CHANGES OF ELECTROLYTES IN URINE AND SERUM AFTER INJURY

THESIS PRESENTED FOR DEGREE OF M.Sc.

BY

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GLASGOW, C.4.

CONTENTS

ACKNOWLEDGEMENTS

The work for this Thesis was carried out in Glasgow Royal Infirmary while I was in receipt of a Fellowship from the World Health Organization in this country.

I would specially like to thank Professor H.G. Morgan for providing facilities in the Biochemistry Department of Pathological Biochemistry for my work.

I also wish to thank as my advisor Sir David Cuthbertson for his help and guidance.

I am grateful to Professor R.M.S. Smellie of the University of Glasgow for acting as my supervisor.

My thanks are also due to Dr. G.S. Fell for his technical advice and help during this investigation.

I wish also to thank the staff of the Intensive Care Unit and the Accident and Orthopaedic Division of Glasgow Royal Infirmary for providing facilities for my work.

I am indebted also to Miss C.M. Smith, Dietitian, Glasgow Royal Infirmary, for preparation of the patients' diets.

I. INTRODUCTION

Injuries disturb the biochemical pathways in the body. These disturbances vary according to the extent of the injury and also depend on the nutritional state of the patient prior to injury and on the temperature of his environment. Generally speaking the severity and duration of the changes vary with the severity of the injury. There is both a catabolic phase and an anabolic phase following all but minor injuries. The catabolic phase which corresponds to the post-shock reaction to the injury, follows a period of depressed heat production which occurs during the shock period. The main anabolic phase takes place during the time the patient starts to convalesce and to regain appetite. The catabolic phase is characterised by nitrogen loss from the injured subject and the anabolic phase by nitrogen retention which is associated with the healing process (Cuthbertson, 1942; 1970). Cuthbertson also introduced the terms of 'ebb' and 'flow' of metabolic activity following injury.

The biochemical changes do not only affect protein but also carbohydrate and lipid metabolism. There is also a disturbance of water and electrolyte balance.

In 1952 Moore and Ball graded injuries from Grade 1 to Grade 10. These numerical gradings are approximately equal to the number of days during which the metabolism of severe cases is seriously disturbed. In Grade 1 they included an injury such as herniorrophy and in Grade 10 a severe burn. Gastrectomy was Grade 5 and while orthopaedic injuries have turned out to be rather higher on the scale than might be expected.

Disturbance of Protein Metabolism

Normally the nitrogenous end products of protein metabolism are excreted in the urine. Significant extra renal losses, however, can occur from diarrhoea, intestinal fistulae, purulent discharges, exudates from burns or pleural and peritoneal effusions.

In the normal adult who is stable in weight, nitrogen intake equals output, when measured over several days and is about 10-15 g nitrogen/day. The conversion from nitrogen to protein can be made by taking 1 g nitrogen as equivalent to 6.25 g of dry protein or to 30 g of wet muscle. During starvation if a patient loses 15 g of nitrogen in the urine, he has utilised approximately 9 g of his body protein. To make effective use of dietary protein, energy needs must be adequately covered.

After moderate to severe trauma, 5-6 g of nitrogen or less are lost daily in the first days because protein intake is low and the energy intake is also generally low. The patient goes into negative nitrogen balance. After severe trauma the urine nitrogen excretion is approximately 15-18 g/day during the first 10-12 days and there may be an additional extra renal loss from the exudate of burns. In gastrectomy the total deficit may sometimes be only 30 g nitrogen over the period. Whilst after severe burns the total deficit rises to several hundred grammes of nitrogen.

The nitrogen loss cannot be completely prevented by increasing protein or energy intake at the height of the catabolic phase, though it may be reduced considerably for a time. This post-traumatic nitrogen loss may be termed obligatory.

Following major injuries not only is the urinary excretion of nitrogen high and the patient in negative balance in respect of nitrogen, but he also goes into a deficit of sulphur and phosphorus. In this laboratory it has been shown that at a high environmental temperature, 30°C, the excretion of nitrogen tends to be reduced. The initial catabolic phase is partially suppressed compared to subjects housed at ordinary temperatures.

The anabolic phase, in terms of nitrogen balance, starts some days or even weeks after the injury, when nitrogen begins to be retained. There is a relation between the degree of nitrogen excretion and the severity of the trauma. This significant loss of nitrogen following trauma was first mentioned by Cuthbertson (1930; 1932; 1936 and 1942). He suggested that it might be a basic reaction by the organism to provide fuel for energy purposes and to enable it to survive the period when out off from food or restricted in its supply through injury.

Amino acid disturbance.

After injury, small increases in amino acid levels occur in the serum. Normally the essential amino acids are not excreted in the urine except in traces. Nardi (1954) found that amino acids were excreted in the urine after burns. He mentioned that both essential and non-essential amino acids were increased in the urine after injury.

The essential amino acids, threonine, valine, leucine, isoleucine, lysine and methionine, not normally detected in the urine were found occasionally. This seems related to the amount of total nitrogen excretion and also depends on the severity of the injury.

Disturbance of carbohydrate metabolism.

Following injury the blood sugar level rises and induces a transient glycosuria for several hours, or even for several days. In animals this is related to the severity of the injury and duration of the 'ebb' phase. The level of lactate rises in the plasma and there is a fall in the basal oxygen consumption. In 1955 Howard et al., found that a partial resistance to insulin developed post-injury. The immediate source of glucose is liver glycogen (hepatic vein blood is richer in glucose than heart blood). The ultimate source of glycogen is partly from breakdown of muscle glycogen to lactate followed by its synthesis to glycogen in the liver and partly by gluconeogenesis from amino acids of protein catabolism. This explains why in animals killed after injury, the muscle stores of glycogen may be depleted whilst those of the liver are near normal. The breakdown of glycogen is mainly a result of a high level of adrenaline in the circulation because the gluconeogenesis control is by glycocorticoid hormone. Nervous impulses probably play a part, because hyperglycaemia may be prevented by previous section of the peripheral nerves to the injured limb.

What is the significance of this hyperglycaemia when the basal metabolism is reduced as seen in shock? Green and Stoner (1949) considered it to be a primitive defence mechanism whereby the body can supply energy for recovery and where there is incomplete breakdown of carbohydrate in the face of increased demands for carbohydrate in the injured limb.

Lipid disturbance.

The free fatty acids are greatly increased for the first days,

because the subsequent rise in heat production is due to the oxidation of protein rather than fat (Cairnie et al., 1957). At first a lot of fatty acids may be oxidised to ketone bodies. Lipidaemia occurs after injury but it has nothing to do with fat emboli, which occurs after haemorrhage, burning or local cold injury (Sevitt, 1967).

Fluid and electrolytes.

Fluid and electrolyte changes after injury can be considered under three headings.

1) There may be an increased dietary intake and/or increased output in the urine.
2) There may be excessive extra renal losses from vomiting or sweating or other sources.
3) There may be an alteration in hormonal control of renal function by antidiuretic hormone and increase in corticosteroid similar to that occurring in hyperaldosteronism.

There may be an endogenous disturbance from existing kidney disease. Finally, there may be an abnormal disturbance of body fluid such as can occur in generalised anasarca of heart failure.

The factors which are responsible and initiated at the local level are the secretion of histamine, serotonin and bradykinin. The role of the hypothalamic, anterior pituitary and the adrenal cortical hormones such as aldosterone and cortisol are very important as are those of the thyroid and pancreas. ACTH is necessary to produce cortisol, but not for the secretion of aldosterone. Renin affects aldosterone secretion, and the

role of increased serum potassium is still being investigated.

Sodium disturbance.

In 1938 Wilson and his co-workers for the first time described that a considerable fall in the level of serum sodium followed extensive burns in man. It was found that this could be restored rapidly to a normal level by deoxycorticosterone acetate. The retention of sodium and chloride has long been known to occur in fevers.

In 1923 Gamble et al., reported that during the first few days of fasting there is a loss of sodium which is in excess of the amount contained in the catabolised tissue and is presumably due to the loss of extra-cellular fluid. After the first six days of a 15 day fast the $\frac{K}{Na}$ ratio in the urine corresponded to that in muscle tissue.

In 1939 Cuthbertson et al., reported that the injured animal fed an adequate diet behaved differently, in that there is either no urinary loss of sodium or only a slight loss. Wilkinson et al., (1949), Moore and Ball (1952) and Wilkinson (1961) provided further description of the changes of sodium and chloride in the body in different forms of injury. Upjohn (1958), Wilkinson (1950) and Wilson (1938) reported that there is retention of body sodium with a concomitant loss of body potassium.

Balance studies showed that an initial period of sodium retention in the body is followed by a period of excretion. The period of retention of sodium depends on the severity of the trauma, but it is slightly less than the period of protein catabolism. During the period of retention the urine sodium excretion amounts to about 10 meq/day. This retention

of sodium in the body cannot be influenced by giving salt to the patient. The retention of sodium in the body following moderate to severe injury seems to be obligatory. Nothing is to be gained by routinely giving saline after trauma unless there is an extra renal loss.

The body has no defence against the overdose of saline fluid which may be retained in the body and cause oedema. The kidneys are responsible for sodium conservation. If there be extra renal loss of sodium such as in vomiting, sweating, gastric aspiration, draining from fistulae, etc., the renal conservation can be nullified.

For the treatment of patients it is important to know about the extra renal losses of sodium and make quantitative corrections. During fever there is some sodium loss in sweat, but there are low levels of sodium in the sweat of stressed subjects. Patients who do not retain sodium in the body may be suffering from suprarenal disease or receiving long-term steroid therapy or have chronic nephritis or some head injury. These patients are obviously at risk, as they have difficulty in maintaining their extracellular volume. Sometimes, in seriously ill patients, the serum sodium concentration may fall although there is no extra renal loss. This is accounted for by a shift of sodium into the intracellular compartment. It is obviously important to recognise this. The giving of sodium will only increase this tendency, therefore one must be wary of giving sodium to patients with no evident extra renal loss or low serum sodium.

Potassium disturbance.

Less than twenty years ago the existence of potassium depletion and

intoxication were virtually unknown. The excess excretion of potassium after trauma was first described by Cuthbertson (1930) and was subsequently noted by Moore and Ball (1952). In 1939 Cuthbertson pointed out that a potassium loss occurs in the rat with experimental fracture and for a period may be relatively greater than that of nitrogen in terms of concentrations initially in muscle. An increased urinary excretion of potassium paralleling the increased urinary nitrogen loss is one of the characteristics of injury (Cuthbertson, 1942; Wilkinson et al., 1950; Wilkinson, 1961).

In 1967 Lewis studied the composition of lymph in the injured limb of experimental animals and composition to that from uninjured limb. He found after a burn of 60°C in the rat that the potassium ion remained intracellular. Even after burning at 80°C there was only a small increase in the concentration of potassium in the lymph and he mentioned that it could be accounted for by the haemolysis which occurred and which resulted in marked increase in serum potassium as a direct result of cellular damage.

Metabolism of potassium after injury.

The metabolism of potassium is in a sense the reverse of that of sodium. After trauma there is an initial period of loss, followed later by a period of retention corresponding to the period of anabolism. About 99 per cent of the total body potassium is intracellular, and during the catabolic phase consequent on injury, potassium is inevitably released from the tissues. The surplus potassium is normally excreted, so that the potassium concentration in the serum remains unchanged. Similarly

during the anabolic phase of convalescence potassium is retained intracellularly.

The daily intake of potassium is approximately 100 m mol and in normal conditions this amount is excreted. Potassium ions are set free during the mobilization of protein. This amounts to about 2.5-3.5 m mol/kg of protein. The patients with a negative balance of protein around 15 g would show a negative balance of potassium of some 45 m mol. This ratio is known as K:N ratio. Increased renal excretion of potassium following trauma starts almost at once and is frequently greatest on the first day and the extent depends upon the severity and duration of the trauma. It has been reported that after gastrectomy the negative balance of potassium is 50 m mol on the first day followed by a loss of 20-30 m mol/day. These figures are less than the figures for normal loss on an average diet. It is thus not necessary to give added potassium following trauma unless the patient is unable to resume normal feeding within a reasonable time. Normally the ratio of K:N in urine is 2.5-3.5 m mol K:1 g nitrogen, but this changes markedly if there is any alteration in potassium metabolism. In extensive burns injury there is little need to give the patient supplementary potassium. The extra renal loss of potassium from the bowel, or from any purulent discharge is usually very small, except in extensive burns, when it is necessary to give some potassium to the burned patient.

After trauma there is a considerable change of distribution of potassium within the body. Since potassium is the main intracellular cation, any shift of water across the cell membrane is accompanied by a

change in intracellular potassium concentration. An indication as to whether potassium is being mobilized by a change in the degree of cellular hydration or by protein breakdown, can be obtained by measurement of the K:N ratio.

If this ratio reaches to 5-6:1 it indicates a change in cellular hydration. This ratio is 2.5-3.5 in the breakdown of protein. It is also stated that following trauma, potassium crosses cell membranes, because of increased membrane permeability. The main result of this change is the development of an alkalosis as a part of the well known hypokalaemia alkalosis syndrome.

Disturbance of chloride.

Not much is known about changes in chloride following injury. In 1952 Moore and Ball pointed out that the disturbance of chloride parallels that of sodium.

Disturbance of magnesium.

Magnesium deficiency can occur in patients post-operatively if intravenous therapy is prolonged and inadequate replacements are given.

In 1968 Walker et al., reported that urinary magnesium tends to behave like nitrogen and shows an increased excretion during the second to fifth or sixth days following injury. Levey et al., (1956) and Macbeth and Mabbott (1964) studied the serum electrolyte concentration in eight patients subjected to gastric surgery. They reported that there is no significant difference between the pre-operative serum magnesium concentration of the patients, as compared with a control group.

They mentioned that surgical patients on drainage need at least 100 mg of magnesium per day given intravenously to remain in balance and that there is no correlation found between magnesium balance and that of sodium, potassium or chloride. But there was a close relationship between the amount of magnesium lost in the gastric drainage fluid and the volume of fluid removed.

Haynes et al.,(1952) studied the urinary magnesium excretion of patients undergoing various surgical procedures, and also the excretion of magnesium by patients given 60 to 150 mg ACTH per day as a substitute for surgical stress.

The injection of ACTH produced greater metabolic changes in magnesium than did the surgery. The patients usually showed decreased urinary excretion of magnesium following the injection of this hormone and the magnesium content of the urine increased for a day or so after cessation of the treatment before returning to its normal level. These investigators suggested that the urinary excretion of magnesium is similar to that of sodium in that it is under the control of the hormones of the adrenal cortex.

Thoren (1963) reported that only small quantities of magnesium are lost in fluid aspirated from the stomach which contains less than 0.5 m mol Mg/L. But the fluid in diarrhoeal stools, or in the discharge from an intestinal fistulae or from an ileostomy may contain as much as 3 m mol Mg/L.

Denick et al.,(1969) studied the urinary excretion of magnesium in

obese men who were on a low magnesium intake. They reported that for ten subjects the mean loss of magnesium was 4.6 m mol per day. More magnesium was lost during the first 25 days of a fast, than thereafter. There is some correlation of magnesium loss with nitrogen loss during the early periods, but none with calcium excretion or with the amount of ketone bodies excreted. The administration of glucose reduces, at least temporarily, the excretion of magnesium. Robert et al., (1970), have stated that the serum magnesium level in severely injured patients such as amputations, drops from 2 mg/100 ml to 1.6 mg/100 ml, returning to normal by the fourth day after operation. Serum levels in their group 2 injuries e.g., appendicectomy, changed from 1.9 mg/100 ml to 1.6 mg/100 ml. They concluded that the serum magnesium level and urinary excretion of magnesium alter immediately post-operatively and then return to normal. There is also a relation in the degree of change to the type of injury.

Calcium and phosphorus disturbance.

Walker et al., (1968) reported that a fall in urinary output following major surgery of the soft tissues and that this correlated well with the fall in sodium output. Drenick et al.,(1969) studied the correlation between magnesium, calcium and nitrogen loss after prolonged fasting of obese males. They pointed out that there is a relation between magnesium and nitrogen output in urine, but none between calcium and nitrogen output.

Min et al., (1970) reported that the ratio of calcium to magnesium

in urine in 20 normal subjects varied between 0.6 to 1.5 m mol (mean 1.1 m mol). In hyperparathyroidism this ratio is higher 0.8-3.7 m mol (mean 2.3 m mol). Ingle et al., (1947) and Wynne et al., (1960) also studied the urinary excretion of calcium and phosphorus after operation and their conclusions from their work on fourteen patients who had received abdominal operations were as follows: -

a) A marked phosphorus diuresis occurs with a peak at 8 to 12 hours post-operation.

b) Phosphorus retention begins 2 days after operation.

c) Post-operative retention of urinary calcium occurs.

Nine further patients whose operations were classed as extensive superficial dissections, exhibited a similar, but much less marked pattern of excretion. A calcium diuresis was a frequent feature of this group. Cuthbertson (1930; 1932) had earlier drawn attention to the parallelism in the excessive urinary excretion of phosphorus, sulphur and nitrogen following fracture but not of calcium.

Disturbance of osmolality after injury.

After injury serum is often found to be hypoosmolar. Hypo-osmolality is always associated with a low plasma sodium. It is produced by (a) sodium depletion (b) excessive water retention (c) potassium depletion, or by any combination of these three conditions. After trauma - including surgical injury - it is usual for plasma osmolality to fall by up to about 7 per cent. Plasma sodium falls from 140 to 130 m mol/L and remains depressed for some 3 to 4 days after injury.

A number of factors may cause a more pronounced and longer lasting hypo-osmolality. They include excessive infusions of hypotonic solutions, severe or prolonged operations with incomplete replacement of blood loss, electrolyte depletion (Na^+ and K^+), pre-existing cardiac failure, hepatic or renal failure or the post-operative development of changes in urine composition. The osmolality of urine rises almost immediately and especially when water intake is restricted, and remains high for a week or ten days.

Water disturbances after injury.

During the past twenty years much work has been done and recorded on water and salt retention which occurs after trauma or operation. In general, and particularly during recent years, this disturbance of salt and water metabolism has been described as due to a secretion of adrenocortical hormones, especially aldosterone, because of the stimulation of the adrenal glands by trauma. It is understood that ACTH or cortisone can cause a retention of salt and water in the body.

Three points are important for electrolytes and water disturbance after injury in the body.

1) Primary water retention.

2) Early sodium retention.

3) Late sodium retention.

All three are due to adrenocortical qotivity. In 1932 Cuthbertson reported oliguria or anuria within 24 hours, in some cases of trauma. In 1949 Cooper, Iob and Coller showed clearly that there was a retention

of water after operation, with an oliguria of high specific gravity. This was shown also by Moyer et al., (1949).

Ariel (1951) and Zimmerman (1951) have observed and noted, the dilution of extracellular fluid which occurs after operation, though not specifically associating this with water retention. Hardy (1950) suggested that the oliguria was due to a release of adrenocortical hormones. It is usually assumed that the metabolic rate rises seven per cent for each 1°F in the body and for 1°C a 13 per cent rise has been calculated. So that a febrile rise causes an increase in insensible water loss after injury. The metabolic rate is increased after accidental or surgical injury by up to 100 per cent or more following severe burns and this also causes an increased insensible loss of water. The rate of water loss by evaporation on the surface area of the body depends upon the humidity of the ambient air as well as its temperature and rate of flow over the body. Fluid shift occurs after injury into the injured area because of the formation of exudate; this is most obvious in burns.

Energy requirement.

There are several explanations for the loss of weight and increased oxygen consumption which occur after major operation and trauma.

It may be that the early increase in the oxidation of fat is to provide for a sudden increase in energy expenditure in man. There is normally about a 10 per cent increase in energy expenditure after surgery, but it does not completely explain this phenomena in some of

the patients studied. It has been reported that the metabolic rate is raised for 5 to 6 days after operation or accidental trauma, and if the patient has not any infection, it then begins to decline. Cuthbertson (1932) has pointed out that during 12 days after severe compound fractures or operation the respiratory quotient varied from 0.76 to 0.85 and gradually increased to 1.15. He concluded that over a period of 4 days oxygen consumption follows the nitrogen excretion in the urine, but then tends to fall from the fourth day onwards although the urinary nitrogen excretion may still remain high. The consumption of food has been resumed by this time and is again providing a major proportion of the energy requirement.

In 1957 Cairnie et al., found that in rats after femur fracture, the rise in heat loss paralleled the extra urinary nitrogen output and oxidation of protein equivalent to the extra nitrogen excreted could account for the increase in heat production. They concluded that the increase in heat production was more likely to be due to an increase in protein catabolism than to any changes in carbohydrate or fat metabolism. In 1957 Cuthbertson re-examined his earlier work on man (1932) and proposed the following explanation: -

1) During the first week after injury the energy liberated can be accounted for by the oxidation of protein equivalent to the extra nitrogen excreted and that there is no increase in the oxidation of fat and carbohydrate.
2) In rats heat production does not rise after injury if the rats have previously been on a protein-free diet.

3) In adrenalectomised rats there is no rise in nitrogen excretion following fracture unless they are maintained on a constant dose of cortisone.

Caldwell (1962) found no protein catabolic response to burns in rats which were kept at 30°C ambient and he pointed out that this was because less heat was lost by evaporation of the exudate at the surface of the injured skin at this high temperature. In 1967 Miksche and Caldwell stated that the loss is due to a smaller heat loss by radiation.

In 1967 Campbell and Cuthbertson confirmed this in fractured rats where there is no exudation demanding extra heat production. Caldwell (1967) also observed this in rats after fracture of the femur. It seems likely that since the high environmental temperature reduces heat loss, and thus energy expenditure, it also reduces the need for tissue catabolism.

Environmental temperature.

In recent years much work has been done on the effect of high temperature and the response to injury. High environmental temperature, humidity and wind velocity together, change the metabolic pathway of injured patients.

Hule et al., (1959) have reported that the weights of kidney, liver and spleen do not increase in rats at a high environmental temperature, but that the thymus gland weight has a direct relationship to the environmental temperature. Heroux and Gridgeman (1958) studied the tissue weights of the rats which were kept in 30°C and 6°C ambient and

they reported that the cold environment does not affect brain, genitalia or lung weight, but reduces the weight of some other organs. When mice were kept in a cold temperature -3°C ambient, their oxygen consumption and hair growth increased and they had a lighter weight of skin than control mice, as reported by Barnett (1956) and Barnett et al., (1965). On theoretical grounds, one might expect cold exposure to result in increased food consumption. The lighter weight of skin reported by Barnett to occur on cold exposure may be due to energy demands preventing peripheral fat deposition. At high environmental temperature food intake and oxygen consumption will fall as will voluntary activity. Thus a reversal of the effect secondary to food intake as noted for cold exposure may be expected. All environmental temperatures below body surface temperature will impose an obligatory heat loss on the animal and may thus be considered stressful. Body surface temperature in the rat is about 34°C, depending on skin blood flow, environmental temperature and the interpretation of "surface". The results of Hume et al., (1959) which indicated that the adrenal weight was lowest at 34°C-35°C would support the above in so far as adrenal weight may or may not reflect adrenal activity.

Knigge et al.,(1960) and Kolby et al., (1967) reported that both cold and hot temperatures will lead to stimulation of corticosteroid secretion within 24 hours, but Tilstone and Roach (1969) reported that the basal plasma corticosterone levels in rats held at 30°C ambient is lower than in the control rats at 20°C ambient.

Effect of environmental temperature on protein metabolism.

You et al., (1950) have reported that the urinary nitrogen is higher in the burned rats at 1.5°C ambient than at normal room temperature and they mentioned that the high excretion of nitrogen in the urine in the burned rat in cold weather appears to depend on thyroid, or on adrenal stimulation. Caldwell et al., (1962; 1966) and Miksche et al.,(1967) reported no increase in oxygen consumption, heat production, or urinary nitrogen excretion when the burned rat is kept in an environmental temperature of 30°C. Cuthbertson and his colleagues (1966; 1968) have shown that in long bone injury in man and in the rat there is a significant reduction in nitrogen excretion in an environmental temperature of 30°C.

Caldwell (1962) suggested that the diminution of the protein catabolic response to burns by rats kept at 30°C was due to the fact that environmental compensation now existed for the obligatory heat loss resulting from fluid evaporation from the burn surface, but as already indicated such an explanation was found to be applicable to bone injury, as Campbell and Cuthbertson (1967) have discussed.

The high environmental temperature of 30°C favours healing of skin wounds in the rat (Cuthbertson and Tilstone, 1967). The cause of this may be an increased peripheral blood flow. Cuthbertson and Tilstone (1968) reported that bone healing is probably not affected by exposure to 30°C ambient. The high environmental temperature (30°-32°C) appears to affect favourably the healing of burns and other skin lesions, but

probably also does have an appreciable effect on the deep tissue. The presence of a high environmental temperature in homeothermic animals appears to include induction of accelerated healing at the surface particularly of the extremities in man, and may cause changes in heat producing biochemical reactions. It obviously produces an increase in peripheral circulation.

Factors which are responsible for changes in metabolic pathways after trauma.

1) Immobilization. Disuse atrophy through immobilization by pain or fixation was thought to account for the wasting of the muscles, etc., following injury, but the classical work of Dietrick (1948) showed that simple immobilization was responsible for only a small negative nitrogen balance (2 g per day) and only a very small negative balance. Sodium/potassium remained normal, therefore the part played by immobilization is small.

Cuthbertson (1930; 1942) had earlier shown that this post-traumatic tissue catabolism is not due to immobilization or disuse atrophy because although when a limb is fixed in a splint there is only a small increment in the urinary output of sulphur, nitrogen and phosphorus and later of calcium, and that these increases last only a short time and are not nearly as large as after injury.

2) Starvation. The effects of starvation on metabolism are generally similar to those of trauma. Nitrogen balance is negative to a similar extent to that seen after moderate trauma, but this is immediately

correctable by giving protein. Potassium is also in negative balance but the early high loss seen on the first day after trauma is absent. Sodium retention is only noted after starving for 4-5 days, whereas it is seen immediately following trauma. It has been shown (Wilkinson, et al., 1950) that while starvation undoubtedly accounts for some of the continuing urinary excretion of nitrogenous material after operation, the large increase in nitrogen, potassium, sulphur and phosphorus excretions are related mainly to the induction of the injury and this pattern of urinary excretion is different to that found during starvation. Therefore it may be concluded that starvation may well contribute to the metabolic response to trauma, but this is by no means the whole story (Clark, 1967).

Role of the corticosteroid.

After injury the pituitary rapidly secretes an increased amount of ACTH and this results in the production by the adrenals of corticosteroids of potent metabolic activity.

Hume and Egdahl (1953; 1959) have helped show the pathways by which the pituitary is activated. These pathways must include stimuli from peripheral nerves because corticotrophic activity is greatly minimized by previous sections of peripheral nerves or their tracts in spinal cord. The different fibres from parts of the vascular tree conduct pressure stimuli in response to haemorrhage or hypotension. The activity of the brain is less well known, but areas of the hindbrain and hypothalamus appear to stimulate the pituitary. The flow of stimuli occurs in the

absence of any nervous connection so stimulation is probably humoral. Experiments involving the removal of the cerebral cortices suggest that these higher centres exert a continuous suppressive role over pituitary corticotrophic activity. As a result of these stimuli the adrenal cortex produces its hormones. The most copiously secreted one is 11-oxy-17-hydroxycorticosterone (hydrocortisone). This is largely responsible for the changes in organic metabolism resulting in increased nitrogen excretion, decreased glucose tolerance and changes in formed elements of blood e.g., eosinophil level. Hydrocortisone also has a mild effect on inorganic metabolism, but is not the most important controller of sodium, potassium and water metabolism.

Aldosterone has been shown to have a powerful action on the inorganic metabolism of the body (Cuthbertson and Tilstone, 1969), and it has been suggested that this hormone is not wholly under the control of ACTH and changes in electrolytes can occur without the participation of anterior pituitary activity. It has been pointed out that this hormone is excreted by the outer cortical adrenal (Zona glomerulosa). A study of a series of "cold" operations showed a consistent rise in the excretion of this hormone. Studies were also performed altering the pre-operative regime (e.g., low sodium intake) and it was found that altering the regime had little effect on aldosterone output. This was more closely related to the magnitude of trauma than to any other variable so far studied.

In 1956 Liddle showed that concentration of sodium (i.e., lowered sodium level) in the serum did not give rise to increased aldosterone

production, but actually caused a decrease in circulating aldosterone, and also they found that dehydration caused increased aldosterone production and they searched for the presence of volume receptors. It has been known that the vascular tree and particularly that which is in the right atrium (volume receptors) is the area which when stimulated causes aldosterone production.

It has been suggested that these receptors have a central connection which is in the diancephalon and that they control the aldosterone production. It seems that production of aldosterone is humoral rather than nervous.

It is also possible that the kidney is the source of the hormone which stimulates aldosterone production in response to volume changes in the vascular tree, especially the juxtamedullary glomeruli. The role of posterior pituitary hormone is important in maintaining water balance in stressed patients. It is known that trauma causes a decrease in urinary output. In this mechanism the role of ADH is important. In the normal person the serum osmolality is controlled by the post pituitary, but the kidneys are also responsible for maintenance of this balance by excretion of solutes and the reabsorption of water. In 1958 Verney stated that ADH is controlled by the activity of ramifications of the carotid circulation, which transmit impulses, controlled by osmotic pressure via the hypothalamus to the neurohypophysis. Normally, if plasma is dilute ADH is inhibited and when plasma is concentrated ADH is stimulated. In traumatic states the plasma tends to be diluted and the urine concentrated, and

production of ADH may be controlled by osmolality of the serum. It is assumed that the need for conservation of fluid and of the circulating volume takes precedence over the mechanism of normal osmotic regulation.

In the traumatised patient his serum is dilute, his osmotic regulating apparatus takes a back seat and he becomes extremely sensitive to overtransfusion with hypotonic fluids (Moyer, 1950). Many authors have postulated the participation of ADH as the prime factor in the genesis of the water retention which characterised the post-traumatic state. The rate of production of ADH is related to the degree and type of the stimulus.

The following factors are responsible for the production of ADH.

a) Blood loss is a potent stimulus.

b) Pulling of the abdominal viscera is one of the strongest stimuli.

c) Anaesthesia is not a strong stimulus.

d) Incision is but a mild stimulus.

The mechanism of ADH control is still being studied but volume receptors in the left atrium have been implicated and distension of the left atrium in dogs produced diuresis, but section of the vagus abolished it.

II.

METHODS

1. Sodium and potassium in serum and urine were measured by IL Flamephotometer Model 144 (Instrumentation Laboratory). C.V. 0.7% for Na C.V. 1.5% for K (C.V. = Co-efficient variation).
2. Chloride in serum and urine were measured by E.E.L. Chloride meter (Evans Electrostenum Ltd). C.V. 1.3% for Cl
3. Calcium, magnesium and zinc in urine and calcium and magnesium in serum were estimated by atomic absorption spectrophotometry (S.P. 90 Pye Unicam). C.V. 1.8% for Ca C.V. 3.6% for Mg C.V. 5% for Zn
4. Serum and urine osmolality were measured by freezing point depression (Advanced Scientific Osmometer).
5. Total alpha amino nitrogen in urine by the method of Rubenstein et al. (1959). C.V. less than 2%
6. Paper chromatography was used for the detection of amino acid in urine by method of Ivor Smith, 2nd Ed. Vol. 1.
7. Creatinine in the urine was measured by the Standard Technicon Method. The Blakiston Co. Ed. p. 506. C.V. 2%
8. Creatine concentration in the urine was estimated by the method Conn, 1960, modified by Tilstone and Fell (1970). C.V. $\simeq$ 4 %
9. Total nitrogen in urine by a modified Kjedahl method. Munro and Fleck, (1962). C.V. less than 2%
10. Ammonium in the urine was estimated by the method of Fawcett et al. (1960). C.V. less than 2%
11. Urea was measured in serum and urine by the method of Searcy et al. (1961). C.V. 2%
12. Glycosuria and ketonuria were detected by the Clinstix test and Aceto test of Ames Co.
13. Oxygen consumption and resting metabolic energy expenditure (R.M.E.) were estimated by the closed circuit method of Benedict and Roth. (See text C.V. > 25%)
14. Skin temperature was measured by a Universal thermometer with 4 probes (Electrolaboratoriet, Copenhagen). less than 0.2% C.V.

15. Two clinical hot rooms were constructed in Ward 27 (Orthopaedic Unit) of Glasgow Royal Infirmary.

16. Daily protein and energy intakes were calculated from the tables of McCance and Widdowson (1960).

17. The Astrup method was used for measuring of blood, pH, Base Excess, and pCO_2.

18. Patients with long bone injury at low and high environmental temperature were studied for 9 - 12 days after injury. The dietary regime was similar for the patients at normal ward temperatures (20-22°C) and those at 29-30°C. The total energy intake of the patients was around 2500 kcal/day and protein accounted for 13-14 per cent of the total calories. The food consumption was slightly higher in the patients who were in the higher ambient temperature, but statistically this was not a significant difference. The diets contained around 13g/N/day. The intake of water or other fluids such as lemonade were taken in greater amount in the patients in the hot clinical rooms. Urine was collected every 24 hours for the various analyses. Faeces were not collected since the faecal excretion of nitrogen is not affected by injury (Cuthbertson, 1929; 1936), and the nitrogen excretion in the faeces is normally around 10 per cent of the dietary nitrogen.

III. MATERIALS

Clinical subjects.

This present investigation was carried out on four groups of patients. Some had been admitted to the Intensive Care Unit and were specially selected, others were cases admitted to Ward 27 of the Orthopaedic Unit of the Glasgow Royal Infirmary.

The first two groups of subjects had either severe head injury with one or more long bone fractures or were cases of mild head injury with chest involvement, and the rest of the patients had one or more major long bone fractures without head or chest injury and were held at 20°C or 30°C ambient.

Patients with severe head injury

Name	Age	Sex	Type of injury
Cumming	32	male	head and chest injury
Norming	56	male	head and bone injury
Miller	80	male	head injury
Dolan	24	male	head and bone injury
Carol	18	female	head injury
Gillespie	20	male	head and bone injury
Irving	41	male	head, bone and spleen injury
Smith	26	male	head injury
Walter	19	male	head and bone injury
McCormack	49	male	head and bone injury

Severe head injury (Fatal cases).

Ten cases were investigated with severe head injury. Nine of them were male and one was female. The age of the patients varied from 18 to 80 years. Five of these patients also had fractures with their head injury.

The patients were studied at ordinary ward temperatures. They had been admitted to the hospital unconscious and never regained consciousness. They died between 4 and 9 days after injury except one who remained alive for 17 days after the day of his injury.

Mild head injury.

This group were admitted unconscious and regained consciousness one or two days after their injury. There were eight such cases, seven male and one female; six of these patients also suffered from chest injury as well as mild head injury. The age of the patients varied between 20 to 57 years. The patients were studied at normal temperature.

Patients with fracture (20-22^{o}C) ambient.

Ten cases were investigated with one or more long bone fractures and were studied in an environmental temperature of 20-22^{o}C ambient. Seven of the patients had one or more long bone fractures, one had a laceration of the left leg and the leg was subsequently amputated. Two underwent the severe operation of Charnley arthroplasty. All of the subjects were male and their age varied from 18 to 74 years.

The severity of their injury ranged between 1½ to 7 units (arbitrary units of damage). The patients were on a controlled but self selected diet, which was provided with the co-operation of the diet kitchen.

Patients with fractures held at high environmental temperature (29-30°C) ambient.

There were nine cases and one of the patients was studied for two periods when he was in hospital. These subjects had fractures and all of them were male and their age varied from 18 to 67 years. The severity of their injuries varied between 2 and 5. The diet of the patients was roughly the same diet which had been given to the patients at 20-22°C ambient.

IV. COLLECTION OF SAMPLES

The samples which were collected for this investigation were blood and 24 hour urine collections.

The blood was drawn on the 3rd, 5th and 10th days after injury from the patients who were studied in low and high environmental temperatures.

Blood samples were collected from the patients who had severe head injury and mild head injury. The serum was removed immediately and stored in the deep temperature. The 24 hour urine was collected in a plastic bottle with 5 ml of 10% thymol in isopropanol as a preservative and stored in deep freeze. For measurement of ammonium ion urine was collected in plastic bottles which contained 0.25 g of chloramphenicol, 0.5 g streptomycin and 50 ml of toluene.

V. RESULTS

a) Results for severe head injury patients.

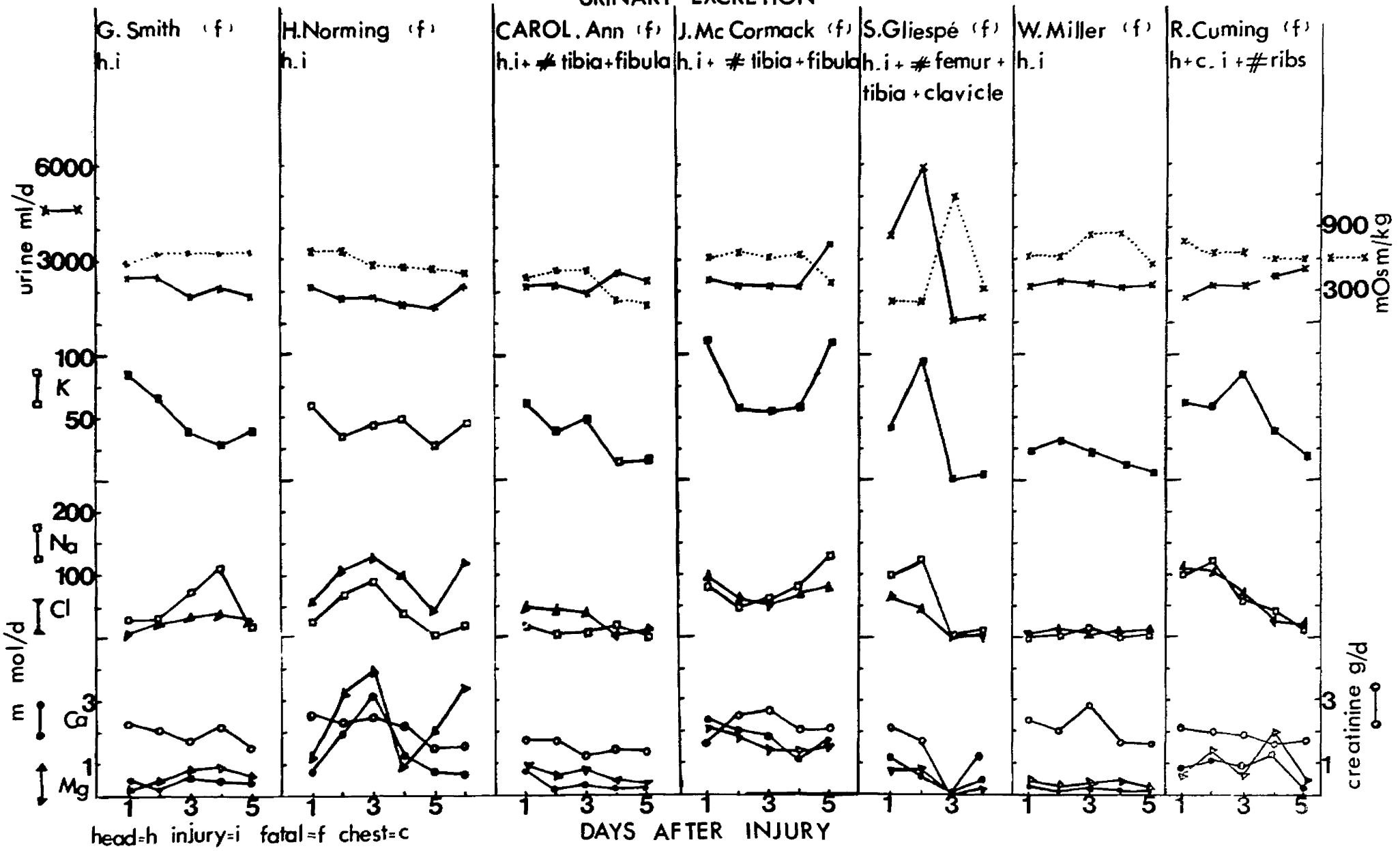
Sodium, chloride, potassium, calcium, magnesium and creatinine excretion were investigated in ten cases of severe head injury. The total daily excretion are expressed as m mol. The volume of urine, amino acids, and the osmolality were also measured during the period of observation. Qualitative tests were used for the excretion of glucose and ketone bodies in the samples. Nine patients died between the 4th and 9th days and one lived to the 17th day after injury.

Changes in urine excretion (Figure 1 and 2).

Sodium and chloride excretion. - It was evident that these ions were parallel in six of the patients after injury. Patients Smith, Norming, Walter and Gillespie showed exceptions to this during the period of investigation. Sodium and chloride excretion were initially parallel in the case of Smith, but sodium excretion rose higher than chloride on the 4th day after injury. Chloride excretion was higher than sodium in Norming on all days of observation. Gillespie showed a higher excretion of sodium than chloride for the first two days after injury, then the excretion of these ions was very low up to 2 m mol/day on the fourth day of observation. This pattern was not observed in other patients. Irving showed a remarkably low sodium and chloride excretion for the first five days after injury. Then he excreted increased amounts of chloride and sodium on the sixth day of observation.

F1

URINARY EXCRETION



F 2

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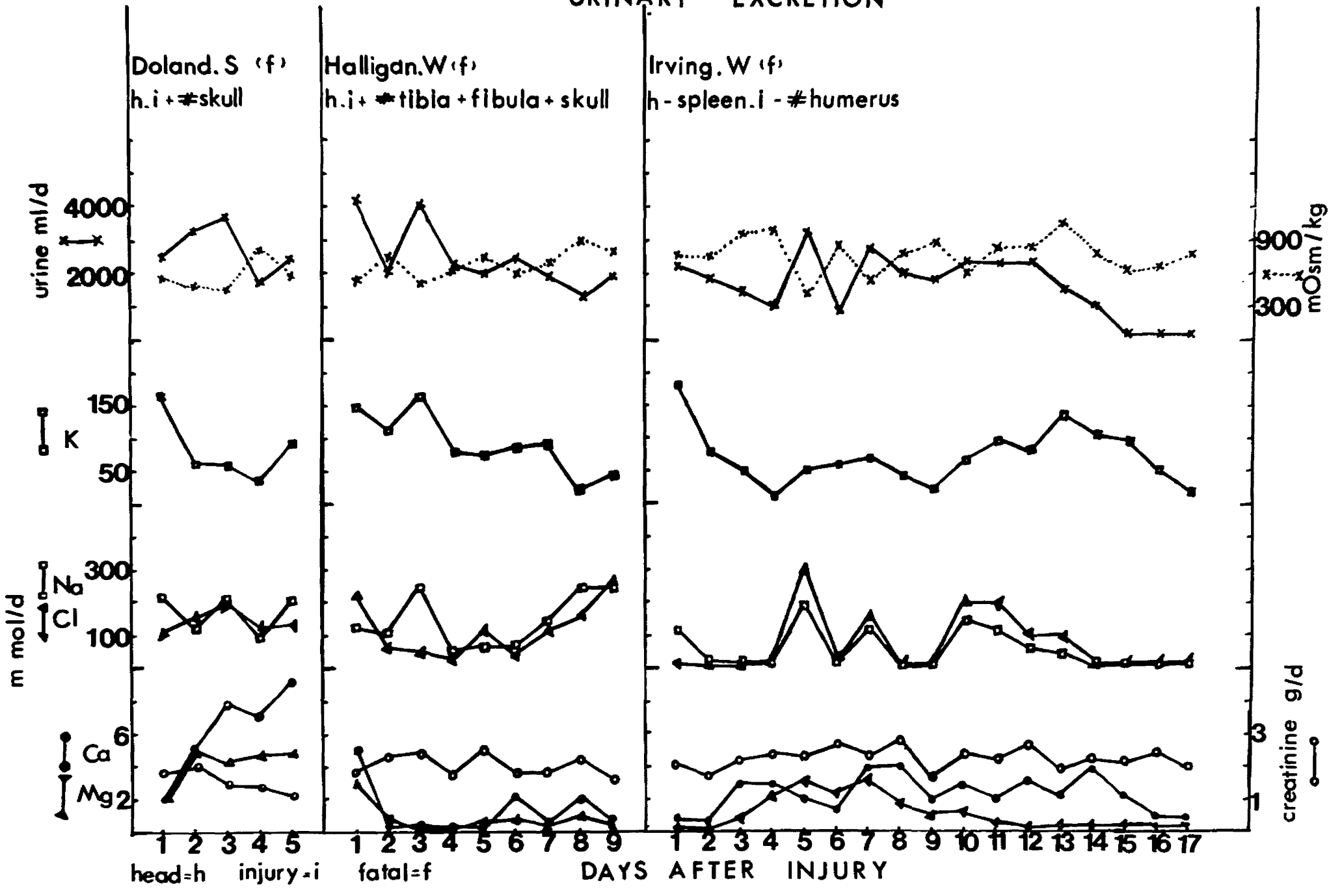


This was followed by a second period of low sodium and chloride excretion. This behaviour in the excretion of sodium and chloride was not observed in the other patients.

Potassium excretion.

The patients were in negative balance of potassium during the first day after injury. The excretion of potassium differed from one day to another in patients during the period of observation. A constancy in the pattern of potassium excretion was not observed in the patients after injury. Gillespie had a low excretion of 2 m mol/day of potassium in urine on the fourth day after injury. This kind of low excretion of potassium was not observed in nine other patients after injury.

Calcium and magnesium excretion.

It was observed that calcium and magnesium excretion were low on all days of investigation in nine of the patients. The exception was Dolan in whom the excretion of calcium and magnesium were high on all days after injury. It was also found that calcium and magnesium excretion were parallel during the period of observation. The ratio of urinary calcium and magnesium excretion was 0.7 to 0.8 showing a rather lower excretion of calcium than is normally found (Normal Ca:Mg = 1.1), (Min et al., 1970).

Creatinine excretion.

The creatinine excretion varied from one day to the other after injury. It was evident that creatinine excretion ranged from 2 to 3 g/day.

Two of the patients Halligan and Irving excreted more than 3 g creatinine/day in the first few days after injury. No relation between creatinine, potassium and magnesium excretion was observed after injury.

Volume of urine and osmolality.

The patients showed polyuria for one or two days after injury. Gillespie excreted the high volume of 3500 ml of urine on the first day after injury. This was followed by an even higher excretion of up to 6000 ml urine/day on the second day. But on the third day he exhibited an anuria and by the fourth day oliguria. This early polyuria was not observed in the nine other patients during investigation.

Irving showed polyuria for the first three days but this was then followed by oliguria for one day and then by a further period of polyuria. This pattern was not observed in nine other patients during investigation. It was observed that urine osmolality was high in the patients after injury.

Glycosuria and ketonuria.

Glycosuria was present in all of the patients for one to three days after injury (Table I). Ketonuria was observed in nine of the patients (except Carol) for one or three days during investigation (Table I). Jaundice was observed on the seventh day in the case of Irving, but none of the other patients showed any sign of jaundice during investigation.

Glycosuria and ketonuria in patients with severe head injury.

TABLE 1

Ambient	20-22°C												20-22°C											
	Glycosuria												Ketonuria											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Cumming	+	+	−	−	+								+	+	+	−	−							
Norming	+	+	+	−	−								+	+	−	−	−	−						
Miller	+	+	+	−	−								+	+	−	−	−							
Dolan	+	+	+	−	−								+	−										
Carol	+	−	−	−	−								−	−	−									
Gillespie	+	−	−	−									+	−	−									
Irving	+	+	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−
Smith	+	+	+	−	−								+	−	−	−	±							
Walter	+	+	−	−	−	−	−	−	−				+	+	+	−	−	−	−	−	−			
McCormack	+	−	−	−	−								+	+	+	−	−							

Serum electrolytes and acid base balance.

Three patients were investigated for Na, Cl, K, Ca, Mg, CO_2, osmolality, urea, pH, pCO_2 and Base excess (BE) in the blood and plasma after injury.

It was observed that the cation and anion concentration in the serum were changed from one day to another during the period of observation (Table II, III and IV). Acidosis and alkalosis either respiratory or metabolic were also observed in the patients during this period. The patients showed hyperchloraemia and hyperosmolality on the last few days of observation. Not much difference was observed in the levels of K, Ca and Mg in the serum during investigation. The concentration of urea in the serum was normal except for Gillespie. This patient had a level of 120 mg/100 ml of urea on the third day after injury. pH, pCO_2 and BE changed from one day to another after injury.

Summary for patients with severe head injury.

The patients showed polyuria and then oliguria and there was also recurrence of polyuria.

Urine osmolality was high, and the patients had an increased urinary loss of sodium and chloride for one or two days which was then followed by retention of these ions. Na and Cl excretion were parallel but there was no consistency in potassium excretion. Calcium and magnesium excretion were low, $\frac{Ca}{Mg}$ ratio, 0.7-0.8 (normal 1.1), and were excreted in parallel. Hypernatraemia, hyperchloraemia and hyperosmolality were observed in the last few days after injury, but with no changes in serum potassium

TABLE 2.

SERUM ELECTROLYTES

IRVING

	mmol/L						mOsm/kg	mg/100 ml	g/100 ml			
Days after injury	Na	Cl	K	CO_2	Ca	Mg	Osmol	Blood urea	Urine urea	pH	pCO_2	BE
1	138	97	3.8	31	2.4	1.2	300	28	-	7.48	30	+1
2	131	96	3.1	30	2.3	1.2	288	15	3.8	7.41	44	+3
3	139	98	3.5	30	2.3	1.1	292	38	3.21	7.45	34	0
4	144	108	3.5	30	2.5	1.2	304	48	2.9	7.35	43	-2
5	144	104	3.8	26	2.4	1.3	308	48	2.8	7.41	32	-4
6	149	109	4.1	29	2.2	1.2	304	59	-	7.29	48	-4
7	158	116	3.0	29	2.3	1.1	330	70	-	7.36	35	-5
8	155	104	3.9	28	2.4	1.2	324	47	2.0	7.36	50	+9
9	147	107	4.2	26	2.5	1.3	318	44	2.4	7.29	95	-3
10	141	104	4.1	30	2.2	1.2	308	46	1.9	7.29	45	-6

TABLE 3

GILLESPIE

SERUM ELECTROLYTES

Date after injury	m mol/l						mOsm/100 ml	mg/100ml	mg/ 100ml			
	Na	Cl	K	CO_2	Ca	Mg	Osmol	Blood urea	Urine urea	pH	pCO_2	BE
1	143	102	4.3	26	2.4	1.2	300	32	0.8	7.33	43	-4
2	146	109	5.5	28	2.5	1.3	302	28	0.4	7.3	62	-7
3	148	107	4.1	27	2.3	1.2	326	120	-	7.35	37	+5
4	137	99	4.1	26	2.5	1.4	308	62	-	7.4	38	-4

TABLE 4

S. Delan

SERUM ELECTROLYTES

	m mol/l						mOsm kg	mg/100 ml	mg/100 ml			
Days after injury	Na	Cl	K	CO_2	Ca	Mg	Osmol	Blood urea	Urine urea	pH	pCO_2	BE
1	135	101	3.4	17	2.5	1.3	279	20	3.1	7.31	47	-4
2	139	99	4.6	26	2.4	1.2	298	31	1.2	7.36	33	-6
3	143	104	3.5	23	2.6	1.3	310	51	0.8	7.4	38	-8
4	148	108	4.7	28	2.5	1.2	328	102	0.4	7.5	36	-6

calcium, magnesium and urea.

Both acidosis and alkalosis, either respiratory or metabolic, were observed. Glycosuria and ketonuria were present on one or two days early after injury.

b) Results for mild head injury patients.

Eight patients were investigated for sodium, chloride, potassium, calcium, magnesium, ammonium, creatinine excretion in 24 hour urine collections after injury. The volume of urine and osmolality were measured during observation. Glycosuria and ketonuria were also checked qualitatively.

Patients with mild head injury

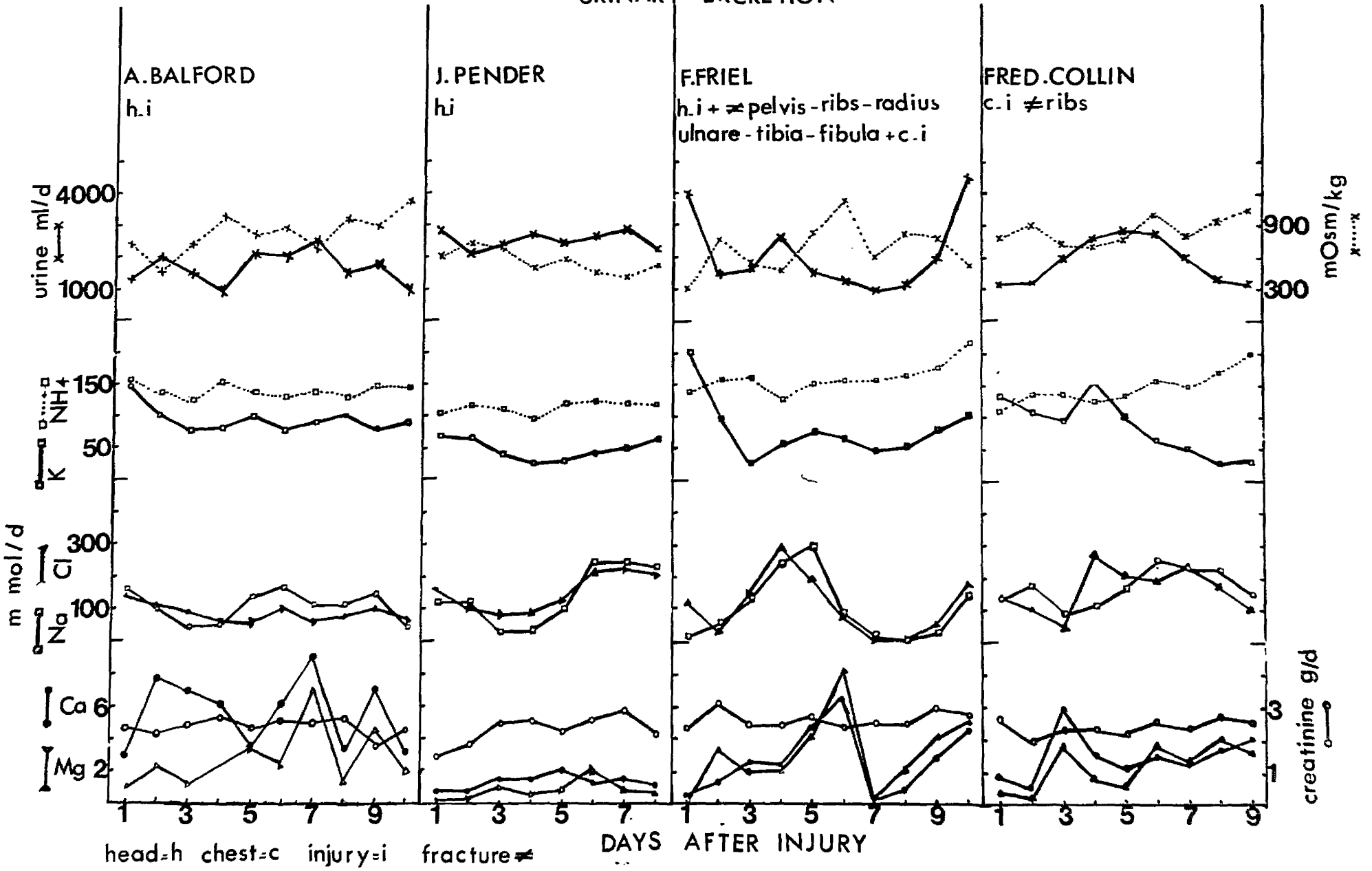
Name	Age	Sex	Type of injury
Collins	24	male	head, chest and bone injury.
Smith	42	male	head, chest and bone injury.
Pender	57	male	head injury
Balford	26	male	head injury
Jackson	40	male	head, chest and bone injury.
Friel	45	male	head, chest and bone injury.
Cassidy	34	female	head and bone injury
Shield	52	male	head, chest and bone injury.

Urinary excretion (Fig. 3 and 4).

Sodium and chloride excretion. - It was evident that sodium and chloride were parallel in seven of the patients after injury. Patient Smith showed a higher chloride than sodium excretion in the 4th, 5th and 6th days after injury.

F 3

URINARY EXCRETION



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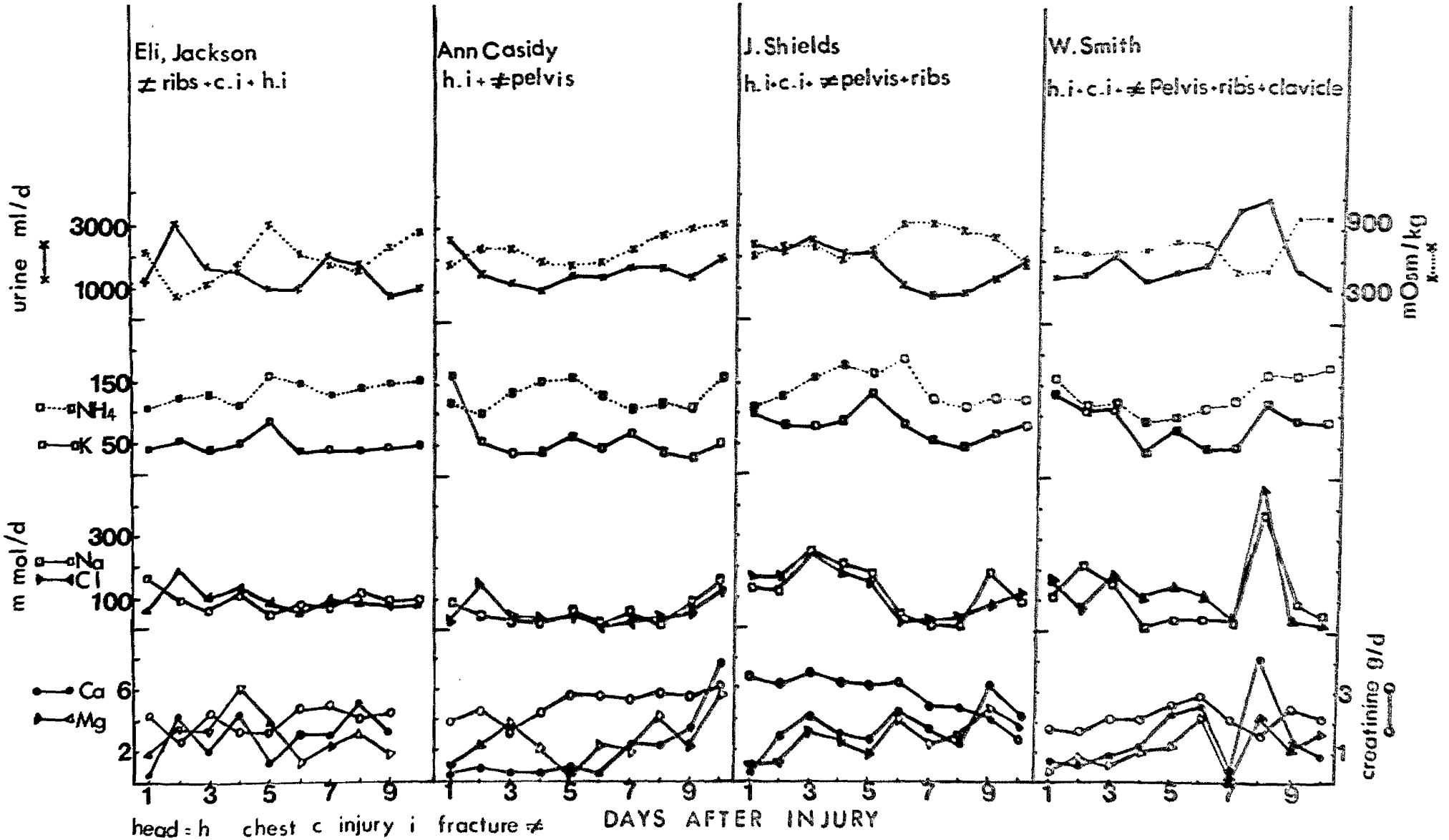


Potassium excretion.

It was observed that the patients were in negative balance of potassium in the first one or two days after injury. Patients Cassidy, Balford and Friel, showed a high potassium excretion of up to 150-200 mmol/day on the first day after injury. This high potassium excretion was not observed in four other patients during investigation. The potassium excretion altered from day to day in the patients after injury.

Calcium and magnesium excretion.

It was evident that calcium and magnesium excretion were parallel in seven patients. Patient Balford showed a high magnesium excretion in the 2nd, 3rd and 4th days after injury. This was not observed in seven other patients. Patient Smith showed a raised calcium and magnesium excretion on the 8th day after injury. The potassium, sodium, chloride and ammonium excretion were also high at this time. Patient Friel showed high calcium and magnesium excretion on the 6th day after injury. He did not show high sodium chloride and potassium on the same day, but ammonium excretion was high. Patient Balford showed high calcium and magnesium excretion on the 7th day after injury. Sodium and chloride excretion were not increased but potassium and ammonium excretion were raised on this day. Patient Pender had a low calcium and magnesium excretion at all times. Cassidy showed low calcium excretion for the first six days after injury, but magnesium excretion was not depressed.

Creatinine excretion.

The excretion of creatinine did not show much alteration. The

patients excreted 2-3.5 g/day of creatinine.

Ammonium excretion.

It was observed that ammonium excretion was high in the patients after injury. The ammonium excretion varied from one day to the other days in the patients after injury.

Excretion of urine volume and osmolality.

Six of the patients showed polyuria for the first one or two days after injury. Patients Jackson and Friel showed oliguria in the first one or two days during observation then followed polyuria in the last few days after injury.

Urine osmolality was high during observation in the patients after injury.

Glycosuria and ketonuria.

Table 5 shows glycosuria and ketonuria in the patients after injury. It was evident that the patients showed glycosuria for one to three days during observation.

Ketonuria was present in six patients for one to three days after injury, but patients Pender and Shield, did not show ketonuria after injury.

Serum electrolytes.

Three patients were investigated for sodium, chloride, potassium, CO_2, calcium, magnesium, urea, osmolality, pH, pCO_2 and Base excess in the blood after injury. Tables 6, 7 and 8 show the serum electrolyte concentrations for the patients after injury.

Patients Pender and Collins showed early hyponatraemia and

Glycosuria and ketonuria in patients with mild head injury, with chest injury, or fractures.

TABLE 5

Ambient	20-22°C												20-22°C											
	Glycosuria												Ketonuria											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Collins	+	+	-	-	-	-	-	-	-				+	-	-	-	-	-	-	-	-			
Smith	+	+	+	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-
Pender	+	-	-	-	-	-	-	-	-				-	-	-	-	-	-	-	-	-			
Balford	+	+	+	-	-	-	-	-	-	-	-	-	+	+	-	-	+	-	-	-	-	-	-	-
Jackson	+	+	-	-	-	+	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-
Friel	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-
Cassidy	+	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	+	-	-	-
Shield	+	+	-	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-

TABLE 6

PENDER

SERUM ELECTROLYTES

	m mol/l						mOsm/kg	mg/100 ml			
Days after injury	Na	Cl	K	CO_2	Ca	Mg	Osmol	Blood urea	pH	pCO_2	BE
1	120	92	3.2	24	2.2	1.1	266	24	7.52	28	0
2	110	82	3.4	24	2.1	1.1	268	23	7.44	34	0
3	130	97	5.2	26	2.2	1.15	284	30	7.4	39	-1
4	132	96	3.7	24	2.1	1.2	288	32	7.36	39	-3
5	137	97	4.0	28	2.2	1.2	290	32	7.46	36	+2

TABLE 7

COLLINS

SERUM ELECTROLYTES

	m mol/l						mOsm/kg	mg/100ml			
Days after injury	Na	Cl	K	CO_2	Ca	Mg	Osmol	Blood urea	pH	pCO_2	BE
1	131	102	4.1	26	2.4	1.2	278	-	7.34	34	-5
2	128	98	3.4	25	2.4	1.1	272	-	7.38	46	+2
3	129	99	4.4	24	2.3	1.2	272	26	-	-	-
4	133	102	3.9	25	2.4	1.3	282	18	7.4	57	-1
5	140	109	3.4	27	2.5	1.2	278	28	7.37	47	0
6	143	108	4.3	23	2.3	1.2	300	29	7.45	35	0
7	138	101	4.0	24	2.3	1.3	278	30	7.46	36	+2
8	135	100	3.5	25	2.5	1.2	-	-	7.47	52	+2
9	134	100	3.6	24	2.3	1.1	280	32	7.4	64	+5

TABLE 8

FRIEL

SERUM ELECTROLYTES

m mol/l							mOsm/kg	mg/100 ml			
Days after injury	Na	Cl	K	CO_2	Ca	Mg	Osmol	Blood urea	pH	pCO_2	BE
1	145	118	3.8	27	2.2	1.1	310	26	7.48	38	+7
2	140	110	3.6	26	2.3	1.15	300	28	7.41	33	-3
3	138	102	4.0	28	2.4	1.2	289	25	7.23	30	-14
4	142	110	4.1	27	2.2	1.2	308	26	7.3	52	-2
5	138	100	3.9	28	2.5	1.1	300	24	7.41	42	-2
6	142	102	4.2	26	2.4	1.2	306	28	7.4	36	-1

hypoosmolality in the first few days after injury. The serum sodium in Pender was only 110 mmol/L , on the second day of observation, and the chloride concentration was also low. This kind of hyponatraemia and hypoosmolality were not observed in the other patients. Serum osmolality reflected the concentration of sodium in the serum. It was also noted that balance of cations and anions was altered when the patients had an acid-base disturbance. No alteration in serum urea was found.

Summary for patients with mild head injury.

Polyuria was observed in the patients, but the volume of urine was lower than the severe head injury patients. Excretion of sodium and chloride were parallel but there was no regular pattern of potassium excretion.

Calcium and magnesium excretion were low in the first one or two days and there was no change in the last few days after injury. Excretion of calcium and magnesium were parallel.

Creatinine excretion and urine osmolality were high after injury. Ammonia excretion was high, but it changed from day to day. Hyponatraemia, hypochloraemia and hypoosmolality were observed in the first few days after injury, then serum values returned to normal. No changes in serum potassium, calcium, magnesium or urea concentration were found.

There was acidosis and alkalosis either respiratory or metabolic after injury. Glycosuria and ketonuria were observed for one or two days.

c) Patients with long bone injury who were studied at 20-22°C ambient.

Ten patients with long bone injury were investigated for sodium, chloride, potassium, calcium, magnesium, creatine and total nitrogen excretion in 24 hour urine collections after trauma. The daily volume of urine and osmolality were also measured.

Glycosuria and ketonuria were detected qualitatively in the samples.

Daily energy intake and nitrogen balance were also calculated for the patients during the period of observation (Urinary N - Food N = $(N_u - N_f)$.

Changes in urinary excretion (Fig. 5 and 6).

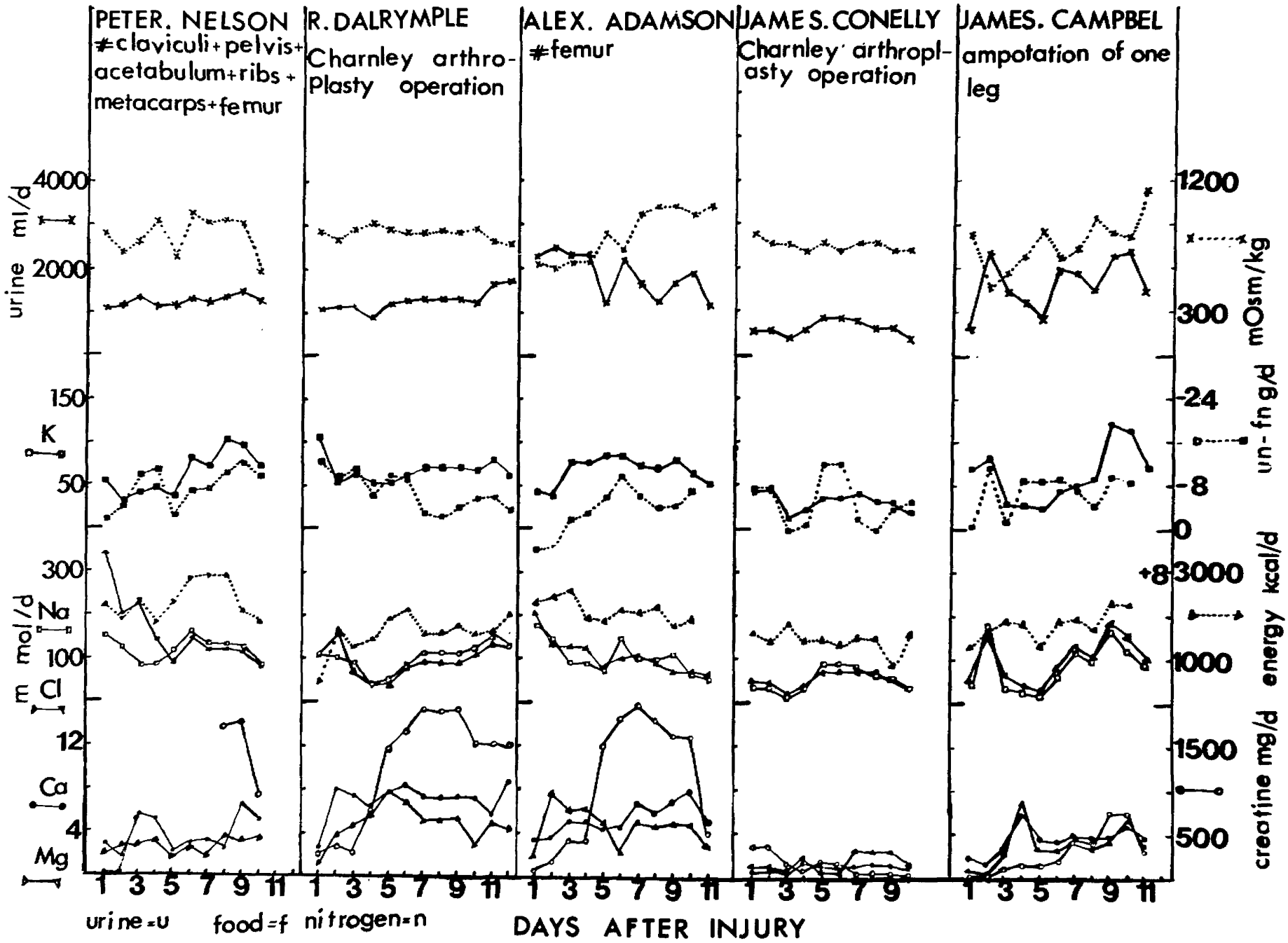
Sodium and chloride excretion. - Nine of the patients showed parallel excretion of sodium and chloride during observation. But Nelson excreted more chloride than sodium during the first three days after injury. Then he showed a parallel excretion of sodium and chloride. There was retention of sodium and chloride in nine of the patients for one or two days after injury but Nelson showed a retention of sodium and chloride for several days during observation.

Potassium excretion.

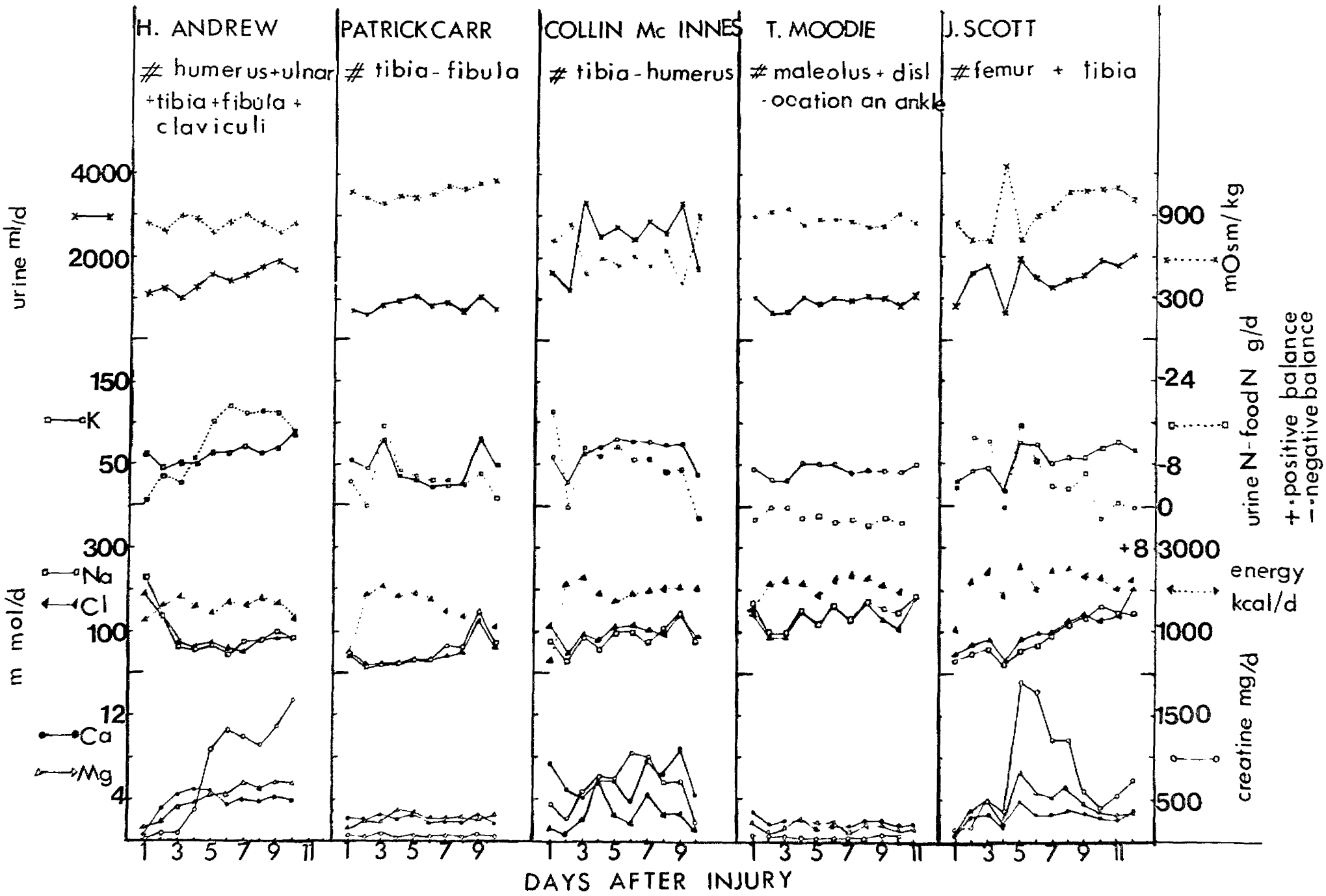
It was observed that potassium excretion followed the total nitrogen excretion in nine of the patients but Scott did not exhibit this parallel excretion of potassium with total nitrogen excretion during the last few days of observation. He was in positive balance of nitrogen during the last few days after injury, but potassium excretion was not much different then as when he was in negative balance of nitrogen.

F 5

Daily energy intake, nitrogen balance and urinary excetion in patients at 20-22 C° ambient



Daily energy intake, nitrogen balance and urinay excretion in patients at 20–22 C° ambient



Patients with long bone injury housed at 20-22°C ambient

Name	Age	Sex	Type of injury	Scale of injury
Nelson	69	male	Fracture of clavicuili ring of acetabulum, femur and metacarpals	6
Andrew	34	male	Fracture of tibia, fibula and humerus	5
Carr	59	male	Compound fracture of tibia and fibula	5
Scott	54	male	Fracture of femur and tibia	5
Campbell	32	male	Amputation of one leg	5
Dalrymple	53	male	Charnley arthroplasty operation	7
McInnes	55	male	Fracture of femur	3
Adamson	18	male	Fracture of femur	2½
Connelly	68	male	Charnley arthroplasty operation	7
Moodie	74	male	Fracture of malleolus and dislocation of ankle	1½

Calcium and magnesium excretion.

It was found that the calcium and magnesium excretion were parallel during observation. Calcium and magnesium excretion were low for the first one or two days after injury. Dalrymple showed high calcium and magnesium excretion for several days after operation. This kind of high calcium and magnesium excretion were not observed in other patients.

Adamson showed high magnesium excretion on the second day after injury which was not happening other patients. Three of the patients (Carr, Moodie and Connelly) showed low calcium and magnesium excretion during the period of observation. This was not observed in the remaining seven patients.

24 hour urine volume.

The patients showed polyuria and oliguria.

Four of the patients (Connelly, Moodie, Dalrymple and Carr) showed oliguria for several days after injury. Adamson, however, showed polyuria for the first four days after injury, then he showed oliguria for one day and this was followed by a second period of polyuria. This pattern was not observed in nine other patients.

Urine osmolality.

It was evident that the patients showed high urine osmolality for the first few days after injury.

Creatine excretion.

In eight of the patients no marked creatinuria was observed during the first ten days after injury. Two of the patients (McInnes and Dalrymple) showed high creatine excretion during the first day after injury.

It was observed that the creatine excretion was also biphasic in seven of the patients (Andrews, McInnes, Scott, Dalrymple, Adamson and Campbell) after injury. They excreted much creatine between the fourth to eighth day after injury.

Three of the patients (Carr, Moodie and Connelly) excreted the normal levels of creatine to be expected on a normal diet and this despite the fact that two of the patients (Carr and Connelly) were in negative balance of nitrogen during the period of observation. Although Connelly had a severe head injury (Grade 7) it was observed that the creatine excretion did not follow the total nitrogen excretion as noted in Dalrymple's case.

Energy intake.

It was observed that there is a relation between the energy intake and total nitrogen excretion in the urine after injury since food protein is a constant proportion of the total intake of food in these cases.

Total nitrogen excretion.

Eight of the ten patients at normal ward temperature were in negative balance of nitrogen after injury. Moodie did not show any negative balance of nitrogen during the first two days after injury but this was followed by a negative balance. Andrew showed negative balance of nitrogen of up to 16 g/day between the fifth to ninth day after injury. Such a high negative balance of nitrogen was not found in the other injured patients during observation.

Glycosuria and ketonuria.

Table 9 shows the results of tests for glycosuria and ketonuria in the patients. Seven of the patients did not show glycosuria during observation, but the others showed glycosuria for one or two days after injury. Andrew showed glycosuria in the second to fifth day after injury, then the glycosuria disappeared for two days but his glycosuria returned again. This exceptional behaviour was not seen in the other patients.

Table 9 shows results of tests for ketonuria in the patients. It was evident that ketonuria was present in six of the patients for one or two days after injury.

Glycosuria and ketonuria in patients with long bone injury housed at 20°-22°C ambient. (10 patients).

TABLE 9

Ambient	20-22°C												20-22°C											
	Glycosuria												Ketonuria											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Nelson	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Carr	-	-	-	-	-	-	-	-	-				-	+	-	-	-	-	-	-	-			
Scott	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Campbell	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dalrymple	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
McInnes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Adamson	-	-	-	-	-	-	-	-	-				-	-	-	-	-	-	-	-	-			
Connelly	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Moodie	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Andrews	-	+	+	+	+	-	-	+	-				+	+	-	-	-	-	-	-	-			

Summary for patients with long bone injury housed at 20-22°C ambient.

Oliguria was observed in the patients. Sodium and chloride excretion were parallel and there was a retention of sodium and chloride for several days. Potassium excretion followed the total nitrogen excretion and the patients showed a negative balance of nitrogen. Calcium and magnesium excretion were in parallel and were low for the first one or two days. No relation between magnesium and total nitrogen excretion was found, but a relationship between total nitrogen excretion and energy intake was noted which was less than that observed at 29-30°C. Creatine excretion was normal at first and then increased markedly towards the end of the period of observation. However, there was no relation between the total nitrogen excretion and the creatine excretion.

Urine osmolality was high and glycosuria and ketonuria were present after injury. Not much change in serum sodium, chloride, calcium, magnesium and osmolality on the third, fifth and tenth day after injury was found but the potassium concentration was higher on the fifth day than on the third and tenth days after injury. Both essential and non-essential amino acids were excreted in the urine. Oxygen consumption and resting metabolic energy expenditure (R.M.E.) were higher at first than in the later period. Axillary temperature was also high in the first three days. Big toe temperature was high at first and decreased after 9-12 days.

d) Patients with long bone injury who were studied in high environmental temperature 29-30°C ambient.

Nine patients with long bone injury were studied in high environmental temperature. One of the Patients (McCaw) was observed during the two periods. Sodium, chloride, potassium, calcium, magnesium, creatine and total nitrogen excretion were observed in 24 hour urine collection (Fig. 7 and 8). Daily urine volume and osmolality were also measured during observation. Glycosuria and ketonuria were tested qualitatively. Daily nitrogen balance and energy intake were also calculated for the patients after injury.

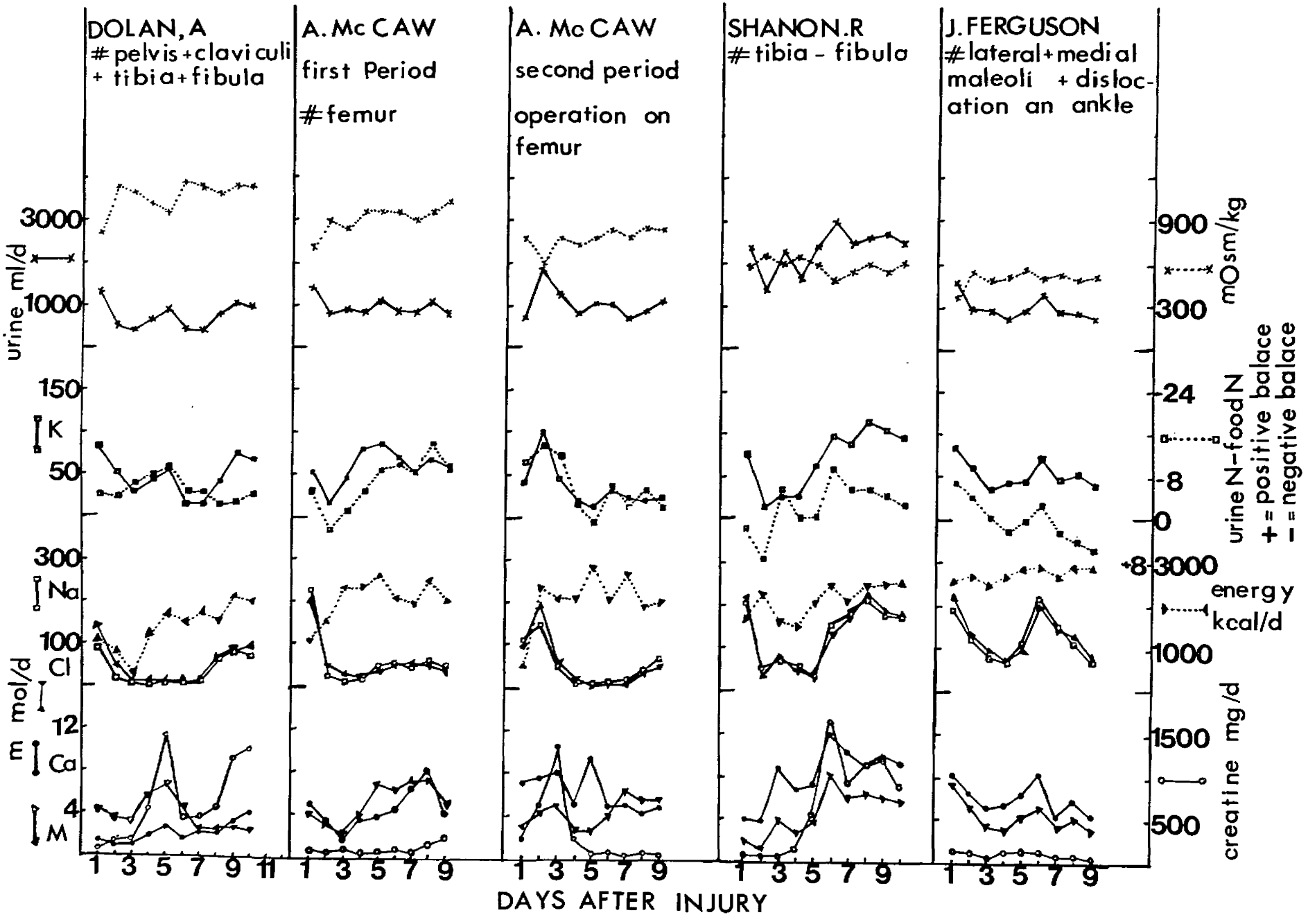
Sodium and chloride excretion.

Eight of the patients showed parallel sodium and chloride excretions during observation. But one patient (Jackson) excreted more chloride than sodium in the urine after injury. He showed a high chloride excretion of up to 400 mmol/day during the first three days after injury. Thereafter he showed parallel excretion of sodium and chloride for four days. Then he showed a high chloride excretion for the second time. This pattern was not found in eight other patients.

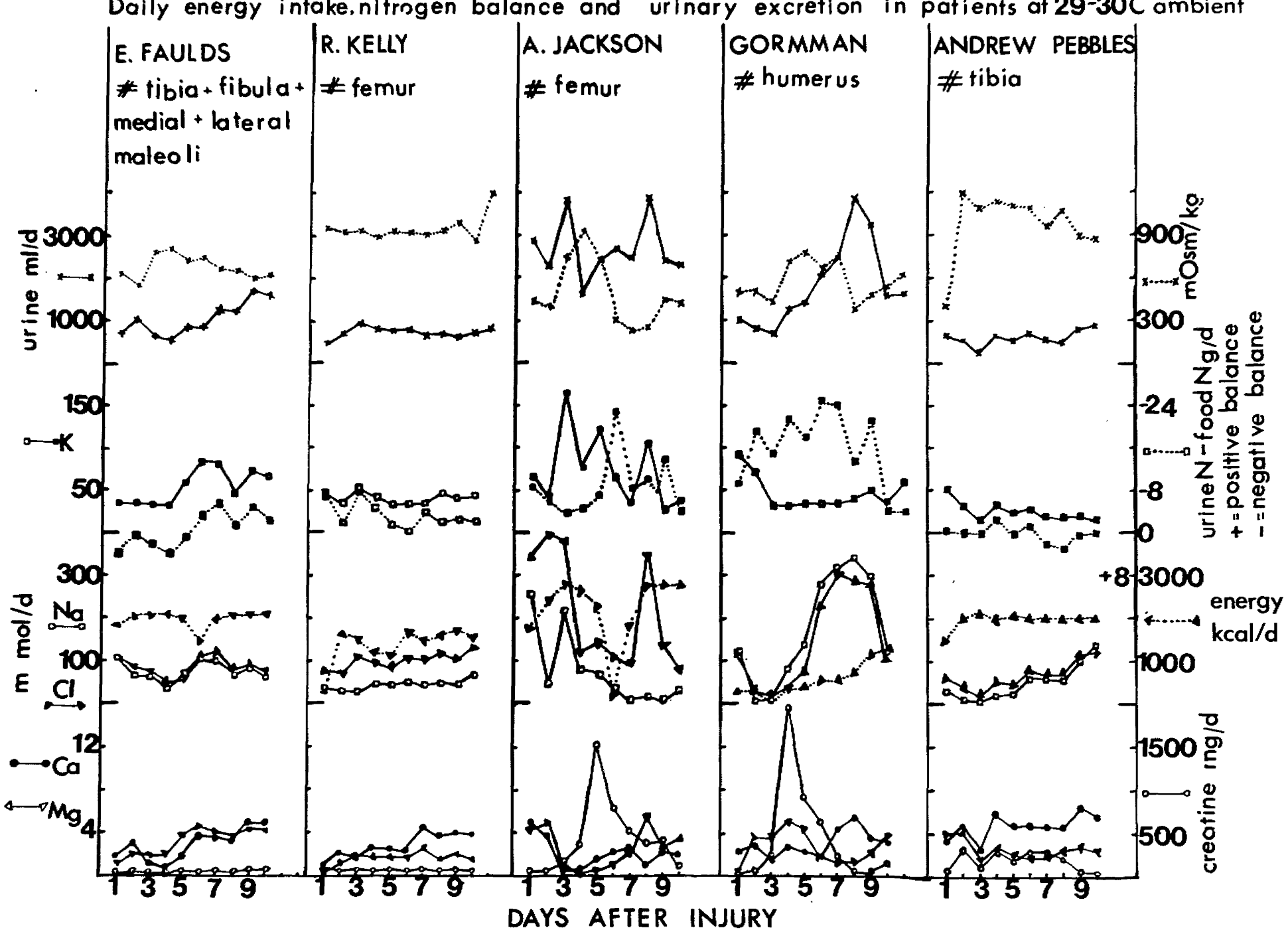
Sodium and chloride excretions were parallel in patient McCaw in the first day after injury and also in the second period after operation during observation.

F 7

Daily energy intake, nitrogen balance and urinary excretion in patients at 29-30C° ambient



F 8


Daily energy intake, nitrogen balance and urinary excretion in patients at 29-30C° ambient
E. FAULDS
tibia + fibula + medial + lateral maleoli
R. KELLY
femur
A. JACKSON
femur
GORMMAN
humerus
ANDREW PEBBLES
tibia
urine ml/d
3000
1000
150
K
50
300
Na
100
Cl
m mol/d
12
Ca
Mg
4
900
mOsm/kg
300
-24
-8
0
+8
urine N - food N g/d
+ = positive balance
- = negative balance
3000
energy
kcal/d
1000
1500
creatine mg/d
500
1 3 5 7 9
DAYS AFTER INJURY

Patients with long bone injury housed at 29-30°C ambient

Name	Age	Sex	Type of injury	Scale of injury
Jackson	17	male	Fracture of femur	5
Gorman	42	male	Fracture of humerus	4
Dolan	14	male	Fractures tibia, fibula, pelvis.	5
Shannon	39	male	Fractures tibia, fibula.	3½
McCaw Period 1	18	male	Fracture femur	3
McCaw Period 2	18	male	Operation on femur	3
Faulds	50	male	Fractures tibia, fibula	3
Kelly	65	male	Fracture femur	2½
Peebles	67	male	Fracture tibia	2
Ferguson	32	male	Fractures medial and lateral malleolus and dislocation of ankle.	2

Potassium excretion.

Excretion of potassium was parallel to the total nitrogen excretion in all of the patients during the observation period. Patient Jackson excreted high potassium in the third day after injury although he did not show the high negative balance of nitrogen which was expected during the same period. Then he showed parallel excretion during the rest of the period of observation. This exceptional behaviour was not observed in other patients.

Calcium and magnesium excretion.

It was observed that the calcium and magnesium excretion were parallel during the period of observation.

Four of the patients (Dolan, Faulds, Kelly and Gorman) showed low calcium and magnesium excretion during the first two days after injury. Calcium and magnesium excretions were low in Kelly at all times after injury. This exceptional behaviour was not seen in the other patients. It was also observed that the calcium and magnesium excretions in the case of McCaw differed during the first period and the second period of observation. He excreted high levels of calcium and magnesium between the seventh to eighth day after injury during the first period, but he showed high calcium excretion only in the first five days of the second period of observation.

24 hour urine volume.

Six of the patients (Dolan, McCaw, Ferguson, Faulds, Kelly and Peebles) showed oliguria for six to ten days after injury. Two of the

patients (Jackson and Shannon) did not show oliguria during the entire period of observation. One of the patients (Gorman) showed oliguria for the first three days after injury, then polyuria. He excreted up to 4000 ml of urine on the eighth day after injury which was not seen in other injured patients.

Osmolality.

Urine osmolality was high in the first few days after injury in these patients during observation.

Creatine excretion.

Four of the patients (Faulds, Kelly, Ferguson and McCaw) in the first period of observation excreted the normal amounts of creatine. Four others (Jackson, Gorman, Shannon and Dolan) did not excrete high levels of creatine in the urine during the first three days after injury but they showed high creatine excretion in the last few days of observation. The excretion of creatine differed in the case of McCaw between his first and second periods of observation. He did not show a high creatine excretion during the first nine days of observation, but the excretion of creatine was high after his operation in the second period.

It was observed that there was not any parallel relation between creatine excretion and the total nitrogen excretion in five patients (Faulds, Kelly, Peebles) and (McCaw in the first period of observation), and in Ferguson after injury. But in five other patients there was a slight relation between creatine and the total nitrogen excretion after injury.

Daily energy intake.

It was observed that an intake of around 2000 kcal energy intake together with a high environmental temperature reduced the total urinary nitrogen. But these two factors did not reduce the total nitrogen excretion in the case of McCaw during the fifth to ninth days of the first period of observation. It was also observed that the patient, McCaw, showed high total nitrogen excretion on the first, second and third days of the second period of observation, although he was on a high energy intake and at the higher environmental temperature.

Total nitrogen excretion.

Total nitrogen excretion was lower at the temperature of 30°C than in patients who were studied at low (normal) ambient environmental temperatures. The patients still showed a negative balance of nitrogen during the period of observation but Gorman, however, exhibited a high negative balance of nitrogen for nine days after injury. This high negative balance of nitrogen was not observed in the other patients at the high ambient temperature. The patient Jackson was exceptional in showing a high negative balance of nitrogen of up to 22 g/day on the sixth day after injury. This behaviour was not found in other patients at the high ambient temperature. It was also observed that the total nitrogen excretion by McCaw was different between periods. It was found that the high environmental temperature together with a sustained energy intake reduced the increment in total nitrogen excretion following injury and so saved body reserves.

Glycosuria and ketonuria.

Table 10 shows the results of tests for glycosuria and ketonuria in the patients.

Four of the patients did not show any glycosuria after injury.

Gorman showed glycosuria for six days after injury. Jackson showed it for only one day. This glycosuria disappeared for three days then it reappeared on a second and third occasion after injury. Glycosuria was not observed during the first and second periods of observation on the patient McCaw.

Glycosuria and ketonuria in patients with long bone injury housed at 29°-30°C ambient. (9 patients).

TABLE 10

Ambient	29-30°C												29-30°C											
	Glycosuria												Ketonuria											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Jackson	+	-	-	-	++	-	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Gorman	+++	++	++	+	+	++	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-
Dolan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Shannon	+	-	+	+	-	-	-	-	-				+	+	-	-	-	-	-	-	-	-	-	-
McCaw 1.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
McCaw 2.	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Faulds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kelly	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Peebles	-	+	+	+	+	-	-	-	-				+	+	-	-	-	-	-	-	-			
Ferguson	-	-	-	-	-	-	-	-	-				-	-	-	-	-	-	-	-	-			

1. First period
2. Second period

Summary for patients with long bone injury housed at 29-30°C ambient.

Oliguria was observed for several days, sodium and chloride excretion were parallel and there was retention of sodium and chloride after injury.

Potassium excretion followed the total nitrogen excretion. The patients were in negative balance nitrogen. Calcium and magnesium excretion were low in the first one or two days after injury. The calcium and magnesium excretion were in parallel, no relation was noted between the total nitrogen excretion and creatine. There was a high urine osmolality, glycosuria, ketonuria, essential and non-essential amino aciduria were observed. No changes were seen in serum sodium, chloride, potassium, calcium, magnesium and osmolality on the third, fifth and tenth days after injury. Oxygen consumption and resting metabolic energy expenditure were high at first. Axillary temperature was high in the first three days then decreased. The extra heat affected the temperature of the skin over the top of the big toe more than the other parts of the body, such as the skin over the biceps, abdomen or forehead, raising the big toe temperature by 8-9°C from its low level, but only increasing the other skin areas by some 0.5-1°C.

e) Urinary excretion of Na, Cl, K, Ca and Mg in patients with bone injury at 20°and 30°C ambient.

Ten patients with long bone injury at 20-22°C ambient and nine patients with long bone injury at 29-30°C ambient were observed for Na, Cl, K, Ca and Mg excretion after trauma. One of the patients (McCaw) was studied in two periods while he was in hospital.

Sodium excretion.

Table 11 shows the results of the daily mean values for Na excretion in both groups at low and high environmental temperature during the periods of observation. Statistical calculation showed ($P>0.05$), that there is no significant difference in the excretions of Na during the low and high ambient temperatures after injury.

Chloride excretion.

Table 12 shows the results of chloride excretion after injury. Statistical results showed ($P > 0.05$) that there is no significant difference in the excretion of chloride between the two groups of patients at the high and low environmental temperatures.

Potassium excretion.

Table 13 describes the excretion of potassium after injury. It was observed that there was a significant difference in the potassium excretion after injury between the groups ($0.05 > P > 0.02$), those at the higher temperature having in general a lower excretion than those at 20°C.

Mean (daily) urinary excretion of sodium in long bone injury housed at 20°C and 30°C ambient.

TABLE 11

	Na m mol/day											
Ambient	20-22°C											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12
Mean	105	91	64	60	71	95	99	106	129	93	125	130
S.D.	65	53	30	39	32	45	24	29	32	36	45	14
Ambient	29-30°C											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12
Mean	142	55	56	44	56	99	95	94	101	86	79	106
S.D.	76	46	65	28	40	86	24	69	75	50	30	31

$P > 0.05$ No significant difference

Mean(daily) urinary excretion of chloride in long bone injury housed at 20-30°C ambient

TABLE 12

	Cl m mol/day											
Ambient	20-22°C											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12
Mean	138	107	88	74	72	93	94	98	114	90	121	148
S.D.	87	57	56	46	30	39	30	33	27	33	41	43
Ambient	29-30°C											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12
Mean	161	112	88	55	63	105	110	143	106	110	91	119
S.D.	81	115	104	34	41	70	85	105	47	44	35	43

$P > 0.05$ No significant difference

Mean (daily) urinary excretion of potassium in long bone injury housed at 20-30°C ambient.

TABLE 13

	K m mol/day											
Ambient	20-22°C											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12
Mean	59	44	50	47	59	64	63	66	75	64	69	73
S.D.	19	15	20	17	24	21	21	23	21	24	14	14
Ambient	29-30°C											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12
Mean	63	52	51	45	60	56	47	56	51	59	57	69
S.D.	20	29	39	18	32	24	22	30	26	23	12	20

$0.05 > P > 0.02$ Significant difference

Mean (daily) urinary excretion of calcium in long bone injury housed at 20-30°C ambient.

TABLE 14

	Ca m mol/day											
Ambient	20-22°C											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12
Mean	2.5	2.9	3.6	4.0	3.7	3.3	3.8	3.5	5.0	3.9	4.6	5.6
S.D.	1.9	2.0	1.9	2.0	2.0	2.0	2.1	1.7	3.1	2.3	2.7	2.4
Ambient	29-30°C											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12
Mean	3.9	4.0	3.2	3.6	4.2	4.6	4.8	5.0	4.6	5.6	4.7	4.5
S.D.	2.3	1.9	2.9	2.1	2.8	3.2	2.3	2.1	2.2	2.5	1.9	2.8

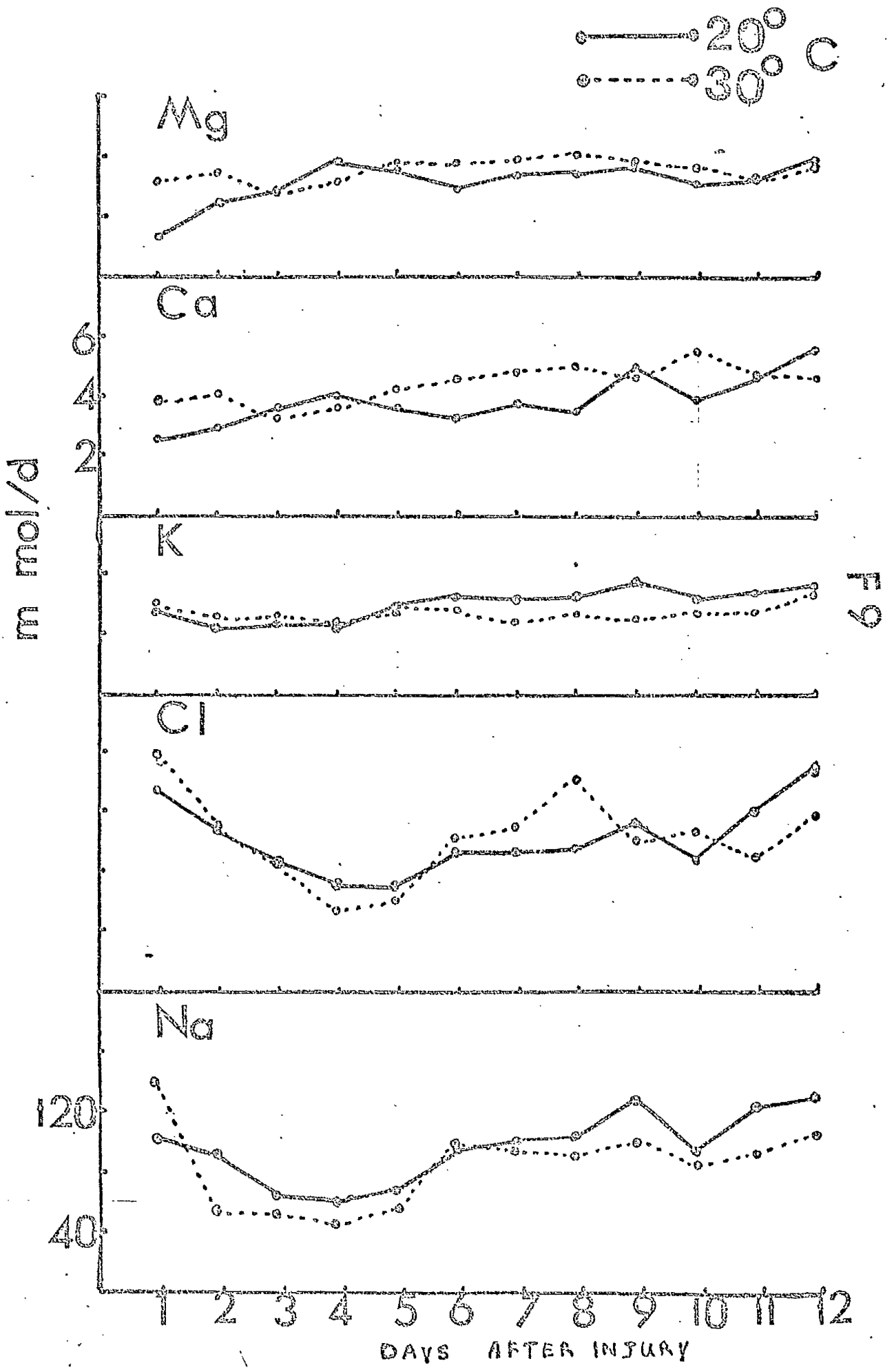
$P > 0.05$ No significant difference

Mean (daily) urinary excretion of magnesium in long bone injury housed at 20°C and 30°C ambient.

TABLE 15

	Mg m mol/day											
Ambient	20-22°C											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12
Mean	1.3	2.4	2.9	3.9	3.6	2.9	3.4	3.4	3.6	3.1	3.3	3.9
S.D.	0.4	2.0	1.6	1.9	2.2	1.8	1.5	1.2	1.6	1.5	1.3	0.6
Ambient	29-30°C											
Days after injury	1	2	3	4	5	6	7	8	9	10	11	12
Mean	3.2	3.5	2.8	3.1	3.8	3.8	3.9	4.1	3.8	3.6	3.2	3.7
S.D.	2.0	1.3	1.3	1.5	2.0	2.3	2.0	2.1	1.5	1.4	1.7	1.2

$P > 0.05$ No significant difference


20° C
30° C
Mg
Ca
K
Cl
Na
m mol/l
6
4
2
120
40
1 2 3 4 5 6 7 8 9 10 11 12
DAYS AFTER INJURY

It was observed that there is no significant difference in the excretion of Ca and Mg in these patients after injury.

Ca	$P > 0.05$	Table 14
Mg	$P > 0.05$	Table 15

Fig. 9 shows the mean urinary excretion of Na, Cl, K, Ca and Mg in patients with long bone injury (10 patients at 20-22°C and 9 patients at 30°C ambient).

It was observed that potassium excretion was lower in the patients in high environmental temperature between the sixth and twelfth days after injury than the patients who were in low ambient. There was an overall significant difference in potassium excretion between the two ambients after injury, that at 20°C being the higher. Although the Na, Cl, Ca and Mg excretion were at times different at the two temperatures there was no significant difference except perhaps in the case of calcium.

f) Serum electrolytes in patients with long bone injury housed at 20°C and 30°C ambient.

Ten patients nursed at normal ward temperature and 9 patients housed in the warm cubicles were observed for the level of Na, Cl, K, Ca, Mg and osmolality in their serum after injury. The samples were collected on the 3rd, 5th and 10th days after injury. Tables 16, 17, 18, 19, 20, 21 and Fig. 10, show the concentration of Na, Cl, K, Ca and Mg and osmolality in the serum on these days after injury.

It was observed that there was not much difference in the concentration of electrolytes of the patients nursed at these two ambient temperatures.

Mean of sodium concentration in serum m mol/l in patients with long bone injury (10 patients at 20°C and 10 patients at 30°C ambient).

S.D. Standard deviation S.E. Standard error

DAYS	3rd		5th		10th	
AMBIENT C°	20	30	20	30	20	30
MEAN	137	138	137	138	139	139
S.D	1.7	2.0	1.1	1.9	1.3	0.9
S.E	0.5	0.7	0.4	0.9	0.4	0.5

TABLE 16

Mean of chloride concentration in serum m mol/l in patients with long bone injury (10 patients at 20°C and 10 patients at 30°C ambient).

S.D. Standard deviation S.E. Standard error

DAYS	3rd		5th		10th	
AMBIENT C°	20	30	20	30	20	30
MEAN	99	100	101	100	99	102
S.D	1.2	1.7	1.7	2.0	1.5	1.9
S.E	0.5	0.9	0.5	0.5	0.2	0.7

TABLE 17

Mean of potassium concentration in serum m mol/l in patients with long bone injury (10 patients at 20°C and 10 patients at 30°C ambient).

S.D. Standard deviation S.E. Standard error

DAYS	3rd		5th		10th	
AMBIENT C°	20	30	20	30	20	30
MEAN	4.4	4.2	5.4	4.8	4.2	4.4
S.D	0.2	0.5	0.4	0.4	0.2	0.1
S.E	0.1	0.2	0.09	0.07	0.04	0.05

TABLE 18

Mean of calcium concentration in serum m mol/l in patients with long bone injury (10 patients at 20°C and 10 patients at 30°C ambient).

S.D. : Standard deviation S.E. Standard error

DAYS	3rd		5th		10th	
AMBIENT C°	20	30	20	30	20	30
MEAN	2.4	2.5	2.4	2.4	2.5	2.5
S.D	0.1	0.2	0.1	0.1	0.1	0.1
S.E	0.04	0.04	0.03	0.1	0.01	0.02

TABLE 19

Mean of magnesium concentration in serum m mol/l in patients with long bone injury (10 patients at 20°C and 10 patients at 30°C ambient).

S.D. Standard deviation S.E. Standard error

DAYS	3rd		5th		10th	
AMBIENT C°	20	30	20	30	20	30
MEAN	1.2	1.25	1.2	1.2	1.2	1.25
S.D	0.05	0.1	0.1	0.05	0.1	0.1
S.E	0.02	0.04	0.02	0.05	0.04	0.02

TABLE 20

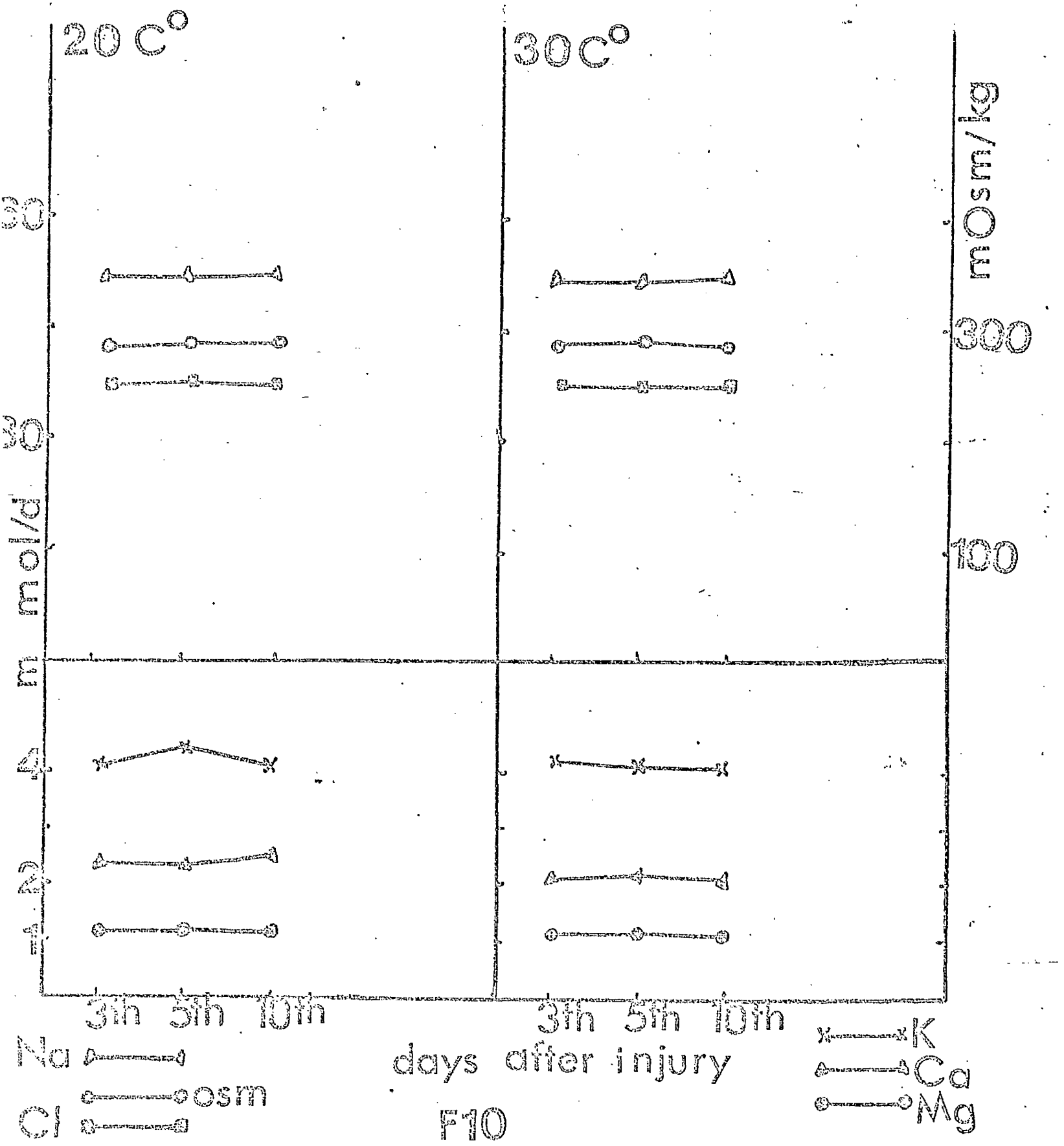
Mean of serum osmolality mOsm/kg in patients with long bone injury (10 patients at 20°C and 10 patients at 30°C ambient).

S.D. Standard deviation S.E. Standard error

DAYS	3rd		5th		10th	
AMBIENT C°	20	30	20	30	20	30
MEAN	284	288	286	290	286	289
S.D	2.8	4	2.6	5	2.4	2
S.E	0.9	1.6	0.8	1.2	1	1.2

TABLE 21

Mean of Na, Cl, K, Ca, Mg osmolality in serum in long bone injury of 10 patients at 20°C ambient and 10 patients at 30°C ambient.



F10

It was found that the potassium concentration was higher in the patients who were held at the lower ambient temperature than in those housed at 30°C on the fifth day after injury.

g) Total nitrogen excretion in patients with long bone injury housed at 20°C and 30°C ambient.

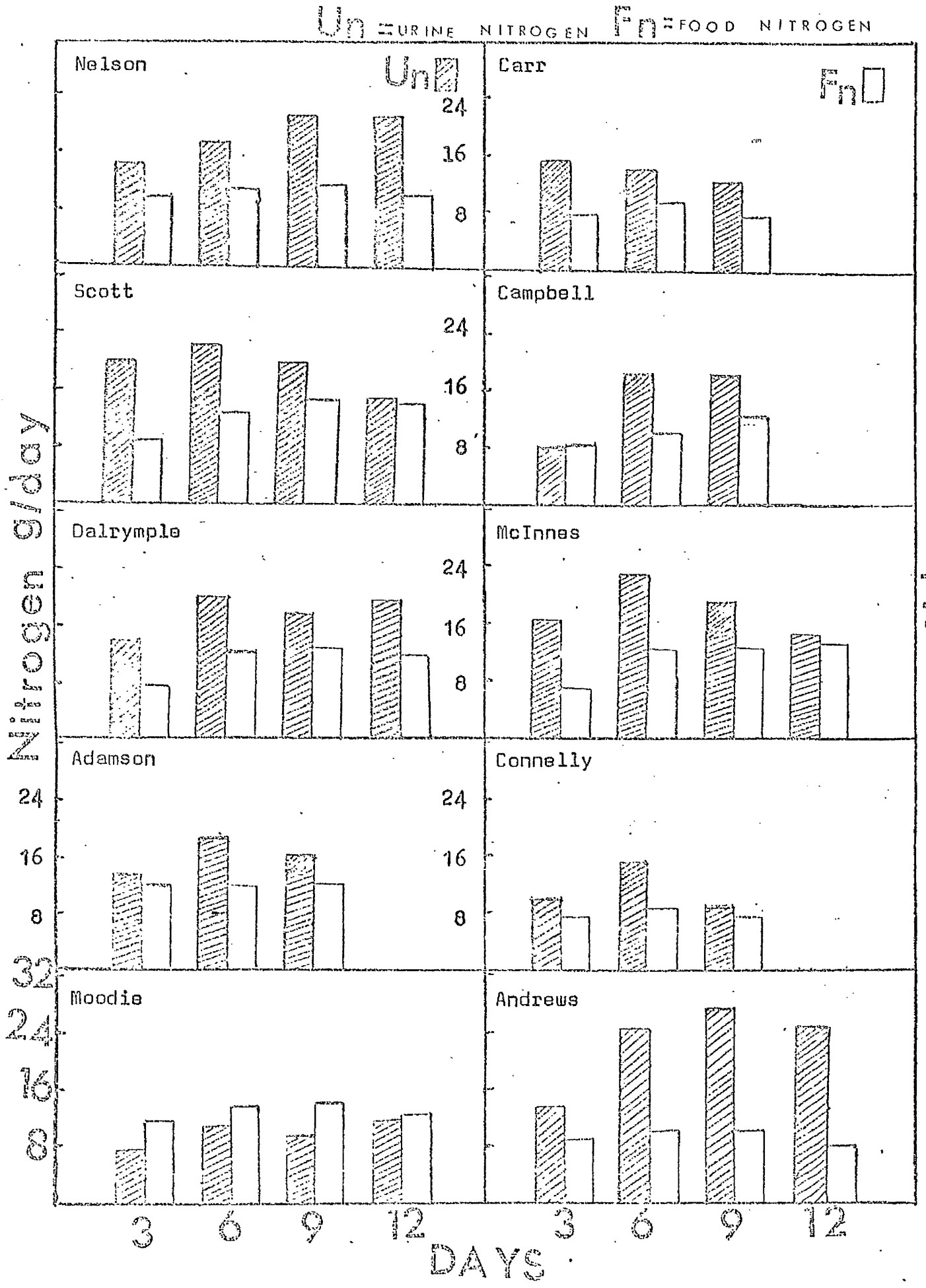
Fig. 11 shows the mean (3 day periods) of nitrogen balance in terms of urinary N - food N ($N_u - N_f$) in patients housed at 20-22°C after injury. It was observed that nine of the patients were in negative balance in this sense during the period of observation. One of the patients, however, did not exhibit a negative balance of nitrogen after injury.

Fig. 12 shows the mean (3 day periods) of nitrogen balance in patients who were held at 29-30°C ambient after injury. It was found that one of these, Andrew, was in positive balance of nitrogen, and eight of the others were in negative balance during the period. Gorman was in considerably greater negative balance in respect of nitrogen than the other patients after injury. It was also found that the nitrogen balance was different in the two periods McCaw was studied. The excretion of total nitrogen in his case was higher during the first three days of the second period than during the comparable period of the first study after injury.

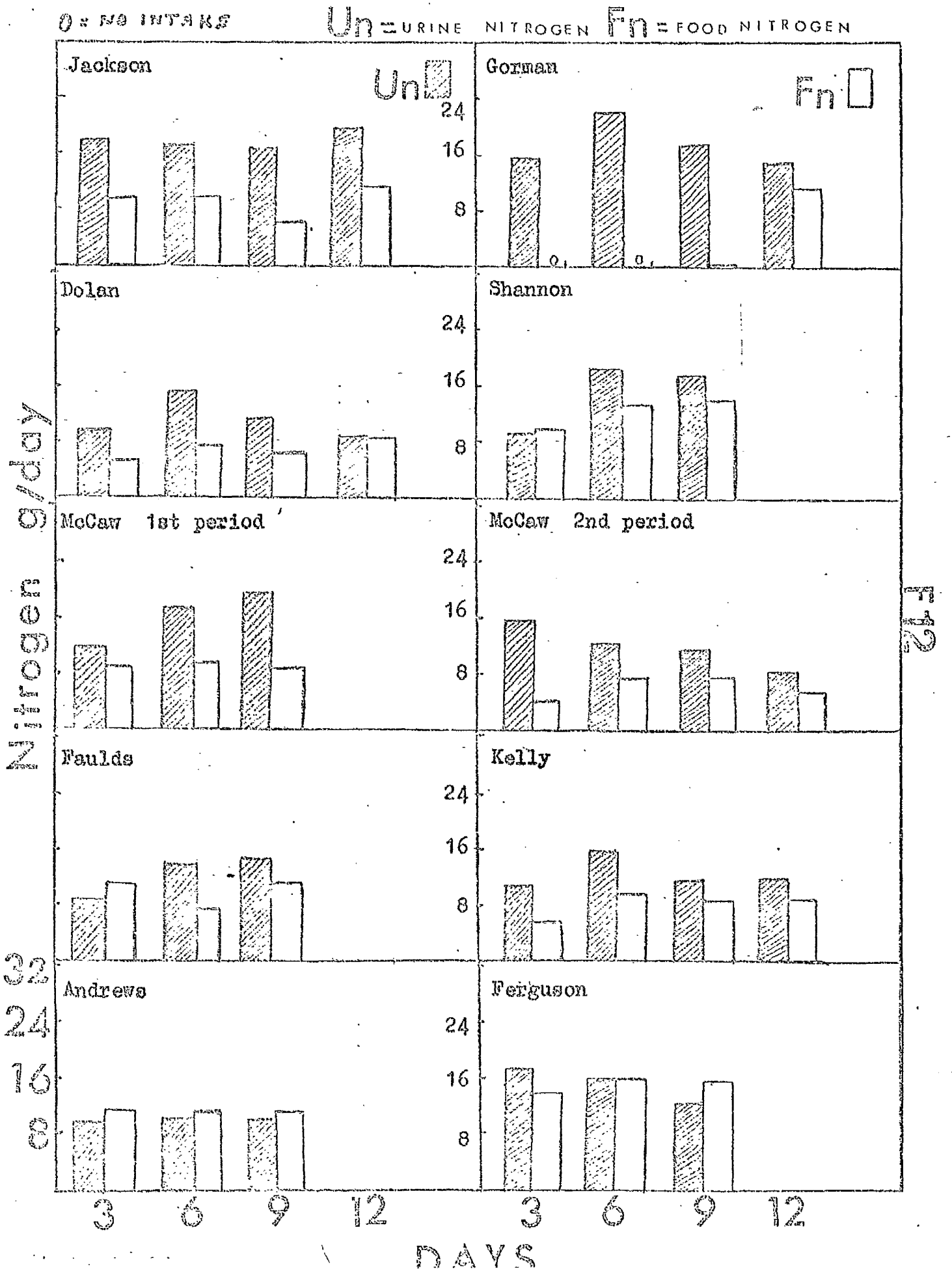
h) Amino acid excretion in urine.

Four patients with long bone injury were investigated for measurement of alpha amino acids. Two of the patients were housed at 20-22°C and two at 29-30°C ambient.

Mean of the food and urinary nitrogen (3 day periods) in patients with long bone injury housed at 20-22°C ambient.



Mean of food and urinary nitrogen (3 day periods) in patients with long bone injury housed at 29-30°C ambient.



Urinary excretion of non-essential amino acids in patients with long bone injury housed at 20°C and 30°C ambient after injury.

TABLE 22

Patients	Jackson	Peebles	Nelson	Connelly
Ambient	30°C		20°C	
Histidine	+++	T	T	+++
Ornithine	+	T	–	–
Alanine	+	T	T	+
Aspartic acid	T	–	+	+
Cystine	T	–	–	–
Glutamic acid	T	T	T	+
Hydroxyproline	+	–	T	–
Serine	+	+++	+++	+
Tyrosine	+	T	T	+
Cysteic acids	+++	T	T	+
Glycine	T	+++	+++	+++
Taurine	+	+	+	–
Glutamine	–	+++	+++	++
Sarcosine	–	T	T	–
Asparagine	–	T	T	–

+++ = Major + = Minor – = Negative

++ = Medium T = Trace

Urinary excretion of essential amino acids in urine in patients with long bone injury housed at 20°C and 30°C ambient after injury.

TABLE 23

Patients	Jackson	Peebles	Nelson	Connelly
Ambient	30°C		20°C	
Lysine	+++	-	-	+++
Phenylalanine	+	T	T	-
Tryptophan	-	+	-	-
Leucine	T	T	T	T
150 Leucine	T	T	T	T
Threonine	T	T	T	+
Methionine	-	-	-	-
Valine	-	T	T	-
Ornithine	-	-	-	-

+++ = major ++ = medium + = minor T = trace - = negative

It was evident that the excretion of amino acids in the urine followed the total nitrogen excretion during the period of observation. Both essential and non-essential amino acids were found in the urine after injury.

Table 22 shows the non-essential amino acids excretion in these four patients, and Table 23 shows the essential amino acids in the urine of the other group of patients. It was evident that the highest excretion of amino acids was in respect of the non-essential glycine, glutamine and serine. The other amino acids showed lower levels in the urine after injury. Methionine and ornithine were not excreted by such patients. Leucine and isoleucine, threonine and lysine were also present in small amount in the urine during the period of observation. The other essential amino acids such as phenylalanine and valine were only present in trace amounts in the urine after injury. Tryptophan was not found in the urine of the patients after injury.

1) Skin temperature.

Two groups of patients with long bone injury were investigated for changes of skin temperature. Nine of the patients housed at 20-22°C and nine others at 29-30°C ambient. The temperature was measured each day at 13.00 to 13.30 h over different but readily accessible parts, mainly anterior of the injured patient's body, namely, forehead, mastoid processes, biceps, axillae, abdomen, thighs and big toe. The room temperature was recorded at the same time during the periof of observation. It was evident that the mean of the big toe (3 day periods) was higher

in the patients who were in the high ambient environment than in the patients who were at low environmental temperatures in the first three days of observation.

Table 24 shows temperature of the skin over the big toe, the axillary, and ambient temperatures in both groups of the patients after injury. It was also evident that the big toe temperature decreased during the last few days after injury. Fig. 13 shows the relation of the big toe temperature to the axillary and ambient temperatures in both groups of the patients after injury.

It was found that the axillary temperature was high in both groups of patients for the first three days after injury. The temperature of the forehead and over the mastoids was higher than the biceps in both groups. It was found that the temperature of the injured limb was higher (1°-1.5°C) than the uninjured limb.

Effect of covering with a blanket or extra blanket.

It was found that one blanket raised the big toe temperature by (3°-5°C) in patients who were in the low ambient temperature, but the addition of a second blanket did not affect the same degree of rise as did one blanket.

One blanket did not increase the biceps, mastoid, axillary or forehead temperature by more than 1°-1.5°C during the period of observation.

The big toe temperature was not increased by a blanket in the

Mean of the big toe, amillary and ambient temperature in long bone injury in 9 patients at 20°C and 9 patients at 30°C ambient in corresponding periods.

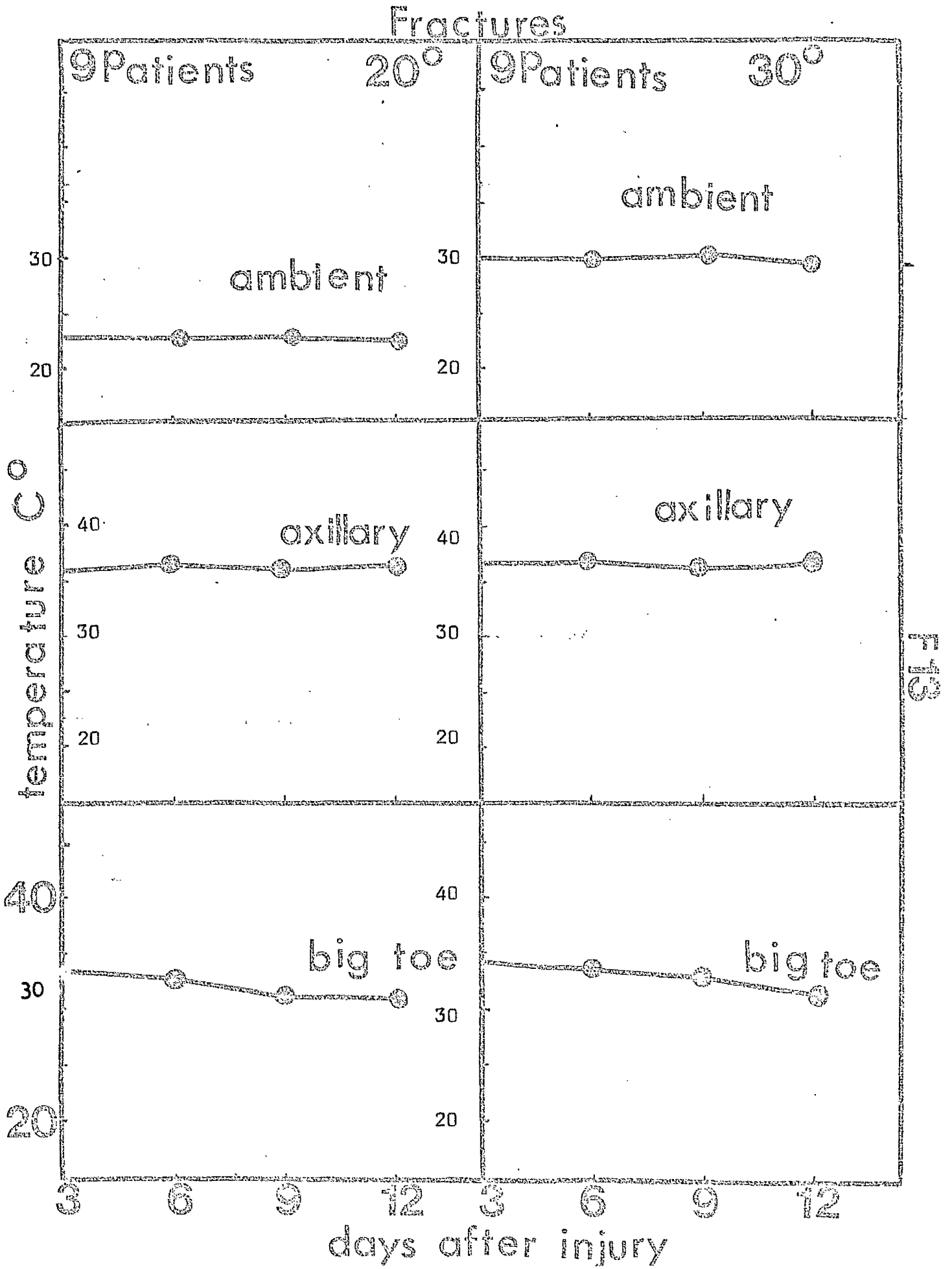
S.D. Standard deviation

TABLE 24

		BIG TOE				AXILLARY				AMBIENT			
DAYS		3	6	9	12	3	6	9	12	3	6	9	12
9. $P_{at\ 21-22^{\circ}C}$	mean	33.8	32.7	31.3	31.2	37.8	37.6	36.7	36.8	22.1	22.3	21.9	21.2
	S.D	1.2	2.3	1.9	2.3	0.6	0.7	0.3	0.6	1.0	0.9	1.4	1.2
9. $P_{at\ 30^{\circ}C}$	mean	34.4	34.0	33.5	33.1	37.1	36.8	36.8	37.1	30.6	29.5	29.7	30.1
	S.D	0.7	0.9	0.4	1.2	0.3	0.4	0.3	0.4	0.9	0.6	0.5	0.8

P = PATIENT

Mean (3 day periods) of the big toe, axillary and ambient temperature in long bone injury in patients housed at 20-30°C ambient.



patients who were at the high environmental temperature and who were already covered with one or two blankets.

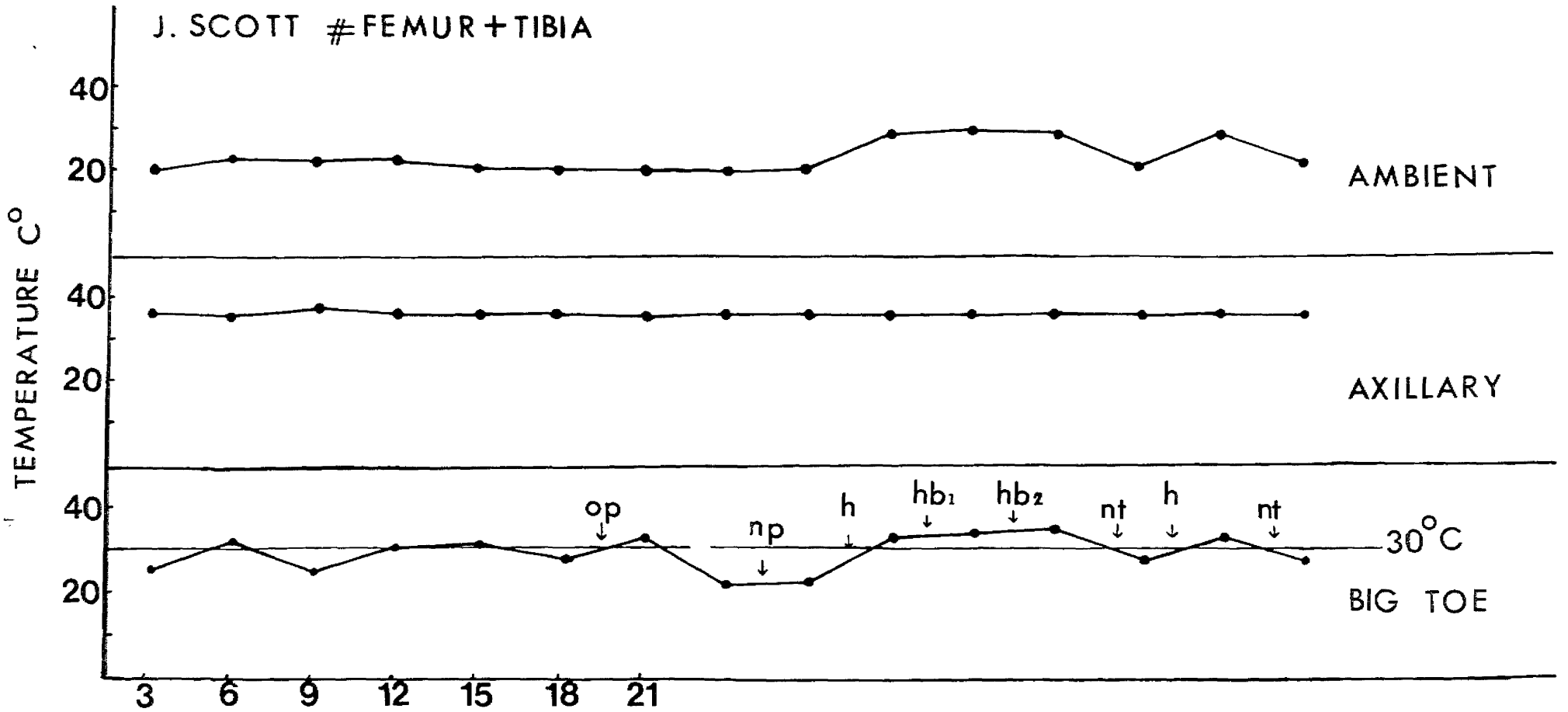
Effect of additional heat.

One patient (Scott) was observed closely for several days for the relation of the temperatures of the big toe, axilla and ambient temperature after injury and at the high environmental temperature. Thereafter he was for the last few days after injury housed at 20-22°C ambient.

Fig. 14 shows the relation of the big toe, axillary and ambient temperatures of the patient. It was evident that when the patient was housed at ward temperature the big toe also had a low temperature. But the big toe temperature was still 3°C higher than the ambient temperature. When the temperature of the ambient was raised to 29.5°C it was found that the big toe temperature was raised to 34°C, a rise of 7-8°C, during the period of observation. When the patient was covered with one or two blankets the big toe temperature changed by only 0.5°C compared to normal environmental temperature. When the experiment was repeated by the same procedure it was found that identical results were obtained.

It was evident that the extra heat raised the big toe temperature by 7° to 8°C from the low temperature. But the other parts of the body were relatively unaffected. It was obvious the big toe temperature was more sensitive than the other parts of the body after injury.

RELATION BETWEEN BIG TOE AND AMBIENT TEMPERATURE (MEAN 3 DAY PERIODS)



op = operation
np = new plaster
h = heat
nt = normal temperature
b1 = one blanket
b2 = two blanket

j) Oxygen consumption and resting metabolic energy expenditure (R.M.E.) in patients at low and high ambient temperature.

Eight patients with long bone injury were investigated for oxygen consumption and R.M.E. after injury.

Four of the patients (Moodie, Dalrymple, Scott and Carr) were at 20-22°C ambient and four others (Ferguson, McCaw, Faulds and Shannon) were at the high environmental temperature of 29-30°C during the period of observation. McCaw, as has already been mentioned, was studied for two periods and his oxygen consumption and RME. determined. The patients were fasted from midnight till the time of measuring the oxygen consumption and were rehearsed several times with the apparatus. It was realised that oxygen consumption was relatively higher in both groups of patients during the first few days than the last few days during the period of observation. Table 25 shows the oxygen consumption in ml/min during all the days of observation. This pattern was not observed in the other patients. Shannon showed a high oxygen consumption on the first day after injury.

In the case of McCaw, who was studied for two periods, it was observed that there was not much difference between the first and second periods. Table 26 shows the RME in both groups of patients after injury. It was naturally found that the RME had a close relation to the oxygen consumption per minute after injury.

Oxygen consumption and R.M.E. during fasting and one hour after lunch.

Two patients with long bone injury were studied for oxygen consumption

Oxygen consumption in patients with long bone injury housed at 20°C and 30°C ambient.

TABLE 25

		Oxygen consumption ml/minute									
Days after injury		1	2	3	4	5	6	7	8	9	10
20°C ambient	Moodie	–	262	–	–	–	–	237	235	245	240
	Dalrymple	354	350	–	–	305	–	–	251	–	–
	Scott	–	–	260	–	–	251	–	–	–	–
	Carr	–	–	303	–	–	401	–	–	–	340
30°C ambient	Ferguson	–	407	–	–	–	–	376	327	–	–
	McCaw 1.	–	–	–	331	–	–	313	–	–	329
	McCaw 2.	–	320	319	–	–	280	–	304	–	–
	Faulds	352	311	–	–	367	261	–	–	318	–
	Shannon	314	–	277	–	250	–	245	–	–	228

1. First period

2. Second period

Resting Metabolic Energy expenditure (R.M.E.) in patients with long bone injury housed at 20°C and 30°C ambient.

TABLE 26

		R.M.E. kcal/kg/hour									
Days after injury		1	2	3	4	5	6	7	8	9	10
20°C ambient	Moodie	-	1.5	-	-	-	-	1.4	1.4	1.4	1.4
	Dalrymple	1.6	1.6	-	-	1.4	-	-	1.1	-	-
	Scott	-	-	1.2	-	-	1.2	-	-	-	-
	Carr	-	-	1.5	-	-	2	-	-	-	1.7
30°C ambient	Ferguson	-	1.7	-	-	-	-	1.5	1.3	-	-
	McCaw 1.	-	-	-	1.7	-	-	1.6	-	-	1.7
	McCaw 2.	-	1.7	1.7	-	-	1.5	-	1.6	-	-
	Faulds	1.8	1.6	-	-	1.9	1.4	-	-	1.6	-
	Shannon	2	-	1.7	-	1.6	-	1.5	-	-	1.4

1. First period
2. Second period

and RME at two different times on the same day. One of the patients, Roden, was in low ambient temperature and the other was in the high environmental temperature. The patients were fasted from midnight until the first of the two times of observation which were carried out on the same day the second test, the second test being made onr hour after lunch.

Table 27 shows the results of this experiment during observation. It was evident that the oxygen consumption was higher in the patient who was in the low ambient temperature than the patient housed at 29-30°C. It was also observed that the oxygen consumption was higher during the fasting time than one hour after lunch in the patient in low ambient environmental temperature. But the patient who was in the high environmental temperature exhibited a rather higher oxygen consumption after lunch than after fasting. The data are too sparse to draw conclusions.

Oxygen consumption and Resting metabolic energy expenditure (R.M.E) in patients with long bone injury housed at 20°C and 30°C ambient, fasting and one hour after lunch.

TABLE 27

	Oxygen consumption ml/minute		R.M.E. kcal/kg/hour		
Patients	Fasting	After meal	Fasting	After meal	Ambient
Roden	380	327	1.9	1.6	20°C
Adams	279	296	1.1	1.2	30°C

VI. GENERAL DISCUSSION

The cause of the polyuria which has been found after both the severe and mild head injuries may be partly due to damage to the pituitary gland resulting in a low secretion of ADH and partly as a result of mannitol therapy because of its diuretic action. Damage to the pituitary gland results in polyuria, low urine osmolality and a high free water clearance, 10-16 ml e.g., as in diabetes insipidus. But in the patients who showed polyuria there then followed oliguria and there was frequently recurrent polyuria and oliguria. Nevertheless the patients studied showed high urine osmolality because of a high urea excretion and low free water clearance.

Mannitol therapy results in diuresis and because of the diuretic there is reduced blood viscosity and vascular resistance and an increase in renal flow (Rhiroze, 1971). However, the amount of mannitol which has been taken by these patients cannot be responsible for the degree of polyuria since it was also noted that the patients also showed polyuria without mannitol therapy. As previously suggested there may be damage to the pituitary gland and that mannitol therapy, together with other factors which are not clear, are the cause of the polyuria.

The cause of the oliguria which has been observed in these patients with long bone injury may be due to the secretion of adrenocortical hormones (Hardy, 1950), especially aldosterone because of the stimulation of the adrenal gland by injury, or it may be due in part to increase in insensible water loss because of the increased metabolic rate which

frequently occurs after the 'ebb' phase is over or may be the ADH takes part for this oliguria. It may also be due in part to the formation of an exudate or extravasation of blood into the injured area. Oliguria has also been reported in some cases during the 24 hours following receipt of injury (Cuthbertson, 1932), Cooper, Iob and Cullen (1949), and Moyer et al., (1949).

Sodium and chloride excretion were parallel in all the patients. The results agree with those of Moore and Ball (1952) who examined different kinds of injury. But four of the patients with severe head injury showed exception to this general rule. The cause may well be transfusion of blood providing extra sodium from sodium citrate, other possibilities are damage to the brain or from induced diuretic action, or as a result of acidosis or alkalosis due to a low excretion of ACTH because of the damage to the pituitary gland.

The cause of the retention of sodium and chloride may be the result of an increased secretion of the adrenal gland, or the retention of water together with Na and Cl in the injured area (Upjohn, 1958; Wilkinson, 1958).

The reason why the sodium and chloride excretions were not significantly different in the patients held at the high and low ambient temperatures may be due to the fact that the high environmental temperature is not of such an order as would induce marked changes in urinary excretion through extra renal loss in sweat. Although more sodium and chloride would be likely to be excreted in the sweat of those at the high environmental ambient it may be that the factors inducing retention of

sodium and chloride are changed in some fashion in those patients housed in the high environmental temperature.

The cause of the variation in potassium excretion from day to day in the patients within the severe and mild head injuries groups may be damage to the pituitary gland with a low secretion of ACTH. Other agents such as mannitol therapy, intravenous therapy with potassium, or infusion of 5% glucose and isotonic solutions, acidosis, alkalosis, polyuria, damage to the kidney, the severity of injury, or it may be that there are other factors which we do not understand.

The reason for potassium excretion being different in the patients and low and high environmental temperature is the fact that at the high environmental temperature there is decreased breakdown of the tissue reserves and perhaps also an effect on the membrane of the cells which decreases the movement of potassium from the intracellular to extracellular space. The potassium excretion followed the total nitrogen output as had been previously observed by Cuthbertson (1942), Wilkinson, et al., (1950) and Wilkinson (1961). The results in general agreed with the finding of these authors, only one patient's behaviour being exceptional.

A high excretion of over 4.5 m mol/day shows a disturbance of calcium metabolism in the body. The severe head injury cases showed low calcium and magnesium excretion during the period of observation. The cause of this may be the low intake of calcium and magnesium by these patients, or due to damage of the brain and there are other

factors affecting the conservation of calcium and magnesium in the body. Only one patient showed a high calcium and magnesium excretion. The cause of this may be the dietary intake of calcium and magnesium before injury. When the calcium and magnesium ratio in urine is low it may be due to the extra potassium released from the breakdown of the tissues, or because of a decreased secretion of ACTH (Haynes et al., 1952) or due to an increase in magnesium excretion caused by the ingestion of glucose.

The reason for the low excretion of calcium and magnesium in mild head injury and bone injury cases for one or two days after injury may be simply the low intake of calcium and magnesium.

Dalrymple and McCaw (second period observation) showed a high calcium and magnesium excretion. The reason for this may be that the Charnley arthroplasty in the former and the application of Küntscher nail into the latter were agents which released calcium and magnesium from the bone, although this was not the case in the patient Connelly who also had the same Charnley operation. This patient showed oligura after the operation, but Dalrymple did not. The volume of urine excreted by the latter might have caused an increase of calcium and magnesium excretion. The excretion of calcium and magnesium was slightly higher in the patients at the high environmental temperature. It may be that this causes an increase in the reabsorption of calcium and magnesium by the intestinal wall, or that the extra heat has an effect on the parathyroid glands causing an increased parathormone secretion, or it may be that the temperature decreases the reabsorption of calcium

and magnesium in the kidney. Little work has been done on the calcium and magnesium excretion of patients with bone injuries held in a high environmental temperature.

A statistical analysis revealed no significant difference in calcium and magnesium excretion for patients at the two ambient temperatures. Walker et al., (1968) suggested that urinary magnesium follows the total urinary nitrogen excretion after injury. In the present investigation no such relationship was found. This may be peculiar to the nature of the injuries studied, varying from one type to another. Walker et al., (1968) also states that in cases studied magnesium excretion increased during the second to fifth days after injury. The present study showed that magnesium excretion was low during the first to second days after injury but there was not much difference in the rest of the period.

Patients Dalrymple and McCaw had a high magnesium excretion for several days after injury and the possible reason for this has already been discussed. That magnesium excretion depends upon the type of injury and the dietary history of the patient before injury is apparent from the results obtained.

Dietrick et al., (1969) studied magnesium excretion in fasting subjects and found that it was related to total nitrogen excretion. But the circumstances of the present observation are considerably different because the magnesium excretion in our patients is partly derived from the breakdown of both soft and bony tissue, and the patients intake also plays a part. The results of Dietrick et al.,(1969)

were on subjects who had fasted and had thus zero intake of magnesium, and also the subjects were not injured.

Robert et al., (1970) concluded that urinary magnesium changes post-operatively and returns later to normal and that it is also related to the type of injury. These last observations agree with the results presented in this thesis.

Walker et al.,(1968) pointed out that calcium excretion falls initially along with sodium. The present investigation did not show any relationship of calcium to sodium excretion. The reason for this might be the types of injury and their severity, or age of the patient, or level of dietary intake of calcium. Dietrick et al., (1969) stated that there is no relation between calcium and total nitrogen excretion in fasting subjects. Our results also did not show any such relationship.

It was observed that the excretion of ammonium was high after trauma. The reason for this may lie in the disturbance of protein metabolism accompanying an increased catabolic rate or decreased anabolic rate, or there may be impairment in transamination of amino acids, or an increased formation of ammonium in the kidneys or even that liver anoxia may prevent the normal conversion to urea of the ammonium released by protein catabolism. This additional ammonium which is excreted in the urine, or the ammonium which may be derived from the subsequent breakdown of urea in the urine, through microbiological activity if the urine preservative is not adequate, may lead to a loss of nitrogen from the urine on storage, and in any event this changes the distribution of the total nitrogen in

the urine. More research is needed to find the exact cause of ammonium excretion after injury.

Urine osmolality was high in all patients after injury. The cause of the high urine osmolality may be the high excretion of urea, ammonium, creatine, creatinine, glucose, phosphate, sulphate, amino acids, ketone bodies and potassium. The increased excretion of urea and ammonium ion has the greatest effect on urine osmolality.

Glycosuria may occur in some cases after injury. The cause of the glycosuria may be the damage to the kidney tubules or is an expression of the gluconeogenesis resulting from the severity of the injury, or may be the result of the hyperglycaemia which occurs after injury due to the mobilization of glycogen to glucose caused by the secretion of catecholamines from the adrenal glands. But it was found that the patients showed glycosuria when the blood sugar was normal for a period of several days. Some of the patients had a second period of glycosuria, suggesting that the renal threshold was also lowered because of temporary renal impairment. The cause of the glycosuria may be insufficient secretion of insulin to allow complete reabsorption of glucose from the renal tubular or that there is damage to that part of the tubules of the kidney which are responsible for the renal threshold of glucose.

The cause of the ketonuria may be an impairment in fat metabolism (Cairnie, 1970). Ketonuria was not seen in all of the patients, probably because it is largely dependent upon the severity of the injury as well as on a disturbance of fat metabolism.

Creatine and creatinine excretion were high in some of the patients after injury. This may arise from the catabolism of muscle tissue or disuse atrophy of muscle, or actual physical damage to muscle. Some patients did not show high creatine excretion even although they were in negative nitrogen balance after their injury or operation. This difference in behaviour is difficult to explain. Sometimes creatine excretion rose immediately after operation, e.g., the patients Dalrymple and McCaw (second period of observation) showed a high creatine excretion, but the patient Connelly who also had had just as severe an operation as Dalrymple but did not show a high creatine excretion at any time.

Dalrymple and McCaw showed a high zinc excretion, but Connelly did not, thus these substances are behaving similarly. Dalrymple showed polyuria, but Connelly did not. The cause of the low excretions of zinc and creatine in Connelly may be related to the degree of urine formation or other factors which are not understood.

Cuthbertson and Tompsett (1935) pointed out that the maximal urinary excretion of nitrogen following the primary injury occurred on average on the sixth day after injury. The present investigation showed a variable pattern of maximum nitrogen excretion and this varied from one patient to the other and is due partly to the differing degrees of injury, the intake of protein, the energy intake and the environmental conditions.

One patient (Moodie) did not show a negative balance of nitrogen although he was in a low ambient temperature during observation. The

cause of this may be that the injury, a fracture of the malleolus, with dislocation of one ankle, did not appear to affect his protein metabolism. Abbott and Albertson (1963); Dudley (1950, 1968) reported that the cause of negative balance of nitrogen may be the low intake of protein in the diet after injury. Such a cause may be a considerable contributory factor in the early days, as for example the patient Gorman, but all the other patients showed a negative balance of nitrogen despite an apparently adequate intake of protein. Moore and Ball (1952), Clark (1952) and Clark (1967) pointed out that a second injury causes less protein disturbance than the first, even though the second may be more severe. Our results agree with this for one patient, McCaw, who was studied for two periods.

The high environmental temperature of 30°C reduces the increased heat production, and the protein catabolic response, resulting from fracture of one or more long bones in the rat and in man (Campbell and Cuthbertson, 1967), Cuthbertson, Smith and Tilstone, (1968). It also enhances the rate of wound healing in the rat (Cuthbertson and Tilstone, 1967; Caldwell, 1962) and in patients with severe burns (Barr, Birke and Liljedahl, 1968). This present investigation agrees with these authors findings with regard to protein catabolism. We observed that a high environmental temperature is one factor which can change the protein response, but the energy intake is also a very important one in reducing the catabolism of protein after injury. The effect of the high environmental temperature may be to reduce the obligatory increment

of heat production which arises from evaporation of water from a burned area, but such an explanation does not fit the situation when long bone injuries are considered for these generally do not exhibit evaporation from the wound area.

The results of Nardi (1954) in severely burned patients showed the presence of both essential and non-essential amino acids in the urine as a consequence of injury. Similar results were found in the present series for bone injuries. The cause of the essential amino aciduria may be that the body cannot use the amino acids for synthesis of protein at the time, or that the amino acids which have been found in the urine are released, from the breakdown of protein, as the result of injury, or that there is a decrease in the reabsorption of amino acids in the tubules of the kidney. The cause of the high excretion of glycine may be that this amino acid is more readily filtered by the glomeruli because of its low molecular weight, or that there may be a specific disturbance in the body which causes the excretion of urine with a high concentration of glycine, glutamic acid and serine rather than other amino acids.

Wilson et al., (1938) pointed out the hyponatraemia of burned patients. This present investigation also showed hyponatraemia, hypochloraemia and hypo-osmolality in cases of mild head injury during the first few days after injury, but there was no hyponatraemia or hypochloraemia or hypo-osmolality after long bone injury at 20°C or 30°C. Severe head injury showed hypernatraemia, hyperchloraemia and hyperosmolality

in the terminal period though there was not much change at first.

The cause of the hyponatraemia, hypochloraemia and hypo-osmolality may be the intravenous therapy or the retention of water or damage to kidney or brain. Hypernatraemia, hyperchloraemia and hyperosmolality in severe head injury may be due to renal failure causing a rise in sodium, chloride, and osmolality. The reason for the absence of changes in sodium chloride and osmolality in the serum of the fracture patients who were on either the low or high ambient temperature may be due to the fact that these patients in general received little in the way of intravenous therapy and that additionally, the high environmental temperature reduced the retention of water. The reason that potassium concentration was slightly higher on the fifth day after injury in patients who were in the normal environmental temperature, compared to the patients who were in high environmental temperature is perhaps caused by the extra potassium released from the breakdown of tissue. The reason that there was no change in the calcium and magnesium concentrations may be that these cations change more slowly in the extracellular space than does sodium, chloride or potassium. It was also observed that there was no significant difference in urinary sodium, chloride, calcium and magnesium excretions at the high and low ambient temperatures, but there was a significant difference in urinary potassium excretion.

Acidosis and alkalosis either respiratory or metabolic arising in mild and severe head injury may be due to damage to the brain, through increased intracranial pressure arising from haematoma, or to

aspiration of the gastric contents, or to aldosterone secretion, diuretic therapy, chest injury, renal failure, or through diminished respiratory function, or as a result of mechanical hyperventilation.

The results of this investigation did not show much difference in oxygen consumption and the resting metabolic energy expenditure (RME) between the low ambient and high ambient environmental temperatures. The causes of this may be the varying severity of the injuries or that the patients were not familiar with the test or that the environmental temperature and noise of the clinical hot rooms accounted for this lack of difference. The experiments were not numerous enough and the results too scattered to be able to show statistically a difference in oxygen consumption and RME between the high and low ambient temperatures. It was also observed that oxygen consumption and RME were not much different when measured after fasting overnight, and when measured one hour after lunch, in these injured patients, but these last observations were too few in number.

Normally the oxygen consumption and RME are increased by emotion, stress or food intake. But in the case of injured patients there are many factors such as pain, with accompanying high secretion of the catecholamines, the fact of hospitalisation, the high environmental temperature, etc., which can all affect the oxygen consumption and RME. It needs more work on many more patients to find out what the effect of food is on the oxygen consumption and RME after injury. More is known about normal subjects.

There is traumatic fever for a few days after injury (Cuthbertson, 1932). In this investigation the skin temperature was measured at the different parts of the patients skin surface when housed at low and high ambient temperatures. The results agree with those of Cuthbertson (1932). The reason that the skin temperature was higher in the early days rather than the last few days of the 10-12 day periods may be due to the release of more heat from the body in the early period reflecting the early traumatic fever. The cause of the slightly higher temperature in the injured limb compared to the uninjured limb may be due to the extra bandages, plaster, or exudate formation of the limb or to increased catabolism arising from damage of the tissue, or it may be that the injured limb releases more heat from the surface than occurs from the uninjured limb.

VII. SUMMARY

Urinary excretion changes

Ten patients with severe head injury, eight patients with mild head injury, and ten patients with long bone injury were hospitalised at 20-22°C ambient and for comparison with the last a group of nine patients with long bone injury were housed in cubicle at 29-30°C ambient, one of the patients being studied over two period when in hospital. The total daily urinary excretion was investigated in the head injuries to determine what changes took place in volume, osmolality, Na, Cl, K, Ca and Mg excretion after injury. The presence of glycosuria and ketonuria were also detected in the samples during observation. Creatinine excretion was also measured in the patients with mild and severe head injury. Ammonia excretion was also measured in the patients with mild head injury.

Total nitrogen and creatine excretion and total nitrogen intake were also estimated in patients with long bone injury housed at 20-22°C and patients at 29-30°C.

1) Polyuria was found in patients with both mild and severe head injury, but the urine volume was lower in those with mild head injury. It was also observed that in patients with severe head injuries a second and third period of polyuria or oliguria could occur, but this alteration did not happen with mild head injuries.

Oliguria was generally observed in bone injuries for one or two

days, but the excretion of urine was higher in the patients who were at the lower environmental temperature.

2) Sodium and chloride excretions were parallel in the cases of bone injury but in severe head injury six of the patients did not show this relationship and likewise two patients in the mild head injury group were also exceptional. There was retention and then depletion of sodium and chloride in both the severe and mild head injury groups. The patients with long bone injury at 20-22°C and at 29-30°C ambient showed early retention of sodium and chloride (for one or two days after injury). The statistical calculations showed that there was no significant difference in sodium and chloride excretions at the two different ambient temperatures.

$$P > 0.05 \quad \text{for} \quad \text{sodium}$$

$$P > 0.05 \quad \text{for} \quad \text{chloride}$$

3) Potassium excretion in the patients with severe and mild head injury differed from one patient to another and showed variation from one day to another.

Potassium excretion in both groups of long bone injury generally followed the total nitrogen excretion after injury. Statistically there is a significant difference in potassium excretion in the patients housed at low and high ambient temperature.

$$0.05 > P > 0.02$$

4) Calcium and magnesium excretion generally were parallel in all

groups of patients. Calcium and magnesium excretion was very low in the patients with severe head injury. The patients who had mild head injury also showed low calcium and magnesium excretion for the first one or two days after injury only.

The calcium and magnesium excretion were low in both groups of patients with long bone injury during the first one or two days after injury. The patients who were at the high environmental temperature showed slightly higher calcium and magnesium excretions than did the patients in low ambient temperature. But statistical calculation did not show any significant difference between the low and high ambient temperature groups.

$P > 0.05$ for calcium

$P > 0.05$ for magnesium

5) Ammonia excretion was high after injury, but this varied from one day to the other and from one patient to another (ammonia excretion was observed only in mild head injury).

6) Urine osmolality was high in all four groups of patients after injury.

7) Glycosuria and ketonuria were present in the four groups of patients for one or two days after injury, although one or two exceptional patients did not show this.

8) Creatinine excretion was high, and this was estimated in mild and severe head injury.

9) Creatine excretion was lower in the first few days than in the last few days of the 10-12 day period after injury. Most of the patients showed high creatine excretion, but three of the patients did not, although two of the patients were in negative nitrogen balance at the time.

Generally the creatine excretion rose immediately after surgery, but one of the patients who had a severe orthopaedic operation (Charnley arthroplasty) did not show a high creatine excretion. It was found that creatine did not follow the total nitrogen excretion in these patients. The creatine excretion varied from one patient to another.

10) Total nitrogen excretion was higher in the patients in the lower ambient environmental temperature compared to the patients at the high ambient environmental temperature. It was also found that the total nitrogen excretion was high between the fourth to ninth days after injury. All the patients showed a negative balance of nitrogen (except one).

The total nitrogen excretion confirmed previous work indicating that at high environmental temperature there was a reduced excretion of total nitrogen. The catabolic phase was thus modified agreeing with the observations from this laboratory (Cuthbertson, Smith and Tilstone, 1968; 1971). (In press).

11) Amino acid excretion showed that both the essential and non-essential amino acids were present in the urine of patients with bone injuries. It confirms previous work (Nardi, 1954) in burned patients. The amino acids excretion followed the total nitrogen excretion after injury.

12) Changes in serum electrolytes.

Three patients with severe head injury and three patients with mild head injury (one with chest injury) were investigated for Na, Cl, K, Ca, Mg, CO_2, urea, osmolality, pH, pCO_2 and Base excess in the blood every day during observation.

The patients who had main long bone injury housed at the low ambient and high ambient temperatures were observed for sodium, chloride, potassium, calcium, magnesium and osmolality in the serum on the 3rd, 5th and 10th days after injury. The following results were observed.

Sodium, chloride, osmolality, pH, pCO_2 and Base excess changed from one day to the other.

Hypernatraemia, hyperchloraemia and hyperosmolality prior to death were observed in severe head injury cases during the last few days of the period of observation.

The potassium, calcium, magnesium and urea concentrations were not much different during these last few days of observation.

Acidosis and alkalosis of either respiratory or metabolic origin were observed during the investigation.

13) Serum electrolytes in mild head injury.

Two of the patients showed hyponatraemia, hypochloraemia and hypo-osmolality in the first four days after injury, but the other patient did not change much during this same time.

Potassium, calcium, magnesium and urea concentrations did not change during the period of observation.

pH, pCO_2 and base excess also varied from one day to another during the period of investigation. Acidosis and alkalosis either respiratory or metabolic were observed in these patients after injury.

It was found that the sodium concentration was slightly lower in the 3rd, 5th and 10th days after injury.

There was no significant difference in sodium, chloride, calcium, magnesium and osmolality in the patients at the two ambient temperatures after injury. The potassium concentration was slightly higher on the fifth day for the patients who were at the low ambient temperature than those at high ambient. Not much difference was observed in calcium, magnesium and in osmolality.

14) Oxygen consumption and Resting Metabolic Energy expenditure (R.M.E.)

Oxygen consumption and R.M.E. were higher in both groups of patients during the first few days of investigation. It was also observed in two patients that there was not much difference in oxygen consumption and R.M.E. between the observation made after fasting in two of the patients, one at each ambient temperature after injury.

15) Energy intake.

It was observed that over 2000 kcal/day reduced the total nitrogen excretion in the patients who were housed at 20-22°C ambient during the investigation. It was also found that over 2000 kcal/day together with a high environmental temperature markedly reduced the total nitrogen excretion, but a low energy intake with high ambient temperature did not produce the same effect as a high energy intake.

16) Skin temperature.

It was observed that the big toe temperature was higher at both environmental temperatures during the first few days after injury than during the last few days of observation. The axillary temperature was also higher in both groups of patients during the first three days after injury than later. The forehead, biceps, abdomen, mastoid and thigh skin temperatures of both groups did not show much difference between the early and later days of observation. The thigh and abdomen temperatures were slightly higher than those over the biceps and forehead in both groups of patients after injury.

An extra blanket raised the big toe temperature of the patients who were kept at 20-22°C ambient (3-4°C) but it did not affect the patients who were in the 29-30°C environmental temperature. Two blankets raised the big toe temperature rather more, but the effect was not additive.

The high environmental temperature raised the big toe temperature by 8-9°C and more effectively than did the blanket during observation.

It was noted that the patients who were in the high environmental temperature did not show much difference between skin temperature of the big toe and the other parts of the body, but the patients who were in low ambient 20-22^{o}C showed a remarkable difference between the big toe temperature and the other parts of the body after injury.

Cuthbertson and Tilstone (1968) showed in rats that the high environmental temperature increased slightly, but significantly, the rate of healing of superficial wounds in rats. Much more work is needed to find out if a high environmental temperature increases the rate of wound healing to the same degree in man as in the rat and if there is a differential effect in the different parts of the body especially is there a difference between the lower or distal parts of the body and the upper or proximal parts of the body? This investigation showed that the temperature of the skin of the big toe is lower than that over the biceps or abdomen and this may affect the rate of wound healing in these distal parts.

VIII BIBLIOGRAPHY

Ariel, I.M. (1951). Arch Surg. (Chicago), 62, 303.

Barnett, S.A., and Widdowson, E.M. (1965). Proc. Roy. Soc. B.162, 502-516.

Barnett, S.A. (1956). J. Exp. Biol. 33, 124-133.

Barr, P.O., Birke, G., Liljedahl, S-O., and Plantin, L-O. (1968). Lancet, 1, 164-168.

Black, B.M. (1953). Hyperparathyroidism. Springfield, Illinois, Thomas.

Cairnie, A.B., Campbell, R.M., Cuthbertson, D.P., and Pullar, J.D. (1957). Brit. J. Exp. Pathol., 38, 504-511.

Caldwell, F.T. (1962). Ann. Surg., 155, 119.

Caldwell,F.T., Hammel, H.T., and Dolan, F. (1966). J. Appl. Physiol., 21, 1665-1671.

Campbell, R.M., and Cuthbertson, D.P. (1967). Quart. J. exp. Physiol., 52, 114.

Campbell, R.M., and Cuthbertson, D.P. (1966). Nature, 210, 206-208.

Clark, R. (1967). Brit. J. Surg., 54, 445-459.

Consolazio, C.F., Matoush, L.O., Nelson, K.A., Hackler, L.R., and Preston, E.E. (1962). J. Nutr., 78, 78.

Conn, R.B. (1960). Clin. Chem. 6, 537. Modifield by W.J. Tilstone and G.S. Fell, Technicon International Symposium, London 1969, p.75.

Cooper, D.P., Iob, V., and Cullen, F.A. (1949). Ann. Surg. 129, 1.

Cuthbertson, D.P. (1930). Biochem. J. 24, 1244-1230.

Cuthbertson, D.P. (1932). Quart. J. Med. 25, 233, 246.

Cuthbertson, D.P. (1936). Brit. J. Surg., 23, 505-520.

Cuthbertson, D.P. (1942). Lancet, 1, 433-437.

Cuthbertson, D.P. (1957). Z. Tierenahr. Futtermitlelk., 12, 259-314.

Cuthbertson, D.P. (1970). Brit. J. Surg., 57, 718-721.

Cuthbertson, D.P., McGirr, J.L., and Robertson, J.S.M. (1939). Quart. J. exp. Physiol. 29, 18-25.

Cuthbertson, D.P., Smith, C.M., and Tilstone, W.J. (1968). Brit. J. Surg., 55, 513 - 516.

Cuthbertson, D.P. Smith, C.M., and Tilstone, W.J. (1971). (In Press).

Cuthbertson, D.P. and Tilstone, W.J. (1967). Quart. J. exptl. Physiol., 52, 249-257

Cuthbertson, D.P., and Tilstone, W.J. (1968). Quart. J. Exptl. Physiol., 53, 422-427.

Cuthbertson, D.P. and Tilstone, W.J. (1968). Quart. J. exptl. Physiol., 53, 428-436.

Cuthbertson, D.P., and Tilstone, W.J. (1969). p.493-516. (Livingstone: Ed. T. Symington).

Cuthbertson, D.P., and Tompsett, S.L. (1935). Brit. J. exp. Path., 16, 471.

Davies, J.W.L., Liljedahl, S-O., and Birke, G. (1969). Adv. Clin. Chem., 12, 1-55.

Deitrick, J.E., Whedon, G.D., and Short, E. (1948). Am. J. Med., 4, 3-13.

Drenick, E.J., Hunt, I.F., Swendseid, M.E. (1969). J. Clin. Endocrin. Metab., 29, 1341-1348.

Fawcett, J.K., and Scott, J.E. 1960. J. Clin. Path. 13, 156.

Gamble, J.L., Ross, C.S., and Tisdall, H.F. (1923). J. Biol. Chem., 57, 633-695.

Green, H.N., Stoner, H.B., Whiteley, H.J., and Englin, D. (1949). Clin. Sci., 8, 65-87.

Hale, H.B., Mefferel, R.B., Vawter, G., Foester, G.E., and Criscuolo, D. (1959). Am. J. Physiol., 196, 520-524.

Hardy, J.D. (1950). Ann. Surg., 132, 189.

Hamond, J.M., Olney, J.M., Fradurley, J.P., Paterson, R.E., Smith, L.H., Davis, J.H., Guerna, S., and Dibsell, W.H. (1955). Ann. Surg., 141, 314-320.

Heroux, O., and Cridgeman, N.T. (1958). Con. J. Biochem. Physiol., 209-216.

Hume, D.M. (1953). Ann. Surg., 138, 518.

Hugh, Y. (1968). Clinical Chemistry, 14, 898.

Higgins, B.W., Crawford, E.S., and Debaky, M.E. (1952). Ann. Surg., 136, 659-667.

Hinton, P., Littlejohn, S., Allison, S.P. and Lloyd, J. Lancet, 767, (1971)

Ingle, D.J., Ward, E.D., and Kuinzega, M.H. (1947). Amer. J. Physiol., 194, 510.

Ivor, Smith, Ed. Chromatography and Electrophoretic Technique, 2nd Ed. Vol. 1

Knapp, E.L. (1947). J. Clin. Invest., 26, 182.

Knigge, K.M. (1960). Federation Proc. 19, No. 4., Part II. Suppl. 5, 45-56.

Kotby, S., and Johnson, H.D. (1967). Life Sci., 6, 1121-1132.

Levey, S., Abbott, W.E., Kreig, E.R.H., and Davies, J.H. (1956). J. Lab. Clin. Med., 47, 437.

Lewis, C.P. (1967). J. Physiol. Lond., 191, 591.

Liddle, G.W., Duncan, L.E., and Bartler, F.C. (1956). Am. J. Med., 21, 380.

Macbeth, R.A.L., and Mabbott, J.D. (1964). Surg. Gynaecol. Obstet., 118, 748

Miksche, L.W., and Caldwell, F.T. (1967). 54, 455-459.

Miksche, L.W., and Caldwell, F.T. (1967). Surgery, 62, 66.

Min, H.K., Shane, S.R. Kettler, H., Flink, E.B. (1970).

Moore, F.D., and Ball, M.R. (1952). The metabolic response to surgery. Thomas, Springfield. Illinois.

Moyer, C.A., Collen, F.A., Iob, V., Bryant, L., Vaughan, H., Kalder, N.B., and Berry, R.E.L. (1949). Surg., 15, 218.

Moyer, C.A. (1950). Surgery, 27, 198.

Nardi, G.L. (1954). J. Clin., Invest., 33 837-854.

Phiroze, B., and Sabawala, M.D. (1971). Texas Medicine, Vol. 67.

Robert, B., Sawyer, M.A., Drew, M.H., Gesink, K.C. Sawyer, K.C. (1970). Arch. Surg., 100, 343-348.

Ruberstein, H.M., and Pryce, J.D. (1959). J. Clin.Path. Vol.12, No.11, 80.

Searcy, R.L., Gough, G.S. Korotzer, B.A., and Bergquist, L.M. (1961). Am. J. Med. Technology. Modified G.R.I., p. 255.

Sevitt, S. (1967). Prescriber's J., 7, 68-77

Thoren, L. (1963). Acta Clin. Scand., Suppl. 306.

Tilstone, W.J., and Roach, P.J. (1969). Quart. J. exp. Physiol., 54, 341-345.

Upjohn, H.L., and Levenson, S.M. (1958). A.M.A. Arch. Internat. Med., 101, 537-550.

Verney, E.B. (1958). Surg. Gynaecol. Obstet., 106, 441-452.

Walker, W.F., Fleming, L.W., and Stewart, W.K. (1968). Brit. J. Surg., 55, 466-469.

Wilkinson, A.W. (1961). Lancet, 2, 783.

Wilkinson, A.W., Billing, B.H., Nagy, G., and Stewart, C.P. (1949). Lancet, 1, 640.

Wilkinson, A.W., Billing, B.H., Nagy, G., and Stewart, C.P. (1950). Lancet, 21, 135-137.

Wilson, J.S., and Stewart, C.P. (1938). Trans. Med.Chir. Soc. (Edinburgh) 153-173.

Wynne, S.H., Charlton and Storr, W., (1960). Vol. 110, 519-523

You, S.S., You, R.W, and Sellars, E.A. (1950). Endocrinology, 47, 156-161.

Zimmerman, B. (1951). In: Surgical Forum (American College of Surgeons) Philadelphia and London: W.B. Saunders Co.

Zimmerman, B. (1965). Surgical Clinics of North America.

The number of patients, type of injury and analyses performed are shown below.

Daily urine analysis

Number of patients	Type of injury	Na, Cl, K, Mg, Osmolality and urine volume	Creatinine	Creatine	Amino acids	Total nitrogen	Glycosuria	Ketonuria
Group I 10	Severe head injury	+	+	-	-	-	+	+
Group II 8	Mild head injury	+	+	-	-	-	+	+
Group III 10	Long bone injury at 20-22°C.	+	-	+	+	+	+	+
Group IV 10	Long bone injury at 29-30°C.	+	-	+	+	+	+	+

Serum analysis

Number of patients	Na,Cl,K,Ca,Mg,Osmolality	pH,pCO_2,BE	Urea
Group I 3	Daily +	+	+
Group II 3	Daily +	+	+
Group III 10	3rd, 5th, 10th +	-	-
Group IV 10	3rd, 5th, 10th +	-	-

Other estimation

Nitrogen and energy intake	Skin temperature	Oxygen consumption & R.M.E.
-	-	-
-	-	-
+	+	4 patients +
+	+	4 patients +

Changes in urine excretion

1) Polyuria was found in Group I and Group II in the first few days after injury, but patients in Group III (20°C) and IV (30°C) showed oliguria.

2) Sodium and chloride excretion were parallel in all groups and there were losses of Na and Cl in Group I and Group II in the first few days after injury, but Group III and IV showed retention of Na and Cl. No significant difference was found in Na and Cl excretion between Group III and IV $P > 0.05$ for Na $P > 0.05$ for Cl.

3) Potassium excretion was variable in Group I and II, but followed the total nitrogen excretion in Group III and IV.

There was a statistically significant difference between Group III (20°C) and IV (30°C) in potassium excretion $0.05 > P > 0.02$.

4) Calcium and magnesium excretion were parallel in all groups, but was lower than normal in Group I. No significant difference between Group III and IV was found. $P > 0.05$ for Ca $P > 0.05$ for

5) Ammonia, urine osmolality and creatinine excretion were higher than normal subjects and rather variable. Glycosuria and ketonuria were present for one or two days after injury.

6) Creatine excretion was higher than for normal subjects, but the increased amount of creatine excreted in the last period studied after injury had no relationship to the total nitrogen excretion.

7) Total nitrogen excretion was higher in Group III ($20^{o}C$) than Group IV ($30^{o}C$) and an energy intake of over 2000 kcal/day together with the extra environmental heat reduced the total nitrogen losses.

8) Both essential and non-essential amino acids were found in the urine.

Changes in serum electrolytes

1) Hypernatraemia, hyperchloraemia and hyper-osmolality were found in Group I in the last few days after injury, but little change in Ca, K, Mg and urea was noted at this time. pH, pCO_2 and Base excess were variable.

2) Hyponatraemia, hypochloraemia, hypo-osmolality were found in Group II at first after injury, but little change occurred in K, Ca, Mg and urea concentration in the serum. pH, pCO_2 and Base excess were variable.

3) No statistically significant difference in serum Na, Cl, Ca, Mg and osmolality was found for patients at low and high environmental temperature. But a tendency for serum K at the 5th day after injury to be lower in the group held at $30^{o}C$ than group $20^{o}C$ was observed.

Other estimation

1) Oxygen consumption and Resting Metabolic Energy expenditure (R.M.E. were increased during the first few days after injury.

2) Skin temperature was higher in the first few days than during the last few days studied after injury. The big toe skin temperature was more dependent upon the environmental temperature than the other parts of the body. An extra blanket raised the big toe temperature by 3-4^{o}C, but the extra environmental heat raised it by 8-9^{o}C.