared the TBKs were lower in PCM than in gastroenteritis and pneumonia. The TBK values of the gastroenteritis cases after rehydration were lower than those of the pulmonary infection group.

There are several possible reasons for low TBK values in pneumonia and gastroenteritis. They can be divided into two groups although the groups overlap considerably. The first group is made up of factors which are mainly related to potassium content and the other of factors that affect potassium capacity. The factors that may decrease potassium content are:

1. Excessive potassium losses.

   In gastroenteritis the increase in stool volume is an obvious route. Hansen[120] has reported losses of as much as 52 mEq/day and there are other similar reports[59,80]. It is possible that children suffering from severe infections also excrete excessive amounts of potassium in the urine as a result of the stress state and its effect on the adrenals, or by simple alterations in acid-base equilibrium. The findings of Wellan[247] suggest that once potassium depletion exists it may result in excessive corticosterone production and lead to further potassium losses.

2. Direct or indirect interference with the sodium pump by the causative agent. The efficiency of the pump is known to be extremely sensitive to changes in pH and electrolyte concentration, drugs and infections (Chapter 1).

The factors which may affect potassium capacity are:

1. Reduced food intake
2. Increased catabolism due to the infection and the adrenal response.

It is possible that these mechanisms, and others, operate simultaneously and may potentiate each other.

In gastroenteritis the stool losses appear to be by far the most important factor. Potassium supplementation had a slight effect on the change in TBK between day 2 and day 5, possibly preventing further losses in most of the cases in this group. The calculation of partial correlation coefficients with change in TBK, stool weight and total potassium intake as variables, failed to show that potassium supplementation was related to changes in TBK. However, even if potassium supplementation had had no effect on TBK, a decision to stop potassium supplementation in gastroenteritis would be premature, as it may play a role by maintaining serum levels and so enabling appropriate excretion of sodium, hydrogen and bicarbonate ions and water to take place (Chapter 1).

In PCM the effect of potassium supplementation was marked. The importance of the fact that both the supplemented groups retained the same amount of potassium has been mentioned previously. The lower level of potassium retention in the non-supplemented group suggests that a total intake of 3 mEq/kg/day may be inadequate for most cases. None of the supplemented PCM cases

had serum potassium levels above 6 mEq/l and from this point of view it appears that an intake as high as 15 mEq/kg/day is safe for most cases. However, this high intake may result in even more rapid changes in the distribution of fluid than an intake of 9 mEq/kg/day (Chapter 5). As there is no obvious advantage in giving the larger supplement, a supplement of 6 mEq/kg/day seems preferable at present. It is possible that further investigation may show that the higher supplement has beneficial effects on metabolism.

The presence of the low thiosulphate space in a child presenting with pulmonary infection is important as the child was not clinically dehydrated. The fact that reduction in extracellular fluid volume may occur, was suggested by the work of Benson et al[31] and Kenmar et al[153]. Although the 8 high percentage predicted values may be due to a reduction in extracellular fluid volume and total body water this seems unlikely as there was no difference between the TBK in mEq/kg or as a percentage predicted value in the gastroenteritis children before and after clinical rehydration. The difference in hydration in these children must surely be greater than in children who show no evidence of dehydration at any stage. The explanation for these high results is not known. Similarly, there is no obvious explanation for the fact that females had lower values than males in PCM and pneumonia when the TBKs were in mEq/kg and as a percentage of the predicted value respectively.

SUMMARY

Low TBK values have been found in PCM, gastroenteritis and pulmonary infections. In the last group there was a relationship between TBK and nutritional status. The time required for the TBK to return to normal appeared to be largely dependent on an adequate potassium intake in PCM and stool losses in gastroenteritis. In children suffering from chronic infections the TBK did not increase to any appreciable extent. These findings suggest that the low TBK values found in PCM are due to chronic or frequent acute infections.

The concept of potassium capacity and content has been discussed. It appears there is a need for further investigation of the concept.

Chapter 4. THE RELATIONSHIP BETWEEN TBK AND SERUM ELECTROLYTE CONCENTRATIONS.

Hyponatraemia is a fairly frequent finding in PCM[99,120] and has been reported in pneumonia[222]. There are numerous studies on acid-base and serum electrolyte levels in gastroenteritis (the references will be introduced in the course of the chapter).

The effects of potassium depletion on renal function raise the possibility that there may be a relationship between TBK and/or serum potassium levels and disturbances in the serum sodium and chloride concentrations. In this chapter this possibility will be examined.

CLINICAL MATERIAL

With one exception, every child investigated in Chapter 3 had serum sodium, potassium, chloride and TBK determinations on admission. Acid-base status was also established in the gastroenteritis cases. Only the day 1 acid-base results are given in Table C-6. On day 2 the pH, pCO_2 and base excess of all the children were within the limits

pH	7.36 to 7.44
pCO_2	35 to 42 mm mercury
base excess	-3 to +3 mEq/l

These results suggest there may have been over-correction of the acidosis with sodium bicarbonate. Detailed results of the PCM, gastroenteritis and pneumonia cases are given in Tables C-5, C-6 and C-7 of Appendix C.

The relationship between TBK and serum sodium, potassium and chloride concentration in PCM

TBK in mEq/kg correlated with the serum chloride concentration ($r = 0.278$, $p<0.05$, Fig. 30). There was no relationship between the serum sodium or serum potassium concentration, or between the serum potassium and serum sodium or chloride concentrations ($p>0.1$). The correlation coefficients are given in Table 26.

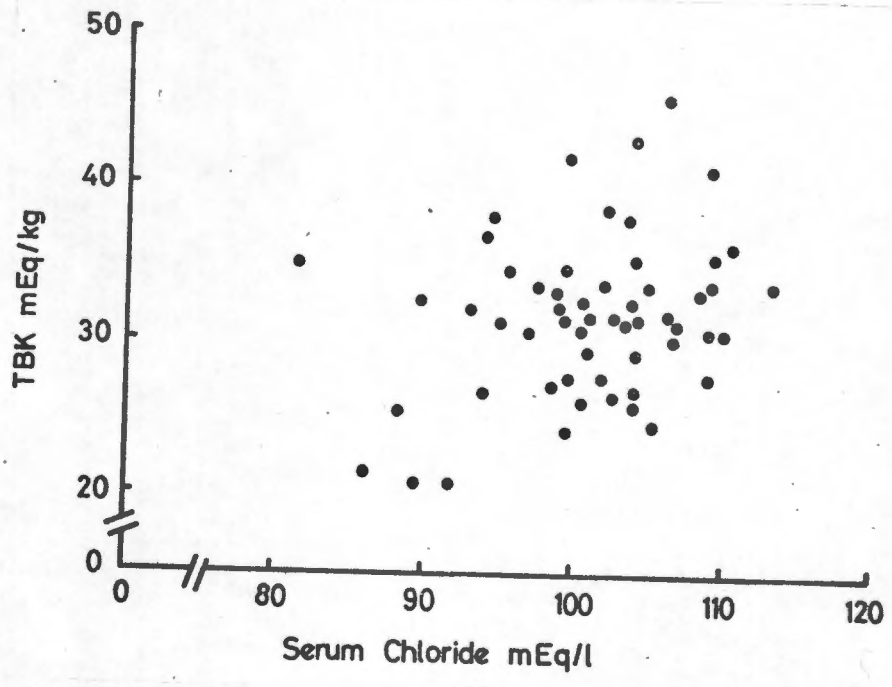
Table 26 Correlations between TBK and serum potassium concentration, and serum electrolyte concentration on admission in PCM (56 cases)

Dependent variable	Independent variable serum concentration mEq/l	r	p
TBK mEq/kg	Na	0.172	>0.1
	K	0.211	>0.1
	Cl	0.278	<0.05
Serum K mEq/l	Na	0.032	>0.1
	Cl	0.197	>0.1

In this series abnormally low and high serum sodium concentrations were found, 14 patients having concentrations less than 130.0 mEq/l and 3 values greater than 149.9 mEq/l. (The distributions, means and S.D.s of the serum sodium, potassium and chloride concentrations of the PCM, gastroenteritis and pulmonary infection cases are given in Tables 32, 33, and 34 on pages 75, 76 and 77.

As regression analysis did not test the possibility that the abnormal serum sodium results were present in children who had low (or high) TBK or serum potassium concentrations, several X^2 tests were performed. The children were divided into two

Fig.30. PCM: The relationship between TBK in mEq/kg and serum chloride in mEq/l.



groups on the basis of the TBK and/or serum potassium result; eg. high and low TBK, high and low serum potassium, low TBK and low serum potassium and the remaining children, etc. Each group was then divided in two using the serum sodium concentration to give a 2 x 2 table. No relationship between TBK and/or serum potassium and serum sodium was found regardless of the limits selected to divide the children into groups.

The relationship between TBK, acid-base status and serum electrolyte concentrations in gastroenteritis

(Only those children who were investigated on day 1 and day 2 are considered in this section).

There was no correlation between TBK in mEq/kg or as a percentage of the predicted value and the serum sodium, potassium or chloride concentrations on day 1 ($p>0.1$). There was a correlation between the TBK in mEq/kg and the pCO_2 ($r = 0.327$, $p<0.05$, Fig. 31) and between the percentage predicted TBK and pH and base excess (BE); ($r = 0.322$ and 0.340, $p<0.05$ respectively, Figs. 32 and 33).

The correlation coefficients are given in Table 27.

Fig. 31. Gastroenteritis: The relationship between TBK in mEq/kg and pCO_2 in mm mercury on admission.

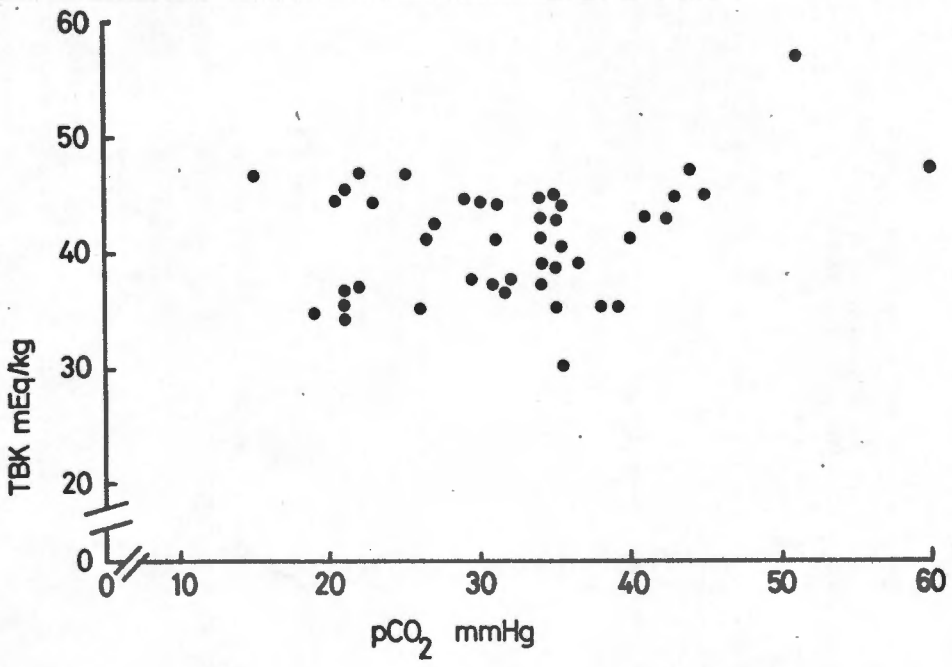


Fig.32. Gastroenteritis: The relationship between the percentage predicted TBK and the pH on admission.

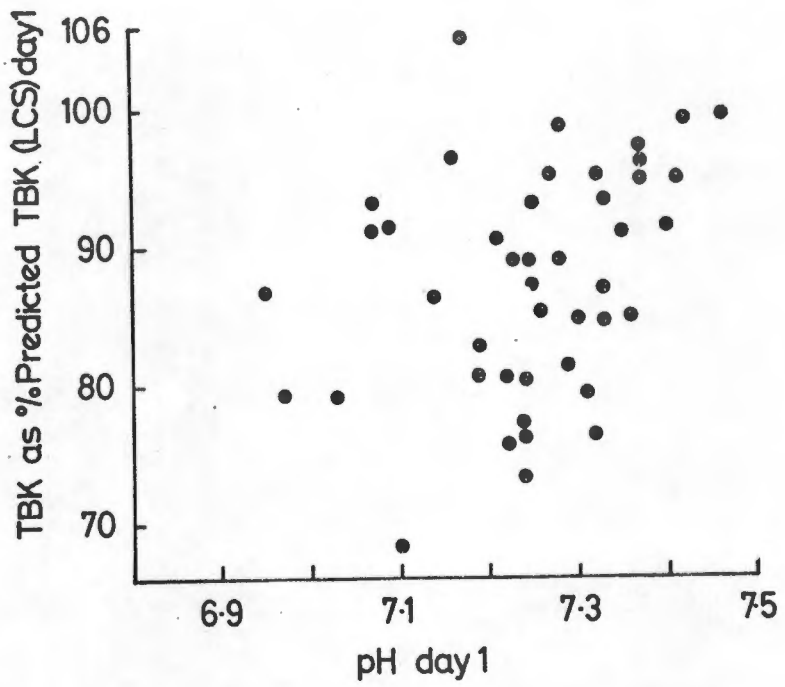


Fig.33. Gastroenteritis: The relationship between the percentage predicted TBK and the base excess in mEq/l on admission.

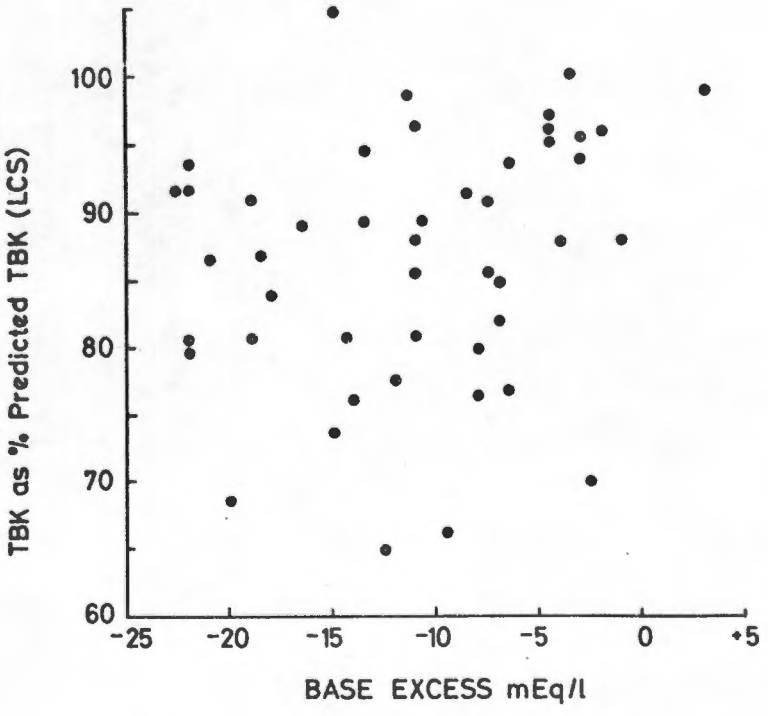


Table 27 The relationship between TBK, acid-base status and serum electrolyte results on admission in gastroenteritis (45 cases)

Dependent variable	Independent variable	r	p
TBK mEq/kg	pH	-0.093	>0.1
	pCO_2	0.327	<0.05
	BE	0.023	>0.1
	Na	0.166	>0.1
	K	0.048	>0.1
	Cl	0.095	>0.1
TBK percent predicted	pH	0.322	<0.05
	pCO_2	0.073	>0.1
	BE	0.340	<0.05
	Na	0.008	>0.1
	K	0.073	>0.1
	Cl	-0.073	>0.1

On day 2 the percentage predicted TBK correlated with the serum potassium concentration ($r = 0.385$, $p<0.01$, Fig. 34). There was no relationship between the TBK in mEq/kg and any of the serum electrolyte concentrations or between the percentage predicted TBK and the serum sodium and chloride levels ($p>0.1$).

There was a relationship between the TBK on day 2 and the admission acid-base status. The findings were similar to those on day 1, i.e. the TBK in mEq/kg correlated with the pCO_2 and the percentage predicted TBK correlated with the pH and base excess. The correlation coefficients are given in Table 28, together with the levels of significance.

Fig.34. Gastroenteritis: The relationship between the percentage predicted TBK and the serum potassium in mEq/l on day 2.

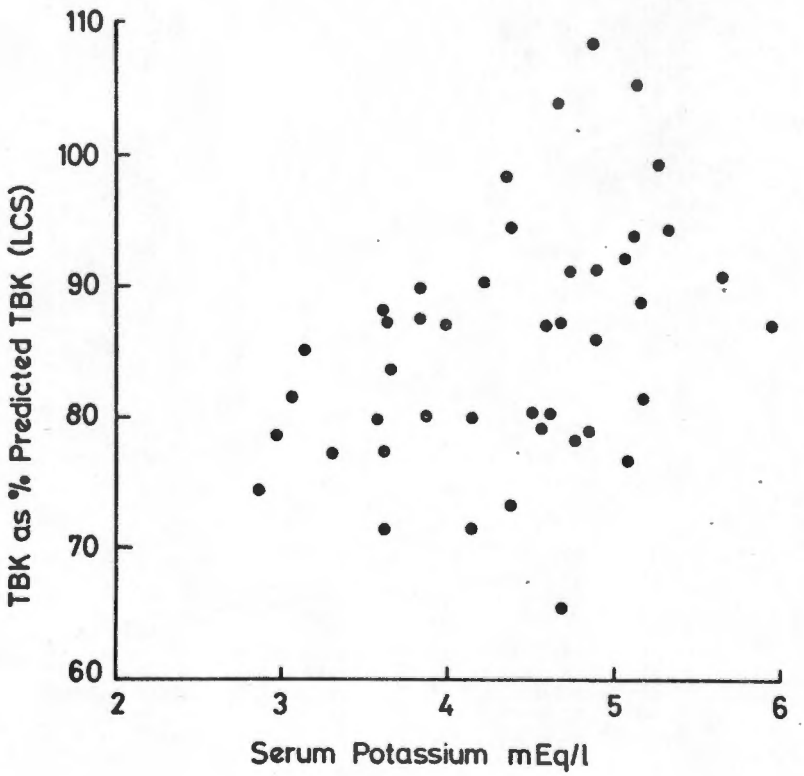


Table 28 Correlations between Day 2 TBK and serum electrolyte concentrations and admission acid-base status

Dependent variable	Independent variable	r	p
TBK mEq/kg	+pH	0.008	>0.1
	+pCO_2	0.363	<0.05
	+BE	0.124	>0.1
	Na	0.191	>0.1
	K	0.220	>0.1
	Cl	0.082	>0.1
TBK percentage predicted	+pH	0.329	<0.05
	+pCO_2	0.199	>0.1
	+BE	0.397	<0.01
	Na	0.089	>0.1
	K	0.385	<0.01
	Cl	0.074	>0.1

+ values on day 1.
all remaining results day 2.

When the serum electrolyte results on day 1 and day 2 were related to the acid-base status on admission, the pH on day 1 correlated inversely with the sodium concentration on day 1 but not on day 2, ($r = 0.357$, $p<0.05$, Fig. 35, and $r = 0.188$, $p>0.1$, respectively). There was a similar correlation between pH and the serum chloride concentration (day 1, $r = 0.391$, $p<0.01$ and day 2, $r = -0.194$, $p>0.1$). In the case of serum potassium levels the situation was reversed, being significant on day 2 but not on day 1 ($r = 0.031$, $p>0.1$ and $r = 0.375$, $p<0.05$ respectively, Fig. 36).

The pCO_2 did not correlate significantly with any of the serum electrolyte levels on day 1 or day 2.

The base excess and day 2 serum potassium concentration correlated but not the day 1 concentration ($r = 0.413$, $p<0.01$, Fig. 37; $r = 0.041$, $p>0.1$). The serum chloride level on

Fig.35. Gastroenteritis: The relationship between the serum sodium in mEq/l and the pH on admission.

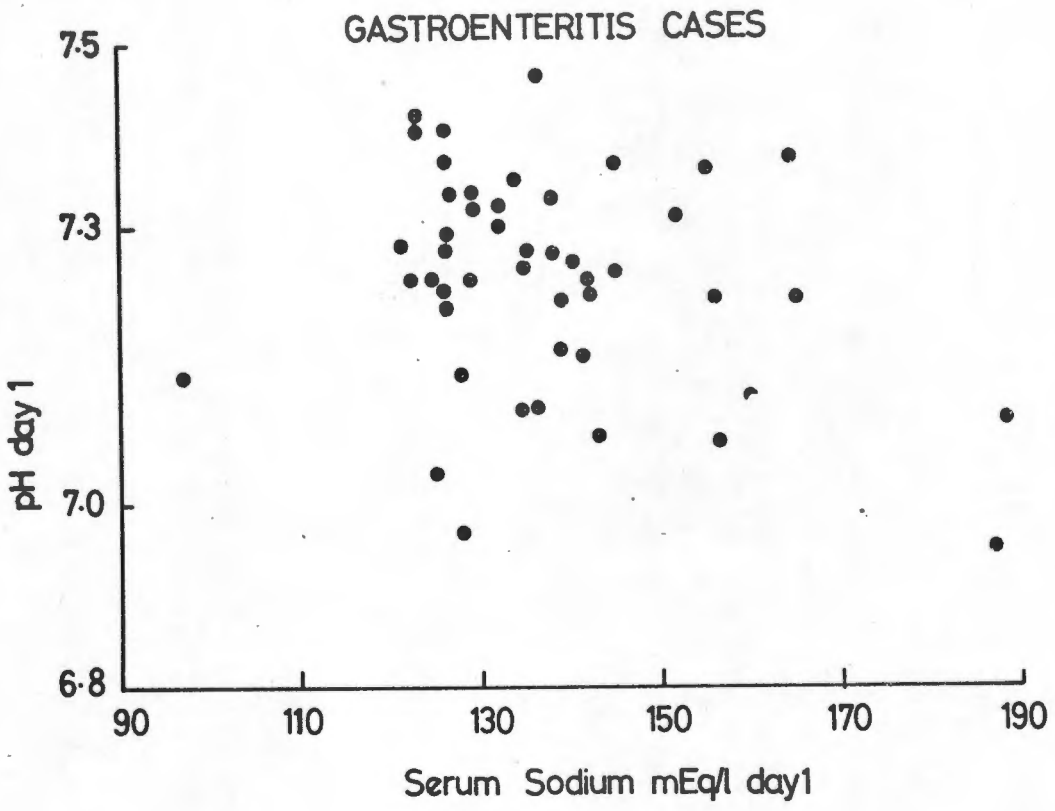
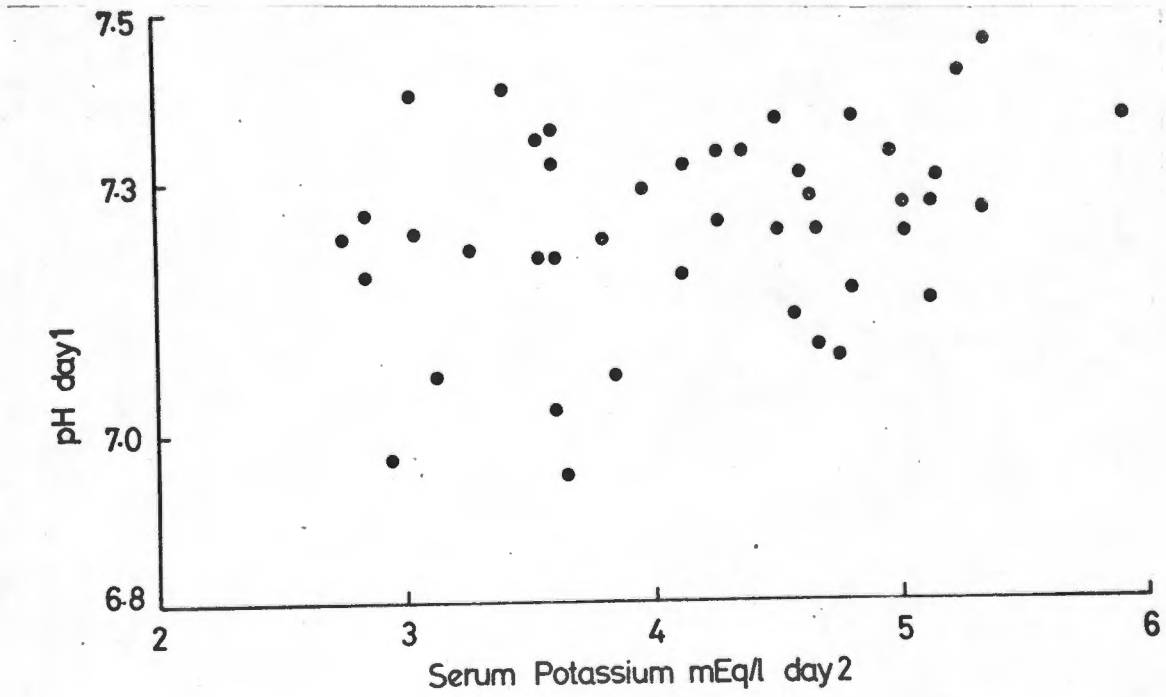


Fig.36. Gastroenteritis: The relationship between the serum potassium in mEq/l on day 2 and the pH on day 1.



admission was inversely related to the base excess (r = 0.404, p<0.01). On day 2 this relationship was only significant at the 10% level (r = 0.270).

The correlation coefficients and levels of significance are given in Table 29.

Table 29

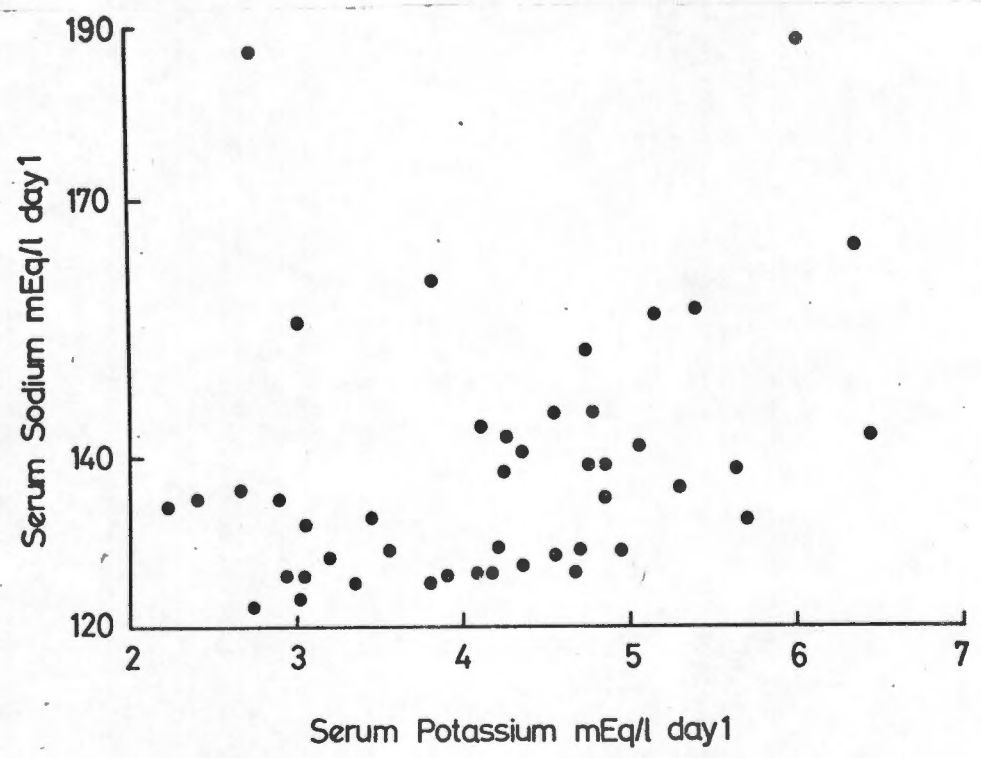
Correlations between acid-base status on admission and the serum electrolyte concentrations on day 1 and 2

Dependent Variable	Independent variable serum electrolyte mEq/l	day	r	p
pH	Na	1	-0.357	<0.05
	K	1	0.031	>0.1
	Cl	1	-0.391	<0.01
	Na	2	-0.188	>0.1
	K	2	0.375	<0.05
	Cl	2	-0.194	>0.1
pCO_2	Na	1	0.162	>0.1
	K	1	0.023	>0.1
	Cl	1	-0.022	>0.1
	Na	2	0.069	>0.1
	K	2	0.025	>0.1
	Cl	2	-0.205	>0.1
BE	Na	1	-0.229	>0.1
	K	1	0.041	>0.1
	Cl	1	-0.404	<0.01
	Na	2	-0.117	>0.1
	K	2	0.413	<0.01
	Cl	2	-0.270	<0.1

The serum sodium and potassium concentrations correlated significantly on day 1 (r = 0.313, p<0.05, Fig. 37), but not on day 2 (r = 0.060, p>0.1).

To exclude the possibility that abnormal serum sodium results were related to low, or high TBK values X^2 tests were

Fig.37. Gastroenteritis: The relationship between the serum sodium and potassium concentration on day 1.



performed in the same manner as in the PCM group. No significant relationship was found.

The mean and S.D. of the pH, pCO_2 and base excess are given in Table 30.

Table 30. Mean and S.D. of the pH, pCO_2 and base excess in gastroenteritis on admission

	Mean	S.D.
pH	7.25	0.12
pCO_2	32.0	9.0
BE	-11.3	6.8

The distribution, mean and S.D. of the serum sodium, potassium and chloride concentrations are given in Tables 32, 33 and 34 on pages 75, 76 and 77.

The relationship between TBK and serum electrolyte concentrations on admission in children suffering from acute pulmonary infections

No significant correlations were found between TBK and the serum sodium, potassium and chloride concentrations, or between the serum potassium concentration and the serum sodium and chloride values ($p>0.1$). X^2 tests failed to show any relationship between TBK and/or serum potassium and serum sodium. The correlation coefficients are given in Table 31.

Table 31

Correlations between TBK and serum potassium, and serum electrolyte concentrations in acute severe pulmonary infections

Dependent variable	Independent variable serum concentration (mEq/l)	r
TBK mEq/kg	Na	0.072
	K	0.241
	Cl	-0.091
TBK percent predicted	Na	0.200
	K	0.093
	Cl	0.220
serum K mEq/l	Na	0.202
	Cl	0.084

The distribution, mean and S.D. of the serum sodium, potassium and chloride results are given in Tables 32, 33 and 34.

Table 32

Distribution, mean and S.D. of serum sodium, results in PCM, gastroenteritis and pulmonary infections

Serum Na mEq/l	Number of cases			
	PCM	Gastroenteritis		Pulmonary infections
		day 1	day 2	
<115.0	0	1	0	0
115.0 - 119.9	2	0	0	0
120.0 - 124.9	6	4	0	0
125.0 - 129.9	6	15	4	8
130.0 - 134.9	14	3	12	11
135.0 - 139.9	13	9	12	9
140.0 - 144.9	10	5	7	5
145.0 - 149.9	2	2	5	5
150.0 - 154.9	2	1	3	1
155.0 - 160.0	1	3	1	2
>160.0	0	5	1	2
Mean	134.8	138.6	139.2	139.0
S.D.	8.6	15.2	8.8	10.5
No. of cases	56	48	45	43

Table 33 Distribution, mean and S.D. of serum potassium results in PCM, gastroenteritis and pulmonary infections

Serum K mEq/l	Number of cases			
	PCM	Gastroenteritis		Pulmonary infections
		day 1	day 2	
<2.00	0	2	0	0
2.00 - 2.49	1	5	0	1
2.50 - 2.99	3	8	2	1
3.00 - 3.49	11	4	4	1
3.50 - 3.99	20	8	10	4
4.00 - 4.49	8	11	6	3
4.50 - 4.99	6	5	13	8
5.00 - 5.45	5	2	8	10
5.50 - 5.99	1	3	2	10
6.00 - 6.49	0	0	0	4
6.50 - 7.00	0	0	0	1
>7.00	1	0	0	0
Mean	3.98	4.18	4.34	5.01
S.D.	0.87	1.07	0.75	0.95
No. of cases	56	48	45	43

Table 34

Distribution, mean and S.D. of serum chloride concentrations in pulmonary infections

Serum Cl mEq/l	Number of cases			
	PCM	Gastroenteritis		Pulmonary infections
		day 1	day 2	
<80.0	0	0	0	0
80.0 - 84.9	1	2	0	0
85.0 - 89.9	4	0	0	3
90.0 - 94.9	5	5	1	1
95.0 - 99.9	12	7	4	3
100.0 - 104.9	20	11	23	14
105.0 - 109.9	10	7	10	17
110.0 - 114.9	4	5	5	1
115.0 - 120.0	0	8	1	3
>120.0	0	3	1	1
Mean	101.1	106.2	105.0	104.7
S.D.	6.6	9.6	5.5	7.21
No. of cases	56	48	45	43

TBK and serum electrolyte concentrations in children who died

a. PCM

Six of the 56 cases of PCM died, all deaths occurring within 5 days of admission to hospital. One child, case 51 in Tables C-2 and C-5, had extensive consolidation of all lobes. Klebsiella was grown from swabs taken at autopsy. The remaining children all died suddenly. One child (case 52) had not received a potassium supplement, one (case 53) had received 13 mEq/kg/day and the other 3 cases (cases 54-56), 6 mEq/kg/day. No specific abnormalities which may have contributed to the sudden deaths of these children were found at autopsy.

Four of the 6 children had a TBK of less than 30 mEq/

kg. One of the 4 had a serum sodium of less than 130 mEq/l. The two children with TBKs of more than 30 mEq/kg had abnormal serum sodium results i.e. 116.6 and 158.4 mEq/l. The last case also had a low serum potassium, 2.56 mEq/l. In the other 5 children the range of serum potassium results was 3.03 to 3.70 mEq/l.

b. Gastroenteritis

The 3 children who died were markedly underweight. The TBK was lower than in most of the other cases, and the serum sodium was abnormal in the three children.

The children died 12 - 18 hours after admission, and autopsy showed cerebral vein thrombosis in two (cases 28 and 29). The remaining case (case 27) who had serum sodium of 97.6 mEq/l on admission, was found to have gross tissue overhydration.

None of the children suffering from pulmonary infections died.

DISCUSSION

In view of the large number of factors that can affect serum sodium concentrations, it is not surprising that there was no obvious relationship between TBK and the serum sodium concentration. The results do not exclude the possibility that potassium losses influence sodium metabolism particularly in children with persistent serum sodium abnormalities. Further total body sodium may be more important than the serum sodium concentration. In PCM where serum sodium is frequently low[99], negative sodium and water balance frequently occur in the first 7-10 days of treatment[120]. Garrow reports that of the biochemical abnormalities found in PCM, hyponatraemia has the worst prognosis[99].

The relationship between TBK and the serum chloride concentration in PCM raises the possibility that a relative, if not absolute chloride depletion may be present in this disease. If this is so it may be a cause or effect of potassium depletion, as potassium depletion results in chloride wasting and vice versa (Chapter 1). Another question raised by this correlation is the nature of the available anion as children with low TBKs tended to have low serum albumin concentrations (Chapter 3).

Another reason for the lack of a significant correlation between TBK and serum sodium may be the fact that "pure" potassium depletion does not occur in any of the illnesses studied. In the pulmonary group some of the children were underweight and/or had low serum albumin concentrations, all required oxygen and there is also the unknown effect of infection. In gastroenteritis acid-base disturbances, alterations in organ and tissue perfusion following dehydration, and the nature of the stool

losses almost certainly override the effects of potassium depletion during the acute stages. Protein-calorie malnutrition is a combination of a wide variety of deficiency states.

The correlation between the percentage predicted TBK and the serum potassium concentration in gastroenteritis on day 2 may be useful in clinical practice. A normal serum potassium concentration does not indicate that TBK is not low because, as shown previously, almost all the children had low TBKs when expressed as a percentage of the predicted value.

The relationship between TBK, in mEq/kg and as a percentage of the predicted value and the pH, pCO_2 and base excess are interesting. The significant correlation between TBK in mEq/kg and pCO_2 and the absence of a significant correlation with pH and base excess can be explained in many ways. If it is accepted that a low TBK indicates that excessive potassium losses have occurred, the relationships may be the result of the duration of the acidosis. The lower pCO_2 and TBK results would be present in children who have compensated to some extent to the acidosis, while the base excess had been altered by renal excretion of excess hydrogen ions. These factors could account for the lack of a correlation between TBK and pH. Another possibility is that the lower TBKs were present in the well nourished (fatter) children who compensated to the acidotic state better than the malnourished (thinner) cases. (There was a negative correlation between TBK in mEq/kg and percentage expected weight for age, Chapter 3, page 52).

The latter seems the more likely explanation as the percentage predicted TBK which takes the quantity of fat into consideration did not correlate with the pCO_2, but did correlate

with the pH and base excess. The correlation between the percentage predicted TBK and pH and base excess suggests that the low TBK values in mEq/kg found in gastroenteritis are due, not only to stool losses but also to the intracellular displacement of potassium by hydrogen ions. The fat free body weight appears to be important perhaps because of the buffering capacity of the proteins. The relationship is most easily expressed in the following manner.

Let w = fat free body weight
x = observed TBK (mEq/kg)
y = predicted TBK (mEq/kg)
z = base excess (mEq/l)

a and b are constants

$x \neq f(z)$

$\frac{x}{y} = f(z)$

$= az + b$

$\therefore x = y(az + b)$

$= f(y,z)$

but $y = f(w)$

$\therefore x = f(w,z)$

z can equally well be the pH (rather than base excess) and the same reasoning followed.

i.e. there is a relationship between the TBK in mEq/kg, the pH (or base excess) and the fat free body weight.

It is difficult to determine the frequency of abnormal serum sodium concentrations in "pure" PCM because of the high incidence of infections. The PCM cases selected for this study did not have severe gastroenteritis or pulmonary infections on admission, i.e. they did not require additional oral or intravenous fluids to maintain hydration and there was no clinical or radiological evidence of a pulmonary infection. These facts and the similarity between the values in this study and those reported from Jamaica[7,8,13,14,15,95,96,180,182] suggest the TBK and serum electrolyte results and the relationship found are true for most cases of PCM of the kwashiorkor type, who do not have severe infections.

Garrow[99] has reported the changes in TBK of one case of infantile gastroenteritis during recovery. He found that TBK returned to normal more rapidly than in PCM. (This is in contrast to the findings presented in Chapter 3. The difference is probably due to differences in the duration and severity of the diarrhoea). However, there are numerous reports on acid-base status and serum electrolyte values in gastroenteritis. The pH of the children in this study is similar to, or slightly higher than, the values reported elsewhere. The pCO_2 and base excess levels are quite markedly higher in this study [5,22,127,150]. The serum electrolyte results are similar to most of those from Cape Town and other centres, apart from the extremely high incidence of hypernatraemia in some studies [4,22,35,51,60,79,80,81,99,143,144,149,164,195,196,224,236]. The extremely high incidence of hyponatraemia (11 out of 20 cases) found in the children admitted to the metabolic unit may be due to the frequency of specific E.coli infections[237]. Only

the 4 children with serum sodium values greater than 150 mEq/l did not have one of these bacteria isolated from the stool. Of these 4, one had Salmonella johannesburg, one had Giardia lamblia and in two no pathogen was isolated.

Thus, it appears that the children suffering from gastroenteritis may not be "typical cases" as the acidosis was not as severe and there was a very high incidence of specific E.coli infections. In view of the relationships found between TBK and acid-base status, it would appear that TBK levels may be lower in more acidotic children.

Shrivastava has reviewed the literature on serum sodium abnormalities. As his series and previous studies investigated a much wider age range, it is not possible to draw any definite conclusions. However, all studies tended to show hyponatraemia and hyperkalaemia.

It has been suggested that the hyponatraemia may be related to adrenal hypofunction[222]. The children in this study tended to have hypernatraemia rather than hyponatraemia. This may be due to the greater severity of the illness and greater water losses associated with tachypnoea, and because children who had a history of diarrhoea and/or vomiting were excluded. The pulmonary infection group is probably representative of children who are extremely ill and who have no diarrhoea, vomiting or clinical evidence of kwashiorkor.

SUMMARY

No relationship was found between the TBK and/or the serum potassium concentration and the serum sodium concentration. In gastroenteritis, TBK and serum electrolyte levels were related to the acid-base status on admission. Hyponatraemia was a more frequent finding than hypernatraemia in PCM and in gastroenteritis, while in pneumonia the reverse was true.

The PCM and pulmonary infection groups are probably representative of most children who are suffering from these illnesses and who do not have other illnesses. The gastroenteritis cases were not as acidotic as those reported from other centres, and of the 20 studied in detail, 15 had specific E.coli infections.

Chapter 5 THE EFFECT OF POTASSIUM SUPPLEMENTATION ON TOTAL BODY WATER AND EXTRACELLULAR FLUID VOLUME IN PROTEIN-CALORIE MALNUTRITION

Potassium depletion and an expansion in extracellular fluid volume are known to occur in PCM[7,8,37]. Because of reports indicating a relationship between potassium depletion and changes in ECFV, as discussed in the Review of the Literature, the effect of potassium supplementation on ECFV in malnourished children was investigated.

CLINICAL MATERIAL AND METHODS

Initially four children suffering from kwashiorkor were studied. The thiosulphate space was measured on the morning after admission and 48 hours later. They received a protein-free diet containing 3 mEq potassium/kg/day until after the second determination. A supplement of potassium chloride supplying 6 mEq potassium/kg/day was commenced immediately after the first determination.

A further 12 children received 120 ml/kg/day of a liquid diet supplying 0.75 grams protein and approximately 3 mEq potassium/kg/day commencing immediately after the first determination. Six of the children were given an additional 6 - 8 mEq potassium/kg/day. In these 12 children the thiosulphate space was measured on the morning after admission, 72 hours later and again when the serum albumin had been normal for 2 weeks. TBK was measured immediately after each thiosulphate space determination. Four children in each of the protein-fed groups had simultaneous total body water determinations using the deuterium oxide dilution technique.

RESULTS

(A) Protein-free group

In three of the four children it was impossible to estimate thiosulphate space on day 5 because of pronounced deviation from linearity of the disappearance curve.

(B) Protein-fed group

The mean values of thiosulphate space in the groups on each day are given in Table 35. Figure 38 shows the changes in thiosulphate space with time.

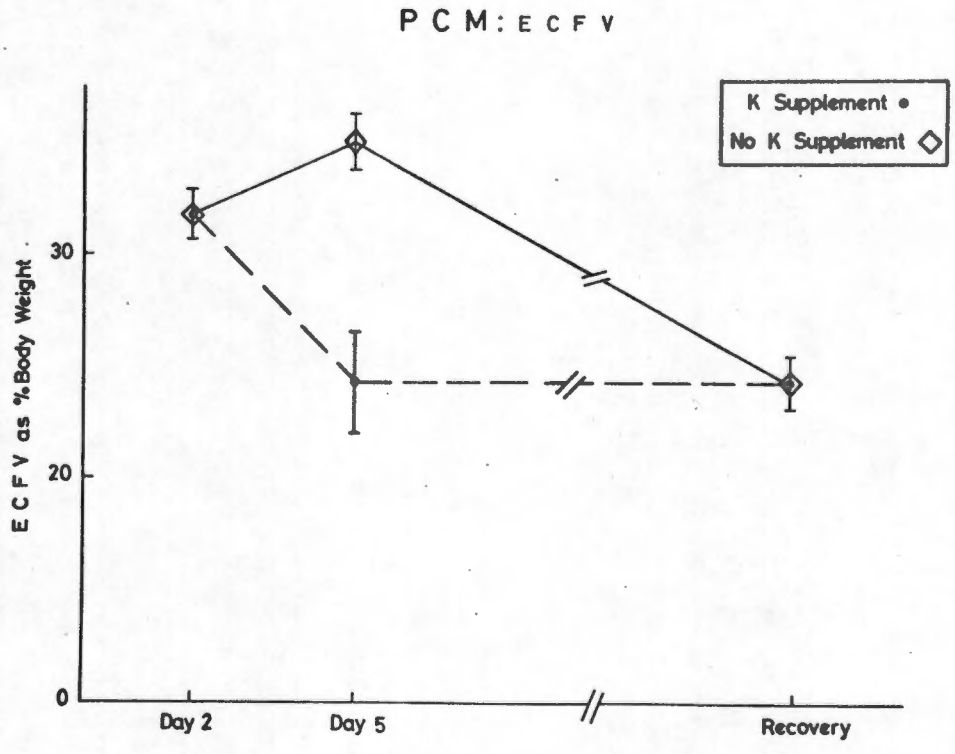
Table 35

Mean and SD of thiosulphate space on day 2, day 5 and recovery

	Day	Mean	SD
Non-supplemented	2	31.61	2.29
	5	35.13	2.12
	recovery	24.81	1.79
Supplemented	2	32.11	2.39
	5	24.27	5.47
	recovery	23.82	2.98
All cases	2	31.86	2.25
	recovery	24.32	2.40

There was no difference in the thiosulphate spaces of the two groups on admission ($p<0.05$, two-tailed). However, on day 5 there was a slight but significant rise in the thiosulphate space of the group which did not receive potassium supplements when compared to admission values ($p< 0.025$, one-tailed). In contrast, the potassium supplemented group showed a fall in the thiosulphate space, the mean value being the same as that on recovery ($p <0.01$, one-tailed). There was a marked difference between the groups

Fig.38. PCM: The effect of potassium supplementation on thiosulphate space.



on day 5 ($p<0.005$, two-tailed), but not on recovery. The degree of oedema present in the two groups of children on day 5 is shown in Table 36.

Table 36

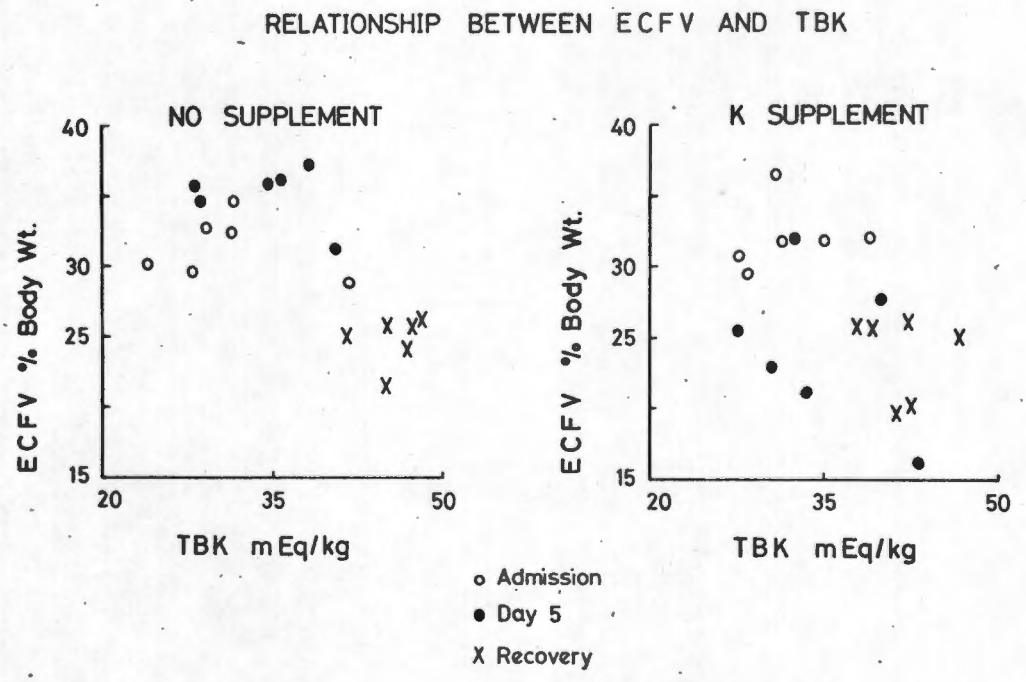
Degree of oedema on day 4

Degree of oedema	Nil	Trace	+	++	+++
Potassium supplement	1	3	1	1	0
No supplement	0	2	1	1	2

Most of the children who received a potassium supplement were still oedematous although the severity of the oedema was less than in those who did not receive the supplement. The relationship between total body potassium and thiosulphate space is shown in Fig. 39.

The results of the group who did not receive a supplement indicates that retention of potassium is not necessarily associated with the decrease in thiosulphate space, while the potassium supplemented group indicates that there can be a marked reduction in thiosulphate space with the same degree of potassium retention. There were no differences between the TBKs of the two groups at any stage ($p < 0.05$). Similarly, there was no difference at 5% level between the serum potassium concentrations of these two groups. However, the difference on day 5 was closer to significance than the differences on day 2 and recovery ($p < 0.1$ and < 0.3 respectively). The slopes of the disappearance curve which are a function of excretion and metabolism of thiosulphate did not differ on day 2 or recovery ($p<0.05$), but did

Fig.39. PCM: The relationship between TBK in mEq/kg and thiosulphate space.



on day 5 ($p < 0.05$). The slopes of the supplemented group were the same as those in the recovered cases, while those of the non-supplemented children were similar to the admission values ($p\ 0.05$).

Of the 8 children who had total body water determinations all the values on admission were greater than the values for the same child on recovery. All the children with the exception of one who did not receive a supplement, had a decrease in total body water between day 2 and day 5. The non-supplemented group reduced the values to approximately the same as those on recovery while the supplemented group had a slightly lower level than on recovery. (Because of the small numbers involved, no statistical tests were applied and the differences found between the two groups of 6 children must also be treated with circumspection).

DISCUSSION

It is not known why 3 of the 4 children who did not receive potassium should show marked deviations from linearity of the disappearance curve of thiosulphate. Friis-Hansen[79] has reported this previously in normal children where it is an infrequent occurrence and suggests three possible explanations.

1. a temporary stoppage or decrease in renal excretion
2. movements of water from one phase of the extracellular phase to another from which thiosulphate is excluded
3. the occurrence of reopening circulation in certain areas of the body when the circulation has been temporarily slowed down at a time when the blood concentration was high.

However, he is unable to provide the definite answer. It seems strange that this should only have occurred in the children who

did not receive protein but it is not known why this should be so. The remaining case shows that a reduction in thiosulphate space can occur when no protein is given. This finding was suggested by the reports that negative sodium and water balance could be initiated by potassium alone in the absence of nitrogen[119,120]. The response to potassium supplementation and the absence of a response when no supplements were given strongly suggests that the expanded extracellular fluid volume found in PCM is related to potassium depletion. As there was no obvious relationship between potassium retention and changes in thiosulphate space by day 5, it seems probable that changes in serum potassium concentration rather than total body potassium are responsible for the reduction. It is well-known that once potassium depletion exists, the impairment of renal function is closely related to serum potassium levels, the function returning to normal when the serum potassium is greater than 4.5 mEq/l[117]. The fact that there were differences between the slopes of the disappearance curves of the supplemented children compared to the non-supplemented children on day 5 is further evidence that there is an alteration in renal function. The reason for the change in renal function is not known. It may be due to an alteration in glomerular filtration rate or to an alteration in the renal tubular function. Alleyne[7] has shown that glomerular filtration rate is markedly reduced on admission.

The changes in thiosulphate space are almost certainly not "apparent changes" due to differences in the excretion rate. If anything, the changes in the slope of the disappearance curves of these children would tend to under-estimate the differences in thiosulphate space.

The presence of oedema on day 5 in the potassium supplemented children when the thiosulphate space was apparently normal, may be due to an alteration in the distribution of fluid between the intravascular and extravascular compartments of the extracellular fluid with a relative excess of fluid in the extravascular phase. Another possibility is that the distribution of the ion within the extracellular fluid may have been altered by potassium supplementation.

The possibility of alterations in renal function and in the distribution of the fluid within the intravascular compartment can only be established by further investigations using Inulin. It is unlikely that a bromide dilution technique would provide an answer to the distribution questions as it is possible that bromide enters the cell during the early stages of recovery.

Like the extracellular fluid volumes, the total body water values found on admission and recovery are similar to those reported previously, the admission values being increased and the recovery values almost "normal".(7,8,37,50,79,80,81,118, 122,254). The change in total body water between day 2 and day 5 appears to be excessive and it is probably an apparent change rather than a true change. If the results do in fact represent the true total body water on each day, it would mean that there is an increase of approximately 200 gms/kg in total body solids between day 2 and day 5. It seems more likely that the day 5 results are falsely low; possibly because of deuterium ions which had previously replaced hydrogen ions in protein and so reduced the effective deuterium "space". However, the serum deuterium concentrations prior to the injection of deuterium on day 5 were below the detectable limits. If the

change had only occurred in those children who had received a potassium supplement, they could have been explained on the basis that parts of the circulation had closed down in response to potassium supplementation resulting in falsely low total body water and extracellular fluid volume. However, the fact that they occurred also in 3 of the 4 children who did not receive supplements indicates that this is not the answer.

SUMMARY

In children receiving a total intake of 3 mEq potassium/kg/day, thiosulphate space increased between day 2 and day 5, while in children who received a total intake of 9 mEq/kg/day there was a fall in thiosulphate space to normal levels during the same time interval. These findings, together with previous reports, strongly suggest that the expanded extracellular fluid volume found in PCM is due to potassium depletion. The response to potassium supplementation is probably the result of changes in serum potassium levels rather than changes in total body potassium. Total body water fell in 7 of the 8 children investigated. Potassium supplementation did not appear to have any obvious effect. The results on day 5 appear to be lower than normal. The reason for this is not known.

Chapter 6

THE EFFECT OF POTASSIUM SUPPLEMENTATION ON GLUCOSE TOLERANCE AND SERUM INSULIN LEVELS IN PCM

The relationship between potassium and glucose tolerance and serum insulin is not as well defined as that between potassium and water metabolism. In view of the severity of the potassium depletion occurring in children suffering from kwashiorkor it was decided to investigate the effect of potassium supplementation on glucose tolerance and serum insulin levels in these children.

CLINICAL MATERIAL

The children were treated in the same way as described in Chapter 3, i.e. they all received 120 ml/kg/day of a liquid diet supplying 0.75 grams of protein/kg/day and 0.3 mEq potassium/kg/day from day 2 until day 5. From day 5 to day 9 the protein intake was increased to 1 gram/kg/day, the potassium content remaining the same. After day 9 solid foods were introduced, the protein and potassium content becoming variable but being greater than 1 gram/kg/day and 3 mEq/kg/day respectively.

Six of the 20 children received no potassium supplements. The remainder received potassium supplement of 13 mEq/kg/day. Serum potassium levels were checked daily. None of the levels rose above 6 mEq/l.

Glucose tolerance test

Intravenous glucose tolerance tests were performed on day 2, day 5, day 9, day 13 and again when serum albumin had been normal for 2 weeks. Blood glucose and serum insulin levels were measured immediately before the injection of glucose

(1g/kg of a 25% dextrose solution) and 5, 20, 45, 60 and 90 minutes after injection. The fasting total protein, serum albumin and serum electrolyte concentrations were also measured. Detailed results are given in Table C-9 of Appendix C.
One child developed measles approximately 5 weeks after admission and was not investigated on "recovery". The number of cases in the supplemented and non-supplemented groups on admission, day 5, day 9, day 13 and recovery, are given in Table 37.

Table 37 Number of cases in the supplemented and non-supplemented groups

Day	Supplemented group	Non-supplemented group
2	12	6
5	12	6
9	5	6
13	5	6
Recovery	11	6

RESULTS

The most marked feature was the variation within an individual during recovery. There seemed to be no pattern to the changes which occurred in supplemented and non-supplemented children. As examples of the variations, the changes in the glucose disappearance rate constant (kg) and in the insulin area of one child, are shown in Figs. 40 and 41.

Effect of potassium supplementation

When the admission values of the supplemented and non-supplemented groups were compared, no differences were found ($p>0.1$).

Fig.40. PCM: Variations in the glucose disappearance rate constant in one child during recovery.

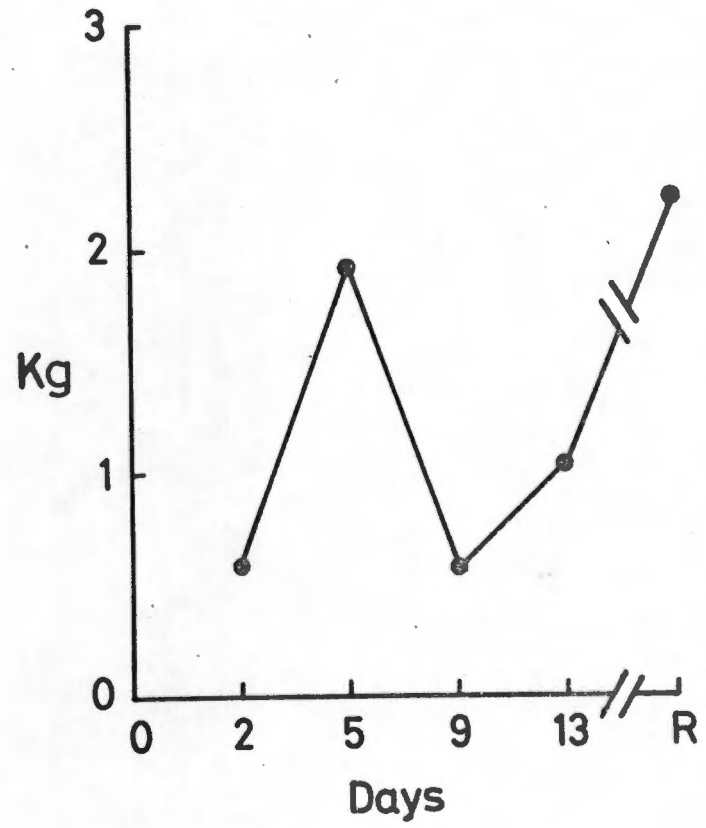
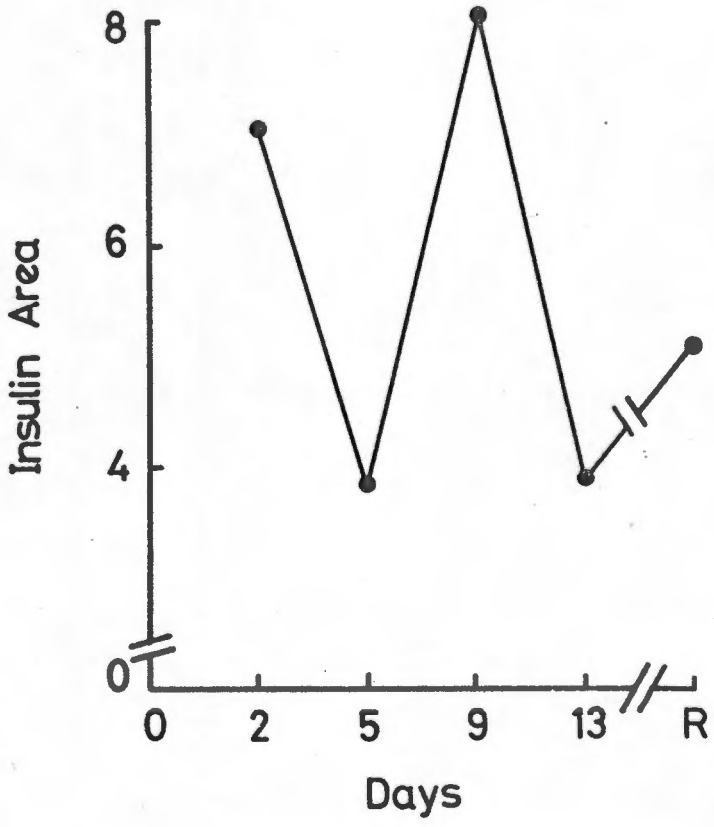


Fig.41. PCM: Variations in the insulin area of one child during recovery.



a. Glucose tolerance

The fasting blood glucose of the supplemented cases was higher than that of the non-supplemented cases on day 5 ($p<0.01$). No other differences were found between the supplemented and non-supplemented cases at any stage ($p>0.1$) i.e. there were no differences between the Kg, glucose area, blood glucose concentrations at 5, 20, 45, 60 and 90 minutes after injection, or between the fasting blood glucose levels (except on day 5).

b. Serum insulin concentration

The 5 and 20 minute insulin concentrations on day 5 were higher in the supplemented group than in the non-supplemented group ($p<0.01$ and $p<0.05$). These differences probably account for the larger insulin area and I/G ratio in the supplemented cases ($p<0.025$).

The fasting, 45, 60 and 90 minute insulin concentrations did not differ.

Correlations between blood glucose concentrations, Kg and glucose are and TBK, serum electrolytes and albumin on admission

The Kg correlated with the TBK in mEq/kg ($p<0.01$, Fig. 42), the total serum protein ($p<0.01$) and the serum albumin ($p<0.001$, Fig. 43). The glucose area was inversely related to the Kg (p 0.01, Fig. 44), and to the TBK in mEq/kg ($p<0.05$, Fig. 45).

The correlation coefficients and levels of significance for the regressions are given in Table 38.

Fig.42. PCM: The relationship between the glucose disappearance rate constant and the TBK in mEq/kg on admission.

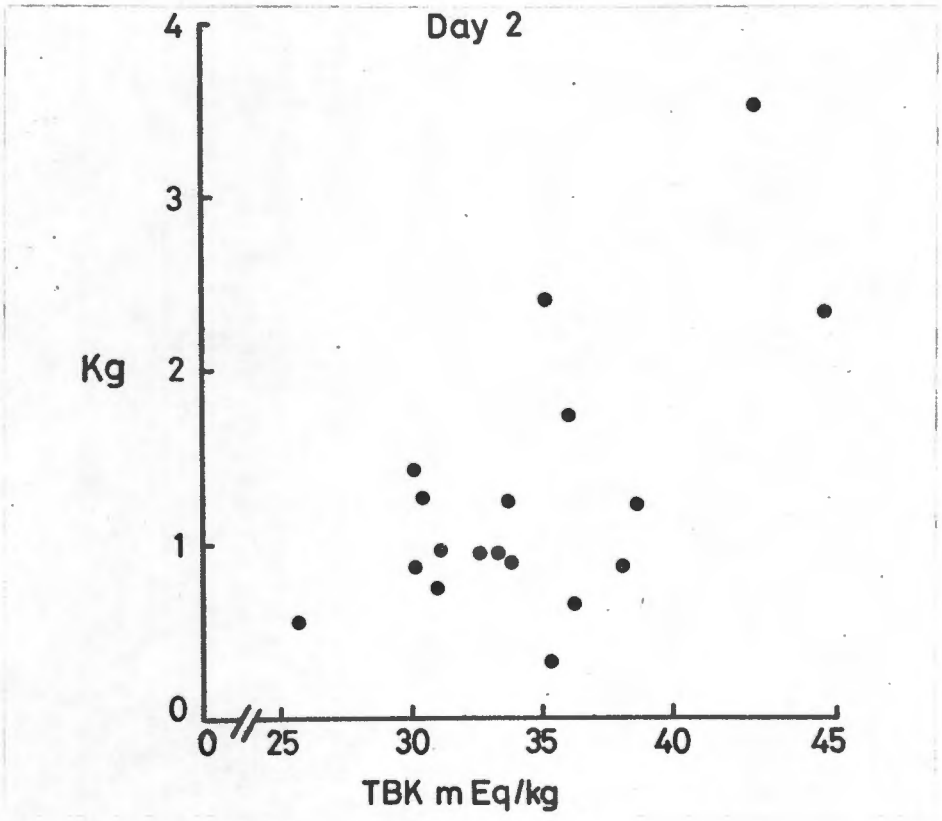


Fig.43. PCM: The relationship between the glucose disappearance rate constant and the serum albumin in g/100ml on admission.

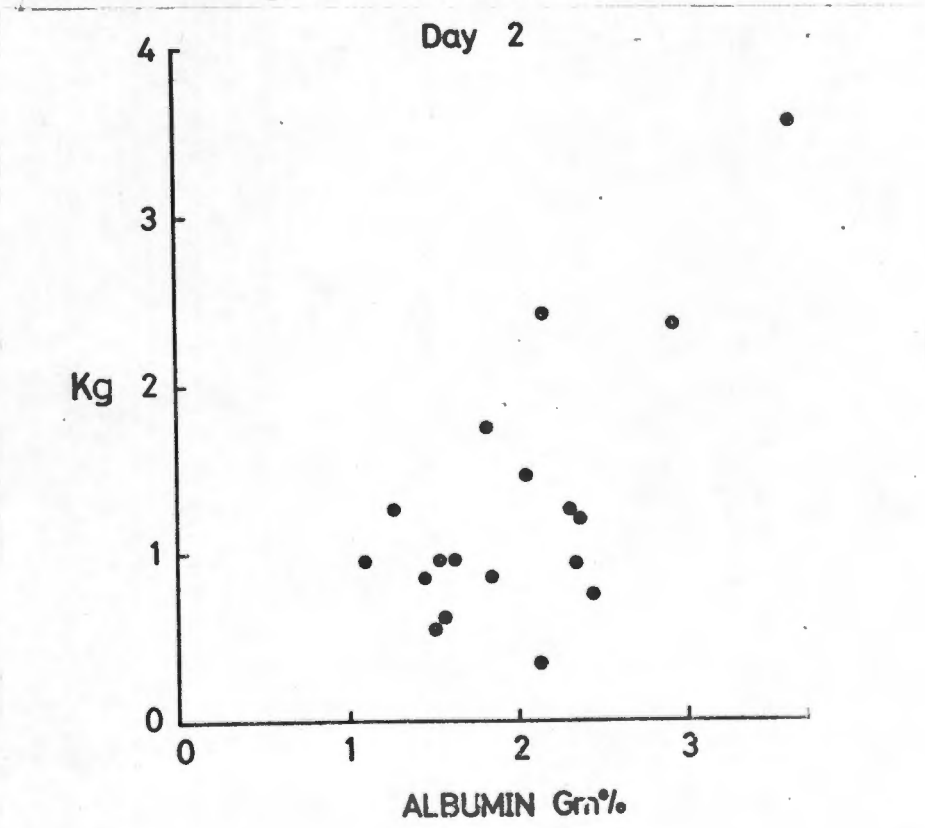


Fig.44. PCM: The relationship between the glucose area and the glucose disappearance rate constant on admission.

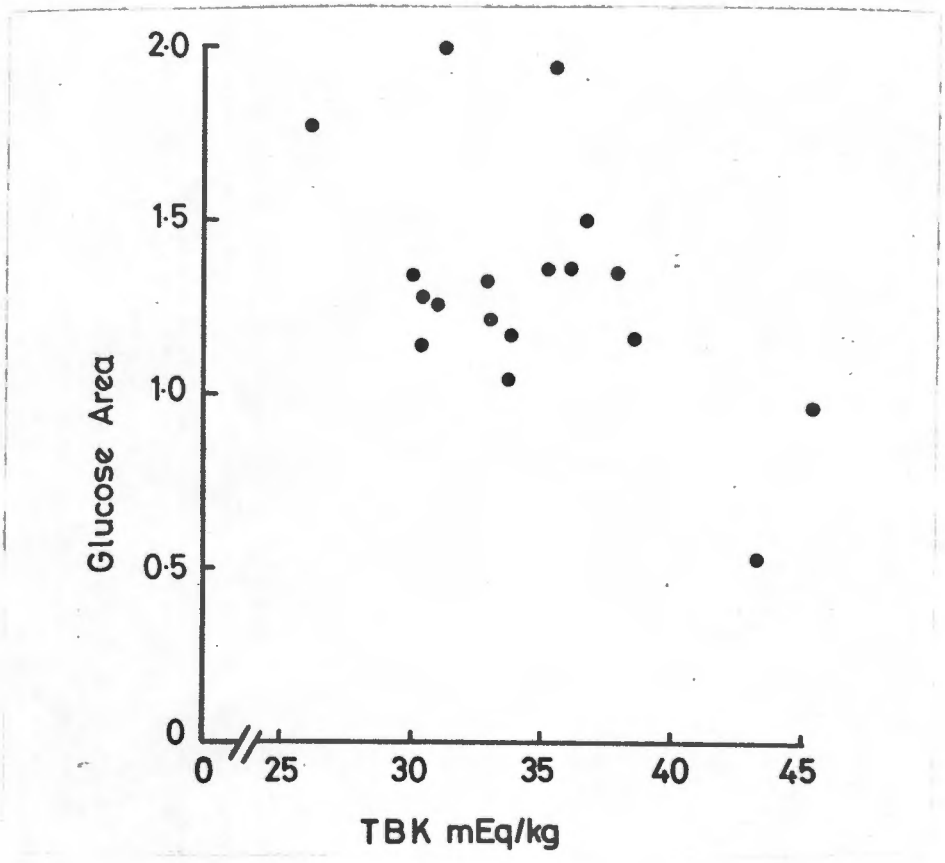


Fig.45. PCM: The relationship between the glucose area and the TBK in mEq/kg on admission.

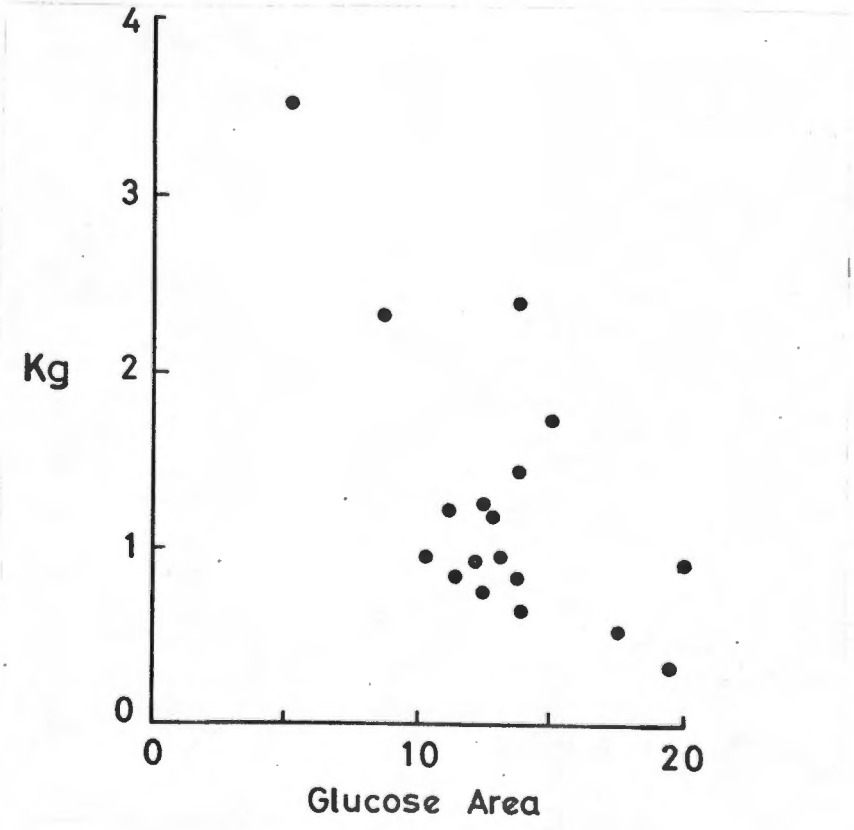


Table 38. Correlations between Kg and glucose area, and TBK, serum electrolyte, total protein and albumin concentrations (18 cases)

Dependent variable	Independent variable	r	p
Kg	TBK mEq	0.379	>0.1
	TBK mEq/kg	0.626	<0.01
	Serum Na mEq/l	0.357	>0.1
	K	-0.071	>0.1
	Cl	0.139	>0.1
	Total protein g/100ml	0.687	<0.01
	albumin g/100ml	0.746	<0.001
Glucose area	TBK mEq	-0.256	>0.1
	TBK mEq/kg	-0.565	<0.05
	Serum Na mEq/l	-0.211	>0.1
	K	0.320	>0.1
	Cl	0.028	>0.1
	Total protein g/100ml	-0.443	<0.1
	Albumin g/100ml	-0.377	>0.1
Kg	Glucose area	-0.659	<0.01

Correlations between serum insulin concentrations, insulin area, and I/G ratio and TBK, serum electrolyte, total protein and albumin concentrations on admission

The insulin area correlated with TBK in mEq and mEq/kg ($p<0.01$, Fig. 46) and with the total serum protein ($p<0.001$), and serum albumin concentration ($p<0.05$). The correlations between I/G ratio and these variables were very similar.

The correlation coefficients and levels of significance are given in Table 39.

Fig.46. PCM: The relationship between insulin area and TBK in mEq/kg on admission.

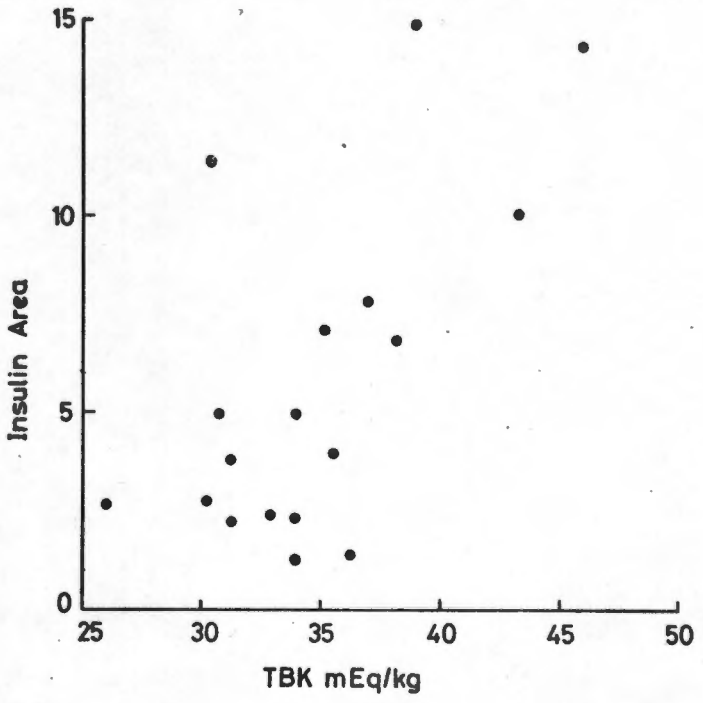


Table 39 Correlations between insulin area and I/G ratio and TBK, serum electrolyte, total protein and albumin concentrations (18 cases)

Dependent variable	Independent variable	r	p
Insulin area	TBK mEq	0.595	<0.01
	TBK mEq/kg	0.630	<0.01
	Serum Na	0.046	>0.1
	K	0.171	>0.1
	Cl	-0.008	>0.1
	Total protein	0.719	<0.001
	Albumin	0.588	<0.05
I/G ratio	TBK mEq	0.513	<0.05
	TBK mEq/kg	0.763	<0.001
	Serum Na	0.146	>0.1
	K	0.001	>0.1
	Cl	0.010	>0.1
	Total protein	0.817	<0.001
	Albumin	0.786	<0.001
Insulin area	I/G ratio	0.868	<0.001
Glucose area	I/G ratio	-0.661	<0.01

The fasting blood glucose correlated with the 20 and 45 minute glucose concentrations ($p<0.05$). There was no relationship between the fasting glucose concentration and the Kg, glucose area, TBK or serum electrolyte and protein concentrations ($p>0.1$).

The correlation coefficients are given in Table 40.

Table 40 Correlation between fasting blood glucose (mg/100ml) and TBK, serum electrolyte and serum protein concentrations ($p>0.1$).

Independent variable	r
TBK mEq	0.371
TBK mEq/kg	0.348
Serum Na	-0.243
K	0.212
Cl	-0.321
Total protein	0.148
Albumin	0.151
Kg	-0.024
Glucose area	0.093

The 5 minute glucose and the serum potassium concentrations were related at the 10% level ($r = 0.414$). The 45 minute glucose concentration correlated inversely with the TBK in mEq/kg, the serum sodium concentration and the total protein concentration at the same level, i.e. 10% ($r = 0.449$, $r = 0.405$, $r = -0.424$, respectively). There was a very similar relationship between the 60 minute glucose level and these 3 variables ($r = -0.448$, $r = -0.421$, $r = 0.449$, respectively).

There was an inverse correlation between the 90 minute glucose concentration and TBK in mEq/kg ($p<0.1$) and total protein ($p<0.05$) but not serum sodium. While relatively few of the correlation tests are significant, possibly because of small numbers, and the multiplicity of factors affecting glucose metabolism, the changes in the correlation coefficients at the various times may be of importance. The simple correlation coefficients are given in Table 41.

Table 41 The correlations between blood glucose (mg/100ml) at time t (mins) and the TBK, serum electrolyte, total protein and albumin concentrations

Independent variable	t	r
TBK mEq	20	0.220
	45	-0.077
	60	-0.149
	90	-0.355
TBK mEq/kg	20	-0.226
	45	-0.449
	60	-0.448
	90	-0.423
Serum Na mEq/l	20	-0.257
	45	-0.404
	60	-0.421
	90	-0.245
Serum K mEq/l	20	0.388
	45	0.254
	60	0.255
	90	0.150
Serum Cl mEq/l	20	-0.172
	45	-0.175
	60	-0.194
	90	-0.146
Total protein	20	-0.137
	45	-0.424
	60	-0.449
	90	-0,521
Serum albumin	20	-0.114
	45	-0.380
	60	-0.388
	90	-0.411

The fasting serum insulin concentration did not correlate with TBK, serum electrolyte or serum protein concentrations ($p>0.1$). There was a correlation between the TBK in mEq and mEq/kg at 5, ($p<0.05$), 20 ($p<0.05$ and $p<0.01$) and 45 minutes ($p<0.01$) but not at 60 and 90 minutes ($p>0.1$).

The relationship between the serum insulin concentration and total serum protein or serum albumin was similar. The correlation coefficients and levels of significance are given in Table 42.

Table 42

Correlations between serum insulin concentrations at time t mins after injection and the TBK, total protein and albumin concentrations

Independent variable	t	r	p
TBK mEq	5	0.541	<0.05
	20	0.530	<0.05
	45	0.595	<0.01
	60	0.375	>0.1
	90	0.373	>0.1
TBK mEq/kg	5	0.555	<0.05
	20	0.642	<0.01
	45	0.670	<0.01
	60	0.134	>0.1
	90	0.003	>0.1
Total serum protein	5	0.619	<0.01
	20	0.713	<0.001
	45	0.646	<0.01
	60	0.274	>0.1
	90	0.157	>0.1
Albumin	5	0.494	<0.05
	20	0.593	<0.01
	45	0.571	<0.05
	60	0.222	>0.1
	90	0.062	>0.1

The relationship between the insulin electrolyte concentrations tended to be the reverse, with no correlation at 5, 20, and 45 minutes while some of the 60 and 90 minute correlations were significant. The correlation coefficients are given in Table 43.

Table 43

Correlations between serum insulin concentrations at time t and the serum electrolyte concentrations

Independent variable	t	r	p
Serum Na	5	-0.054	>0.1
	20	-0.094	>0.1
	45	-0.141	>0.1
	60	-0.565	<0.05
	90	-0.512	<0.05
Serum K	5	0.113	>0.1
	20	0.038	>0.1
	45	0.465	<0.1
	60	0.223	>0.1
	90	0.268	>0.1
Serum Cl	5	0.059	>0.1
	20	0.094	>0.1
	45	-0.141	>0.1
	60	-0.341	>0.1
	90	-0.530	<0.05

Correlations between blood glucose concentrations, Kg and glucose area and serum insulin concentrations and insulin area on admission

The 45 and 60 minute concentrations correlated with the 90 minute insulin concentrations ($r = 0.508$ and $r = 0.494$, $p<0.05$ respectively). The 60 minute glucose concentrations were inversely related to 20 minute insulin concentrations ($p<0.05$) and to a lesser extent to 5 minute level ($p<0.1$). There was a negative correlation between the 90 minute glucose value and

the 5, 20 and 45 minute insulin concentrations ($p<0.05$).

The Kg correlated with the serum insulin levels at 5 minutes ($p<0.05$), 20 minutes and 45 minutes ($p<0.01$). It also correlated with the glucose area ($p<0.01$, negative correlation), insulin area ($p<0.05$) and I/G ratio ($p<0.001$). The 20 minute insulin concentration was inversely related to the glucose area ($p<0.05$). There was no correlation between glucose area and any of the other insulin concentrations or between glucose area and insulin area ($p>0.1$).

Correlations between blood glucose concentrations, Kg and glucose area and TBK, serum electrolyte, total protein and albumin concentrations on day 5

The Kg correlated with the TBK in mEq/kg ($p<0.05$) and with the serum potassium concentration ($p<0.01$). There was no relationship between the Kg and total protein or serum albumin ($p>0.1$).

The correlation coefficients and levels of significance are given in Table 44.

Table 44 Correlation between Kg and TBK, serum electrolyte, total protein and albumin concentrations on day 5 (12 cases)

Independent variable	r	p
TBK mEq	0.168	>0.1
TBK mEq/kg	0.621	<0.05
Serum Na	-0.048	>0.1
K	0.791	<0.01
Cl	-0.203	>0.1
Total protein	0.283	>0.1
Albumin	0.278	>0.1

The glucose area correlated with the TBK in mEq/kg ($p<0.01$) but not with the serum potassium concentration ($p>0.1$).

The correlation coefficients are given in Table 45.

Table 45 Correlation between glucose area and TBK, serum electrolyte and protein concentrations on day 5

Independent variable	r	p
TBK mEq	0.089	>0.1
TBK mEq/kg	-0.736	<0.01
Serum Na	-0.324	<0.1
K	-0.356	>0.1
Cl	-0.263	>0.1
Total protein	-0.147	>0.1
Albumin	-0.213	>0.1
Kg	-0.396	>0.1

There was no relationship between the fasting glucose concentration and any of the above variables ($p>0.1$).

The later blood glucose concentrations and the TBK, serum electrolyte protein and albumin concentrations were related in about the same manner as they were on admission (Table 46).

Table 46

Correlations between blood glucose concentration at time t, and the TBK, serum electrolyte, total protein and albumin concentrations (12 cases)

Independent variable	t (mins	r	p
TBK mEq	20	0.079	>0.1
	45	-0.057	>0.1
	60	-0.165	>0.1
	90	-0.484	>0.1
TBK mEq/kg	20	-0.504	<0.1
	45	-0.686	<0.05
	60	-0.695	<0.05
	90	-0.581	<0.005
Serum Na mEq/l	20	-0.246	>0.1
	45	-0.092	>0.1
	60	-0.074	>0.1
	90	-0.067	>0.1
Serum K mEq/l	20	-0.504	<0.1
	45	-0.590	<0.05
	60	-0.621	<0.05
	90	-0.380	>0.1
Serum Cl mEq/l	20	0.150	>0.1
	45	0.183	>0.1
	60	0.256	>0.1
	90	0.540	<0.1
Total protein	20	-0.033	>0.1
	45	-0.215	>0.1
	60	-0.282	>0.1
	90	-0.340	>0.1
Albumin	20	-0.055	>0.1
	45	-0.247	>0.1
	60	-0.277	>0.1
	90	-0.217	>0.1

Correlations between serum insulin concentrations, insulin area and I/G ratio and TBK, serum electrolyte, total protein and albumin concentrations on day 5

The insulin area did not correlate with TBK, serum electrolyte, total protein or albumin concentrations ($p>0.1$). The correlations between I/G ratio and TBK in mEq/kg and serum albumin were only significant at the 10% level.

The fasting serum insulin correlated with the total protein ($p<0.05$) and the serum albumin concentrations ($p<0.01$) and with insulin area and I/G ratio ($p<0.01$).

The 5 minute insulin concentration correlated with TBK in mEq/kg ($p<0.05$) but not with the serum electrolyte or protein levels. At the later times the correlations varied as described previously. The values are given in Table 47.

Table 47 Correlation between serum insulin concentrations at time (t), and the TBK, serum electrolyte, total protein and albumin concentrations

Independent variable	t	r
TBK mEq	0	0.142
	5	0.491
	20	0.220
	45	0.600*
	60	0.524°
	90	0.455
TBK mEq/kg	0	0.316
	5	0.668*
	20	0.032
	45	-0.269
	60	-0.269
	90	-0.135
Serum Na	0	-0.202
	5	-0.044
	20	-0.330
	45	-0.412
	60	-0.303
	90	-0.261
Serum K	0	0.093
	5	0.357
	20	0.269
	45	-0.327
	60	-0.447
	90	-0.142
Serum Cl	0	-0.161
	5	-0.214
	20	-0.154
	45	-0.589*
	60	-0.339
	90	-0.106

* $p<0.05$

° $p<0.1$

Correlations between blood glucose concentrations, Kg and glucose area and serum insulin concentrations, and insulin area on day 5

There was no correlation between the Kg and the glucose area, insulin area or I/G ratio ($p>0.1$). The Kg and the glucose area correlated with the 5 minute serum insulin concentration ($p<0.05$) and, at the 10% level, with the 20 minute serum insulin. There was no relationship between the glucose and insulin areas ($p>0.1$).

The 45, 60 and 90 minute blood glucose concentrations correlated with the insulin levels at 5 minutes ($p<0.05$) and 20 minutes ($p<0.1$).

Correlations between blood glucose concentration, Kg and glucose area and TBK, serum electrolyte, total protein and albumin concentrations on recovery (17 cases)

The Kg correlated with the serum albumin concentration ($p<0.01$), but not with TBK, or serum electrolyte and total serum protein concentrations ($p>0.1$).

The correlation coefficients are given in Table 48.

Table 48 Correlations between Kg and TBK, serum electrolyte, total serum protein and serum albumin concentrations on recovery

Independent variable	r
TBK mEq	0.206
TBK mEq/kg	-0.104
Serum Na mEq/l	-0.152
K	-0.272
Cl	-0.351
Total serum protein g/100ml	0.103
Albumin	0.644*

* $p<0.01$

There was no relationship between glucose area and any of the variables ($p>0.1$). The correlation coefficients are given in Table 49.

Table 49

Correlations between glucose area, and TBK, serum electrolyte, total protein and albumin concentrations on recovery ($p>0.1$)

Independent variable	r
TBK mEq	0.306
TBK mEq/kg	-0.216
Serum Na mEq/l	0.113
K	0.052
Cl	-0.033
Total protein g/100ml	0.036
Albumin	-0.169

The relationship between the fasting blood glucose and the TBK in mEq was significant at the 10% level ($r = 0.457$). None of the other variables correlated with the fasting blood glucose concentration.

The correlation coefficients between the later blood glucose concentrations and the TBK, serum electrolytes and protein followed a pattern similar to that found on admission and day 5 (Table 50).

Table 50 Correlations between blood glucose concentration at time t and the TBK, serum electrolyte, total protein and albumin concentrations on recovery

Independent variable	t (mins)	r
TBK mEq	20	0.560*
	45	0.218
	60	0.189
	90	-0.116
TBK mEq/kg	20	-0.186
	45	-0.092
	60	-0.034
	90	0.200
Serum Na mEq/l	20	-0.083
	45	0.092
	60	0.055
	90	0.087
Serum K mEq/l	20	-0.029
	45	0.154
	60	0.156
	90	0.128
Serum Cl mEq/l	20	-0.018
	45	0.201
	60	0.196
	90	0.414°
Total protein g/100ml	20	0.363
	45	0.112
	60	0.149
	90	-0.042
Albumin g/100ml	20	0.034
	45	-0.381
	60	-0.439°
	90	-0.666*

* $p<0.05$

° $p<0.1$

Correlations between serum insulin concentrations, insulin area and I/G ratio and TBK, serum electrolyte, total protein and albumin concentrations on recovery

The insulin area and the I/G ratio did not correlate with TBK, serum electrolyte, total protein or albumin concentrations ($p>0.1$). The correlation coefficients for the insulin concentration at time (t_1) and these variables are given in Table 51.

Table 51 Correlations between serum insulin concentration at time (t) and the TBK, serum electrolyte, total protein and albumin concentrations on recovery

Independent variable	t	r
TBK mEq	0	0.073
	5	0.329
	20	0.359
	45	0.305
	60	0.510*
	90	0.302
TBK mEq/kg	0	0.091
	5	-0.197
	20	-0.257
	45	-0.176
	60	-0.268
	90	0.027
Serum Na mEq/l	0	0.057
	5	0.401
	20	0.189
	45	0.066
	60	0.015
	90	0.267
Serum K mEq/l	0	0.030
	5	-0.440°
	20	-0.193
	45	-0.122
	60	0.034
	90	-0.029

Serum Cl mEq/l	0	0.451°
	5	-0.120
	20	0.026
	45	0.035
	60	-0.021
	90	0.064
Total serum protein g/100ml	0	-0.203
	5	-0.041
	20	-0.001
	45	-0.030
	60	0.130
	90	-0.125
Albumin g/100ml	0	-0.136
	5	0.194
	20	0.103
	45	0.131
	60	0.070
	90	0.032

* $p<0.05$
° $p<0.1$

Correlations between blood glucose concentrations, Kg and glucose area and serum insulin concentrations and insulin area on recovery

The Kg and glucose area correlated at the 10% level. There was no relationship between Kg or glucose area and insulin area or any of the serum insulin concentrations.

The fasting blood glucose concentration correlated with the fasting serum insulin level ($r = 0.571$, $p<0.05$). There was a significant correlation between the blood glucose level at 20 and 45 minutes and the 60 minute serum insulin concentration ($r = 0.555$ and $r = 0.526$, $p<0.05$, respectively).

The assessment of the importance of blood glucose, TBK, serum electrolyte, total protein and albumin concentrations in determining serum insulin levels, insulin area and I/G ratio

Many factors can affect insulin secretion in response to potassium (Chapter 1). The results presented so far in this chapter suggest that different factors are important in determining the serum insulin concentration at a particular time on a given day. Moreover it appears that there are changes during recovery. In an attempt to assess the relative importance of the variables investigated in this study, partial correlation coefficients have been calculated. No attempt has been made to attribute levels of significance to the partial correlation coefficients as the number of cases investigated is small and many theoretically important factors were not measured, eg. serum calcium, magnesium and amino acid concentrations. The partial correlation coefficients are given in the following 8 tables (Tables 52 to 59). The variables in every case were TBK in mEq, TBK in mEq/kg, serum sodium, potassium and chloride concentrations and the total serum protein and albumin concentrations. In the calculation of the partial correlation coefficients with Kg, the insulin area was also considered. The glucose area was used for the insulin area partial correlations. When the partial correlation coefficients with the serum insulin concentration at time t were calculated, one of the blood glucose concentrations was used. The blood glucose selected was either the concentration at the same time or one of the preceding times (excluding the fasting level), whichever had the highest simple correlation coefficient with the particular insulin concentration.

Table 52

Partial correlations with Kg (variable 1) on admission, on day 5 and on recovery

X_i	r Admission	r day 5	r Recovery
Insulin area	0.250	0.238	0.380
TBK mEq	0.330	-0.152	-0.521
TBK mEq/kg	0.210	0.326	-0.456
Serum Na	0.479	-0.009	0.211
K	-0.140	0.808	-0.114
Cl	-0.143	-0.461	0.447
Total protein	-0.377	0.455	0.230
Albumin	0.575	0.122	0.710

Table 53

Partial correlations with insulin area (variable 1) on admission, day 5 and recovery

X_i	r Admission	r day 5	r Recovery
Glucose area	-0.167	-0.276	0.351
TBK mEq	0.515	0.396	0.490
TBK mEq/kg	0.269	-0.045	0.627
Serum Na	-0.021	0.527	-0.485
K	0.230	0.034	-0.563
Cl	0.416	0.389	-0.027
Total protein	-0.628	-0.359	-0.420
Albumin	-0.352	-0.613	-0.226

Table 53

Partial correlations with insulin area (variable 1) on admission, day 5 and recovery

X_i	r Admission	Day 5	Recovery
Glucose area	-0.167	-0.276	0.351
TBK mEq	0.515	0.396	0.490
TBK mEq/kg	0.269	-0.045	0.627
Serum Na	-0.021	0.527	-0.485
K	0.230	0.034	-0.563
Cl	0.416	0.389	-0.027
Total protein	-0.628	-0.359	-0.420
Albumin	-0.352	-0.613	-0.226

Table 54

Partial correlations with the 5 minute serum insulin concentration (variable 1) on admission, day 5 and on recovery

X_i	r Admission	Day 5	Recovery
Blood glucose	0.178	-0.170	0.029
TBK mEq	0.410	0.382	0.346
TBK mEq/kg	0.445	0.553	-0.276
Serum Na	-0.255	-0.144	0.297
K	-0.021	0.142	-0.323
Cl	0.427	0.034	-0.453
Total protein	-0.293	0.084	-0.353
Albumin	-0.060	-0.060	-0.005

Table 55

Partial correlations with the 20 minute serum insulin concentration (variable 1) on admission, on day 5 and on recovery

X_i	r Admission	Day 5	Recovery
Blood glucose	0.283	0.584	-0.006
TBK mEq	0.274	0.376	0.103
TBK mEq/kg	0.513	-0.450	-0.414
Serum Na	-0.051	-0.323	0.328
K	-0.236	0.399	-0.198
Cl	0.061	0.109	0.376
Total protein	-0.315	-0.175	-0.204
Albumin	-0.235	-0.333	0.210

Table 56

Partial correlations with the 45 minute serum insulin concentration (variable 1) on admission, day 5 and on recovery

X_i	r Admission	Day 5	Recovery
Blood glucose	-0.345	-0.389	0.323
TBK mEq	0.371	0.503	-0.050
TBK mEq/kg	-0.006	-0.448	-0.324
Serum Na	-0.169	-0.518	0.116
K	0.615	-0.380	-0.287
Cl	-0.074	-0.256	0.367
Total protein	0.046	0.112	-0.224
Albumin	0.305	0.116	0.314

Table 57

Partial correlations with the 60 minute serum insulin concentration (variable 1) on admission, on day 5, and on recovery

X_i	r Admission	Day 5	Recovery
Blood glucose	0.009	-0.029	0.137
TBK mEq	0.156	0.451	0.328
TBK mEq/kg	0.120	-0.166	-0.117
Serum Na	-0.486	-0.276	0.059
K	0.025	-0.340	0.169
Cl	-0.008	0.035	-0.059
Total protein	-0.473	-0.183	-0.245
Albumin	-0.381	-0.127	-0.081

Table 58

Partial correlations with the 90 minute serum insulin concentration (variable 1) on admission, on day 5 and on recovery

X_i	r Admission	Day 5	Recovery
Blood glucose	0.509	-0.128	-0.134
TBK mEq	0.090	0.523	0.403
TBK mEq/kg	-0.280	-0.269	0.119
Serum Na	-0.250	-0.065	0.058
K	0.084	-0.089	0.107
Cl	-0.376	0.299	-0.145
Total protein	0.254	-0.105	-0.338
Albumin	0.058	-0.082	-0.230

Table 59

Partial correlations with I/G ratio (variable 1) on admission, day 5 and recovery

X_i	r		
	Admission	Day 5	Recovery
TBK mEq	0.287	0.241	-0.158
TBK mEq/kg	0.368	0.609	-0.566
Serum Na	-0.001	-0.451	0.441
K	-0.064	-0.197	-0.543
Cl	0.135	-0.294	0.688
Total protein	0.039	-0.533	-0.125
Albumin	0.308	-0.623	0.572

DISCUSSION

There are several papers describing the changes that occur in glucose tolerance and serum insulin levels in PCM during the development of the disease, before and after treatment[23,36,54,114,124,125,126,138,173,185,197,198]. The patterns of insulin secretion found on admission and recovery in this study are similar to those reported elsewhere[29]. Most cases improved after treatment but some remained abnormal or deteriorated[41,74,103,174,246]. In this study an attempt has been made to determine the role of potassium depletion in the abnormal glucose tolerance test and patterns of insulin secretion and the relative importance of the variables measured. Because the number of cases is relatively small and many factors that are known to affect insulin secretion were not measured, the results can only suggest the relative importance of the variables measured, particularly in view of the great variations found with an individual.

The higher 5 and 20 minute serum insulin levels and fasting glucose level in the supplemented group on day 5 indicates that potassium depletion may play a role in the abnormal patterns found in PCM.

In assessing the relative importance of the various factors, conclusions based on the simple correlation coefficients tend to be the same as those drawn from the partial correlation coefficients. However, in some cases the differences are marked, eg. the factors affecting the 5 minute serum insulin level on admission. The simple correlation coefficients suggest the factors most closely related to the 5 minute serum insulin are the TBK in mEq and mEq/kg and the total protein and

albumin concentrations, with the serum sodium, potassium and chloride levels being unrelated to the insulin level. (Tables 42 and 43 on pages 99 and 100). The partial correlation coefficients suggest that the 5 minute insulin level is most closely related to the TBK in mEq and mEq/kg and the serum chloride concentration. The 5 minute blood glucose level and the serum sodium and total protein concentrations are of lesser importance, while the serum potassium and albumin levels are of little, if any, importance. (Table 54, page 113). Differences like the one shown emphasize the dangers of concluding that a cause and effect relationship exists, when the simple correlation coefficient is significant. The partial correlation coefficients are a better guide but the qualifying statements made earlier must be borne in mind.

The partial correlation coefficients suggest that the TBK in mEq and/or in mEq/kg are frequently among the more important variables on admission, on day 5 and on recovery. The TBK in mEq and mEq/kg may be an estimate of different factors at different times or of the same factor throughout. On recovery the most likely explanation is that the TBK in mEq is an estimate of the fat free weight or of the mass of the child while the TBK in mEq/kg is an estimate of the fat free body weight per kilogram body weight. These explanations may also be true on admission and day 5 because as previously mentioned, potassium losses are small when potassium capacity is taken into account and the TBK is above 35 or even 30 mEq/kg (Chapter 3). In fact, on admission and day 5 the TBKs may be an index of the intracellular fat free mass, as most potassium is in the cells of the "fat-free" tissues. If this is the case, TBK may prove to be extremely useful as an estimate of the mass of the

tissues with high metabolic rates. It is also possible that on admission and on day 5 the TBK, particularly when expressed in mEq/kg, is an index of potassium depletion. It is not possible to state definitely which of these possibilities are true and if true, which are the most important.

The principal factors influencing the glucose disappearance constant (Kg) on admission appear to be the serum sodium and albumin concentrations. On day 5 the variables give the two lowest partial correlation coefficients with Kg. The serum potassium concentration and Kg have by far the highest partial correlation coefficient, with the serum chloride and total protein levels playing a lesser role. On recovery the serum albumin concentration appears to be the most important, with the serum chloride level, and TBK in mEq and mEq/kg being less important. The relationship between serum albumin and Kg on recovery is almost certainly due to the definition of recovery used in this study, i.e. when the serum albumin had been greater than 3g/100ml for two weeks. Recovery is not complete at this stage which was normally 4 to 6 weeks after admission. The partial correlation coefficients for Kg and TBK in mEq and in mEq/kg are negative. The relationship between Kg and TBK in mEq/kg suggests that the duration of the malnutrition may be important. The children with the higher TBK in mEq/kg presumably had less body fat and were closer to the marasmic end of the PCM spectrum. The negative partial correlation between Kg and the TBK in mEq suggests that age may be important. The age would be the body composition age and there was no relationship between Kg and chronological age[160].

Insulin area was most closely related to the total serum

protein (a negative correlation), TBK in mEq and the serum chloride concentration on admission. The serum sodium concentration had the lowest partial correlation coefficient in contrast to day 5 when with serum albumin, it appeared to be the most important factor in determining insulin area.

On recovery the TBK in mEq/kg and the serum potassium (a negative correlation) were the main factors with the TBK in mEq, the serum sodium and total protein less important. There seemed to be little relationship between insulin area and Kg or glucose area on admission, on day 5 or on recovery.

On admission the main factors related to the 5 minute serum insulin concentration were TBK in mEq and mEq/kg and the serum chloride concentration, while on day 5 the only factor of any apparent importance was the TBK in mEq/kg. Serum chloride was the main factor on recovery.

The 20 minute serum insulin level was related to the TBK on admission, day 5 and recovery. On day 5 the blood glucose concentration was also an important factor.

The serum potassium concentration was most closely related to the 45 minute insulin concentration on admission. On day 5 the TBK in mEq and mEq/kg and the serum sodium concentration were the main factors. None of the variables seemed to be of any great importance on recovery.

The sixty minute serum insulin level was largely determined by the serum sodium and total protein concentrations on admission, while the TBK was the main factor on day 5. As was the case with the 45 minute insulin level, none of the factors measured seemed to be of great importance on recovery.

On admission the blood glucose level was the main factor determining the 90 minute serum insulin concentration, while the TBK in mEq was important on day 5 and on recovery.

Thus it appears that, in general terms, TBK and serum electrolyte levels are more important in determining the insulin response to an intravenous glucose stimulus than the serum total protein and albumin values, which in turn are more important than the blood glucose levels, although there are several exceptions. These findings are not completely unexpected as insulin secretion seems to be related to ionic flux (Chapter 1).

The finding that the serum potassium concentration was important in determining the 5 and possibly 20 minute serum insulin levels while the serum sodium concentration influenced the later levels suggest that in PCM the effects of these ions on insulin secretion do not differ markedly from normal (Chapter 1).

SUMMARY

Potassium supplemented children have higher fasting blood glucose levels and 5 and 20 minute serum insulin concentrations than non-supplemented children on day 5.

Of the factors measured, the TBK in mEq and in mEq/kg appeared to be one of the most important in determining serum insulin levels. The serum potassium concentration seemed to be more closely related to the 5 and 20 minute insulin concentrations than to later levels. The reverse was true for serum sodium. These findings suggest that the mechanism of insulin secretion in PCM is similar to that in the normal pancreas. A surprising finding was that the serum albumin and blood glucose levels were not closely related to the insulin levels.

Chapter 7

SUMMARY, CONCLUSIONS AND SPECULATION

In the Introduction to this thesis the aims were set out as:

1. The solution of the problem of interpretation of total body potassium (TBK) results;
2. The comparison of the TBK results of children suffering from protein-calorie malnutrition (PCM), gastroenteritis and acute pulmonary infections;
3. The investigation of certain abnormalities which may be due to or result in potassium depletion.

CLINICAL MATERIAL

Four groups of children were studied.

1. Control series

This was made up of 30 normal children, 16 recovered ward cases and 41 children who had recovered from the acute phase of PCM (page 25).

2. PCM

Clinically these children were all suffering from kwashiorkor, although some were also marasmic. None of them had severe diarrhoea or any clinical or radiological evidence of infection. Some received no potassium supplement, some received an additional 6 mEq/kg/day and others a supplement of 12 mEq/kg/day. In all other respects the treatment of the three sub-groups was the same. The diet supplied 3 mEq of potassium per kilogram per day.

3. Gastroenteritis

Children suffering from acute dehydrating gastroenteritis were investigated. They had no clinical evidence of any other

pathology (apart from being under-weight).

4. Acute pulmonary infections

These cases all required oxygen. They had been ill for less than 48 hours and gave no history of diarrhoea or vomiting. There was no clinical evidence of any other pathology apart from being under-weight.

METHODS

The methods used have been described in Appendix A. Briefly they were:

1. TBK - whole body counting using a Packard model 5107 whole body counter.
2. Skinfold thickness - Harpenden skinfold calipers.
3. The total serum protein concentration - the Biuret method.
4. The serum albumin concentration - Beckman microzone electrophoresis.
5. The serum sodium and potassium concentrations - Perkin-Elmer model 303 atomic absorption spectrophotometer.
6. The serum chloride concentration - a Buchler-Cotlove chloridometer.
7. The acid-base status (i.e. arteriolized capillary blood pH, pCO_2 and base excess) - Astrup microequipment Type AME1c.
8. Extracellular fluid volume (ECFV) - the thiosulphate space was measured.
9. Total body water - the deuterium oxide dilution technique.
10. Blood glucose concentration - the glucose oxidase-ferricyanide method for the Technicon Autoanalyzer.
11. Serum insulin concentration - a double antibody immunoassay.

Principal findings

The total body potassium of the control children was predicted with a reasonable degree of accuracy (100 ± 6.0%) from a function of skinfold thickness, and the percentage expected weight for height (page 29). As the measurement of skinfold thickness is inaccurate in oedematous children, the use of various functions of weight and height was investigated. None of these methods proved satisfactory; the best of them gave very wide 95% tolerance limits, 100 ± 17.1% (page 33). The TBK values of the control series were similar to the values reported by other centres (page 37).

The TBK of 56 children suffering from PCM was lower than in 49 cases of gastroenteritis and 45 children with pulmonary infections on admission to hospital. The gastroenteritis and pulmonary infection cases did not differ on admission. There was a difference between these groups after the gastroenteritis cases were rehydrated, although the values obtained for the gastroenteritis cases before and after rehydration did not differ, (page 43).

Potassium supplementation had a marked effect in PCM but not in gastroenteritis where duration and severity of the diarrhoea appear to be the dominant factors (page 44). Children receiving a potassium supplement of 12 mEq/kg/day retained as much potassium as children receiving a supplement of 6 mEq/kg/day in spite of the fact that their initial TBKs were higher than those of the latter group.

The TBKs of supplemented and non-supplemented gastroenteritis cases and PCM cases receiving a potassium supplement of 12 mEq/kg did not differ from the control values 13 days after admission. The non-supplemented PCM cases still had

low values at this stage (page 48).

When the percentage predicted TBKs of the control series and the gastroenteritis and pulmonary infection groups were compared, the findings were similar to those obtained when the TBK was expressed in mEq/kg (page 51). (The percentage predicted TBK is the observed TBK expressed as a percentage of the predicted value).

There was a correlation between the TBK in mEq/kg and the serum albumin concentration on admission in PCM but not in gastroenteritis or pneumonia. In all three illnesses there was a negative correlation between the TBK in mEq/kg and the percentage expected weight for age (page 53). In the pulmonary infection series there was a positive correlation between the percentage predicted TBK and the percentage expected weight for age (page 54).

The percentage predicted TBK of almost all cases of gastroenteritis was below the lower limit of normal until day 9, approximately half the cases had low values on day 13 and a few were still low on day 17, (page 53). In the pulmonary infection group low percentage predicted TBKs were found in approximately half the children who were below 80% expected weight for age and in just under one-third of the "well-nourished" children (page 54).

There was a correlation between the TBK in mEq/kg and the serum chloride concentration in PCM on admission (page 69). In gastroenteritis the TBK, in mEq/kg and as a percentage of the predicted value was related to the acid-base status on admission. After rehydration the percentage predicted TBK correlated with the serum potassium concentration (page 70).

In PCM and gastroenteritis the children who died had lower TBKs than most of the other children and/or abnormal serum chloride concentrations.

Potassium supplementation appeared to have a marked effect on the thiosulphate space, the values returning to "normal" in 5 days. In contrast, the thiosulphate space of the non-supplemented cases increased over the first 5 days. The changes seemed to be related to serum potassium rather than total body potassium levels (page 86).

Potassium supplementation also influenced the fasting blood glucose level and the serum insulin concentrations 5 and 20 minutes after the injection of a glucose load (page 94). There was a tremendous variation within an individual during recovery (page 93). There was no obvious reason for this and together with the small numbers investigated, emphasizes the need for caution in assessing the relative importance of the variables measured in determining the insulin response to glucose. It appears that the TBK in mEq and in mEq/kg and the serum electrolyte concentrations are more closely related to the serum insulin levels than the total serum protein, serum albumin and blood glucose levels (pages 111 and 121).

Conclusions and speculation

The major obstacle to the clinical use of TBK readings is the difficulty in deciding whether or not the observed value is normal for that particular individual. The only estimate of normal value is the mean for a group of normal people of the same age; (in subjects older than those studied for this thesis it is also necessary to take sex into account). Because the coefficient of variation in normals in this study

was 10.7%, it was not possible to say that any patient had a low total body potassium on the basis of a single measurement unless the observed value was at least 21% below the mean. In this way a considerable loss of potassium might go undetected. There have been several studies relating TBK to "biochemical" measurements such as total body water, extracellular fluid volume, total body chloride and urinary creatine excretion. All of these "predictors" are affected to a greater or lesser extent by potassium losses. In this study anthropological measurements were used to assist in the interpretation of total body potassium results.

The function of skinfold thickness and percentage expected weight for height provides a readily available reference value for comparison with the observed TBK. However, this method is not completely satisfactory. Accurate measurements of skinfold thicknesses are not easy in young children and small errors in the positioning of the calipers can result in appreciable differences in the measured skinfold thickness. This is most marked in the midtriceps and subscapular skinfold thicknesses. Measurement of the mid-thigh skinfold thickness was abandoned because of inaccuracies in measurement. Another disadvantage in this method of prediction is that it does not allow for differences in the composition of the fat free body weight. In fact, more work will have to be done to establish the validity of the method particularly by direct analysis of biopsy material. Unfortunately, technical difficulties with analysis prevented any detailed studies in this field. The few satisfactory results obtained were similar to the findings of Nichols et al. However, simple analysis alone will not provide the complete answer. Several basic questions will

remain. (i) Does potassium content decrease before or while potassium capacity decreases? (ii) Is it a cause and effect relationship? (iii) If so, which is the cause or is it a vicious circle? (iv) Do the potassium losses interfere with metabolism? The meaning of low TBK values will remain debateable until these questions have been answered and the relationship between potassium capacity and content established. If, as seems likely, potassium capacity is to some extent potassium dependent, the current concept of potassium capacity cannot be used in defining potassium depletion. A definition based on metabolic effects is required. However, difficulties in separating the primary effects of potassium depletion from the effects of changes secondary to potassium depletion will probably be too great for such a definition to be of practical value. In these circumstances some other denominator or denominators will have to be found. The most practical solution may be to express the tissue potassium content in two or more ways, eg. relating the potassium content to:

(a) tissue fractions with rapid turnover rates eg. glycogen, alkali-soluble nitrogen and

(b) more fixed components eg. DNA and residual nitrogen.

The relationship between all these values may provide a more accurate indication of the presence of potassium depletion than the current concept of potassium capacity. Such a method would have to be developed after the relationship between potassium content and capacity was established. Once this has been done and suitable tissue analysis procedures developed, it may be possible to relate these multiple values to changes in TBK through some formula.

Thus, the first objective of this thesis is only partly

reached. The major obstacle is the lack of precise definition of potassium depletion.

TBK was found to be lower than normal in most children suffering from gastroenteritis and, almost certainly, in all cases of PCM. In acute pulmonary infections low values were particularly common in malnourished children. The findings in gastroenteritis and pneumonia and length of time taken to return to normal suggests that chronic or frequent acute infections may be responsible for the low TBK values found in PCM. It is usual ly assumed that potassium levels follow nitrogen levels but as mentioned previously, potassium depletion can influence protein metabolism.

The failure to show any marked differences in the TBKs of the supplemented and non-supplemented cases of gastroenteritis may be due to the relatively small numbers investigated. Even if this finding is confirmed in a larger series, factors other than changes in TBK will have to be considered before amending the rule that children suffering from gastroenteritis should receive potassium supplements. Potassium supplementation may play its role by maintaining adequate serum levels rather than by raising TBK. In this way, it would assist in the correction of acid-base disturbances and the maintenance of appropriate osmolar clearance.

In PCM potassium supplementation had a marked effect on TBK which rose more rapidly in children on a total intake of 15 mEq/kg/day than in those receiving 3 or 6 mEq/kg/day. An intake of 15 mEq/kg/day does not appear to be excessive as serum potassium levels were below 6 mEq/l in all cases.

From the work done in this study it seems likely that

some of the abnormalities found in PCM are related to potassium depletion. The effect of potassium supplementation on thiosulphate space was striking. However, in view of the difficulty in explaining the total body water results, more work needs to be done on distribution of water in the body and its excretion, during recovery from PCM. In the past most studies have concerned children on admission and again on recovery. In Alleyne's study the finding that the bromide space decreased progressively rather than suddenly as in the present potassium supplemented group may be due to differences in potassium intake or to the method of measurement. A study on the distribution of water and its excretion during recovery after an acute episode of gastroenteritis is also warranted. Children admitted to the metabolic unit all gained weight over the first few days. The weight then decreased slightly before rising again. The duration of the period of weight gain varied from one child to another. This finding may be due to an increase in extracellular fluid volume and/or total body water while potassium depletion exists.

The failure to show any relationship between TBK and serum sodium concentration disturbances is not surprising. Many factors other than potassium depletion are operative in the children and the findings do not exclude the possibility that potassium depletion may be a factor in those cases where serum abnormalities persist.

The increase in peak serum insulin levels shown in the potassium supplemented group suggests that this abnormality may be due in part to potassium depletion. However, many other factors may be more important eg. the levels of other

hormones.

Serum albumin levels do not seem to be closely related to the serum insulin concentration. The TBK in mEq and in mEq/kg and the serum electrolyte concentrations appear to be more important.

In the past, most of the work on the development of malnutrition has concentrated on the protein and calorie intakes and the role between infection and malnutrition. Almost all the animal models and the children studied during recovery have received potassium supplements. It is possible that in this way the importance of the potassium depletion found in PCM has been overlooked. Three questions seem to be particularly important:

(i) Are the changes in enzyme levels and amino acid patterns adaptations to repeated episodes of potassium losses as much as to a low protein intake?

(ii) Is nitrogen retention and albumin synthesis as high in children who do not receive potassium supplements?

(iii) Can the spectrum between kwashiorkor and marasmus be due to differences in the severity of the potassium deficit and the attendant changes?

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APPENDIX A

LABORATORY METHODS

TOTAL BODY POTASSIUM

Instrument used:

Packard Model 5107 Whole Body Counter.

Situation of the Whole Body Counter

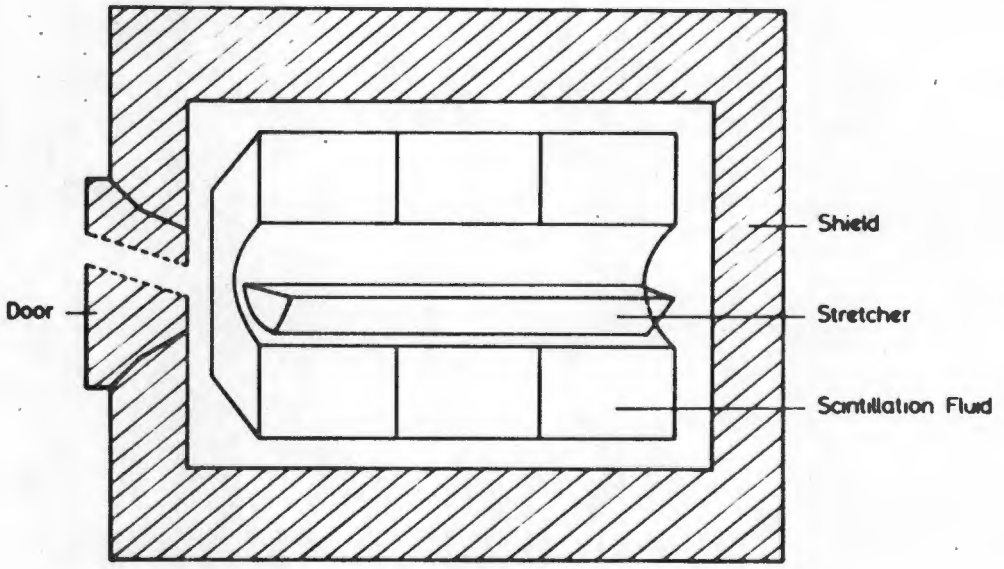
The counter was installed in a prefabricated building about 40 metres from the main hospital buildings. The room housing the counter was air-conditioned (the temperature ranging from 24 to 28^{o}C with constant humidity). The room can be entered either through a waiting-room used by the mothers of the out-patient children studied, or through an office used by the laboratory staff. The counter is over 100 metres from the X-ray Department which is on the other side of the main hospital buildings. No isotopes are used or stored at the hospital (apart from the ^{42}K used in determining the correction factor for self absorption.)

Design of the Whole Body Counter

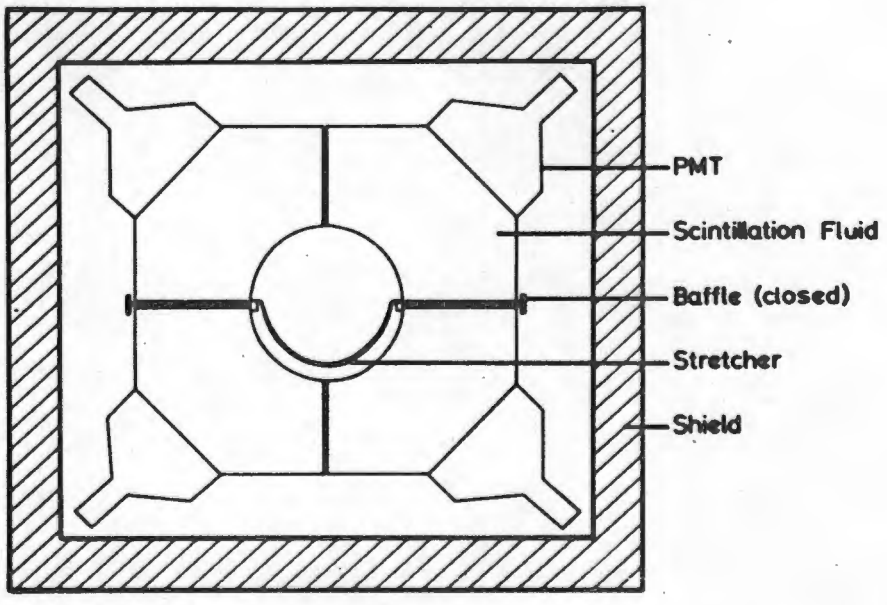
Diagrammatic sections of the counter are shown in Figs. A1 and A2. The planes shown are both vertical and are perpendicular to each other. The child (or source of the gamma radiation) lies on a stretcher which slides into a cylinder 76 cms long and 30 cms in diameter. This cylinder is the centre of a tank containing scintillation fluid. The tank is divided into 6 sections. Each section is viewed by 2 photomultiplier tubes (PMT). The PMTs are situated so that a flash of light occurring anywhere in a section is "seen" by one, if not both, of the PMTs. Each section can be divided into two by a baffle. Closing the baffles ensures that a flash of light is only seen by one PMT. The counter is enclosed by steel plates 15 cms thick.

Figs. A1 and A2. Diagrammatic sections of the Packard Model 5107 Whole Body Counter.

CROSS SECTION THROUGH BODY COUNTER
(SIDE VIEW)



CROSS SECTION THROUGH BODY COUNTER
(FRONT VIEW)



The interior of the counter can be illuminated and in the door of the counter there is a lead glass window.

Principle of the Whole Body Counter

Because of the 4Π geometry and efficient shielding against background radiation, this whole body counter is sufficiently sensitive to measure naturally occurring radio-isotopes in the human body. The most common of these isotopes is ^{40}K which emits gamma radiation of an energy 1.46 meV. ^{40}K is one of three naturally occurring isotopes of potassium. The other two isotopes, ^{39}K and ^{41}K, are stable.

Gamma rays emitted from a radioactive source in the counter enter the surrounding scintillation matrix. (^{40}K also emits beta radiation but this does not affect the counter). The scintillation fluid consists of two or three scintillators in solution. The manufacturers have not disclosed the nature of the organic compounds used. They convert high energy electromagnetic radiation (gamma radiation) into electromagnetic radiation of a lower energy (visible light). More than one scintillator is necessary for efficient conversion as the frequency of the light incident upon the cathode of the PMT is critical.

When light of that frequency strikes the cathode, electrons are emitted; the number being proportional to the intensity of the incident light which is, in turn, proportional to the total energy of the gamma radiation entering the scintillation fluid.

The electrons leaving the cathode are accelerated and focussed on the first of 13 dynodes, by a high constant potential difference between the cathode and the thirteenth

dynode. At each of the dynodes electrons are emitted in proportion to the number of incident electrons. The "output signal" is the potential difference between the eleventh and twelfth dynodes. The output signal from each PMT passes through a preamplifier. The gain of the preamplifier can be altered to compensate for variations in the sensitivity of the individual PMTs.

The signal from each PMT is then fed into a common pathway of two electronic circuits in tandem. Only signals falling between two preselected voltages pass through an anti-coincidence gate. The signal is then amplified and the pulses counted. (The amplification can be altered by changing the gain. The gain and voltage settings determine the energy level counted).

Calibration of the Whole Body Counter

The sensitivity and accuracy of the whole body counter depends to a great extent on the background count rate. The basic aim in calibrating the counter is to ensure that the ratio $\frac{\text{Source plus background count rate}}{\text{Background count rate}}$ is as high as possible. The highest ratio is not necessarily the most satisfactory when counting statistics are considered but this will be discussed further under the heading "Selection of the Optimum Window for ^{40}K" on page A8.

Two sources were used in calibrating the counter. One was a ^{137}Cs source supplied by the manufacturers. It gave a high count rate and approximated to a point source. The other source was made up of 5 containers each containing 2.2 kg of potassium chloride B.P. When this source was used the containers were placed so that the potassium was as evenly

distributed as possible along the axis of the counter. (^{40}K comprises a constant percentage of potassium, i.e. 0.0119%).

Selection of the Optimum PMT High Voltage (H.T.)

The photo peaks for ^{137}Cs from each PMT were roughly aligned to the same lower bias by scanning the spectrum for each PMT with a 4% window and adjusting the preamplification on each PMT. With all the PMTs switched on, the ^{137}Cs source in the centre of the counter, a gain of 45% and a window of 100-500 (the ^{137}Cs photo peak fell approximately in the centre of the window), the H.T. between the cathode and the dynode was varied. Background (b) and background plus ^{137}Cs source (c) count rates were determined for each H.T. The optimum H.T. setting was selected by using the formula $Q = c - b$. The highest value of Q, 186, gives the optimum H.T. setting, 1,110 volts. The results are shown in Table A-1. The count rates are the mean of three 20 second counts. The count rates were determined 4 hours after altering the H.T. to allow the PMTs to settle to a constant state.

Table A-1 Selection of the Optimum PMT H.T.

H.T. (volts)	b (counts per sec.)	c (counts per sec.)	Q
1000	85.8	3199	149
1050	96.5	4146	173
1090	105.7	4679	184
1100	112.0	4725	184
1105	107.4	4714	184
1110	115.5	4758	186
1115	120.0	4735	184
1120	121.9	4726	182
1125	128.5	4672	180

All the subsequent steps in the calibration and all the counts on patients were done with an H.T. setting of 1110 volts.

Selection of the most efficient gain for ^{137}Cs.

The spectrum for ^{137}Cs, and the background spectrum were scanned using a 4% window at gains of 30%, 40%, 45%, 50% and 60%. The spectra were then plotted and the gain giving the best photopeak to valley ratio, and the highest ratio of total counts (^{137}Cs plus background) to background counts was selected. This was a gain of 45%.

Accurate alignment of spectra of the PMTs for ^{137}Cs.

The output signal from each PMT was fed into a multichannel analyzer kindly provided by the local agents for the instrument. The focussing was adjusted to give the maximum photopeak to valley ratio and the spectra were then accurately aligned by adjusting preamplification for each PMT.

At a gain of 45% the ^{137}Cs photopeak for each PMT was situated at a lower window of 260-280 using a 4% window. The valley between the Compton scatter and the peak was flat between a lower window of 120-140, again using a 4% window. At a window setting of 500-540 the ^{137}Cs count rate was very low relative to the background count rate. The counting conditions selected for ^{137}Cs were:

H.T.	1110 volts
Gain	45%
Window	150-500

Statistical check to compare reproducibility and sensitivity of PMTs

Each PMT was checked by placing a ^{137}Cs source

at intervals along the central horizontal axis of the counter in such a manner that the solid angle subtended at each PMT surface by the source was identical. Twenty 10 second counts of background and background plus ^{137}Cs were done for each PMT. A one way analysis of variance test of all the nett ^{137}Cs count rates showed no significant difference between the PMTs, ($p < 0.05$). The chi-square test on the nett ^{137}Cs count rates from each PMT showed the count rates were consistent with the expectation of random disintegrations.

Table A-2 gives the mean count rate in counts per sec., the value of chi-squared and of p for each PMT.

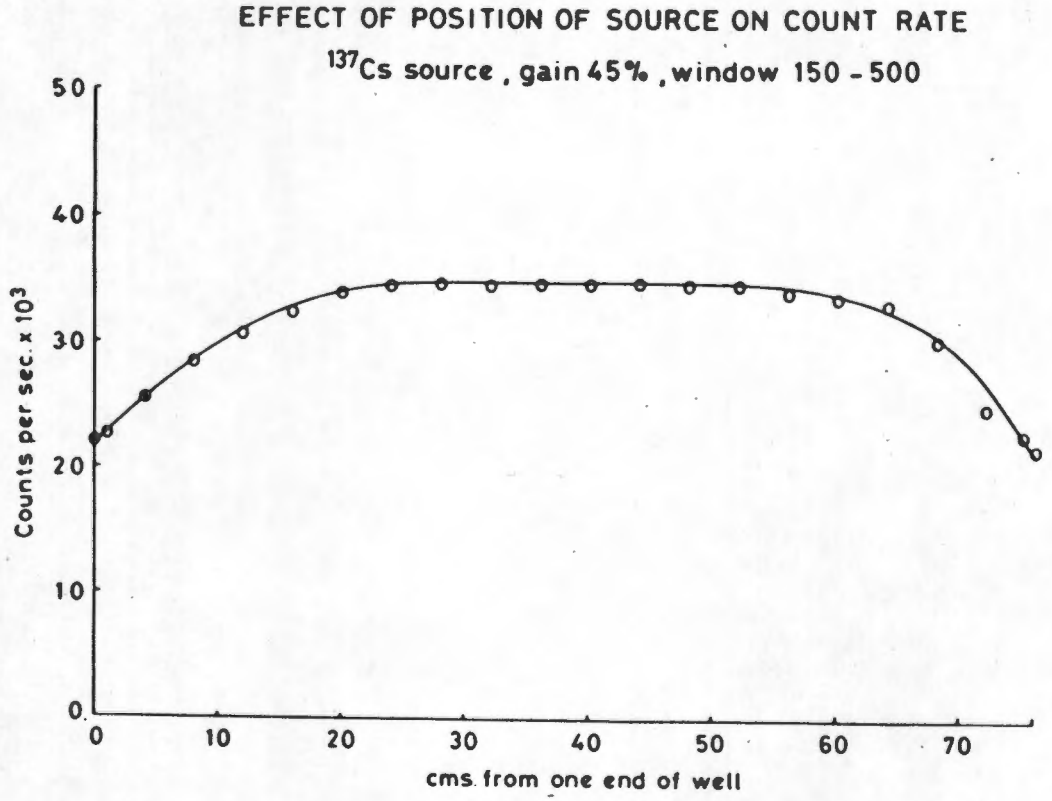
Table A-2 Reproducibility and Sensitivity of Individual PMTs

PMT	Mean (counts per sec.)	Chi-square chi-squared	P
A1	6915	15.2	> 0.7
A2	6987	14.5	> 0.7
A3	6943	14.6	> 0.7
A4	7005	15.2	> 0.7
B1	6922	15.4	> 0.6
B2	6965	14.7	> 0.7
B3	6985	15.8	> 0.6
B4	6962	15.4	> 0.6
C1	6986	14.1	> 0.7
C2	6947	15.1	> 0.7
C3	6926	13.7	> 0.7
C4	6981	13.7	> 0.7

Relationship between counting efficiency and the position of a point source

Fig.A3 shows the variation in the count rate for a point source moved along the central axis of the counter. The count rate was practically the same for the centre 60 cms of the counter and decreased at the same rate at both ends. The curve is similar to the ideal curve discussed by Garrow[4].

Fig.A3. The variation in the count rate for a point source moved along the central axis of the counter



Selection of the optimum gain for ^{40}K

The spectrum for ^{40}K was scanned using a 4% window at gains of 10%, 15%, 20%, 25% and 30%. The gain giving the best photopeak to valley ratio and the highest ratio of total counts to background counts was selected. This was a gain of 20%.

Accurate alignment of the spectra of the PMTs for ^{40}K

The output signal from a PMT was fed into a multichannel analyzer. The focussing was adjusted to give the maximum photopeak to valley ratio and the spectra were then accurately aligned.

At a gain of 20% the valley between the Compton scatter and the photopeak lay between window settings of 180 and 200 using a 2% window. The peak was situated at a window of 280 to 300, again using a 2% window. A window of 600 to 650 gave a count rate which was 20% of the count rate at the peak.

Twenty 1000 second counts of background and background plus ^{40}K were done. The counting conditions for each PMT were:

Gain 20%
Window 200-650

The chi-square test of the net ^{40}K count rates from each PMT was again consistent with the expectations of random disintegrations. One way analysis of variance did show significant differences between the tubes, but this was probably the result of the distribution of ^{40}K in the counter. If the position of the potassium containers was altered slightly, tubes which had previously differed significantly no longer showed differences and vice versa.

Selection of the optimum counting window for ^{40}K.

The lower level was set at 200 as this was in the centre of the valley for ^{40}K at a gain of 20%. A slight "drift" of the lower level would have little effect on the background count rate. It also insured that contamination of the counter by isotopes with a much lower energy than ^{40}K, or the presence of such an isotope in the source did not increase the background or background plus source count rates. (^{137}Cs peak, for example, was at a window setting of 120-150 at a gain of 20%).

The number of counts necessary to determine the ^{40}K content of a child to a given degree of accuracy (V) depends on the ratio (r)

$\frac{Rt}{Rb}$ where Rt is the combined count rate (i.e. child plus background) and Rb is the background count rate. In Table A-3 the number of combined counts (Nt) and the number of background counts (Nb) necessary for a maximum error of 5% are given for the different values of r. These values have been calculated from the formula

$$Nt = \frac{100^2 \ (r + 1) \ r^{3/2}}{V^2 \ (r - 1)^2}$$

$$Nb = \frac{Nt}{r^{3/2}}$$

The three formulae given above are discussed by Loevinger and Berman[5].

Table A-3 Minimum counts necessary for a maximum error of 5%

r	Nt	Nb
1.08	143100	127500
1.10	94400	81900
1.12	67800	57200
1.14	51400	39500
1.16	40600	32500
1.17	33000	28500

The time taken to reach the required number of counts depends on the count rate. Table A-4 gives the number of counts per minute per milliequivalent of potassium (cpm/mEq K), the background count rate (Bg cpm), the calculated ratio (r) for a child containing 200 mEq of potassium (assuming no self absorption) and the minimum time in minutes required to achieve a maximum error of 5% using different windows.

Table A-4 Minimum time required to achieve a maximum error of 5%

Window	cpm/mEq K	Bg cpm	r	time (mins)
200- 600	1.890	2655	1.142	17.0
200- 700	2.132	2888	1.148	15.5
200- 800	2.211	3106	1.142	14.5
200- 900	2.292	3253	1.141	13.9
200-1000	2.302	3406	1.141	13.3

From this table it can be seen that the highest ratio, 1.148, is not the most efficient and that the best window is from 200-1000. (If the gain is reduced to 19% and the same procedure adopted, the background count rate is higher for a given net potassium count rate. The time required for the same degree of accuracy is greater than 14 minutes for any window).

To ensure that the window selected, i.e. 200-1000, did not include isotopes other than potassium, 5 children were counted at different window settings to a maximum error of 5%. All the values for a particular child fell within 3% of the mean value and the difference between the highest and lowest values was less than 4% of the lowest value. The results are given in Table A-5.

Table A-5 Total body potassium (mEq) determined at different window settings

Window	Child				
	A	B	C	D	E
200- 600	225.3	306.8	167.6	252.4	283.4
200- 700	221.6	300.2	169.4	249.6	287.4
200- 800	220.5	303.5	164.9	250.6	285.9
200- 900	217.4	297.2	170.1	250.9	283.7
200-1000	226.0	296.0	166.6	251.4	284.5

The effect of coincident counting on background and ^{40}K count rates

Twenty 1000 second counts of background and background plus ^{40}K were done under "normal" counting conditions with the baffles open and with the baffles closed. The procedure was repeated for coincident counting. One way analysis of variance showed no significant differences ($p>0.05$) between the net ^{40}K count rates (and between the background count rates) obtained from coincidence counting and from counting with the baffles closed. The background count rate with the baffles open was approximately 4% higher than the background count rate with the baffles closed. The difference is significant ($p>0.05$).

All the subsequent steps in the calibration and all counts on patients were done under "normal" counting conditions with the baffles closed. (The results shown in Tables A-4 and A-5 were also obtained under these counting conditions).

Correction factor for self-absorption in the sourse

The following procedure was adopted for determining the counting efficiency for a given weight. ^{42}K as KCl suitable for injection was obtained from the South African

Atomic Energy Board. It was diluted in half-strength Darrow's solution with 2.5% Dextrose. 5 gms of the diluted solution (approximately 0.5 μC) were placed in a polythene tube identical to the ones used to hold the ^{40}K standard prepared later. Ten children who were in hospital awaiting discharge and who had had no clinical, laboratory or radiological evidence of illness for at least two weeks were selected (although some were still underweight). Their ^{40}K count rate was determined to a maximum error of 3%. Approximately 0.01 μC of ^{42}K per kilogram body weight were injected intravenously. The syringe was weighed before and after injection and the time of injection noted. Seven to eight hours were allowed for equilibration[2,5]. The children were then counted ten times at three-hourly intervals. The maximum error of each count was 1%. The standard was counted thirty times during this period.

The net ^{42}K count rates for the children were corrected for isotope decay. The halflife of ^{42}K was taken as 12.41 hours.

$$\text{Corrected count rate} = \frac{(^{42}K + ^{40}K + \text{background count rate}) - \text{background count rate} - ^{40}K \text{ count rat}}{e^{-bt}}$$

where t is the time after injection in hours and b is equal to $\frac{\log_e 2}{\text{half-life in hours}}$.

These corrected values were then plotted against time to allow for excretion. It was assumed that the ^{42}K excretion rate was constant during the test period. Using the least squares technique, a linear regression of the ten points was performed. The intercept on the y axis was taken as the theoretical count rate at the time of injection

i.e. the count rate which would have occurred had there been immediate equilibration of the ^{42}K. The correlation coefficient for the line through the points was equal to, or less than -0.98 for each of the children. The net standard count rates were also corrected for isotope decay (in the same way as the net ^{42}K count rates for the children were corrected). The mean of the corrected ^{42}K standard count rates was taken as the true count rate at the time of preparation of the standard. The count rates of the standard at the time of the injection of the ^{42}K into each child were calculated using the formula

$$Ct = Co\ e^{-bt}$$

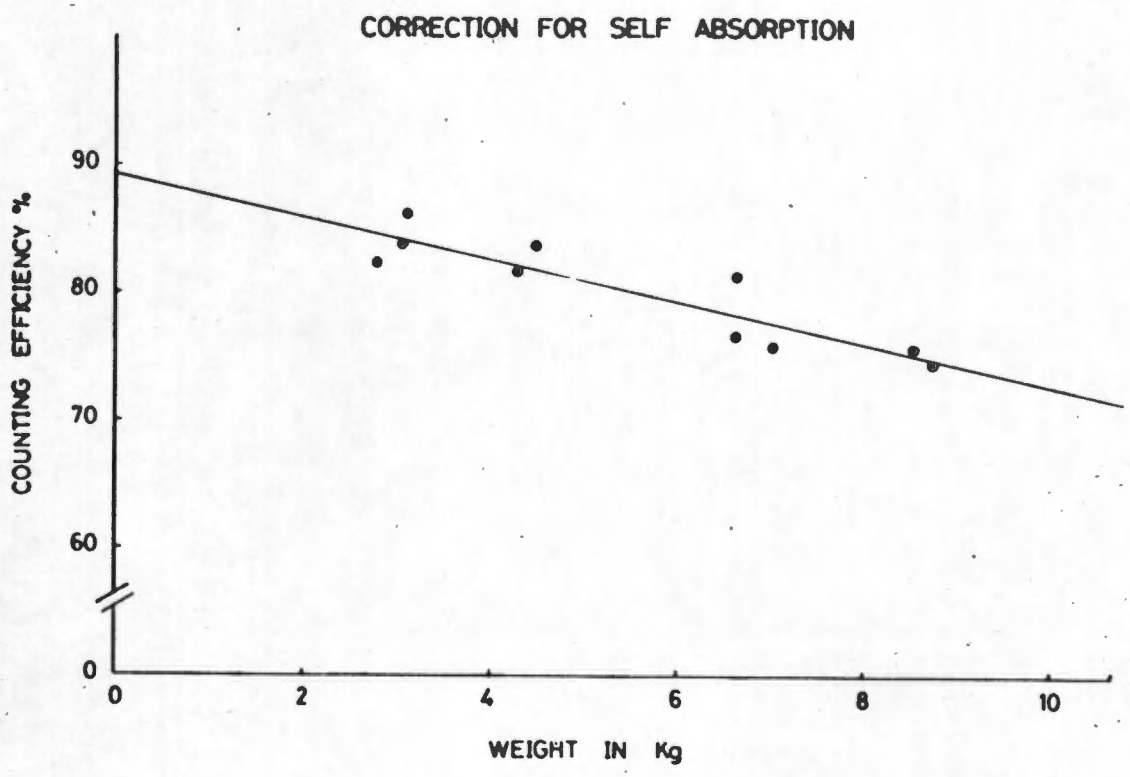
where Ct is the count rate at time t and Co is the true count rate of the standard. t is the time interval in hours between the preparation of the standard and the injection of the ^{42}K into the child. b is the same as mentioned above i.e.

$$\frac{\log_e 2}{\text{half-life in hours}}$$

The count rate of the child divided by the standard count rate (at the time of injection) gave the counting efficiency. For convenience it is expressed as a percentage. The percentage counting efficiency of each child was plotted against the weight of the child. A line was drawn through the points using the least squares technique. The slope and intercept are almost identical to those reported by Garrow for a counter of the same make[4]. (Garrow's figures have been calculated from a graph).

	Cape Town	Garrow
Intercept	89.2	90.2
Slope	-1.6	-1.7

Fig.A4. Percentage counting efficiency against weight



The correlation coefficient of the line was -0.93. (Garrow does not state the correlation coefficient of his line).

The graph and points are shown in Fig.A4.

Depression of background by the subject

In all counters the presence of a non-radioactive mass in the well depresses the background count rate.

Fifteen 1000 second counts were done with the counter empty and with 4 empty polythene containers in the stretcher. Three litres of distilled water were then placed in each container and the procedure repeated. Two way analysis of variance failed to show any significant differences (p 0.1), i.e. background depression was not detectable for a mass of 12 kg.

Background scan and variations in the background

A background scan using a 4% window was performed to make it possibly to identify isotopes which may contaminate the counter at a later stage. The scan is shown in Fig.A5. 500,000 counts were done at each window setting. Fortunately, the steps taken to prevent contamination of the counter proved satisfactory and a repeat background scan at the end of the study was nearly identical.

The background variation during one day is shown in Fig.A6. The time required to accumulate 50,000 counts was measured repeatedly from 8.30 a.m. to 5.00 p.m. Fig.A7 shows the mean background count rate on the first two working days of each month, i.e. the mean of the background counts which happened to be done while counting patients or checking the counter. The reason for the low background count rates in the middle of 1970 is not known. They did coincide with

Fig.A5. Background scan using a 4% window

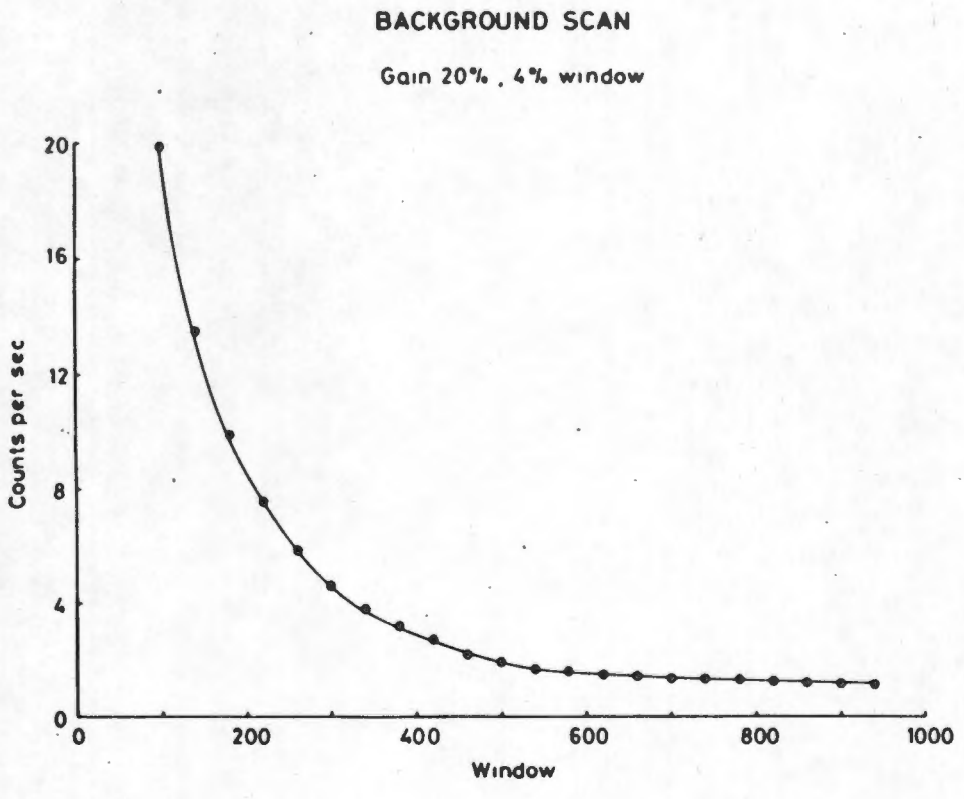


Fig.A6. Background variation between 8.30 a.m. and 5 p.m. on one day.

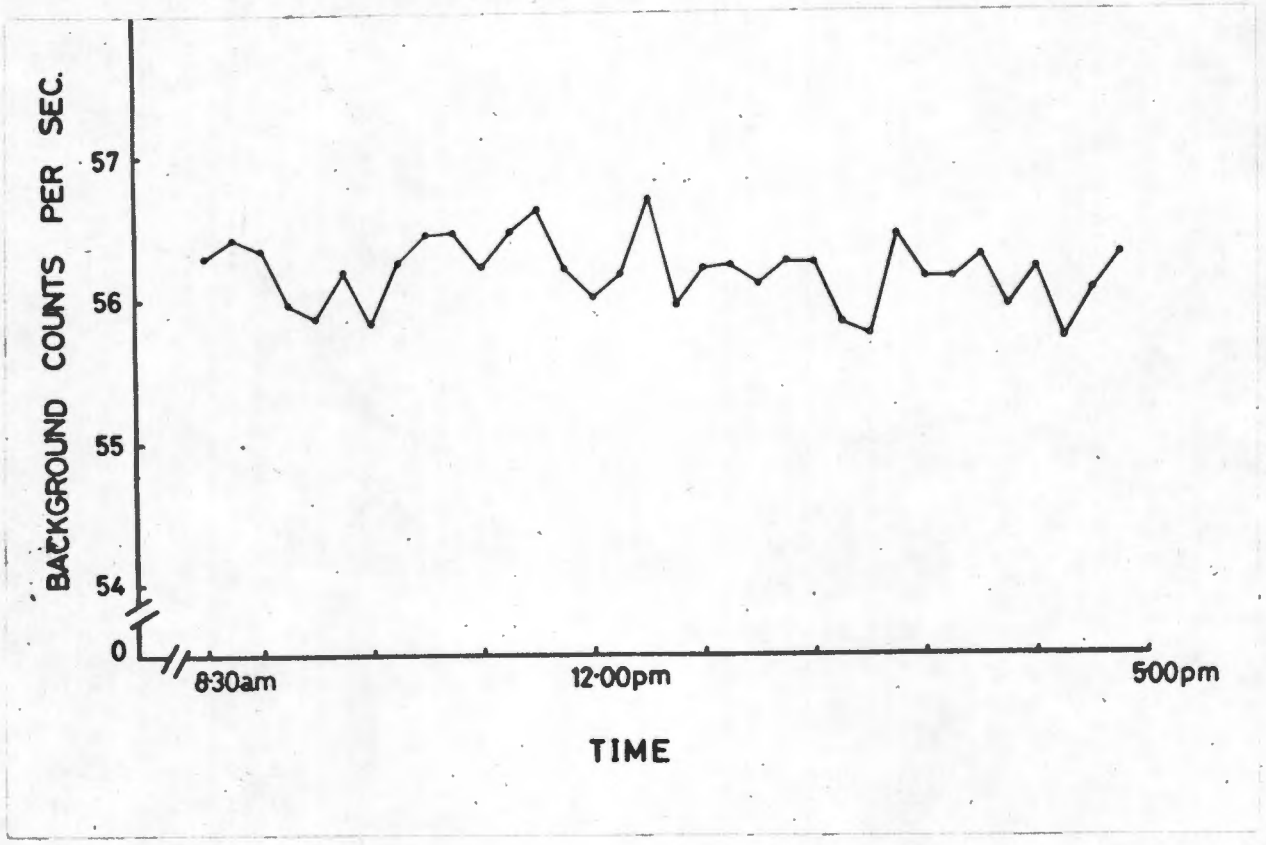
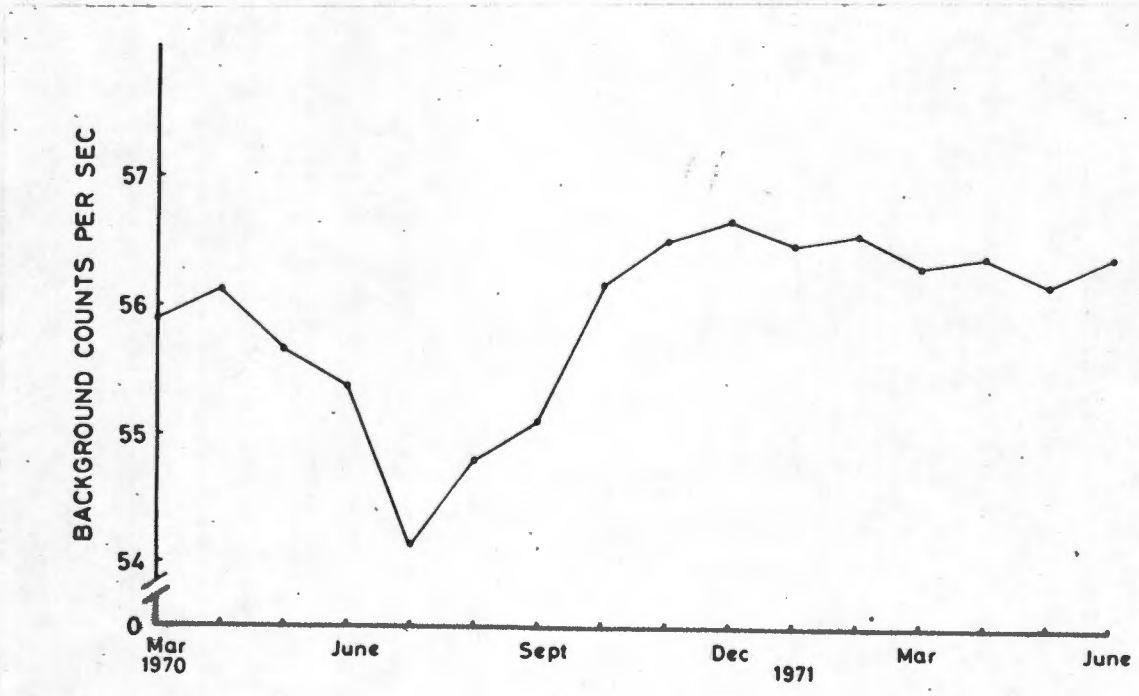


Fig.A7. Mean background count rate on first two working days of each month.



period of wet weather, and a similar fall in background count rate occurred late in June 1971.

Precautions taken to prevent contamination and cross-infection

The stretcher was always lined with a plastic sheet covered by disposable napkins. This lining was removed with the child (or source) after each count and discarded. The children were stripped down to vest and napkin and then wrapped in a draw sheet so that only the head was not "enclosed". The legs were folded up close to the abdomen. Children known to be excreting pathogens were counted at the end of each counting session, and out-patients and in-patients were not counted during the same session. The normal children were counted in the morning before any other children.

When ^{42}K was used, a plastic sheet was also placed inside the draw sheet.

Access to the room housing the counter was controlled and no articles were brought into the room if there was any chance that they would contaminate the counter.

The position of the child in the counter

When a point source is brought very close to the wall of the cylinder, count rate increases suddenly(4). In this counter the distance at which this occurred (^{137}Cs source) was less than 3 cms. The stretcher held the source at least 4 cms above the wall of the cylinder at any point in the lower half of the counter. The central axis of a child in the counter was slightly lower (approximately 2 cms) than the central axis of the counter. This is not ideal but if the central axis of the child was raised, the legs and abdomen came within 3 cms of the upper half of the counter.

The child was always placed so that his head was 10 cms from the front (door) end of the well. With the legs folded up there was a variable gap which was never less than 6 cms at the other end.

Preparation of ^{40}K standard

Two polythene tubes 50 cms long and 3.75 cms in diameter were filled with 4,000 mEq potassium as potassium chloride and the ends stoppered. Twenty 500 second counts of background and background plus source were done. One way analysis of variance showed no significant differences between the two tubes. One tube was arbitrarily selected as being the "standard".

Reproducibility of TBK determinations

Some of the investigations have been mentioned under the heading "Selection of the most efficient window for ^{40}K" on page A8, i.e. 5 TBK determinations at different window settings gave the same result allowing for a maximum error of 5% in the determination. As a further check, 5 determinations were done on one child on one day with a maximum error of 5%. Three children were studied in this way. Any one TBK determination was within 3% of any other determination for the same child. The results are shown in Table A-6.

Table A-6 Variation in TBK expressed in mEq

Determination	Child F	G	H
1	382.3	155.2	230.5
2	380.4	156.3	224.9
3	374.1	154.0	228.0
4	371.8	154.0	226.0
5	381.9	157.7	229.8

To check day to day variation, 10 children who had recovered from gastroenteritis at least 3 weeks previously, were counted on four consecutive days. When the TBK was expressed in mEq, i.e. the total amount of potassium as opposed to the amount per unit weight, the TBK on any one day was higher than it had been the previous day in 7 of the 10 children. Any one TBK determination was within 8% of any other determination for the same child. The results are shown in Table A-7.

Table A-7 Day to day variation in TBK expressed in mEq

	Day			
Child	1	2	3	4
I	269.9	275.3	274.1	280.3
J	221.3	224.8	229.6	230.7
K	389.8	386.0	387.9	378.6
L	221.3	223.7	230.3	236.0
M	324.8	331.6	343.2	350.1
N	269.6	275.1	273.7	271.0
O	141.4	146.6	148.8	145.1
P	229.9	233.4	235.7	239.1
Q	127.6	130.2	130.9	137.6
R	130.4	133.1	136.4	136.7

When the TBK was expressed in mEq per kg, any determination was within 2.5% of any other determination on the

same child and there was no general trend of a rise or fall in the TBK in mEq per kilogram. The results are shown in Table A-8.

Table A-8 Day to day variation of TBK in mEq/kg

Child	Day 1	2	3	4
I	46.8	47.5	46.3	47.3
J	40.4	40.8	41.0	40.4
K	44.9	45.1	45.0	44.1
L	44.3	43.9	45.2	44.9
M	47.1	47.5	48.2	48.1
N	51.5	52.3	52.2	51.2
O	42.3	42.0	43.0	43.1
P	44.0	43.1	43.7	44.2
Q	48.0	48.8	47.7	48.3
R	47.8	48.4	48.7	47.1

Balance studies lasting 3 days were performed on 2 children recovering from gastroenteritis. The increase in body potassium was greater by balance than by body counting; body counter values were 91.7% and 93.1% of the balance study increments. These values are similar to those found elsewhere[3,8].

Comment on the calibration procedure

The calibration procedure used was not completely satisfactory but was the only practical one. Difficulties in evenly distributing large masses of ^{40}K along the axis of the counter prevented the use of ^{40}K in some of the calibration procedures. In experiments where the position of the source was critical, the best point source available, ^{137}Cs, was selected. Other slightly larger sources were available eg. ^{60}Co. However, the use of these sources would have

increased the error in positioning the source. The gamma radiation emitted by ^{137}Cs has a far lower energy level than ^{40}K. It is possible that the response of the counter to the two energy levels is not the same eg. 1,110 volts may not be the optimum HT setting for ^{40}K.

In the calculation of the correction factor for self-absorption some assumptions were made. The half-life of ^{42}K was taken as 12.41 hours[9]. This differed slightly from the half-life determined by repeated counting of the standard 12.32 hours. This difference may have been experimental error. However, in retrospect, the first three count rates of the ^{42}K standard appeared to be slightly lower than expected. It is possible that the counter was on the verge of saturation, or the source may have been slightly closer to one end of the counter. The three results were included in the calculations because there was no specific reason for excluding them, and their mean fell within two standard deviations of the mean of the remaining count rates.

The method of correcting count rates was selected rather than the more usual method of preparing a standard for each patient and dividing the patient count rate by the appropriate standard count rate at the same time, because it was impossible to measure the patient and standard count rates at exactly the same time. The time taken (approximately 30 minutes) to complete the background-patient-standard-background cycle of counts was not negligible considering the short half-life of ^{42}K. With such a counting cycle it would have taken approximately 4 hours to count the 10 children as opposed to the 2½ hours required when one standard was used for all the children. This increased the number of counts possible for

the child and for the standard.

It was not possible to measure the ^{42}K excreted because of difficulties in the collection of all excreta during each 3 hour period, or over the whole test period. However, the very good correlation between the corrected count rate and time after injection suggests that the assumption that the excretion rate was constant was valid. The number of children studied was small and the correlation between counting efficiency and weight was not completely satisfactory. Multiple linear regression using functions of weight, height and skinfold thickness did not improve the correlation. The similarity between the Cape Town and Jamaican results suggests that the final correction factor is probably correct.

Compared to the counter in Jamaica[4], the Cape Town counter gave a higher count rate per mEq of potassium with a lower background count rate.

	Cape Town	Jamaica
cpm/mEq	2.1 - 2.3	1.8 - 2.0
background cpm	3300	4400

It was decided that it was not necessary to carry out further calibration procedures or to repeat any of those already performed.

Monthly check on counter performance

Once a month the background and ^{40}K count rates (using the ^{40}K standard) were determined for each PMT. The background and ^{40}K standard count rates done during the determination of the TBKs of the children provided a day to day check.

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2. Dean, P.N.
Los Alamos Scientific Laboratory, 1964.

3. Donath, A. Personal communication, 1971.

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The use and calibration of a small whole body counter for the measurement of total body potassium in malnourished infants.
West Indian Med.J. 14: 73-81, 1965.

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Clin. Sci. 32: 495-502, 1967.

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Efficiency criteria in radioactivity counting.
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Measurements with a liquid whole body counter of a representative group of the Swiss population.

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Body potassium measurements with a total body counter.
J. Nucl. Med. 11: 255-259, 1970.

9. Veal, N. and Vetter, H.
In: Radioisotope techniques in Clinical Research and Diagnosis. p. 20. Butterworth and Company, London, 1958.

SKINFOLD THICKNESS

Harpenden skinfold calipers were used to measure midtriceps, subscapular and paraumbilical skinfold thicknesses.

The skinfold thicknesses were measured on the left-hand side only. Five measurements were taken at each site. When the midtriceps and subscapular skinfold thicknesses were measured, the children were sitting, the arm was abducted 90^{o}, the elbow flexed 90^{o} and the hand pronated. The midtricep skinfold thickness was measured at the point halfway between the posterior tip of the acromion and the olecranon. The subscapular skinfold thickness was measured 2.5 cms inferior to and medial to the inferior angle of the scapula. The paraumbilical skinfold thickness was measured 2.5 cms lateral to the umbilicus with the child supine.

When the skinfold thickness was between 4 and 7 mm, the coefficient of variation was approximately 2%. At either extreme, i.e. approximately 3 mm and approximately 12 mm, the coefficient of variation increased to approximately 5%.

WEIGHT

The weights reported are all nude weights. The children in hospital were weighed daily at 11 a.m. The out-patients were weighed immediately prior to the counting procedure. All the weights are to the nearest 5 grams.

HEIGHT

The height was measured supine on a measuring board to the nearest eighth of an inch. The results were then converted to cms.

Analytical reagent quality (A.R.)

Sodium carbonate was used as the primary standard for standardising all acids used in the following methods. Alkalis were standardised by titration against either hydrochloric acid or sulphuric acid which had previously been standardised against sodium carbonate. Methyl orange was used as indicator for titrations of sodium carbonate or sodium hydroxide against hydrochloric acid or sulphuric acid. The sodium carbonate was prepared in the manner described by Vogel with appropriate changes for differences in the normality of the solution to be standardised, e.g. to standardise 0.1 N hydrochloric acid A.R. sodium carbonate was heated to 260^{o}C for half an hour and allowed to cool in a dessicator. Approximately 0.2 gms of the pure sodium carbonate were accurately weighed and dissolved in approximately 50 ml of water. Titrations were performed in triplicate.

TOTAL SERUM PROTEIN

The Biuret method was used[5].

Solutions required

(1) 0.2 N sodium hydroxide (Merck Titrosol)

(2) Biuret solution; 90 gms A.R. sodium potassium tartrate, 10 gms A.R. copper culphate pentahydrate and 10 gms A.R. potassium iodide were dissolved in the order given in approximately 1½ litres of 0.2 N sodium hydroxide, and made up to 2 litres.

Method

All determinations were done in duplicate. The optical density (O.D.) was read on a Klett Summerson calorimeter at 520-580 mmu. Versatol and versatol A (Warner

Chilcott Diagnostic Laboratories) were used as standard sera.

Turbidity

5 ml of 0.2 N sodium hydroxide was added to 4.8 ml of water and 0.2 ml of serum. The O.D. was read.

Protein content

5 ml of Biuret was added to 4.8 ml of water and 0.2 ml of serum. The O.D. was read 30 minutes later.

Calculations

Protein factor =

$$\frac{\text{total protein standard serum}}{\text{O.D. standard serum - turbidity standard serum - blank}}$$

The factor was calculated for versatol and versatol A and the mean factor used in the subsequent calculations.

Total protein sample or total protein of unknown serum =

$$\text{protein factor} \times \left(\frac{\text{O.D. unknown serum - turbidity}}{\text{unknown serum - blank}}\right)$$

Reproducibility of results

By dilution of versatol and versatol A, four sera of known concentration were prepared. Ten total protein determinations were done in duplicate on each serum. The results are shown in Table A-8.

Table A-8

Theoretical concentration G/100ml	Observed concentration G/100ml	Coefficient of variation %
2.25	2.32	2.6
3.7	3.78	2.4
4.5	4.54	1.5
7.4	7.31	0.8

SERUM ALBUMIN

The method used was Beckman microzone electrophoresis[1-4].

Solutions required

1. Beckman B-2 buffer (part number 320024). This is a buffer of diethyl barbituric acid and its sodium salt. It has a pH of 8.6
2. Beckman fixative dye solution (part number 324340). This solution contains Ponceau-S trichlorocetic acid and sulphocetic acid.
3. 5% acetic acid (A.R.)
4. Denatured ethanol solution. This was prepared by adding 5 ml of A.R. methanol to 95 ml of A.R. ethanol.

   To 95 ml of this solution 5 ml of isopropanol was added.
5. 30% solution of A.R. cyclohexanone in denatured ethanol.

Method

Beckman cellulose acetate membrane (part number 324330) were prepared by soaking in the buffer for 2 minutes. They were then blotted and placed on the frame of the electrophoresis cell (model R101). Eight samples of serum, seven unknowns and one standard serum (either versatol or versatol A) were placed on each membrane by means of a Beckman micro applicator (part number 324399).

For 20 minutes a current at a constant voltage of 250 volts (as supplied by a Beckman Model RB-2 duostat) was passed through the membrane. The membrane was placed in a fixative dye solution for 8 minutes before being washed in 5% acetic acid until no further dye could be removed. The

membrane was then agitated for between 1 and 1½ minutes consecutively in denatured ethanol and in the cyclohexanone solution. The membrane was then placed on a glass slide. The excess cyclohexanone was removed with a squeegee and the membrane dried at 100°C for 15 minutes. It was allowed to cool to room temperature, removed from the slide and placed in a Beckman plastic envelope (part number 326189). The envelopes were stored in a dessicator. The prepared membrane was scanned on a Beckman Model R110 densitometer using a 0.4 mm slit and a 1.4 cal filter.

Calculation of results

Guassian curves were projected to the baseline for each of the five components. Verticals were dropped through the integrated trace from the curve intersections. A number of integrated tracings under each section of the scan were counted and the proportions calculated.

Check on serum albumin values obtained using the Beckman microzone electrophoresis method

Thirty serum albumin determinations were done in duplicate on the same serum by three different operators using two methods. The methods were:

1. Beckman microzone electrophoresis
2. The Biuret method after precipitation of the globulins by 28.3% sodium sulphate[5].

Two-way analysis of variance showed no significant differences between (i) the three "groups" of values obtained using Beckman microzone electrophoresis i.e. there was no operator variability ($p>0.05$).

(ii) there were significant differences between the values obtained by the three technicians using sodium sulphate

precipitation ($p<0.05$), i.e. there was operator variability. The results obtained by operator C differed significantly from those of operators A and B, which did not differ significantly from each other (p 0.05). There were no significant differences between the sodium sulphate precipitation results of operators A and B and the Beckman microzone electrophoresis results of operators A, B and C ($p>0.05$).

Reproducibility of serum albumin determinations by Beckman microzone electrophoresis

Twenty determinations were done on three different sera. The mean values obtained and the coefficient variation are shown in Table A-9.

Table A-9

Mean serum albumin G/100ml	Coefficient of variation %
2.7	3.6
3.7	3.8
4.5	3.0

REFERENCES

1. Beckman manual RM-IM-3, 1970.
2. Beckman manual RM-TB-005
3. Beckman manual RM-TB-010A, 1968.
4. Beckman manual RM-TB-011, 1967.
5. Wolfson, W.Q., Cohn, G., Calvary, E. and Ichaba, F. Studies in serum proteins. Amer.J.Clin.Path. 18: 723, 1948.

SERUM, URINE AND STOOL, SODIUM AND POTASSIUM CONCENTRATIONS[1-3]

These were measured using a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer with a Hitachi recorder. Single element Perkin-Elmer hollow cathode tubes and a three-slot burner were used. In Table A-11 the instrument settings for each of the elements are given. The values for the current, wavelength, noise suppression, gain and fuel flow are approximate. They were adjusted to give maximum sensitivity after the alignment of the burner.

Table A-11 Instrument settings of potassium, sodium and magnesium determinations

	Potassium	Sodium	Magnesium
Current	8 mA	10 mA	4 mA
Wavelength	383	295	285
Range	vis	vis	vis
Slit	4	4	5
Filter	in	in	out
Noise suppression	1	2	1
Gain	6	3	4
Air flow	9	9	9
Fuel flow	9	9	8
Air pressure (lbs/sq.in.)	30	30	30
Fuel pressure (lbs/sq.in.)	8	8	8

The light beam passed through the flame with the long axis of the burner parallel to the beam for all determinations except serum sodium. Serum sodium was measured with the long axis of the burner at right angles to the light beam. Standard solutions were prepared for each element by suitable dilution of stock solutions so that

the concentration of most of the specimens was approximately halfway between the concentration of standard 1 and standard 5. If the absorption by the specimen was lower than standard 1 or higher than standard 5, further dilutions of the standards and/or unknowns were prepared. The concentrations of the standard solution used for serum are given in Table A-12.

Table A-12 Concentrations in mEq/l of standard solutions used for serum determinations

	Potassium *	Sodium
Standard 1	0.01278	0.4349
Standard 2	0.02556	0.8698
Standard 3	0.03834	1.3046
Standard 4	0.05112	1.7396
Standard 5	0.06390	2.1744

* The potassium standard solutions also contained sodium, 2.1744 mEq/l, to allow for the enhanced potassium absorption found in the presence of sodium

Versatol and versatol A were run as "unknowns" with each batch of specimens. The concentrations specified by the manufacturers, the mean concentrations and the coefficients of variation are given in Table A-13.

Table A-13 Reproducibility of determinations

	Number of determinations	Theoretical value mEq/l	Mean determined concentration mEq/l	Coefficient of variation %
Potassium	30	3.9	3.81	1.7
Sodium	30	143.0	144.6	2.8

The stock solutions were prepared from A.R. sodium chloride and A.R. potassium chloride. The concentrations

of the stock solutions are shown in Table A-14.

Table A-14 Concentrations of stock solutions used

	grams/litre	mEq/l
Potassium	1	25.8
Sodium	1	43.48

Serum for electrolyte determinations was separated within 20 minutes of the blood being taken and stored at -20°C. A 1:100 dilution was prepared on the day the specimens were run. Specimens and standards were determined alternately.

Urine dilutions varied depending on the concentration as did the dilution of the stool extract. The stool extract was prepared in the following manner. A known weight of stool (approximately 50 g) was boiled with 3 ml concentrated A.R. nitric acid. The mixture was filtered and the residue washed several times with distilled water. The filtrate and washings were mixed and made up to a known volume.

All dilutions were done in duplicate and the concentration of each duplicate was determined twice. If the concentration of any duplicate differed by more than 5% from any other, fresh dilutions were prepared.

Calculations

$$\text{Absorption by specimen} = \frac{\text{height of specimen peak}}{\text{height of 100\% absorption peak}} = A$$

$$\text{Absorbance} = \log_{10} \frac{1}{1-A}$$

The least square regression line for absorbance against concentration was calculated. From this unknown the concentrations were calculated.

Comment

The methods used are based on those given in the Perkin-Elmer manual and elsewhere. However, there were some modifications.

1. A dilution of 1:100 was used for the serum rather than the specified dilution of 1:50 as this increased the accuracy of the measurement. At a dilution of 1:100 there was a linear relationship between absorbance and concentration.

2. The Perkin-Elmer manual advises the use of the secondary band, at a wavelength setting of 330, for serum sodium determinations. The instrument and lamp used did not give a peak of sodium at this wavelength. (This finding is not confined to the instrument used).

For measurement of the sodium concentration at the primary wavelength, 295, with the burner normally aligned parallel to the light beam, serum has to be diluted approximately 1:2500. It was found that there was considerable variation in the height of the peak found for any one diluted specimen and an even greater difference between the dilutions. The method used gave the most reproducible results, i.e. with the burner placed at right angles to the light beam.

REFERENCES

1. Perkin-Elmer Instructions for Model 303 Atomic Absorption Spectrophotometer, Manual 990-9415, 1964.

2. Perkin-Elmer Revision of Analytical Methods for Atomic Absorption Spectrophotometry, Manual 990-9638, 1968.

3. Willis, J.B.
The determination of metals in blood serum by atomic absorption spectrocopy 111. Sodium and Potassium. Spectrochim. Acta 16: 551, 1960.

SERUM CHLORIDE CONCENTRATIONS[1]

A Buchler-Cotlove chloridometer was used. 0.1 ml of serum was added to 4 ml of nitric acid-acetic acid mixture. Three to four drops of gelatin were added. Versatol and Versatol A were run as unknowns. Titrations were done at the "high rate" initially. If the concentration of the unknown was found to be low (i.e. titration time of less than 30 secs), 0.2 ml of the specimen was used. All titrations were done in duplicate. They were repeated if the duplicates differed by more than 2%.

Solutions required

1. Standard solutions. Two solutions were prepared using A.R. sodium chloride. The one contained 160 mEq chloride per litre and the other 80 mEq per litre.
2. Nitric acid-acetic acid mixture. 0.1 N A.R. nitric acid and 10% A.R. glacial acetic acid.
3. Gelatin reagent. The gelatin was supplied by the manufacturers. It is a mixture of gelatin, thymol blue and thymol. The solution used contained 0.62 g gelatin/100 ml.

Calculations

Calibration factor f =

$$\frac{\text{ml of NaCl standard x concentration of standard in mEq/l}}{\text{average net titration time of standard (secs)}}$$

Concentration of chloride in unknown in mEq/l =

$$\frac{\text{f x average net seconds unknown}}{\text{.ml of unknown}}$$

Reproducibility of results

Twenty Versatol and Versatol A determinations were done. The coefficient of variation for the two specimens

was 1.1% and the mean values differed from those specified by the manufacturer by less than 0.5%.

REFERENCE

Cotlove, E., Trantham, H.V. and Bowman, R.L.
An instrument and method for automatic, rapid, accurate and sensitive titration of chloride in biological samples.
J. Lab. clin. Med. 50: 358, 1958.

BLOOD pH, PCO_2 AND BASE EXCESS

These were measured on Astrup micro equipment, Type AME1c (Radiometer Electronic Measuring Instruments).

After warming, the patient's heel was pricked so that drops of blood formed rapidly. Heparinized capillary tubes were filled, sealed and the contents mixed. Tests were done immediately. The actual pH and the pH at partial carbon dioxide pressures of approximately 30 and 60 mm of mercury were measured at 37°C. The actual PCO_2, mm mercury, and base excess, mEq/l, were read off the standard mammograph.

REFERENCES

1. Astrup Micro Equipment Type AME1c Instruction Manual 4th ed. Radiometer, Copenhagen 1963.

2. Astrup, P., Jørgensen, K., Siggaard Andersen, O. and Engel, K.
The acid-base metabolism, a new approach.
Lancet 1: 1035, 1960.

3. Siggaard Andersen, O., Engel, K., Jørgensen, K. and Astrup, P.
A micro method for determination of pH, carbon dioxide tension, base excess and standard bicarbonate in capillary blood.
Scand. J. Clin. Lab. Invest. 12: 172, 1960.

4. Siggaard Andersen, O.
The pH-log pCO_2 blood-acid base nanogram revised.
Scand. J. Clin. Lab. Invest. 14: 598, 1962.

5. Siggaard Andersen, O.
On the acid-base status of the blood.
Scand. J. Clin. Invest. 15: Suppl.70, 1963.

EXTRACELLULAR FLUID VOLUME[1]

The thiosulphate space was measured in the manner described by Friis Hansen[1].

The tests were started 2 - 2½ hours after the children were given a bottle of milk (120 ml/kg). No fluids were given during the test period. None of the children were clinically dehydrated at the time of testing.

The 10% solution of sodium thiosulphate injected intravenously was prepared by the dispensary at the Red Cross War Memorial Children's Hospital. The sodium thiosulphate was dissolved in distilled pyrogen-free water and placed in ampoules which were sealed and autoclaved after all air had been displaced by nitrogen. 1.5 ml/kg body weight of this solution was injected at a rate of 10 ml/min. Six blood samples were taken. One immediately before the infusion (for the serum blank and electrolyte and protein concentration) and a further five (samples 2-6) between 30 and 60 minutes after the start of the infusion. The exact time of injection and sampling were recorded.

Solutions used[2]

All solutions were made up with recently boiled, cooled, distilled water. All chemicals were A.R. The following

stock solutions were prepared and stored in a refrigerator or on the shelf:

0.67 N sulphuric acid
2 N hydrochloric acid
10% (W/V) sodium tungstate
0.1 N potassium iodate
0.1 N sodium thiosulphate (with 1 ml of chloroform as preservative).

The following solutions were prepared from the stock solutions on the day of the test:

1. Precipitating mixture. 20 ml sodium tungstate and 20 ml sulphuric acid made up to 200 ml.
2. 0.0004 N sodium thiosulphate
3. 0.001 N potassium iodate

A 10% W/V solution of potassium iodide and a 1% solution of soluble starch were prepared each day.

Test procedure

Each titration was done in duplicate. If the difference between duplicates were greater than 1 drop (0.04ml), the titration was repeated.

As soon as each sample was taken, it was spun and the serum separated. From three different samples, 0.2 ml of serum was weighed, dried to constant weight at 100^{o}C and reweighed to determine the percentage serum solids.

1 ml of the infusion mixture was diluted to 200 ml. (At least two dilutions were prepared. 4.9 ml of precipitating mixture was pipetted into the following tubes and 0.1 ml of serum or distilled water, or the diluted infusion mixture, added.

reagent blank
infusion mixture 1
infusion mixture 2 etc
serum blank (sample 1)
serum unknown A (sample 2)
serum unknown B (sample 3) etc
serum unknown E (sample 6)

After standing for 10 minutes, the tubes were centrifuged. 2 ml of the supernatant was pipetted into 2 ml of potassium iodate and 1 ml of hydrochloric acid added. After exactly 7 minutes 0.2 ml of potassium iodide was added. The titration against sodium thiosulphate was started immediately. Three drops of starch were added when the yellow colour had almost disappeared.

Calculation

Serum concentration (mg/100ml) =

$$\frac{(\text{titration "serum blank"} - \text{titration "serum unknown"} \times 98.82)}{\text{titration "reagent blank"}}$$

Infusion mixture concentration (mg/100ml) =

$$\frac{(\text{titration "reagent blank"} - \text{titration "dilution infusion mixture"} \times 98.82 \times 200)}{\text{titration "reagent blank"}}$$

The regression line and correlation coefficient for the $\log_{10}$ serum concentration against time were calculated using the least squares technique. The intercept gave serum concentration at time 0, i.e. C_t.

The corrected extracellular fluid volume =

$$\frac{V \times I \times (100 - P)}{100\ C_t}$$

where V = volume infused

P = % serum solids

The results were accepted if the correlation coefficient of the regression line was equal to, or less than, -0.98. In all cases where this condition was not met, the line had "flattened" in the manner described by Friis-Hansen.

Comment

The method used differs from that of Friis-Hansen in the following ways:

1. Times of sampling. The time of equilibrium was not important in this study and all samples were taken after equilibrium had, theoretically, taken place.
2. Sodium thiosulphate solution. A 0.0004 N solution was used instead of a 0.0005 N solution. This reduced the coefficient of variation without increasing the difference between duplicates. More dilute solutions of sodium thiosulphate increased the error mainly because of difficulties with the end point.
3. Times stated (i.e. the 10 min wait before centrifugation and the 7 min wait before commencing the titration) fall within the time intervals specified by Friis-Hansen. Setting a definite time rather than an interval gave better reproducibility.

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The extracellular fluid volume in infants and children.
Acta Paediatrica (Uppsala) 43: 444, 1954.

2. Vogel, A.I.
A Textbook of Quantitative Inorganic Analysis, Theory and Practice, 2nd edition, p. 331-335. Longmans, Gree and Co., London, 1959.

TOTAL BODY WATER

The deuterium oxide (D_2O) method was used. All deuterium oxide determinations were done by Mr. P. Johnson of the Department of Chemistry, University of Cape Town. The method used was similar to that described by Turner et al[2] and by Graystone[1]. 1.5 ml/kg body weight deuterium oxide were mixed with an equal volume of normal saline and injected at the same time as the sodium thiosulphate. Blood was taken immediately before infusion and 4 hours later. The children were given milk (120 ml/kg body weight) immediately after the last sample for sodium thiosulphate determination had been taken. As the results are difficult to explain the method used is given below.

Preparation of samples

Approximately 0.3 grams of anhydrous copper sulphate was added to 5 ml of the unknown serum. The sample was mixed thoroughly with a stirring-rod and placed in a water-bath at $90^{o}C$ for 5 minutes. After centrifugation the supernatant was placed in an all-glass microstill. Standards were prepared by adding known amounts of deuterium oxide to distilled water.

Reading of samples

The Beckman IRI2 spectrometer and fixed and variable pathlength calcium fluoride cells were used. A fixed path-length of 0.0848 mm was used. With water in both cells the variable pathlength cell was adjusted to give 0 difference of absorption in the cells between 2200 and 2800 cms^{-1}. A sample was then placed in the fixed pathlength cell and the spectrum scanned between 2200 and 2800 cms^{-1} at a scanning

speed of 20 cms^{-1} min^{-1}. The reading between 2700 and 2800 cms^{-1} was taken as the baseline. The peak height was read at the maximum value which corresponded to a wave number of 2512.5 cms^{-1} (3.98 mμ M).

The instrument was used at a convenient scan expansion to give suitably sized peaks for the range of concentrations covered and with the slit programmed to have a value of 1.7 mm at 2512.5 cms^{-1}. The constancy of 0 absorption difference between the cells and the readings obtained with the standard solutions were measured at frequent intervals. With the instrument used as described, the peak height at maximum absorption is a measure of the concentration of the sample. Consideration of the curves obtained with the lowest standard (0.0618 gms deuterium oxide per 100 ml), shows that a value of 0.2 grams deuterium oxide per 100 ml would definitely be detectable and that the lower limit of detection is approximately 0.01 grams per 100 ml.

Apart from the specimens which contained no obvious detectable deuterium, the deuterium concentration ranged from 0.118 - 0.310 grams deuterium oxide per 100 ml. The mean difference between duplicates of the serum distillates was 2.38%. Table A-15 gives the concentration of the standard solutions used. The peak height in cms and the standard deviation at the three scale expansion settings used is also shown.

Table A-15

Concentration of standard g D20/100ml	Scale Expansion 80-65% peak	S.D.	n	80-55% peak	S.D.	n	85-65% peak	S.D.	n
0.06180				6.41	0.55	2	10.50	0.83	2
0.10472				10.80	0.57	8	17.85	0.37	4
0.12764				13.23	0.50	9*			
0.15343				15.92	0.36	8			
0.17828				18.35	0.51	8			
0.19146	11.07	0.14	4	19.60	0.36	15+			
0.21263	12.08	0.08	5	21.43	0.06	4			
0.25532	14.14	0.24	4						
0.26267	14.53	0.22	4						

* Coefficient of variation 3.79%

\+ Coefficient of variation 1.86%

Turner et al report a coefficient of variation of 1.78% at a deuterium concentration of 0.2945%.

Calculation

Total body water (litres)=

$$\frac{\text{volume of } D_2O \text{ injected (ml)}}{a-b}$$

where a and b are the concentrations of deuterium oxide in the serum water (ml/litre) at 4½ hours and prior to injection respectively. In practice b was always zero.

REFERENCES

1. Graystone, J.E. in Human Growth, Body Composition, Cell Growth, Energy and Intelligence, ed. Cheek, D.B. p.668, Lea and Febiger, Philadelphia 1968.

2. Turner, M.D., Heely, W.S. and Hardy, J.D.
Rapid determination of deuterium oxide in biological fluids.
J.Appl.Physiol. 15: 309, 1960.

BLOOD GLUCOSE

The glucose oxidase-ferricyanide method for a Technicon autoanalyzer was used. All determinations were performed by Mrs. A. Hardcastle and Mr. G. Toyer of the Endocrine Research Unit (Director, Professor W.P.U. Jackson) of the University of Cape Town. The method is that described by the manufacturers and is a modification of Hoffman's method[2]. Blood for blood glucose and serum insulin determinations was taken after an 8 hour fast and 5, 20, 45, 60 and 90 minutes after the intravenous injection of 1 gram of dextrose/kg body weight. To ensure that comparisons with work previously done in this Unit were valid, the concentrations of 48 specimens were determined by the Somogyi-Nelson method as well[4]. The concentrations ranged from 50 to 450 mg per 100 ml. The difference between the concentrations of any one specimen determined by the two methods was always less than 3% and the glucose disappearance rate constant and the (kg) value the same to three decimal places.

Calculation of Kg values[1,3]

These were calculated in the manner described by Amatuzio et al[1] and Ikkos et al[3].

$$Kg = \frac{\log_e 2}{t_{\frac{1}{2}}} \times 100$$

$t_{\frac{1}{2}}$ is the time taken for the glucose concentration to be halved.

Calculation of glucose area

The glucose area was calculated by dividing the area under the graph (increment in blood glucose concentration vs time) into a series of triangles and rectangles.

REFERENCES

1. Amatuzio, D.S., Stutzman, F.L., Vanderbilt, M.J. and Nesbitt, S.
Interpretation of the rapid intravenous glucose tolerance test in normal individuals and in mild diabetes mellitus.
J. Clin. Invest. 32: 428, 1953.

2. Hoffman, W.S;
A rapid photoelectric method for the determination of glucose in blood and urine.
J. Biol. Chem. 120: 51, 1937.

3. Ikkos, D. and Luft, R.
On the intravenous glucose tolerance test.
Acta Endocrinol. 25: 312, 1957.

4. Somogyi, M.
Notes on sugar determination.
J. Biol. Chem. 195: 19, 1952.

SERUM INSULIN

The serum immunoreactive insulin concentrations were determined by a modification of the method of Morgan and Lazarow[2]. The method is described in detail elsewhere[1]. All the determinations were performed by Mrs. D. Hendricks, Miss P. Murray and Mr. S. Hendricks of the Isotope Unit (Director, Dr. B.L. Pimstone) of the Department of Medicine, University of Cape Town.

Calculation of insulin area and insulin glucose ratio

The insulin area was calculated in the same method as the glucose area. The insulin-glucose ratio (I/G ratio) was simply the insulin area divided by the glucose area. The ratio calculated in this manner was almost identical to those determined by planimetry. The areas themselves differed

by a constant factor because of scale differences.

REFERENCES

1. Becker, D.J. M.D. thesis (In preparation).

2. Morgan, C.R. and Lazarow, A.
Immunoassay of insulin: Two antibody systems.
Diabetes 12: 115, 1963.

APPENDIX B

STATISTICAL METHODS

STATISTICAL METHODS

Parametric and non-parametric tests have been used in this thesis. The parametric methods used were:

1. The mean standard deviation and standard error of the mean
2. Linear regression
3. Multiple linear regression
4. Analysis of variance

The non-parametric methods were:

1. The median
2. The chi-squared test (for one or more samples)
3. The Mann-Whitney U test
4. The Wilcoxin matched-pairs signed-ranks test
5. The Spearman rank correlation coefficient
6. Kruskal-Wallis one-way analysis of variance

Parametric tests were used when the distribution was normal and the sample size was greater than 10. When the coefficients of skewness and kurtosis deviated from normal the result of the parametric test was checked by performing a similar non-parametric test. When the sample size was less than 10 only non-parametric tests were used.

Total body potassium was almost always normally distributed. (Table B-1).

For ease of cross-reference the tests used in each chapter are outlined below.

Chapter 2. The interpretation of total body potassium results.

The tests used in this section were the mean, standard deviation, standard error of the mean and tolerance limits; linear regression and correlation with analysis of variance and

Table B-1

Coefficients of skewness and kurtosis of the total body potassium results

TBK	Group	Coefficient of skewness	Coefficient of kurtosis	Number of cases
mEq/kg	Control	0.23	-0.19	87
	PCM	0.24	0.36	56
	Gastroenteritis day 1	0.40	0.56	49
	Gastroenteritis day 2	0.79*	2.05°	46
	pneumonia	0.24	1.18°	45
% predicted	Control	0.153	0.260	87
	Gastroenteritis day 1	-0.47	-0.27	49
	Gastroenteritis day 2	0.41	0.10	46
	pneumonia	0.14	0.13	45

* significant skewness

° significant kurtosis

$p<0.05$

tolerance limits; and multiple linear regression and analysis of variance.

Modifications could have been made to the procedure followed in finding a mathematical relationship between TBK and the various predictors tested. In the calculation of the normal range for the percentage predicted TBK it would have been better, in theory, to have used another series of matched children, i.e. the regression line for TBK mEq/kg and the log transformation of corrected skinfold thickness would be calculated from one series. From this line the predicted values of the second series and the normal range for the percentage predicted TBK would be calculated. The objections to this method are difficulties with matching and the number of cases required. It seems unlikely that the resulting tolerance limits would have differed markedly from those used. There is some evidence of this in the return to "normal values" during recovery from gastroenteritis and the results of the three children with pulmonary infections.

Chapter 3. In this section, one-way analysis of variance with Scheffe's S method was used. Some of the findings were checked using Kruskal-Wallis one-way analysis of variance and the Mann-Whitney U test, e.g. in some of the groups of children suffering from gastroenteritis. No discrepancies were found.

The chi-squared test (2 x 3 table) was used to test differences in the distribution of the pneumonia cases above and below 80% expected weight for age. As the expected frequencies of two cells were below 5 (i.e. 3.02 and 4.98) the result was checked by forming a 2 x 2 table by combining adjacent categories, i.e. one test differentiating the children

above the upper limit of normal and those below that limit, and a second test dividing the groups at the lower limit of normal. The conclusions drawn were the same.

Chapter 4. Both parametric and non-parametric tests were used in an attempt to find correlations. The values reported are the Pearson product-moment correlation coefficient.

The chi-squared test (2 x 2 and 2 x 3) were used to compare the frequencies of abnormal results.

Chapter 5. The mean and standard deviation are reported as there was very little difference between the mean and the median. The Mann-Whitney U test was used to detect differences between the supplemented and non-supplemented children, while the Wilcoxin matched-pairs signed-ranks test was used to detect differences within the groups.

Chapter 6. The Mann-Whitney U test was used to test for differences between the groups and, when the same children were not investigated on each day within the groups. Wherever possible the Wilcoxin matched-pairs signed-rank test was used to detect differences within groups. Linear regression, rather than rank correlation was used although the number of cases was small. The main reason for this was the extension of the analysis to include partial correlation coefficients. Theoretically the use of Kendall partial correlation coefficients may have been preferable.

Level of significance

No rigid rules were made for setting the level of significance. The values given for p are for two-tailed tests except where the direction of the difference is stated.

Correlation

Correlation coefficients have been used extensively in an attempt to find relationships. It is accepted that a significant correlation coefficient does not necessarily imply that there is a cause and effect relationship.

Formulae used

The formulae used are given in the following pages.

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   New York, 1969.
2. Documenta Geigy.
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   Biostatistics: an introductory text.
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4. Hald, A.
   Statistical theory with engineering applications.
   John Wiley and Sons, New York, 1965.
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   The analysis of variance.
   John Wiley and Sons, New York, 1967.
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   International student edition.
   McGraw-Hill, New York, 1956.
7. Snedecor, G.W. and Cochran, W.G.
   Statistical methods, 6th edition.
   The Iowa State University Press, Ames, 1967.
8. Steel, R.G.D. and Torrie, J.H.
   Principles and procedures of statistics.
   McGraw-Hill, New York, 1960.

PARAMETRIC TESTS

The Mean, $\bar{X}$, Standard deviation, s_x, Standard error of the mean, $s_{\bar{x}}$, and Tolerance limits[2,7].

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

$$\bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$$

$$s_x = \left(\frac{\sum_{i=1}^{n} X_i^2 - n\bar{X}^2}{n-1} \right)^{1/2}$$

$$s_{\bar{x}} = \frac{s_x}{n^{1/2}}$$

Tolerance limits = $\bar{X} + KS_x$ where K is a constant.

Coefficient of skewness g_1, & Coefficient of Kurtosis g_2,

$$g_1 = \frac{m_3}{m_2^{3/2}}$$

$$g_2 = \frac{m_4}{m_2^2} - 3$$

$$m_2 = \frac{1}{n}\sum_{i=1}^{n} X_i^2 - \bar{X}^2$$

$$m_3 = \frac{1}{n}\sum_{i=1}^{n} X_i^3 - \frac{3}{n}\sum_{i=1}^{n} X_i^2 + 2\bar{X}^3$$

$$m_4 = \frac{1}{n}\sum_{i=1}^{n} X_i^4 - \frac{4}{n}\bar{X}\sum_{i=1}^{n} X_i^3 + \frac{6}{n}\bar{X}^2\sum_{i=1}^{n} X_i^2 - 3\bar{X}^4$$

Linear regression.

The least squares regression line for the equation

$$y = aX + b$$

$$a = \frac{n\sum_{i=1}^{n} X_i Y_i - \sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{n\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i\right)^2}$$

$$b = \bar{Y} - m\bar{X}$$

The correlation coefficient r.

$$r = \frac{n\sum_{i=1}^{n} X_i Y_i - \left(\sum_{i=1}^{n} X_i\right)\left(\sum_{i=1}^{n} Y_i\right)}{\left[n\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i\right)^2\right]^{1/2}\left[n\sum_{i=1}^{n} Y_i^2 - \left(\sum_{i=1}^{n} Y_i\right)^2\right]^{1/2}}$$

Tolerance limits $Y/x = \bar{Y} + byx\ (X-\bar{X}) \pm t_{2\alpha} S_T$

$$DF_t = n-2$$

$$b_{yx} = \frac{n \sum_{i=1}^{n} X_i Y_i - \sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{n \sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i\right)^2}$$

$$S_T = S_{bxy} \left[(1+1/n)Sx + (X-\bar{X})^2\right]^{1/2}$$

$$S_x = \sum_{i=1}^{n} X_i^2 - \bar{X} \sum_{i=1}^{n} X_i$$

$$Sbyx = \left[\frac{Sy}{Sx}\left(\frac{1-r^2}{n-2}\right)\right]^{1/2}$$

$$Sy = \sum_{i=1}^{n} Y_i^2 - \bar{Y} \sum_{i=1}^{n} Y^2$$

Partial correlation coefficient

$$r_{ij.} = \frac{C_{ij}}{(C_{ii}\ C_{jj})^{1/2}}$$

where C_{ij} is the element in the ith row and jth column of the inverted matrix of simple correlation coefficients.

One Way Analysis of Variance.

$$\text{sum}_i = \sum_{j=i}^{n} x_{ij} \quad \text{for } i = 1,2 \ldots k = \text{no. of treatments}$$

$$\text{mean}\bar{X}_i = \frac{\sum_{j=i}^{n_j} x_{ij}}{n_j}$$

$$\text{total SS} = \sum_{i=1}^{k} \sum_{j=1}^{n_2} (X_{ij} - \bar{\bar{X}})^2 = \sum_i \sum_j X_{ij}^2 - \frac{\left(\sum_i \sum_j X_{ij}\right)^2}{n^i}$$

$$\text{total df} = \sum_{i=1}^{k} n_i - 1$$

$$\text{treatment SS} = \sum_{i=1}^{k} (\bar{X} - \bar{\bar{X}})^2 = \sum_{i=1}^{k} \frac{\left(\sum_{j=i}^{n_i} X_{ij}\right)^2}{n_i} - \frac{\left(\sum_i \sum_j X_{ij}\right)^2}{\sum n_i}$$

$$\text{Treat df} = k-1$$

$$\text{Treat MS} = \frac{\text{Treat SS}}{\text{Treat df}}$$

$$\text{Error SS} = \text{Total SS} - \text{Treat SS}$$

$$\text{Error df} = \text{Total df} - \text{Treat df}$$

$$\text{Error MS} = \frac{\text{Error SS}}{\text{Error df}}$$

$$F = \frac{\text{Treat MS}}{\text{Error MS}}$$

Scheffé's S method of multiple comparison.

$$\sum_i^r c_i \mu_i \in \Sigma c_i Y_i \pm \left[(r-1)F_{\alpha} : r-1, N-r\right]^{1/2} S\left(\sum_i^r \frac{c_i^2}{n_i}\right)^{1/2}$$

Linear Regression with Analysis of Variance.

The Doolittle technique was used to reduce the matrices from which the SS_{REG}, additional sums of squares and estimates of the coefficients were obtained.

$SS(b_i \mid b_{i-1} \ldots b_o)$ = additional SS for b_i given that $b_{i-1} \ldots b_o$ are in model.

$$F(b_i \mid b_{i-1} \; b_o) = SS(b_i \mid b_{i-1} \ldots b_o) MS_{RES}$$

NONPARAMETRIC TESTS

chi-square test

2 x 2 contingency tables

$$\chi^2 = \frac{N(|AD - BC| - \frac{N}{2})^2}{(A+B)(C+D)(A+C)(B+D)}$$

r x k contingency tables

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{k} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

Mann-Whitney U test

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1$$

R_1 = sum of ranks of groups of size n_1

$$U = n_1 n_2 - U'$$

Kruskal-Wallis one-way Analysis of Variance

$$H = \frac{12}{N(N+1)} \sum_{j=1}^{k} \frac{R_j}{n_j} - 3(N+1)$$

where k = number of samples

n_j = number of cases in jth sample

$N = \Sigma n_j$.

R_j = sum of ranks in jth sample

Spearman Rank Correlation Coefficient

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d^2}{\left[2 \quad \Sigma x^2 \, \Sigma y^2\right]^{1/2}}$$

where Σx^2 and $\Sigma y^2 = \frac{N^3 - N}{12} - \Sigma \frac{(t^3 - t)}{12}$

where t = number of observations at a given rank

APPENDIX C

DETAILED RESULTS

Table C-1. Control cases (Chapter 2)

The following details are given for each of the children studied:

- sex
- age
- weight
- height
- * total protein
- * albumin
- TBK mEq
  mEq/kg
- skinfold thickness - midtriceps
  subscapular
  paraumbilical

* These children had serum protein and albumin determinations performed in the week prior to the TBK determination. All the children had a serum albumin greater than 3.50 g/100 ml.

Cases 1 - 30 Normal children

31 - 46 Recovered ward cases

47 - 87 Recovered PCM

Table C-1.

Case	Sex	Age months	wt (kg)	ht (cms)	Protein (G/100 ml)		TBK		Skinfold thickness (mm)		
					Total	Albumin	mEq	mEq/kg	mid-triceps	Sub-scapular	Para-umbilical
1	M	2	5.64	59.1	5.06	3.15	215.00	38.12	9.6	9.0	6.5
2	M	1.5	3.99	53.3	4.87	2.96	196.51	49.25	5.5	4.8	4.8
3	F	7.5	7.43	65.7	6.86	3.54	293.56	39.51	8.6	7.4	5.9
4	M	3	5.76	59.4	5.63	3.51	214.22	37.22	9.6	9.6	8.8
5	M	11.5	9.36	72.1	6.05	3.58	411.56	43.97	8.0	6.8	5.4
6	M	1.5	3.86	51.1	5.82	3.55	185.63	48.09	6.2	5.4	4.5
7	F	4.5	6.69	61.9	6.22	3.99	222.91	33.32	15.9	12.8	8.0
8	M	7.75	7.40	66.0	6.99	3.66	298.81	40.38	8.8	6.4	4.6
9	F	5.25	6.86	61.6	6.20	3.74	287.02	41.84	6.8	6.4	5.6
10	M	11.5	8.99	73.0	6.25	3.18	391.07	43.50	7.0	4.9	4.7
11	F	10	9.08	73.3	6.54	3.71	381.27	41.99	7.2	7.2	5.5
12	F	5.75	6.44	59.1	5.87	3.32	258.76	40.18	6.9	6.5	6.2
13	F	3.25	6.47	61.9	5.39	3.55	252.52	39.03	9.6	7.6	7.5
14	M	6.25	8.14	70.2	6.27	3.62	316.56	38.89	8.5	7.5	6.8
15	F	4	4.93	57.2	5.77	3.39	220.77	44.78	5.8	5.8	5.7
16	F	3.5	5.78	60.6	5.89	3.50	239.81	41.49	7.8	7.6	6.2
17	M	2.75	6.07	59.4	5.84	3.48	223.19	36.77	11.1	9.2	8.8
18	F	5.75	5.56	61.0	5.78	3.33	221.68	39.87	7.6	7.0	6.5
19	M	1.5	4.71	51.4	5.50	3.57	183.64	38.99	10.1	8.0	5.4
20	F	1.5	4.14	54.6	5.21	3.31	196.44	47.45	5.1	5.0	4.9
21	M	4.5	6.18	60.3	6.37	3.86	279.65	54.25	5.8	5.6	5.6
22	F	3.25	3.86	51.4	5.20	3.42	199.64	51.72	4.9	3.7	3.2
23	M	3	4.85	54.9	6.19	3.83	231.88	47.81	6.0	5.2	4.6

24	F	1.5	3.09	49.9	5.63	3.49	147.76	47.82	5.8	4.4	3.1
25	F	1.5	3.69	51.1	5.61	3.51	168.82	45.75	6.4	5.8	4.2
26	M	1.5	4.28	55.9	4.96	3.24	194.83	45.52	6.4	6.4	5.2
27	M	2	4.48	54.9	5.29	3.28	216.56	48.39	5.8	5.6	4.4
28	M	4	7.91	65.4	5.90	3.22	327.95	41.46	6.8	6.7	4.6
29	M	1.5	4.60	56.2	5.50	3.32	185.93	40.42	8.5	6.5	4.8
30	M	2	6.41	57.8	5.47	3.49	229.80	35.85	11.0	10.8	6.5
31	F	13	6.66	62.4			333.00	50.00	5.6	4.2	3.5
32	M	3	3.83	53.2			212.57	55.50	3.4	3.1	2.0
33	F	1.5	3.15	48.3			140.43	44.58	6.2	5.2	5.2
34	F	2	3.92	51.4			165.71	42.71	7.8	6.2	5.8
35	M	4	5.84	61.0			280.38	48.01	6.4	5.9	4.2
36	M	8	4.65	61.0			228.41	49.12	5.1	4.5	4.2
37	M	2.5	2.73	47.6			132.0	48.35	5.3	4.1	3.5
38	F	2.75	2.95	48.3			143.19	48.54	5.4	4.9	4.0
39	M	1.5	3.16	49.2			177.37	56.13	3.6	2.7	2.3
40	M	9	6.61	68.1			349.14	52.82	4.6	3.2	2.2
41	M	2	4.48	58.4			177.14	39.54	8.0	6.1	5.0
42	M	3	4.28	61.0			197.65	46.18	4.9	4.8	3.0
43	F	12	8.52	71.1			381.18	44.74	5.8	4.8	4.1
44	M	1.5	2.80	48.3			127.27	45.50	6.4	5.5	5.4
45	M	5	3.01	53.3			159.77	53.08	4.1	2.8	2.6
46	M	2.5	5.16	55.9			235.04	45.95	6.6	5.5	4.7
47	F	18	7.76	67.9	7.54	4.04	329.18	42.42	11.4	4.5	4.4
48	M	15	8.91	70.5	7.28	4.14	380.90	42.75	7.8	7.4	6.8

49	M	16	5.70	62.9	7.20	3.29	269.72	47.32	6.6	4.1	3.2
50	F	17	8.32	70.5	7.66	3.78	323.15	38.84	8.2	7.1	6.8
51	F	16	8.19	69.2	7.07	3.75	381.82	46.62	6.1	4.8	3.5
52	M	12	6.60	62.2	7.23	3.69	359.45	39.31	8.8	8.1	7.3
53	M	5.5	4.27	57.8	6.32	3.30	206.75	48.42	7.4	3.5	2.7
54	M	14	7.09	69.2	6.86	3.71	336.61	47.48	5.8	3.8	3.8
55	M	11	6.20	63.2	6.73	3.81	240.34	38.76	10.2	8.9	4.8
56	F	17	8.15	71.8	7.09	3.92	399.90	49.07	5.8	3.0	4.2
57	M	23	5.23	66.0	7.78	3.59	265.42	48.04	4.7	4.2	3.1
58	M	3	4.36	53.0	5.97	3.17	204.84	46.98	5.5	4.1	3.6
59	F	23	8.16	73.0	7.03	3.68	364.96	44.73	5.7	4.4	4.2
60	F	8	5.15	59.7	6.50	3.81	258.77	50.25	4.2	3.7	2.8
61	F	11	7.30	66.7	7.39	3.76	337.07	46.17	6.3	4.2	4.1
62	M	9	6.10	61.6	6.61	3.42	270.26	44.30	8.4	6.0	4.8
63	M	13	6.41	64.5	6.90	3.31	295.57	46.11	5.2	3.7	3.3
64	F	26	9.24	71.7	8.21	3.69	414.84	44.90	6.8	5.4	4.3
65	M	15	6.71	64.5	6.89	3.65	308.01	45.94	7.6	5.5	3.4
66	M	12	6.59	66.4	7.12	3.63	286.08	43.41	8.2	5.6	4.4
67	F	12	5.36	67.3	6.05	3.37	277.09	51.70	4.1	3.2	1.9
68	M	14	8.31	69.5	7.18	3.67	363.70	43.77	7.4	5.2	4.1
69	F	11	6.25	67.3	7.53	3.56	258.45	41.39	6.9	5.6	4.9
70	M	5	3.99	54.0	6.28	3.81	224.33	56.22	3.4	3.3	2.6
71	M	10	5.9	63.8	7.06	4.22	274.46	46.52	6.6	5.1	4.7
72	M	11	5.9	59.7	7.71	4.21	249.59	42.30	9.1	5.0	3.6
73	F	25	10.23	75.6	7.25	3.43	420.21	41.08	11.6	7.1	4.3
74	F	18	9.19	72.7	7.67	3.77	376.61	40.98	11.3	5.6	3.9

75	M	25	9.64	75.9	8.60	3.39	411.64	43.70	8.2	6.9	3.8
76	F	19	9.69	74.9	7.90	3.69	403.75	41.93	8.9	7.1	4.8
77	M	13	8.55	70.8	7.05	4.16	335.02	39.18	11.8	7.9	6.1
78	M	13	7.07	70.8	7.33	3.80	338.14	47.83	5.1	3.2	3.0
79	F	22	8.85	67.6	7.73	3.53	372.53	42.09	6.8	5.8	5.2
80	M	11	6.02	64.5	7.52	3.62	292.18	48.53	6.2	3.4	2.1
81	M	12	4.28	57.8	6.30	3.34	214.35	50.14	4.8	3.6	2.3
82	F	24	8.73	72.1	7.82	3.89	480.57	55.05	5.2	2.8	2.1
83	M	12	7.05	62.6	7.13	3.64	278.17	39.48	9.3	6.6	6.2
84	F	8	8.38	67.6	6.90	4.19	390.90	46.65	9.6	3.5	2.1
85	F	23	10.85	75.8	8.51	4.24	486.50	44.84	6.3	5.2	4.5
86	M	16	9.66	75.6	7.06	3.72	366.38	37.93	11.1	9.7	6.9
87	M	18	9.73	75.9	7.66	3.34	437.09	44.92	7.2	5.9	3.6

Table C-2 PCM cases (Chapter 3)

The following details are given for each of the children studied:

sex
age
height
weight
total protein
serum albumin
TBK mEq
mEq/kg

The appropriate results are given for Day 2, 5, 9 etc.

Cases 1 - 16 did not receive a potassium supplement
17 - 30 received a supplement of 12 mEq potassium/kg/day
31 - 42 received a supplement of 6 mEq potassium/kg/day
51 - 56 died

Table C-2

Case	Sex	Age months	Height cms	Day	Weight kg	Total protein gms %	Albumin gms %	TBK mEq	TBK mEq/kg
1	F	11	63.2	2	5.73	3.87	1.85	178.47	31.15
				5	5.36			136.90	25.54
				9					
				13	5.70	5.90	2.98	203.42	35.68
2	M	16	70.5	2	5.88	4.12	2.14	191.13	32.50
				5	6.03			198.91	33.01
				9	5.98			201.63	33.32
				13	6.41	6.22	3.31	244.99	38.22
3	F	11	66.4	2	5.69	4.60	2.18	199.61	35.11
				5	5.76			189.63	32.90
				9	5.67			189.67	33.43
				13	5.94	6.32	3.17	246.34	41.47
4	F	23	73.0	2	7.45	4.17	2.09	226.02	30.34
				5	7.35			237.53	32.32
				9	7.27			265.94	36.61
				13	7.38	5.17	2.60	310.91	42.13
5	M	27	71.1	2	7.88	3.62	1.69	267.12	33.92
				5	7.59			260.57	33.34
				9	7.53			302.24	40.14
				13	7.73	6.89	2.83	328.30	42.47

6	F	9	61.6	2	5.46	3.07	1.53	141.67	25.95
				5	5.52			155.91	28.24
				9	5.82			147.82	25.40
				13	5.86	3.67	1.74	166.30	28.32
7	F	14	67.3	2	6.58	4.19	2.10	214.49	32.60
				5	6.67			248.78	37.31
				9	6.79			255.61	37.65
8	M	19	74.3	2	8.16	3.35	1.07	251.23	30.79
				5	9.01			257.01	28.52
				9	9.22			269.09	29.19
9	F	6	57.8	2	5.96	3.43	1.47	189.02	31.72
				5	5.48			199.57	36.42
				9	4.48			182.14	40.70
				13	4.27	6.17	2.55	206.75	48.42
10	F	23	66.0	2	4.48	4.32	1.59	161.92	36.18
				5	4.70			208.81	44.30
				9	4.72			211.65	44.89
				13	4.86	6.26	2.65	214.76	44.19
11	M	8	59.7	2	4.51	4.45	2.33	152.99	33.92
				5	4.73			164.46	34.77
				9	4.96			173.83	35.05
				13	4.77	4.85	2.68	222.60	46.72
12	F	16	71.2	2	8.63	2.94	0.97	214.12	24.89
				5	9.12			227.22	24.91
				9	9.25			267.72	28.86

13	M	20	70.8	2	6.47	3.37	1.34	180.09	27.81
				5	6.25			216.13	34.58
				9	6.68			245.64	36.44
14	F	26	75.8	2	10.17	3.70	1.23	298.68	29.37
				5	9.07			321.76	35.47
				9	9.21			341.79	37.11
15	M		63.8	2	4.84	4.84	2.49	203.86	42.12
				5	4.95			202.64	43.52
				9	5.07			220.64	43.52
16	M	13	64.5	2	5.52	4.37	1.20	173.61	31.48
				5	4.93			187.41	38.05
				9	5.15			205.33	39.87
17	M	12	67.3	2	5.02	5.84	2.97	229.88	45.84
				5	5.06			222.83	44.04
				9	5.18			247.84	47.84
				13	5.36	6.05	3.37	277.99	51.79
18	F	13	64.5	2	4.80	3.13	1.45	149.68	31.22
				5	4.81			176.30	36.65
				9	4.77			166.57	34.92
				13	4.60	4.18	1.81	182.26	39.67
19	M	11	66.7	2	6.52	5.19	2.06	268.39	41.16
				5	6.55			271.33	41.42
				9	6.52			292.18	44.85
				13	6.80	6.36	3.07	285.11	41.93

20	F	3	53.0	2	3.95	3.70	2.14	140.06	35.46
				5	3.79			138.65	36.58
				9	3.79			138.64	36.63
				13	3.93	6.12	3.13	142.48	36.25
21	M	17	71.3	2	7.49	4.08	1.84	276.02	36.88
				5	7.27			292.88	40.31
				9	7.38			320.12	43.38
				13	7.51	6.44	3.54	329.15	43.83
22	F	15	64.5	2	5.83	6.23	3.66	251.97	43.22
				5	5.47			243.32	44.48
				9	5.52			254.19	46.41
				13	5.74	7.19	4.22	258.66	45.06
23	F	14	69.2	2	6.50	3.25	1.10	219.95	33.86
				5	6.63			252.90	38.14
				9	6.67			268.85	40.31
				13	7.05	6.00	3.19	285.72	40.53
24	M	18	67.9	2	6.98	3.90	1.61	229.34	32.88
				5	7.22			271.48	37.63
				9	7.66			329.02	42.44
25	F	12	57.8	2	4.19	2.97	1.29	125.76	30.67
				5	3.61			169.36	46.91
				9					
				13	4.13	6.30	3.34	213.42	51.67

26	F	16	62.9	2	4.44	3.74	1.87	133.90	30.19
				5	4.97			179.57	36.17
				9	5.35			196.92	36.84
27	M	17	70.5	2	7.15	5.95	2.36	277.94	38.87
				5	7.62			316.20	41.50
				9	7.90			319.16	40.40
28	F	12	62.2	2	5.65	3.82	1.93	144.38	25.58
				5	5.89			192.25	32.64
				9	5.91			212.00	35.87
				13	6.23	5.18	2.68	246.10	39.49
29	F	15	70.5	2	7.88	4.70	2.35	236.97	31.18
				5	7.95			304.83	38.37
				9	8.56			349.44	40.85
				13	8.79	7.28	4.14	380.91	42.75
30	M	16	69.2	2	7.00	4.12	1.46	266.59	38.11
				5	6.66			309.46	46.47
				9	7.13			328.12	46.02
31	F	10	63.2	2	5.64	3.79	1.63	180.73	32.06
				5	5.45			226.77	41.60
				9	5.36			242.97	45.33
32	F	17	71.0	2	6.33	3.82	2.26	203.74	32.19
				5	6.58			233.24	35.47
				9	6.69			261.79	39.13

33	F	10	61.0	2	6.72	4.27	2.19	143.73	21.39
				5	5.45			155.73	28.59
				9	5.25			172.05	32.80
34	F	11	58.7	2	5.71	4.18	1.74	193.28	33.85
				5	5.83			229.83	39.42
				9	5.78			246.78	42.70
35	F	20	74.8	2	8.11	3.86	1.63	225.93	27.85
				5	8.17			272.16	33.31
				9	7.93			286.15	36.08
				13	8.41	7.31	3.75	369.11	43.89
36	F	14	69.5	2	8.11	3.36	1.44	216.00	26.65
				5	8.50			236.34	27.80
				9	8.44			288.84	34.22
				13	7.91	6.42	3.03	282.15	35.67
37	F	17	59.6	2	5.78	5.88	2.79	224.51	38.88
				5	5.63			243.38	43.23
				9	5.66			244.01	43.17
38	F	24	67.6	2	6.40	3.26	1.42	223.93	34.99
				5	6.34			251.24	39.63
				9	6.95			303.54	43.67
39	M	19	70.9	2	7.76	3.77	1.92	202.61	26.11
				5	7.39			254.70	34.41
				9	7.51			286.17	38.11

40	F	16	67.6	2	7.15	3.55	1.26	199.85	27.95
				5	7.03			219.83	31.27
				9	7.36			281.59	38.26
41	M	13	75.6	2	8.44	3.21	1.36	232.80	27.60
				5	8.50			274.94	32.35
				9	8.66			316.75	36.57
42	F		67.3	2	5.68	4.95	1.75	172.44	30.36
				5	5.70			176.31	30.93
				9	5.79			220.97	38.14
43	M	22	72.4	2	7.35	3.23	1.70	245.21	33.36
44	F	25	71.1	2	6.69	4.04	1.72	212.04	31.72
45	M	12	60.0	2	4.31	4.31	2.11	134.73	31.26
46	M	17	69.8	2	7.12	3.69	1.54	248.03	34.84
47	M	25	75.9	2	8.52	3.79	1.04	283.10	33.23
48	F	25	75.6	2	9.25	3.02	1.09	271.76	29.38
49	F	19	74.9	2	8.80	3.65	1.47	276.08	31.37
50	F	9	60.7	2	4.52	4.15	2.03	92.99	20.62
51	M	7	63.2	2	6.24	3.59	1.74	166.42	26.69
52	F	3	55.9	2	3.43	4.09	1.91	71.80	20.76
53	F	13	61.3	2	6.45			158.89	24.63
54	M	20	73.0	2	6.82	3.08	1.67	239.03	35.05
55	M	17	67.4	2	7.11	2.58	0.78	191.02	26.87
56	M	20	69.5	2	6.23	5.49	2.55	209.71	33.69

Table C-3 Gastroenteritis cases (Chapter 3)

The following details are given for each of the children studied:

sex
age
height
weight
total protein
serum albumin
TBK mEq
mEq/kg
skinfold thickness

The appropriate results are given for Day 1, 2 5 etc.

Cases 1 - 29 were treated in the drip room

30 - 39 did not receive a potassium supplement

40 - 49 received a potassium supplement of 6 mEq/kg/day

27 - 29 died

Table C-3

Case	Sex	Age months	Height cms	Day	Weight kg	Total Protein gms %	Albumin gms %	TBK mEq	TBK mEq/kg	Mean Skin-fold thickness mm
1	F	6	62.9	1	4.14			197.00	47.56	2.6
				2	4.32	6.37	3.43	193.68	44.88	2.8
2	M	10	69.9	1	6.24			271.22	43.48	4.7
				2	6.61	5.98	2.86	259.87	39.31	5.1
3	F	11	69.5	1	8.17			308.87	37.80	4.9
				2	8.56	6.81	3.45	295.23	34.47	5.2
4	F	2	53.3	1	3.12			145.71	46.76	2.6
				2	3.73	6.32	3.66	147.33	39.50	2.9
5	F	7	65.7	1	6.81			281.44	41.33	6.9
				2	7.46	5.45	2.66	298.28	39.88	7.7
6	M	3	60.0	1	4.76			211.66	44.43	5.1
				2	5.05	6.80	3.51	237.51	47.03	5.2
7	M	2	53.3	1	3.35			146.78	43.93	3.0
				2	3.38	5.70	3.08	152.32	45.07	3.1
8	M	7	63.2	1	5.56			203.49	36.60	5.7
				2	6.07	5.52	2.82	191.41	31.53	6.0
9	M	7	60.3	1	4.82			177.86	36.90	4.3
				2	5.09	6.58	3.45	187.13	36.76	4.5
10	F	3	50.2	1	3.09			136.29	44.14	3.5
				2	3.14	5.29	3.16	146.74	46.67	4.0

11	M	2	52.7	1	3.00			139.76	46.53	3.7
				2	3.37	6.93	4.00	133.37	39.55	4.0
12	M	2	51.4	1	3.69			136.32	36.96	5.3
				2	3.90	5.05	2.75	137.18	35.22	5.4
13	F	4	54.6	1	4.42			180.82	40.89	5.4
				2	4.39	5.86	3.06	180.59	41.10	5.8
14	F	6	61.9	1	6.10			209.47	34.19	7.8
				2	6.41			210.59	32.84	8.2
15	M	6	54.0	1	3.91			172.59	44.12	2.6
				2	4.09	5.25	2.45	181.25	44.31	3.0
16	F	2	51.8	1	2.61			122.34	46.95	2.2
				2	2.86	6.38	3.05	115.82	40.44	2.5
17	F	2	55.9	1	4.48			171.40	38.27	4.8
				2	4.76	4.22	2.36	197.06	41.36	4.8
18	M	5	65.1	1	5.99			246.30	41.15	5.9
				2	5.99	5.11	2.70	214.06	35.76	6.5
19	F	4	53.0	1	4.37			187.11	42.86	7.0
				2	4.37	5.77	3.32	186.26	42.66	7.8
20	M	5	58.7	1	4.93			185.95	37.70	4.1
				2	5.10	7.26	3.50	193.19	37.92	4.3
21	M	6	64.8	1	6.52			278.56	42.70	5.4
				2	7.26	6.50	3.13	293.02	40.34	6.3
22	M	9	72.4	1	7.77			297.23	38.23	5.2
				2	8.28	6.55	3.59	301.09	36.35	5.4

23	M	5	63.5	1	6.15			184.93	30.05	7.8
				2	6.38	5.72	3.43	191.34	29.97	8.2
24	F	4	56.7	1	4.69			176.70	37.68	3.1
				2	4.81	6.47	3.15	163.71	34.03	3.7
25	M	8	66.8	1	6.66			237.55	35.67	4.8
				2	6.72	5.67	3.21	238.13	35.44	4.9
26	F	11	70.1	1	7.81			300.78	38.51	5.3
				2	8.13	6.71	3.11	309.94	38.12	5.6
27	F	4	51.0	1	3.81			131.60	35.45	3.1
28	M	10	68.0	1	5.81			203.62	35.03	3.5
29	F	3	56.6	1	3.71			131.50	35.63	2.9
30	M	2	50.2	1	2.78			157.37	56.61	2.3
				2	2.72	5.01	2.63	158.54	58.26	2.7
				5	2.94			145.71	49.56	2.7
				9	2.73			125.13	45.83	2.7
				13	3.09	6.80	3.43	124.92	40.44	2.9
				17	3.20			162.91	50.95	2.9
31	M	5	60.6	1	5.88			236.34	40.19	5.4
				2	6.16	5.63	3.26	246.73	40.05	5.7
				5	6.01			222.75	37.06	5.7
				9	5.86			221.00	37.70	5.8
				13	5.76	6.25	3.59	222.00	38.61	5.7
				17	5.79			257.61	45.04	5.8

32	M	10	69.2	1	6.38			287.95	45.13	4.2
				2	6.87	4.10	2.04	253.11	36.84	4.5
				5	6.99			226.75	32.44	4.5
				9	6.44			249.02	38.67	4.6
				13	7.31	5.79	3.59	292.34	40.02	4.9
				17	7.36			328.54	44.64	4.9
33	M	3	57.8	1	4.14			165.94	41.59	4.6
				2	4.39	4.83	2.88	165.60	40.00	5.0
				5	4.62			170.85	36.98	4.9
				9	4.80			174.09	36.27	4.9
				13	4.50	5.79	3.59	186.52	41.45	4.9
				17	4.21			195.59	46.46	5.0
34	M	11	72.1	1	6.57			262.30	39.92	6.0
				2	7.81	5.01	2.76	259.05	33.17	6.5
				5	7.65			299.88	38.64	6.3
				9	7.93			303.52	38.25	6.3
				13	7.78	6.27	3.43	309.29	39.76	6.3
				17	8.18			348.91	43.86	6.5
35	F	10	68.0	1	6.99	5.52	3.01	310.09	44.36	4.1
				2	7.46			321.67	43.13	4.4
				5	7.32			292.65	39.98	4.4
				9	7.20			290.74	40.38	4.5
				13	7.60	5.93	3.42	344.51	45.33	4.8
				17	7.61			340.42	44.78	5.0

36	M	5	59.1	1	5.16			225.39	45.55	3.9
				2	5.09	7.21	3.21	222.33	43.68	4.1
				5	5.32			224.77	42.25	4.4
				9	5.16			225.23	43.65	4.5
				13	5.27	7.07	3.92	233.42	44.29	4.7
				17	5.64			248.16	44.00	5.1
37	M	12	73.0	1	8.96			341.29	38.19	7.1
				2	9.15	6.76	3.82	331.60	36.24	7.6
				5	8.95			305.82	34.17	7.7
				9	9.07			331.06	36.50	7.9
				13	9.29	6.81	3.93	358.87	38.63	7.9
				17	9.39			381.42	40.62	8.0
38	M	7	66.0	1	6.37			298.88	46.92	4.5
				2	6.40	7.17	3.59	281.66	44.01	4.6
				5	6.53			243.56	37.29	4.6
				9	6.47			248.74	38.44	4.7
				13	6.39	7.31	3.98	292.03	45.70	4.6
				17	6.82			302.93	44.42	5.2
39	F	9	70.4	1	7.30			324.34	44.43	3.7
				2	7.35	6.76	3.54	335.31	45.62	3.7
				5	7.48			308.48	41.24	3.9
				9	7.31			322.50	44.10	3.8
				13	7.34	7.54	4.29	344.39	46.92	3.9
				19	7.77			381.58	49.11	4.2

40	M	5	62.2	1	5.79			206.58	35.68	5.4
				2	6.09	6.27	3.64	211.66	34.76	5.7
				5	6.20			229.30	36.12	5.9
				9	6.43			245.30	40.41	6.0
				13	6.50	6.28	3.55	261.33	40.20	6.0
				17	6.44			275.7	42.81	6.2
41	M	2	54.6	1	4.03			177.97	44.16	4.4
				2	4.43	5.68	2.92	178.44	40.18	4.9
				5	4.34			193.29	44.59	5.0
				9	4.43			198.80	44.87	5.0
				13	4.75	6.05	3.21	209.6	44.11	5.1
				17	4.77			226.1	47.40	5.2
42	M	2	54.9	1	3.61			161.91	44.85	4.0
				2	4.14	5.87	3.09	157.62	38.07	4.4
				5	4.30			177.07	41.18	4.5
				9	4.32			185.19	42.87	4.5
				13	4.19	6.03	3.48	201.59	48.11	4.6
				17	4.47			216.03	48.01	4.7
43	M	9	70.8	1	9.05			313.85	34.68	8.8
				2	9.66	5.98	3.15	288.02	29.82	8.9
				5	9.61			288.47	30.02	8.9
				9	9.92			339.04	34.42	9.1
				13	10.08	6.37	3.36	345.37	34.18	9.2
				17	10.11			369.19	36.63	9.2

44	M	3	56.5	1	4.49			159.49	35.52	4.5
				2	4.53	4.98	2.97	173.39	38.28	4.5
				5	4.32			181.12	41.97	4.6
				9	4.42			189.91	42.97	4.8
				13	4.47	5.58	3.38	195.82	43.86	4.7
				17	4.52			201.26	44.53	4.7
45	M	5	56.9	1	4.63			167.73	35.84	7.3
				2	4.75	5.52	3.01	171.18	36.04	7.2
				5	4.74			191.58	40.25	7.5
				9	4.74			193.34	40.79	7.6
				13	4.81	5.93	3.42	204.08	42.43	7.6
				17	4.82			204.29	42.38	7.6
46	M	6	61.9	1	5.37			242.23	45.11	4.2
				2	5.49	5.73	3.24	239.13	43.59	4.3
				5	5.58			210.65	37.75	4.2
				9	5.62			228.30	40.62	4.2
				13	5.82	6.91	3.73	259.51	44.59	4.4
				17	6.10			286.58	46.98	4.6
47	F	12	71.3	1	7.56			338.23	44.74	3.5
				2	7.84	4.98	2.97	332.70	42.46	3.9
				5	7.79			312.38	40.10	4.1
				9	7.82			306.05	39.14	4.2
				13	8.21	5.58	3.38	368.88	44.93	4.5
				17	8.40			396.40	47.19	4.8

48	F	2	57.4	1	4.17			157.50	37.77	5.4
				2	4.23	3.97	2.38	160.29	37.89	5.5
				5	4.31			143.65	33.33	5.5
				9	4.26			171.89	40.35	5.6
				13	4.61	5.35	3.23	193.25	41.92	5.8
				17	4.96			216.93	43.74	5.9
49	M	3	59.3	1	4.40			193.69	44.02	4.6
				2	4.51	5.55	3.22	201.64	44.71	4.8
				5	4.57			194.50	42.56	4.8
				9	4.80			190.86	39.76	4.7
				13	4.99	6.37	3.36	216.61	43.41	4.9
				17	5.35			241.55	45.15	5.3

Table C-4 Cases with acute pulmonary infections (Chapter 3)

The following details are given for each of the children studied:

sex
age
height
weight
total protein
serum albumin
TBK mEq
mEq/kg
skinfold thickness
clinical diagnosis B = bronchiolitis
P = bronchopneumonia
PS= bronchopneumonia with bronchospasm

Cases 43 - 45 were admitted to the metabolic unit for thiosulphate space determinations.

Table C-4

Case	Sex	Age months	Height cms	Day	Weight kg	Total protein gms %	Albumin gms %	TBK mEq	TBK mEq/kg	Mean skinfold thickness mm	Diagnosis
1	F	6	63.8	1	5.93	5.81	2.87	254.83	42.94	5.2	P
2	F	13	69.5	1	7.68	6.49	3.39	322.12	43.26	6.1	P
3	F	21	74.6	1	7.76	6.93	3.16	276.04	35.57	4.9	P
4	M	3	57.2	1	4.39	5.66	3.30	214.03	48.80	4.2	PS
5	M	8	67.9	1	7.26	7.45	3.53	312.52	43.07	4.8	P
6	F	3	56.5	1	4.74	6.21	3.16	210.15	44.38	6.4	P
7	F	3	51.4	1	3.26	5.40	3.29	153.58	47.11	4.4	P
8	F	7	68.0	1	8.04	6.40	2.89	215.90	26.85	9.0	PS
9	F	2	55.0	1	3.26	5.31	2.44	151.11	46.32	3.0	P
10	F	8	68.9	1	7.48	6.27	3.25	303.67	40.60	5.6	B
11	M	9	70.5	1	8.66	6.43	3.39	317.45	36.66	7.2	B
12	M	10	66.0	1	6.36	6.64	2.91	241.41	37.96	4.4	PS
13	M	6	60.3	1	5.29	5.49	2.93	226.04	42.77	5.3	PS
14	F	8	66.0	1	7.54	6.75	3.35	305.63	40.53	7.3	P
15	M	2	56.2	1	4.14	5.36	3.24	208.90	50.46	3.9	B
16	F	9	70.2	1	7.31	5.77	2.34	291.11	39.81	6.0	PS
17	F	2	53.0	1	4.19	5.43	2.90	244.01	58.24	4.3	P
18	F	7	63.2	1	7.31	6.05	3.07	270.67	37.02	8.9	B
19	F	11	68.9	1	7.31	6.81	2.58	285.78	39.09	7.8	P
20	M	15	72.4	1	8.49	5.58	2.44	323.40	38.09	6.0	P
21	F	2	55.2	1	4.13	5.88	3.31	193.83	46.89	6.4	P
22	M	3	57.2	1	4.56	5.69	2.96	200.88	44.09	5.7	P

23	M	4	59.4	1	5.82	6.30	3.57	272.54	46.83	7.0	B
24	F	2	55.9	1	5.01	5.34	3.20	227.51	45.45	7.9	B
25	M	9	67.9	1	7.79	5.89	2.30	307.14	39.43	6.9	P
26	F	4	57.6	1	5.91	6.56	3.58	220.06	37.26	11.1	B
27	F	3	55.6	1	4.39	5.68	3.33	175.22	39.95	4.5	PS
28	M	7	61.6	1	7.20	6.11	3.19	319.54	44.38	8.7	B
29	M	25	72.7	1	7.82	4.74	1.57	345.20	44.15	4.0	P
30	M	6	61.6	1	6.69	7.19	2.94	253.97	37.96	7.7	P
31	F	6	63.5	1	8.16	5.41	2.99	303.95	37.27	9.4	P
32	M	9	65.7	1	6.13	6.00	2.92	260.11	42.43	5.5	P
33	M	11	70.5	1	7.28	6.49	3.35	329.73	45.27	5.0	P
34	M	10	69.2	1	7.48	7.13	3.42	330.29	44.15	6.7	B
35	F	8	66.0	1	6.08	6.17	3.03	261.42	43.03	3.8	P
36	M	2	49.2	1	3.21	6.02	3.25	163.63	51.04	3.0	B
37	M	3	61.6	1	5.71	4.97	2.99	231.38	40.52	6.7	PS
38	F	11	67.3	1	5.85	6.52	3.00	235.06	40.18	5.3	P
39	F	4	61.6	1	6.24	6.26	3.54	250.87	40.19	10.0	B
40	F	3	55.2	1	5.25	5.53	3.23	227.34	43.34	5.5	B
41	M	4	61.3	1	4.53	6.67	3.83	225.79	49.87	3.5	B
42	F	4	50.2	1	2.78	5.98	3.73	148.47	53.33	2.3	B
43	M	11	73.3	1	9.23	7.17	3.59	361.98	39.22	7.6	P
				5	9.66			372.32	38.54	7.9	
				9	9.57			386.48	40.34	7.9	
				13	9.75	8.27	3.70	403.08	41.33	7.9	
				17	9.80			403.42	41.16	7.9	

44	M	7	69.9	1	9.06	7.31	3.98	307.21	33.91	7.6	PS
				5	8.90			314.12	35.36	7.6	
				9	8.99			346.56	38.55	7.6	
				13	9.44	6.40	3.63	360.50	38.19	7.8	
				17	9.57			368.27	38.48	7.6	
45	F	7	68.6	1	7.32	6.76	3.54	284.15	38.82	7.3	B
				5	7.19			266.70	37.09	7.4	
				9	7.20			282.45	39.23	7.3	
				13	7.37	7.54	4.29	293.91	39.91	7.4	
				17	7.60			299.02	39.34	7.4	

Table C-5.

PCM Cases (Chapter 4)

TBK and serum electrolyte results

The following results are given for each child studied on Day 2:

TBK mEq
mEq/kg
Serum sodium mEq/l
potassium mEq/l
chloride mEq/l

The case numbers are the same as those in Table C-2.

Table C-5.

Case	TBK mEq	TBK mEq/kg	serum sodium mEq/l	serum potassium mEq/l	serum chloride mEq/l
1	178.47	31.15	135.4	3.61	99.5
2	191.13	32.50	143.5	4.19	104.2
3	199.61	35.11	152.9	3.88	109.5
4	226.02	30.34	122.1	3.75	110.7
5	267.12	33.92	119.9	3.72	105.0
6	141.67	25.95	133.4	4.82	104.3
7	214.49	32.60	138.7	4.05	100.7
8	251.23	30.79	139.6	5.47	100.6
9	189.02	31.72	148.2	3.90	103.5
10	161.92	36.18	136.8	4.66	110.4
11	152.99	33.92	135.9	3.42	109.3
12	214.12	24.89	136.2	3.12	105.4
13	180.09	27.81	145.6	5.93	109.6
14	298.68	29.37	131.1	3.16	104.0
15	203.86	42.12	134.0	3.20	99.7
16	173.61	31.48	143.7	5.10	103.8
17	229.88	45.84	143.6	5.03	106.3
18	149.68	31.22	129.2	3.99	106.7
19	268.39	41.16	130.0	4.10	109.1
20	140.06	35.46	127.0	5.27	104.1
21	276.02	36.88	120.6	7.30	94.3
22	251.97	43.22	136.9	3.62	104.3
23	219.95	33.86	135.4	4.02	97.6
24	229.34	32.88	128.2	3.71	89.9
25	125.76	30.67	141.7	4.10	109.1
26	133.90	30.19	142.6	3.89	106.7
27	277.94	38.87	129.4	4.32	94.6
28	144.38	25.58	121.7	2.71	88.4
29	236.97	31.18	135.5	3.99	106.4
30	266.59	38.11	142.9	4.82	103.5
31	180.73	32.06	129.5	3.82	93.0
32	203.74	32.19	131.0	3.75	99.2
33	143.73	21.39	120.5	4.61	86.7
34	193.28	33.85	139.7	5.17	102.6
35	225.93	27.85	141.6	3.73	101.9

36	216.00	26.65	144.0	3.85	102.7
37	224.51	38.88	131.7	3.90	102.4
38	223.93	34.99	130.9	2.36	95.7
39	202.61	26.11	137.9	2.94	100.1
40	199.85	27.95	134.7	4.14	99.8
41	232.80	27.60	130.9	3.09	98.4
42	172.44	30.36	132.0	3.40	97.4
43	245.21	33.36	140.2	4.80	108.3
44	212.04	31.72	150.0	4.49	104.3
45	134.73	31.26	127.6	4.75	95.1
46	248.03	34.84	137.3	3.21	99.6
47	283.10	33.23	134.5	3.32	98.7
48	271.76	29.38	132.1	3.74	101.8
49	276.08	31.37	135.6	3.50	101.4
50	92.99	20.62	123.4	3.71	89.6
51	166.42	26.69	131.3	3.03	94.1
52	71.80	20.76	121.3	3.29	91.7
53	158.89	24.63	131.6	3.69	99.5
54	239.03	35.05	116.6	3.70	81.4
55	191.02	26.87	142.0	3.35	104.4
56	209.71	33.69	158.4	2.56	113.2

Table C-6. Gastroenteritis cases (Chapter 4)

The following results are given for each child on day 1 and day 2:

TBK mEq
TBK mEq/l
+ Blood pH
+ pCO_2 mm mercury
+ base excess mEq/l
Serum sodium mEq/l
potassium mEq/l
chloride mEq/l

+ Only the day 1 results given

The case numbers are the same as those in Table C-3.

Table C-6.

Case	Day	TBK		pH	pCO_2	BE	Na	K	Cl
		mEq	mEq/kg		mmHg	mEq/l	mEq/l	mEq/l	mEq/l
1	1	197.00	47.56	6.95	60	-18.5	187.7	2.75	128.2
	2	193.68	44.88				157.8	3.65	115.3
2	1	271.22	43.48	7.32	42	- 4.5	129.5	4.20	102.7
	2	259.87	39.31				131.9	3.60	101.6
3	1	308.57	37.80	7.19	22	-19	136.9	2.67	111.2
	2	295.23	34.47				133.3	2.85	110.5
4	1	145.71	46.76	7.19	25	-18	160.7	3.80	121.8
	2	147.33	39.50				148.3	4.13	109.4
5	1	281.44	41.33	7.42	31	+ 3	123.6	3.06	82.1
	2	298.28	39.88				136.9	5.26	100.4
6	1	211.66	44.43	7.28	31	-11	126.5	4.15	103.6
	2	237.51	47.03				130.7	4.65	100.0
7	1	146.78	43.93	7.29	41	- 7	126.8	4.35	92.2
	2	152.32	45.07				129.6	3.98	95.7
8	1	203.49	36.60	7.33	35	- 7	126.0	3.80	97.1
	2	191.41	31.53				134.8	4.37	101.7
9	1	177.86	36.90	7.24	34	-12	129.0	4.70	101.0
	2	187.13	36.76				146.0	3.05	104.7
10	1	136.29	44.14	7.26	34	- 7.5	140.6	4.35	113.9
	2	146.74	46.17				140.3	5.32	113.0

11	1	139.76	46.53	7.07	15	-22.5	143.3	4.10	117.4
	2	133.37	39.55				142.6	3.86	106.8
12	1	136.32	36.96	7.22	31	-14.5	156.2	3.02	116.3
	2	137.18	35.22				150.4	3.61	108.1
13	1	180.82	40.89	7.27	26.5	-13.5	135.7	2.4	110.1
	2	180.59	41.10				136.6	5.06	108.8
14	1	209.47	34.19						
	2	210.59	32.84						
15	1	172.59	44.12	7.32	35	- 8	132.7	5.70	106.3
	2	181.25	44.31				138.3	4.14	103.7
16	1	122.34	46.95	7.03	44	-24	125.5	3.80	105.2
	2	115.82	40.44				130.4	3.61	99.4
17	1	171.40	38.27	7.24	34	-11	142.8	6.45	118.6
	2	197.06	41.36				136.6	4.65	109.0
18	1	246.30	41.15	7.37	34	-45	145.1	4.78	104.4
	2	214.06	35.76				148.5	5.93	105.9
19	1	187.11	42.86	7.17	35.5	-15	139.2	4.85	116.0
	2	186.26	42.66				152.2	4.86	109.4
20	1	185.95	37.70	7.22	31.5	-14	139.0	4.76	102.7
	2	193.19	37.92				141.2	3.29	101.1
21	1	278.56	42.70	7.27	27	-13.5	138.1	5.62	107.3
	2	293.02	40.34				138.7	5.11	101.6

22	1	297.23	38.23	7.30	29.5	-11	132.0	3.07	109.6
	2	301.09	36.35				136.8	5.17	109.1
23	1	184.93	30.05	7.31	35.5	- 8	152.1	4.74	115.2
	2	191.34	29.97				154.5	4.60	113.8
24	1	176.70	37.68	7.10	32	-20	135.4	4.88	101.3
	2	163.71	34.03				132.4	4.68	102.7
25	1	237.55	35.67	7.24	21	- 6.5	142.3	4.28	106.9
	2	238.13	35.44				134.1	5.08	98.3
26	1	300.78	38.51	7.39	26	- 8.5	134.3	2.21	102.2
	2	309.94	38.12				130.9	3.41	103.3
27	1	131.60	35.45	7.14	43.0	-12.5	97.6	4.5	82.2
28	1	203.62	35.03	7.28	51	- 2.5	121.4	5.2	93.9
29	1	131.50	35.63	7.22	41	- 9.5	165.3	3.32	117.4
30	1	157.37	56.61	7.16	51	-11	141.5	5.06	104.2
	2	158.54	58.26				136.3	5.12	102.0
31	1	236.34	40.19	7.25	35.5	-11	145.3	4.52	104.1
	2	246.73	40.05				148.0	4.21	102.9
32	1	287.95	45.13	7.37	34	- 3	164.5	6.37	117.9
	2	253.11	36.84				143.8	4.84	112.7
33	1	165.94	41.59	7.23	40	-10.7	126.8	2.91	90.1
	2	165.60	40.00				127.0	3.83	93.6
34	1	262.30	39.92	7.37	36.5	- 4.5	126.5	4.10	94.9
	2	259.05	33.17				140.8	4.50	99.0

35	1	310.09	44.36	7.35	29	- 8.5	129.1	3.55	102.4
	2	321.67	43.13				134.3	3.83	104.3
36	1	225.39	45.55	7.40	21	- 7.5	126.3	3.02	99.1
	2	222.33	43.68				135.6	5.16	107.3
37	1	341.29	38.19	7.33	35	- 6.5	129.4	4.96	99.3
	2	331.60	36.24				139.0	5.64	104.0
38	1	298.88	46.92	7.46	22	- 3.5	136.9	5.34	105.6
	2	281.66	44.01				140.2	4.37	109.4
39	1	324.34	44.43	7.24	23	-16.5	122.8	2.74	97.2
	2	335.31	45.62				128.9	4.89	102.5
40	1	206.58	35.68	6.97	21	-22	128.5	3.21	94.8
	2	211.66	34.76				136.3	2.96	103.3
41	1	177.97	44.16	7.07	30	-22	156.8	5.15	112.4
	2	178.44	40.28				133.0	3.13	101.3
42	1	161.91	44.85	7.09	20.5	-22	188.7	6.00	127.9
	2	157.62	38.07				171.5	4.76	121.4
43	1	313.85	34.68	7.21	19	-19	126.9	4.68	98.6
	2	288.02	29.82				140.6	3.57	104.0
44	1	159.49	35.52	7.24	26	-15	125.0	3.35	106.4
	2	173.39	38.28				128.5	4.56	102.4
45	1	167.73	35.84	7.36	38	- 4	157.0	5.40	117.4
	2	171.18	36.04				149.0	3.62	102.0

46	1	242.23	45.11	7.26	45	- 3	135.2	2.83	101.7
	2	239.13	43.59				138.4	4.73	102.1
47	1	338.23	44.74	7.33	43	- 1	138.2	4.24	99.9
	2	332.70	42.46				136.7	4.89	100.5
48	1	157.50	37.77	7.14	21	-21	128.3	4.55	112.4
	2	160.29	37.89				133.5	4.59	114.5
49	1	193.69	44.02	7.41	35	- 2	123.0	3.43	97.2
	2	201.64	44.71				130.8	4.34	103.9

Table C-7 Cases with acute pulmonary infections (Chapter 4)

The following results are given for each of the children studied:

TBK mEq
mEq/kg
Serum sodium mEq/l
Serum potassium mEq/l
Serum chloride mEq/l

The case numbers are the same as those in Table C-4.

Table C-7

Case	TBK mEq	TBK mEq/l	Serum sodium mEq/l	Serum potassium mEq/l	Serum chloride mEq/l
1	254.83	42.94	143.6	5.30	109.0
2	322.12	43.26	134.9	4.85	100.0
3	276.04	35.57	125.1	4.10	101.2
4	214.03	48.80	138.3	6.05	104.5
5	312.52	43.07	143.3	5.00	106.1
6	210.15	44.38	138.7	6.16	104.3
7	153.58	47.11	156.8	5.65	115.4
8	215.90	26.85	137.0	2.81	109.6
9	151.11	46.32	129.3	5.45	88.6
10	303.67	40.60	131.4	3.15	102.6
11	317.45	36.66	134.5	5.33	106.5
12	241.41	37.96	140.8	3.95	99.2
13	226.04	42.77	149.9	4.94	115.7
14	305.63	40.53	137.6	4.74	106.6
15	208.90	50.46	146.0	5.75	105.2
16	291.11	39.81	135.0	4.72	104.7
17	244.01	58.24	146.1	4.20	107.6
18	270.67	37.02	146.8	3.88	106.9
19	285.78	39.09	133.0	5.87	104.1
20	323.40	38.09	129.7	5.45	100.1
21	193.83	46.89	141.2	4.18	107.3
22	200.88	44.09	134.3	6.00	106.3
23	272.54	46.83	137.4	2.45	106.7
24	227.51	45.45	130.8	4.74	100.3
25	307.14	39.43	139.1	5.19	105.8
26	220.06	37.26	148.7	4.63	109.0
27	175.22	39.95	139.5	6.35	102.7
28	319.54	44.38	134.9	5.45	106.8
29	345.20	44.15	130.7	3.70	103.8
30	253.97	37.96	140.3	5.02	108.4
31	303.95	37.27	137.6	5.16	126.8
32	260.11	42.43	172.8	6.75	126.8
33	329.73	45.27	132.2	3.75	102.6

34	330.29	44.15	125.4	5.90	93.3
35	261.42	43.03	126.7	4.84	89.0
36	163.63	51.04	129.8	5.69	89.6
37	231.38	40.52	127.9	5.55	99.1
38	235.06	40.18	129.1	5.08	97.7
39	250.87	40.19	166.7	5.90	118.7
40	227.34	43.34	131.6	5.80	105.7
41	225.79	49.87	133.2	5.80	100.3
42	148.47	53.33	150.4	5.60	109.9
43	361.98	39.22	156.9	4.74	111.8
44	307.21	33.91			
45	284.15	38.82			

Table C-8 (Chapter 5)

The following details are given for each of the children studied:

	age (months)		
	height (cms)		
	weight (kg)		
	thiosulphate space	litres	
		ml/kg	
*	total body water	litres	On day 2, 5 and
		ml/kg	recovery
	TBK	mEq	
		mEq/kg	
	serum sodium	mEq/l	
	potassium	mEq/l	
	chloride	mEq/l	
	total protein	g/100ml	
	albumin	g/100ml	

Cases 1 - 6 did not receive a potassium supplement
7 -12 received a potassium supplement

* Cases 5, 6, 11 and 12 did not have total body water determinations.

Table C-8

Case 1

Age (months) 18 Height (cms) 70.8

Day		2	5	R
Weight (kg)		8.60	9.53	9.19
Thiosulphate space	litres	2.60	3.21	2.30
	ml/kg	302.3	346.6	250.4
Total body water	litres	5.698	8.22	5.398
	ml/kg	662.6	862.5	587.4
TBK	mEq	210.42	267.22	376.60
	mEq/kg	24.47	38.86	40.98
Serum sodium	mEq/l	146	136	134
potassium	mEq/l	2.8	3.4	4.8
chloride	mEq/l	107	105	104
Total protein	g/100ml	2.87	2.96	7.65
Albumin	g/100ml	0.84	0.99	3.77

Case 2

Age (months) 13 Height (cms) 70.8

Day		2	5	R
Weight (kg)		5.52	4.93	6.02
Thiosulphate space	litres	1.92	1.84	1.54
	ml/kg	347.8	373.8	264.4
Total body water	litres	4.592	3.268	4.378
	ml/kg	832.6	663.6	727.2
TBK	mEq	173.61	187.41	292.18
	mEq/kg	31.48	38.05	48.53
Serum sodium	mEq/l	144	139	142
potassium	mEq/l	5.1	4.2	4.5
chloride	mEq/l	104	102	105
Total protein	g/100ml	4.37	5.45	7.52
Albumin	g/100ml	1.20	1.93	3.62

Case 3

Age (months) 20 Height (cms) 70.8

Day	2	5	R
Weight (kg)	6.48	6.25	7.07
Thiosulphate space litres	1.93	2.24	1.82
ml/kg	298.2	358.6	268.4
Total body water litres	4.950	3.310	4.520
ml/kg	764.5	529.6	639.3
TBK mEq	180.09	216.13	338.14
mEq/l	27.84	34.58	47.83
Serum sodium mEq /l	146	143	133
potassium mEq /l	5.9	6.0	3.7
chloride mEq /l	110	110	103
Total protein g/100ml	3.35	4.04	7.33
Albumin g/100ml	1.34	1.66	3.80

Case 4

Age (months)	26	Height (cms)	75.8	
Day		2	5	R
Weight (kg)		10.17	9.07	10.85
Thiosulphate space				
	litres	3.35	3.28	2.31
	ml/kg	329.4	361.5	215.0
Total body water				
	litres	7.092	4.630	6.410
	ml/kg	697.4	510.5	590.8
TBK	mEq	298.68	321.76	486.50
	mEq/l	29.37	35.47	44.84
Serum sodium	mEq/l	131	134	132
potassium	mEq/l	3.2	4.2	3.9
chloride	mEq/l	104	103	103
Total protein	g/100ml	3.70	6.35	8.51
Albumin	g/100ml	1.23	2.60	4.24

Case 5

Age (months) 15 Height (cms) 63.8

Day		2	5	R
Weight (kg)		4.84	4.95	5.89
Thiosulphate space				
	litres	1.40	1.54	1.43
	ml/kg	289.9	312.0	246.2
Total body water				
	litres	-		
	ml/kg			
TBK	mEq	203.86	202.09	274.46
	mEq/kg	42.12	40.87	46.52
Serum sodium	mEq/l	134	133	135
potassium	mEq/l	3.2	3.5	3.7
chloride	mEq/l	100	102	100
Total protein	g/100ml	4.84	4.75	7.06
Albumin	g/100ml	2.49	2.56	4.22

Case 6

Age (months)	19	Height (cms)	74.3	
Day		2	5	R
Weight (kg)		8.19	9.07	9.73
Thiosulphate space				
litres		2.70	3.23	2.51
ml/kg		329.7	356.0	257.9
Total body water				
litres				
ml/kg				
TBK mEq		251.23	257.01	437.10
mEq/kg		30.79	28.52	44.9
Serum sodium	mEq/l	140	139	131
potassium	mEq/l	5.5	3.9	5.4
chloride	mEq/l	101	99	97
Total protein	g/100ml	3.35	3.90	7.66
Albumin	g/100ml	1.07	1.15	3.34

Case 7

Age (months) 13 Height (cms) 70.8

Day			2	5	9
Weight (kg)			7.86	7.29	8.55
Thiosulphate space					
	litres		2.33	1.55	2.20
	ml/kg		296.4	212.5	257.5
Total body water					
	litres		4.850	3.257	5.000
	ml/kg		617.6	446.8	584.8
TBK	mEq		222.62	244.07	335.02
	mEq/kg		28.32	33.48	39.18
Serum sodium		mEq/l	146	149	144
potassium		mEq/l	4.9	5.9	3.9
chloride		mEq/l	102	100	104
Total protein		g/100ml	3.77	4.95	7.05
Albumin		g/100ml	1.92	2.36	4.16

Case 8

Age (months) 15 Height (cms) 67.6

Day		2	5	9
Weight (kg)		8.85	7.15	8.70
Thiosulphate space				
	litres	2.84	1.82	1.84
	ml/kg	318.4	154.7	262.4
Total body water				
	litres	5.384	3.497	5.027
	ml/kg	607.5	489.1	577.8
TBK	mEq	199.85	219.83	372.53
	mEq/kg	27.95	31.25	42.09
Serum sodium	mEq/l	135	133	142
potassium	mEq/l	4.1	5.7	3.7
chloride	mEq/l	100	100	104
Total protein	g/100ml	3.55	4.56	7.73
Albumin	g/100ml	1.23	1.94	3.53

Case 9

Age (months)	17	Height (cms)	67.6	
Day		2	5	R
Weight (kg)		6.40	6.34	8.38
Thiosulphate space				
	litres	2.04	1.76	2.08
	ml/kg	319.5	278.3	250.3
Total body water				
	litres	4.717	3.367	5.500
	ml/kg	737.0	531.1	656.3
TBK	mEq	223.93	251.24	390.56
	mEq/kg	34.99	39.63	46.65
Serum sodium	mEq/l	131	138	132
potassium	mEq/l	2.4	3.9	4.8
chloride	mEq/l	96	98	96
Total protein	g/100ml	3.26	4.10	6.90
Albumin	g/100ml	1.42	2.00	4.19

Case 10

Age (months) 21 Height (cms) 75.6

Day		2	5	R
Weight (kg)		8.44	8.50	9.66
Thiosulphate space				
	litres	2.58	2.72	2.51
	ml/kg	306.3	319.4	258.4
Total body water				
	litres	5.405	4.188	6.170
	ml/kg	640.4	492.7	638.7
TBK	mEq	232.80	274.94	366.38
	mEq/kg	27.60	32.35	37.93
Serum sodium	mEq/l	131	143	140
potassium	mEq/l	3.1	4.3	4.9
chloride	mEq/l	98	102	104
Total protein	g/100ml	3.20	3.95	7.06
Albumin	g/100ml	1.36	1.74	3.72

Case 11

Age (months) 19 Height (cms) 67.3

Day		2	5	9
Weight (kg)		5.67	5.81	6.24
Thiosulphate space				
	litres	2.09	1.30	1.24
	ml/kg	368.6	223.7	198.7
Total body water				
	litres			
	ml/kg			
TBK	mEq	172.44	176.31	258.45
	mEq/kg	30.36	30.36	41.39
Serum sodium	mEq/l	132	131	141
potassium	mEq/l	3.4	5.9	4.2
chloride	mEq/l	97	98	100
Total protein	g/100ml	4.97	5.01	7.53
Albumin	g/100ml	1.75	1.77	3.56

Case 12

Age (months) 10 Height (cms) 59.7

Day		2	5	9
Weight (kg)		5.77		
Thiosulphate space				
	litres	1.85	0.91	1.19
	ml/kg	319.9	161.6	202.1
Total body water				
	litres			
	ml/kg			
TBK	mEq	224.51	243.4	249.6
	mEq/kg	38.88	43.23	42.30
Serum sodium	mEq/l	132	129	140
potassium	mEq/l	3.9	4.8	3.7
chloride	mEq/l	102	98	105
Total protein	g/100ml	5.88	5.40	7.71
Albumin	g/100ml	2.79	3.13	4.21

Table C-9 PCM cases (Chapter 6)

The following results are given for each of the children studied:

age (months)
weight (kg)
height (cms)

Blood glucose (mg/100ml)
fasting
5 min
20 min
45 min
60 min
90 min
after intravenous injection of glucose

Glucose disappearance rate constant (kg

Serum insulin (μU/ml)
fasting
5 min
20 min
45 min
60 min
90 min
after intravenous injection of glucose

Glucose area
Insulin area
I/G ratio
TBK mEq
mEq/kg
Serum sodium mEq/l
potassium mEq/l
chloride mEq/l
total protein g/100ml
albumin g/100ml

The results are given for day 2, 5, 9, 13 and recovery (Some children did not have tests done on days 9 and 13).

Cases 1 - 6 did not receive a potassium supplement
7 -18 received a supplement of 12 mEq potassium/kg/day

Table C-9 Case 1

Age (months) 11	Weight (kg) 5.61				Height (cms) 66.4
Day	2	5	9	13	R
Blood glucose mg/100ml					
fasting	68	60	72	86	69
5 min	500	400	420	400	340
20 min	340	286	300	287	224
45 min	191	185	177	144	105
60 min	130	141	120	98	71
90 min	83	95	78	88	71
Kg					
Serum insulin µU/ml					
fasting	2	0	0	2	2
5 min	16	10	30	19	31
20 min	10	8	13	9	9
45 min	6	4	8	6	6
60 min	2	2	4	2	2
90 min	0	0	0	2	2
Glucose area	1.38	1.28	1.13	0.86	0.66
Insulin area	7.05	3.85	8.10	3.90	5.10
I/G ratio	5.09	3.02	7.16	4.52	7.72
TBK mEq	199.61	189.63	189.67	246.34	286.08
mEq/kg	35.11	32.92	33.43	41.47	43.41
Serum Na mEq/l	153	138		137	136
K mEq/l	3.9	5.3		4.7	5.0
Cl mEq/l	110	106		106	105
Total protein g/100ml	4.60	5.20		6.32	7.12
Albumin g/100ml	2.18	2.65		3.17	3.63

Case 2

Age (months) 23	Weight (kg) 4.48			Height (cms) 66.0	
Day	2	5	9	13	R
Blood glucose mg/100ml					
fasting	29	63	62	74	85
5 min	312	316	406	360	295
20 min	211	272	292	280	178
45 min	173	186	158	148	103
60 min	161	160	121	111	80
90 min	135	112	79	86	81
Kg	0.69	1.29	2.24	2.21	2.02
Serum insulin µU/ml					
fasting	3	2	3	5	2
5 min	4	8	19	18	26
20 min	2	8	14	14	20
45 min	2	10	9	10	4
60 min	3	8	7	7	2
90 min	2	8	4	6	2
Glucose area	1.39	1.21	1.15	0.95	0.50
Insulin area	1.33	5.65	6.05	4.70	6.40
I/G ratio	0.95	4.67	5.24	4.96	12.71
TBK mEq	161.92	208.81	211.67	214.76	265.42
mEq/kg	36.18	44.30	44.89	44.19	48.04
Serum Na mEq/l	129	134		140	137
K mEq/l	4.8	4.6		5.3	4.7
Cl mEq/l	100	112		111	110
Total protein g/100ml	4.34	4.55		6.26	7.78
Albumin g/100ml	1.59	1.67		2.65	3.59

Case 3

Age (months) 23		Weight (kg) 7.25		Height (cms) 73.0	
Day	2	5	9	13	R
Blood glucose mg/100ml					
fasting	57	55	78	84	68
5 min	362	282	284	284	320
20 min	286	261	272	257	255
45 min	206	200	199	139	135
60 min	161	156	154	98	104
90 min	110	109	101	81	88
Kg	1.45	1.26	1.41	2.41	2.27
Serum insulin µU/ml					
fasting	1	0	1	3	2
5 min	56	20	19	52	52
20 min	12	9	14	40	35
45 min	8	7	13	23	5
60 min	9	7	7	5	4
90 min	4	2	0	5	1
Glucose area	1.37	1.24	1.04	0.74	0.87
Insulin area	11.35	7 .07	9.78	17.05	14.28
I/G ratio	8.26	5.72	9.39	23.16	16.39
TBK mEq	226.02	237.53	265.94	310.91	364.96
mEq/kg	30.34	32.32	36.61	42.13	44.73
Serum Na mEq/l	122	136		136	138
K mEq/l	3.8	4.1		5.5	5.2
Cl mEq/l	111	115		105	112
Total protein g/100ml	4.17	4.29		5.17	7.03
Albumin g/100ml	2.09	2.06		2.60	3.68

Case 4

Age (months) 27	Weight (kg) 7.50			Height (cms) 71.1	
Day	2	5	9	13	R
Blood glucose mg/100ml					
fasting	68	72	82	86	102
5 min	300	380	320	300	500
20 min	255	230	290	247	420
45 min	209	150	163	198	210
60 min	175	100	127	160	162
90 min	119	98	70	94	99
Kg	0.92	2.04	2.09	1.06	2.42
Serum insulin µU/ml					
fasting	2	5	2	6	2
5 min	23	24	45	42	40
20 min	6	4	14	18	14
45 min	6	8	10	19	12
60 min	6	6	9	20	12
90 min	4	3	6	10	4
Glucose area	1.21	0.88	1.11	0.94	1.43
Insulin area	4.90	5.78	10.48	12.35	10.75
I/G ratio	4.07	6.55	9.42	13.16	7.50
TBK mEq	267.12	260.57	302.24	328.30	414.84
mEq/kg	33.92	33.34	40.14	42.47	44.90
Serum Na mEq/l	120	122		140	137
K mEq/l	3.7	4.3		4.9	4.5
Cl mEq/l	105	101		104	106
Total protein g/100ml	3.62	4.32		6.84	8.21
Albumin g/100ml	1.69	1.78		2.83	3.69

Case 5

Age (months) 9	Weight (kg) 5.46			Height (cms) 61.6	
Day	2	5	9	13	R
Blood glucose mg/100ml					
fasting	50	47	59	56	77
5 min	370	382	254	257	290
20 min	280	356	239	248	248
45 min	245	176	204	197	158
60 min	221	173	189	164	100
90 min	186	142	150	134	61
Kg	0.59	1.90	0.59	1.02	2.22
Serum insulin µU/ml					
fasting	4	1	2	1	1
5 min	8	8	22	13	20
20 min	7	4	8	7	14
45 min	3	2	7	8	10
60 min	4	2	9	8	8
90 min	4	3	8	4	2
Glucose area	1.76	1.64	1.27	1.23	1.03
Insulin area	2.58	2.03	6.68	5.83	8.03
I/G ratio	1.46	1.24	5.24	4.75	7.80
TBK mEq	141.67	155.91	147.82	166.30	270.26
mEq/kg	25.95	28.24	25.40	28.38	44.30
Serum Na mEq/l	133	139		134	137
K mEq/l	4.8	4.2		3.8	5.6
Cl mEq/l	104	111		107	112
Total protein g/100ml	3.07	3.17		3.67	6.61
Albumin g/100ml	1.53	1.54		1.74	3.42

Case 6

Age (months) 8 Weight (kg) 4.51 Height (cms) 59.7

Day	2	5	9	13	R
Blood glucose mg/100ml					
fasting	39	51	58	68	81
5 min	280	281	280	270	460
20 min	237	212	200	230	298
45 min	171	128	133	168	182
60 min	144	105	95	129	111
90 min	121	78	62	67	76
Kg	1.25	1.78	1.84	1.43	2.38
Serum insulin µU/ml					
fasting	0	0	0	4	2
5 min	4	10	18	23	34
20 min	2	4	8	11	1
45 min	0	2	8	18	6
60 min	1	1	2	12	2
90 min	1	1	6	2	3
Glucose area	1.26	0.87	0.75	0.88	1.16
Insulin area	1.18	2.58	6.35	11.15	5.73
I/G ratio	0.93	2.97	8.52	12.68	4.92
TBK mEq	152.99	164.46	173.83	222.60	258.77
mEq/kg	33.92	34.77	35.05	46.72	50.25
Serum Na mEq/l	136	142		137	147
K mEq/l	3.4	4.1		4.9	4.69
Cl mEq/l	109	112		105	106
Total protein g/100ml	4.45	4.33		4.85	6.50
Albumin g/100ml	2.33	2.24		2.68	3.81

Case 7

Age (months) 12	Weight (kg) 5.00		Height (cms) 67.3	
Day	2	5	9	13
Blood glucose mg/100ml				
fasting	68	76	61	89
5 min	426	366	346	264
20 min	188	218	216	219
45 min	103	142	135	144
60 min	74	103	93	105
90 min	56	51	52	67
Kg	2.34	1.86	2.08	1.82
Serum insulin µU/ml				
fasting	2	20	0	4
5 min	71	26	27	48
20 min	20	10	13	17
45 min	17	9	10	20
60 min	4	6	4	10
90 min	4	1	2	3
Glucose area	0.877	1.17	0.96	0.94
Insulin area	14.25	24.13	8.50	13.18
I/G ratio	16.26	20.57	8.84	14.04
TBk mEq	229.88	222.83	247.8	277.99
mEq/kg	45.84	44.04	47.84	51.79
Serum Na mEq/l	144	131		140
K mEq/l	5.0	4.8		5.1
Cl mEq/l	106	101		109
Total protein g/100ml	5.84	6.20		6.05
Albumin g/100ml	2.97	3.43		3.37

Case 8

Age (months) 13	Weight (kg) 4.56		Height (cms) 64.5		
Day	2	5	9	13	R
Blood glucose mg/100ml					
fasting	69	76	60	82	61
5 min	300	310	320	300	370
20 min	253	253	262	243	230
45 min	211	210	255	212	195
60 min	187	181	250	191	166
90 min	142	128	241	114	104
Kg	0.75	0.83	0.11	0.60	0.81
Serum insulin µU/ml					
fasting	0	0	0	2	0
5 min	6	10	10	12	24
20 min	2	6	6	6	10
45 min	2	6	5	8	2
60 min	2	5	5	6	2
90 min	2	3	6	2	0
Glucose area	1.25	1.17	1.75	1.09	1.22
Insulin area	2.15	4.98	4.98	3.90	5.25
I/G ratio	1.71	4.25	2.84	3.57	4.32
TBK mEq	149.68	176.30	166.57	182.26	295.57
mEq/kg	31.22	36.65	34.92	39.67	46.11
Serum Na mEq/l	129	130		150	142
K mEq/l	4.0	5.0		4.6	4.7
Cl mEq/l	107	111		110	107
Total protein g/100ml	3.13	3.42		4.18	7.48
Albumin g/100ml	1.45	1.51		1.81	3.31

Case 9

Age (months) 3	Weight (kg) 3.71			Height (cms) 53.0	
Day	2	5	9	13	R
Blood glucose mg/100ml					
fasting	118	93	102	88	41
5 min	480	416	386	300	280
20 min	364	354	340	241	237
45 min	346	247	224	175	171
60 min	318	218	189	145	144
90 min	243	183	147	109	120
Kg	0.32	1.23	1.49	1.27	1.25
Serum insulin µU/ml					
fasting	1	2	1	2	4
5 min	3	12	11	28	36
20 min	3	4	13	16	19
45 min	7	4	6	8	9
60 min	7	4	8	7	6
90 min	6	2	3	6	4
Glucose area	1.95	1.57	1.27	0.85	1.24
Insulin area	3.90	2.25	6.28	8.33	7.65
I/G ratio	2.00	1.43	4.95	9.77	6.16
TBK mEq	140.06	138.65	138.64	142.48	203.89
mEq/kg	35.46	36.68	36.63	63.25	46.95
Serum Na mEq/l	127	132		131	139
K mEq/l	5.3	4.9		5.4	4.9
Cl mEq/l	104	112		115	108
Total protein g/100ml	3.70	4.08		6.12	5.97
Albumin g/100ml	2.14	2.33		3.13	3.17

Case 10

Age (months) 17	Weight (kg) 7.26		Height (cms) 71.8		
Day	2	5	9	13	R
Blood glucose mg/100ml					
fasting	64	66	61	95	87
5 min	400	404	434	436	422
20 min	350	300	320	302	310
45 min	214	210	191	178	176
60 min	176	172	152	137	125
90 min	92	101	81	88	91
Kg	1.74	1.39	1.88	1.99	2.27
Serum insulin µU/ml					
fasting	2	2	2	6	5
5 min	22	26	14	21	20
20 min	6	9	10	17	15
45 min	18	13	10	17	15
60 min	8	9	11	17	9
90 min	5	6	2	3	4
Glucose area	1.50	1.39	1.39	1.13	1.05
Insulin area	7.80	8.18	6.43	13.25	8.03
I/G ratio	5.19	5.90	4.64	11.73	7.64
TBK mEq	276.02	292.88	320.12	329.15	399.99
mEq/kg	36.88	40.31	43.38	43.83	49.10
Serum Na mEq/l	121	126		128	137
K mEq/l	7.3	4.7		5.0	5.3
Cl mEq/l	94	108		110	111
Total protein g/100ml	4.08	4.93		6.44	7.09
Albumin g/100ml	1.84	2.43		3.54	3.92

Case 11

Age (months) 15	Weight (kg) 5.44		Height (cms) 64.5		
Day	2	5	9	13	R
Blood glucose mg/100ml					
fasting	66	73	56	68	107
5 min	247	400	300	300	300
20 min	197	250	214	240	250
45 min	86	136	103	129	153
60 min	77	88	66	83	90
90 min	72	76	54	64	68
Kg	3.54	2.59	2.94	2.64	2.49
Serum insulin µU/ml					
fasting	4	12	6	8	15
5 min	25	46	40	61	76
20 min	14	26	31	37	43
45 min	15	5	19	22	47
60 min	6	6	6	8	10
90 min	2	7	5	5	5
Glucose area	0.52	0.85	0.71	0.80	1.16
Insulin area	10.00	15.13	12.63	18.78	33.23
I/G ratio	19.35	17.89	17.81	23.56	28.67
TBK mEq	251.97	243.32	256.19	258.66	309.10
mEq/kg	43.22	44.48	46.41	45.06	45.94
Serum Na mEq/l	137	134		130	137
K mEq/l	3.6	5.8		5.2	4.7
Cl mEq/l	104	113		108	113
Total protein g/100ml	6.23	7.17		7.19	6.89
Albumin g/100ml	3.66	4.31		4.22	3.65

Case 12

Age (months) 12	Weight (kg) 3.61		Height (cms) 57.8
Day	2	5	R
Blood glucose mg/100ml			
fasting	15	60	60
5 min	297	342	296
20 min	203	210	178
45 min	147	108	76
60 min	121	65	54
90 min	101	62	54
Kg	1.28	2.90	3.02
Serum insulin µU/ml			
fasting	6	1	0
5 min	6	48	20
20 min	4	16	7
45 min	7	6	0
60 min	7	0	0
90 min	3	5	0
Glucose area	1.29	0.69	0.59
Insulin area	4.90	10.85	3.40
I/G ratio	3.80	15.67	5.78
TBK mEq	125.76	169.36	218.35
mEq/kg	30.67	46.91	51.99
Serum Na mEq/l	142	137	137
K mEq/l	4.1	5.8	5.9
Cl mEq/l	109	108	108
Total protein g/100ml	2.97	4.26	6.52
Albumin g/100ml	1.29	2.06	3.96

Case 13

Age (months) 16	Weight (kg) 4.43	Height (cms) 62,9
Day	2	5	R
Blood glucose mg/100ml			
fasting	32	58	60
5 min	262	307	300
20 min	200	254	232
45 min	154	202	113
60 min	142	171	71
90 min	105	131	71
Kg	0.88	0.98	2.95
Serum insulin µU/ml			
fasting	2	0	0
5 min	4	11	22
20 min	0	4	10
45 min	1	4	8
60 min	0	0	1
90 min	2	3	0
Glucose area	1.17	1.29	0.73
Insulin area	2.70	3.15	6.03
I/G ratio	2.31	2.44	8.24
TBK mEq	133.90	179.57	269.31
mEq/kg	30.19	36.17	47.32
Serum Na mEq/l	143	147	137
K mEq/l	3.9	4.3	3.9
Cl mEq/l	107	104	104
Total protein g/100ml	3.74	4.63	7.20
Albumin g/100ml	1.87	2.32	3.72

Case 14

Age (months) 18	Weight (kg) 7.15	Height (cms) 70.5
Day	2	5	R
Blood glucose mg/100ml			
fasting	78	74	64
5 min	369	378	339
20 min	279	281	240
45 min	208	206	113
60 min	172	159	66
90 min	91	80	57
Kg	1.21	1.40	3.20
Serum insulin µU/ml			
fasting	1	8	0
5 min	50	33	52
20 min	17	10	21
45 min	17	16	6
60 min	12	22	2
90 min	8	6	4
Glucose area	1.18	1.18	0.84
Insulin area	14.83	10.90	11.65
I/G ratio	12.52	9 .22	13.82
TBK mEq	277.94	316.20	322.96
mEq/kg	38.87	41.50	38.84
Serum Na mEq/l	129	139	135
K mEq/l	4.3	4.9	3.8
Cl mEq/l	95	100	101
Total protein g/100ml	5.95	6.21	7.66
Albumin g/100ml	2.36	2.67	3.78

Case 15

Age (months) 15	Weight (kg) 7.84		Height (cms) 70.5
Day	2	5	R
Blood glucose mg/100ml			
fasting	48	71	71
5 min	443	408	435
20 min	346	324	260
45 min	271	229	154
60 min	238	185	95
90 min	144	120	46
Kg	0.94	1.40	2.47
Serum insulin µU/ml			
fasting	0	3	2
5 min	6	36	58
20 min	1	12	47
45 min	5	24	36
60 min	4	24	16
90 min	7	12	5
Glucose area	2.01	1.49	1.37
Insulin area	3.75	15.38	25.00
I/G ratio	1.87	10.33	18.27
TBK mEq	236.97	304.83	380.91
mEq/kg	31.18	38.37	42.75
Serum Na mEq/l	136	130	140
K mEq/l	4.0	4.8	4.7
Cl mEq/l	106	100	99
Total protein g/100ml	4.70	5.80	7.28
Albumin g/100ml	2.35	2.74	4.14

Case 16

Age (months) 16	Weight (kg) 6,66		Height (cms) 69,2
Day	2	5	R
Blood glucose mg/100ml			
fasting	75	68	66
5 min	324	369	363
20 min	276	251	197
45 min	220	147	71
60 min	196	98	56
90 min	181	60	56
Kg	0.86	2.33	3.24
Serum insulin µU/ml			
fasting	3	0	0
5 min	20	43	68
20 min	6	5	22
45 min	3	8	4
60 min	0	1	0
90 min	2	2	1
Glucose area	1.37	1.02	0.71
Insulin area	6.80	7.43	12.15
I/G ratio	4.96	7.26	17,14
TBK mEq	266.59	309.46	382,32
mEq/kg	38.11	46.57	46.68
Serum Na mEq/l	143	139	141
K mEq/l	4.8	5.0	3,9
Cl mEq/l	104	101	101
Total protein g/100ml	4.12	5.02	7.07
Albumin g/100ml	1.47	2.38	4,38

Case 17

Age (months) 14 Weight (kg) 6.45 Height (cms) 69.2

Day	2	5	R
Blood glucose mg/100ml			
fasting	78	64	76
5 min	297	335	334
20 min	249	239	229
45 min	192	174	119
60 min	168	138	83
90 min	120	75	69
Kg	0.99	1.36	2.54
Serum insulin µU/ml			
fasting	3	6	6
5 min	6	47	69
20 min	4	32	41
45 min	4	29	25
60 min	2	30	11
90 min	3	10	6
Glucose area	1.05	1.03	0.78
Insulin area	2.25	19.90	18.23
I/G ratio	2.13	19.41	23.38
TBK mEq	219.95	252.90	336.61
mEq/kg	33.86	38.14	47.48
Serum Na mEq/l	135	131	147
K mEq/l	4.0	4.1	4.0
Cl mEq/l	98	104	105
Total protein g/100ml	3.25	4.09	6.86
Albumin g/100ml	1.10	2.14	3.75

Case 18

Age (months) 18	Weight (kg) 6.95		Height (cms) 67.9
Day	2	5	R
Blood glucose mg/100ml			
fasting	75	74	70
5 min	322	352	341
20 min	281	253	295
45 min	228	127	162
60 min	191	71	124
90 min	130	27	68
Kg	0.95	3.13	2.19
Serum insulin µU/ml			
fasting	3	5	2
5 min	5	33	10
20 min	7	31	7
45 min	4	21	13
60 min	6	7	8
90 min	6	4	3
Glucose area	1.31	1.50	1.06
Insulin area	2.33	14.90	5.50
I/G ratio	1.78	9.94	5.19
TBK mEq	229.34	271.48	363.11
mEq/kg	32.88	37.63	42.42
Serum Na mEq/l	128	129	131
K mEq/l	3.7	5.6	4.5
Cl mEq/l	90	97	101
Total protein g/100ml	3.90	4.73	7.54
Albumin g/100ml	1.59	2.14	4.19

Table C-10 (Chapter 2)

Multivariate Prediction of TBK from $f(W/H)$. The equation is of the form:

$$y = a + b_{x_1} + c_{x_2}$$

Table C-10

X_1	X_2	$F_{reg.}$ y in mEq	$F_{reg.}$ y in mEq/kg
W	W^2	332.10	11.25
	W^3	332.47	11.14
	$W^{1/2}$	331.27	11.04
	$W^{1/4}$	331.13	10.96
	$W^{3/2}$	331.85	11.23
	H	331.43	11.11
	H^2	386.86	14.32
	H^3	393.17	16.77
	$H^{1/2}$	394.33	18.87
	$H^{1/4}$	379.85	12.59
	$H^{3/2}$	390.58	15.55
	$H^{3/4}$	384.67	13.72
	W/H	393.96	22.72
	W^2/H	339.36	7.68
	W^3/H	329.96	9.47
	W/H^2	398.37	21.55
	W/H^3	397.72	19.27
	W^2/H^3	396.26	20.10
	W^3/H^2	332.83	7.72
	$(W/H)^{1/4}$	376.46	22.21
	$(W/H)^{1/2}$	372.16	22.86
	$(W/H)^2$	384.90	15.32
	$(W/H)^3$	353.40	9.24
W^2	W^3	325.96	10.77
	$W^{1/2}$	333.28	11.18
	$W^{1/4}$	333.78	11.12
	$W^{3/2}$	330.72	11.23
	$W^{3/4}$	332.72	11.23
	H	396.04	7.08
	H^2	386.12	8.19
	H^3	370.26	9.70
	$H^{1/2}$	398.62	6.68
	$H^{1/4}$	399.37	6.52
	$H^{3/2}$	391.89	7.58
	$H^{3/4}$	397.52	6.87

	W/H	288.29	21.96
	W^2/H	288.08	21.52
	W^3/H	358.26	6.44
	W/H^2	300.04	22.00
	W/H^3	330.82	16.46
	W^2/H^3	294.61	22.54
	W^3/H^2	341.30	9.26
	$(W/H)^{1/4}$	292.00	19.99
	$(W/H)^{1/2}$	399.76	20.69
	$(W/H)^2$	290.15	22.34
	$(W/H)^3$	310.18	16.10
W^3	$W^{1/2}$	333.91	11.17
	$W^{1/4}$	334.08	11.15
	$W^{3/2}$	329.74	11.00
	$W^{3/4}$	333.36	11.17
	H	372.40	4.35
$W^{1/2}$	$W^{1/4}$	328.92	10.83
	$W^{3/2}$	332.45	11.13
	$W^{3/4}$	330.57	10.98
	H	355.23	19.30
	H^2	370.52	21.16
	H^3	380.66	21.99
	$H^{1/2}$	346.66	18.10
	$H^{1/4}$	342.36	17.47
	$H^{3/2}$	363.35	20.34
	$H^{3/4}$	350.97	18.72
	W/H	351.16	18.97
	W^2/H	306.52	8.68
	W^3/H	323.74	10.07
	W/H^2	370.27	21.34
	W/H^3	364.28	20.56
	W^2/H^3	345.80	18.30
	W^3/H^2	308.73	8.79
	$(W/H)^{1/4}$	387.72	22.56
	$(W/H)^{1/2}$	330.20	22.09
	$(W/H)^2$	307.64	11.64
	$(W/H)^3$	298.97	8.99

$W^{1/4}$	$W^{3/2}$	332.76	11.05
	$W^{3/4}$	330.09	10.89
	H	335.97	21.23
	H^2	355.37	22.31
	H^3	369.30	22.37
	$H^{1/2}$	325.37	20.31
	$H^{1/4}$	320.10	19.77
	$H^{3/2}$	346.16	21.91
	$H^{3/4}$	330.68	20.80
	W/H	293.42	16.46
	W^2/H	299.05	9.15
	W^3/H	321.42	10.24
	W/H^2	332.78	21.26
	W/H^3	332.86	21.12
	W^2/H^3	299.48	17.47
	W^3/H^2	300.57	9.20
	$(W/H)^{1/4}$	341.15	21.60
	$(W/H)^{1/2}$	305.32	20.31
	$(W/H)^2$	273.20	10.89
	$(W/H)^3$	278.32	9.21
$W^{3/2}$	$W^{3/4}$	332.15	11.19
	H	399.61	9.97
	H^2	397.13	11.87
	H^3	389.11	14.04
	$H^{1/2}$	398.90	9.20
	$H^{1/4}$	398.14	8.87
	$H^{3/2}$	399.07	10.87
	$H^{3/4}$	399.40	9.57
	W/H	336.44	23.01
	W^2/H	382.59	12.46
	W^3/H	340.59	8.39
	W/H^2	361.66	21.77
	W/H^3	381.18	17.86
	W^2/H^3	359.79	21.61
	W^3/H^2	366.22	6.84
	$(W/H)^{1/4}$	327.26	21.01
	$(W/H)^{1/2}$	394.68	21.82
	$(W/H)^2$	361.43	20.25
	$(W/H)^3$	377.30	11.63

$W^{3/4}$	H	372.93	16.86
	H^2	383.77	19.20
	H^3	389.55	20.79
	$H^{1/2}$	366.39	15.59
	$H^{1/4}$	363.04	14.96
	$H^{3/2}$	378.85	18.09
	$H^{3/4}$	369.70	16.22
	W/H	392.43	21.29
	W^2/H	318.67	8.12
	W^3/H	326.51	9.81
	W/H^2	393.51	21.44
	W/H^3	386.99	19.94
	W^2/H^3	381.89	19.20
	W^3/H^2	319.25	8.29
	$(W/H)^{1/4}$	395.04	22.63
	$(W/H)^{1/2}$	353.20	22.89
	$(W/H)^2$	349.92	13.09
	$(W/H)^3$	324.80	8.49
H	H^2	271.00	4.62
	H^3	271.07	4.55
	$H^{1/2}$	270.71	4.69
	$H^{1/4}$	270.64	4.69
	$H^{3/2}$	270.93	4.64
	$H^{3/4}$	270.78	4.68
	W/H	356.79	19.18
	W^2/H	399.81	10.65
	W^3/H	390.31	5.69
	W/H^2	337.80	21.27
	W/H^3	335.73	20.88
	W^2/H^3	358.93	18.68
	W^3/H^2	401.23	7.90
	$(W/H)^{1/4}$	333.61	21.42
	$(W/H)^{1/2}$	270.39	20.83
	$(W/H)^2$	383.18	14.96
	$(W/H)^3$	398.15	11.00

H^2	H^3	271.05	4.47
	$H^{1/2}$	270.98	4.64
	$H^{1/4}$	270.96	4.65
	$H^{3/2}$	271.02	4.58
	$H^{3/4}$	270.99	4.63
	W/H	377.78	20.26
	W^2/H	399.15	12.09
	W^3/H	375.90	6.16
	W/H^2	368.02	21.35
	W/H^3	365.62	19.85
	W^2/H^3	382.31	19.28
	W^3/H^2	393.40	8.68
	$(W/H)^{1/4}$	359.53	22.10
	$(W/H)^{1/2}$	270.91	21.67
	$(W/H)^2$	395.20	16.15
	$(W/H)^3$	400.62	11.91
H^3	$H^{1/2}$	271.08	4.59
	$H^{1/4}$	271.09	4.60
	$H^{3/2}$	271.06	4.51
	$H^{3/4}$	271.07	4.57
	W/H	387.02	21.09
	W^2/H	389.82	13.69
	W^3/H	353.93	6.88
	W/H^2	378.63	21.44
	W/H^3	364.34	18.75
	W^2/H^3	389.32	19.82
	W^3/H^2	375.83	9.68
	$(W/H)^{1/4}$	374.50	22.47
	$(W/H)^{1/2}$	271.11	22.19
	$(W/H)^2$	394.62	17.28
	$(W/H)^3$	390.29	12.90
$H^{1/2}$	$H^{1/4}$	270.40	4.71
	$H^{3/2}$	270.87	4.67
	$H^{3/4}$	270.62	4.69
	W/H	343.06	18.57
	W^2/H	397.11	10.04
	W^3/H	394.39	5.55

$H^{1/2}$	W/H^2	317.53	21.23
	W/H^3	312.32	21.34
	W^2/H^3	342.56	18.37
	W^3/H^2	401.38	7.60
	$(W/H)^{1/4}$	317.85	20.98
	$(W/H)^{1/2}$	270.00	20.32
	$(W/H)^2$	373.23	14.38
	$(W/H)^3$	392.42	10.62
$H^{1/4}$	$H^{3/2}$	270.83	4.68
	$H^{3/4}$	270.53	4.70
	W/H	335.69	18.26
	W^2/H	395.13	9.76
	W^3/H	395.67	5.49
	W/H^2	306.62	21.21
	W/H^3	299.42	21.55
	W^2/H^3	333.59	18.22
	W^3/H^2	400.61	7.48
	$(W/H)^{1/4}$	309.59	20.74
	$(W/H)^{1/2}$	269.78	20.05
	$(W/H)^2$	367.54	14.10
	$(W/H)^3$	388.63	10.43
$H^{3/2}$	$H^{3/4}$	270.90	4.65
	W/H	368.58	19.75
	W^2/H	400.57	11.34
	W^3/H	384.15	5.90
	W/H^2	355.00	21.31
	W/H^3	354.14	20.38
	W^2/H^3	372.45	18.98
	W^3/H^2	398.60	8.26
	$(W/H)^{1/4}$	347.72	21.80
	$(W/H)^{1/2}$	270.69	21.29
	$(W/H)^2$	390.67	15.56
	$(W/H)^3$	400.99	11.45

$H^{3/4}$	W/H	350.12	18.88
	W^2/H	398.68	10.34
	W^3/H	392.61	5.61
	W/H^2	327.97	21.25
	W/H^3	324.52	21.11
	W^2/H^3	351.04	18.52
	W^3/H^2	401.60	7.75
	$(W/H)^{1/4}$	325.89	21.21
	$(W/H)^{1/2}$	270.20	20.58
	$(W/H)^2$	378.47	14.67
	$(W/H)^3$	395.62	10.81
W/H	W^2/H	268.42	21.39
	W^3/H	236.06	19.77
	W/H^3	371.66	20.32
	W^2/H^3	318.80	17.89
	W^3/H^2	218.15	18.72
	$(W/H)^{1/4}$	180.34	14.62
	$(W/H)^{1/2}$	312.71	14.71
	$(W/H)^2$	183.20	15.25
	$(W/H)^3$	184.64	15.52
W^2/H	W^3/H	262.40	15.46
	W/H^2	327.29	21.91
	W/H^3	368.03	17.54
	W^2/H^3	319.63	22.47
	W^3/H^2	289.48	9.41
	$(W/H)^{1/4}$	262.54	18.82
	$(W/H)^{1/2}$	387.35	19.62
	$(W/H)^2$	306.72	22.60
	$(W/H)^3$	367.43	11.26
W^3/H	W/H^2	218.35	22.33
	W/H^3	259.44	14.84
	W^2/H^3	215.04	23.31
	W^3/H^2	-	19.88
	$(W/H)^{1/4}$	244.54	18.25
	$(W/H)^{1/2}$	396.83	18.76
	$(W/H)^2$	223.47	21.55
	$(W/H)^3$	215.04	20.87

W/H^2	W/H^3	319.60	21.26
	W^2/H^3	311.49	21.69
	W^3/H^2	234.70	22.27
	$(W/H)^{1/4}$	324.64	21.21
	$(W/H)^{1/2}$	272.57	21.30
	$(W/H)^2$	341.62	21.80
	$(W/H)^3$	243.19	22.19
W/H^3	W^2/H^3	358.34	19.84
	W^3/H^2	298.56	15.80
	$(W/H)^{1/4}$	321.83	21.26
	$(W/H)^{1/2}$	258.98	20.99
	$(W/H)^2$	380.53	18.68
	$(W/H)^3$	329.75	16.86
W^2/H^3	W^3/H^2	219.29	23.61
	$(W/H)^{1/4}$	181.81	15.74
	$(W/H)^{1/2}$	305.03	16.21
	$(W/H)^2$	344.14	22.26
	$(W/H)^3$	210.33	23.90
W^3/H^2	$(W/H)^{1/4}$	223.28	17.25
	$(W/H)^{1/2}$	395.44	17.71
	$(W/H)^2$	211.38	12.26
	$(W/H)^3$	222.72	21.42
$(W/H)^{1/4}$	$(W/H)^{1/2}$	284.38	14.47
	$(W/H)^2$	183.19	14.90
	$(W/H)^3$	185.55	15.16
$(W/H)^{1/2}$	$(W/H)^2$	348.65	15.02
	$(W/H)^3$	374.46	15.30
$(W/H)^2$	$(W/H)^3$	183.48	15.91