PROCEEDINGS OF THE NUTRITION SOCIETY

The Four Hundred and Twelfth Scientific Meeting (One Hundred and Sixty-third Scottish Meeting) was held at the Coylumbridge Hotel, Aviemore, on 25/26 April 1985

WORKSHOP ON 'WHY, WHEN AND HOW TO FEED PATIENTS IN HOSPITAL'

Why I feed patients with trauma and sepsis

By M. J. McMAHON, *University Department of Surgery, The General Infirmary, Leeds LS1 3EX*

I feed patients with sepsis and trauma in the belief that nutritional support is an aspect of management which is fundamental to optimal recovery, even though it is but one of numerous modes of therapy, many of which may be of equal or greater importance. The severely ill patient with multiple trauma, sepsis, severe burn injury or pancreatitis, challenges the limits of medical technology and applied physiology. It is an important challenge to meet because many of the patients are relatively young, and have the potential for restoration to a normal or near-normal quality of life if the acute illness can be overcome. It is my view that medicine is gaining ground in this area but advances are difficult to document because of the multivariant nature of the problems.

Determinants of the metabolic and nutritional consequences of sepsis and trauma are both quantitative and qualitative. Severity may vary between the almost unnoticed consequences of a small superficial laceration to the catastrophic events associated with severe crush injury, a major burn or overwhelming septicaemia. Although there is a general similarity between the responses of the body to different types of sepsis and trauma, the nature of the insult can be important. For instance a severe burn produces a loss of lean body mass characterized by a high nitrogen:potassium ratio due to the dominant loss of extracellular protein (plasma, epidermis and dermal collagen), and in patients with acute pancreatitis glucose tolerance may be impaired to a high degree because the β cell is compromised. Moreover, the body's response to injury depends on factors such as age, nutritional status and concurrent disease. Although a pyrexial response is expected in both sepsis and trauma, frail elderly patients may be unable to mount it, or even preserve their normal body temperature.

Such variation makes a working definition of trauma and sepsis difficult to achieve. For present purposes it is perhaps sufficient to include all patients in whom the combination of an acute illness with trauma (whether a primary or secondary event) or an inflammatory response (which may or may not be associated with infection) is such that their condition is liable to be compromised by undernutrition.

In some respects, severe trauma or sepsis produces net effects on the body which are similar to accelerated starvation, but the physiological and metabolic responses of the body may be very different. What then is the evidence that the patient with sepsis and trauma needs nutritional support? What benefit does it confer and how should it be supplied?

Metabolic consequences of trauma and sepsis

Severe trauma and sepsis cause perturbation of almost all the body's activities, but it is relevant to discuss those aspects which appear to be related to nutrition.

Changes of body composition in patients with trauma and sepsis. Most patients with trauma and sepsis suffer immobilization and loss of appetite and many also lose the ability to eat, swallow, digest or absorb food. Loss of weight is to be expected therefore, but it occurs at a rate which is considerably in excess of that which results from starvation alone. Whereas a weight loss of about 0·5 kg/d would be expected to result from starvation, as much as 1·5 kg/d may be lost by patients with sepsis (Moore, 1959). The ratio of protein:fat components in the weight lost during sepsis or trauma is probably greater than that during starvation alone (Kinney, 1978). The magnitude of the weight loss is dependent on the severity and duration of the trauma or sepsis and also on other factors such as the nutritional status of the patient and the management which he has received. Weight loss may be more pronounced in an individual who was normally nourished before the onset of trauma or sepsis than in an individual who was adapted to starvation by chronic illness such as inflammatory-bowel disease or malignancy. It is often difficult to weigh a patient who is on a ventilator in an intensive care ward. Furthermore, fluid sequestration, a common occurrence when patients with sepsis are treated with large amounts of fluid and electrolytes, can mask the loss of body cell mass. Cuthbertson *et al.* (1972) showed that environmental temperature influences the rate of loss of lean body mass in the traumatized patient, losses being less when the patients were nursed at temperatures between 28° and 30° than when they were nursed between 20° and 22°. Initially, K:N of the lost weight is high (Moore, 1959), suggesting that K is escaping from the body cell mass independently of the lysis of protein, thus indicating a fall in intracellular K concentration ('sick cell'). After the first few days, K and N are usually lost at a rate of approximately 3 mmol K/g N, which is equivalent to the ratio in which the two elements are incorporated into intracellular protein: hence it probably reflects loss of intracellular protein, particularly from muscle. In burned patients, a lower K:N value may be observed, probably because much of the protein is lost from plasma, dermis and epidermis and is largely

extracellular (or from keratinized cells) and has a lower K:N value (Moore & Ball, 1952). There is controversy concerning the exact magnitude and relation of changes in N and K in states of starvation, trauma and sepsis. Whereas evidence from neutron activation analysis supports a disturbance of the normal relation between K and N in malnourished subjects (McNeill *et al.* 1979; Almond *et al.* 1985), and more rapid gains of K than of N on the introduction of effective feeding regimens (Jeejeebhoy *et al.* 1982; Almond *et al.* 1984), analysis of individual tissues suggests that the normal K:N value is maintained in a variety of clinical situations, including trauma (Wood *et al.* 1984). In addition to the pronounced losses of protein and body fat, glycogen is rapidly depleted in starvation, and probably in patients with trauma and sepsis. It has been suggested that the intracellular accumulation of glycogen is accompanied by accumulation of water and K (Chan *et al.* 1982) but this is not a universally accepted view.

More recently it has been possible to examine metabolism of protein in patients with trauma and sepsis by calculating synthesis and breakdown rates after infusion of a marker such as [^{14}C]leucine or [^{15}N]alanine. Trauma increases both synthesis and breakdown of protein, the latter becoming increasingly large compared with the former, with greater degrees of severity of trauma (Birkhahn *et al.* 1980, 1981; Clague *et al.* 1983). The magnitude of protein breakdown measured by infusion of [^{15}N]glycine was less in children with acute systemic infections who were malnourished than in well-nourished children, but very high in both groups compared with uninfected controls (Tomkins *et al.* 1983). Infusions using [^{15}N]alanine have confirmed that muscle is the principal source of the net breakdown of body protein that occurs after multiple skeletal trauma (Long *et al.* 1981).

The effect of continuing sepsis or repeated trauma is to prolong the 'flow' phase and to prevent the development of the 'convalescent' phase, i.e. to attenuate recovery. There is thus a dynamic component which makes the outcome difficult to predict in many patients. If the insult is short-lived, the patient may not show signs of undernutrition, but if it persists for many days or weeks the cumulative effect on body composition becomes serious. A mean weight loss of 24% of body-weight was recorded by Blackburn *et al.* (1976) amongst patients with severe acute pancreatitis, and loss of muscle mass was particularly noted. Others have also documented the large amounts of weight lost by patients with pancreatitis (Feller *et al.* 1974).

Fuel utilization in trauma and sepsis. The increased losses of N and K in the urine of patients with trauma and sepsis, are accompanied by changes in intermediary metabolism which are often in contrast to those observed in the starving subject (Beisel & Wannemacher, 1980; Popp & Brennan, 1983). Muscle is degraded to provide fuels, some of which are used by the liver for gluconeogenesis. The liver itself accelerates production of 'acute-phase proteins' which probably help to combat some aspects of traumatic and infective illness. Gluconeogenesis is increased, in contrast to the adaptive reduction which occurs during fasting, probably as a result of increases in the secretion of glucagon and catecholamines

coupled with a rich supply of gluconeogenic substrates. Although insulin levels in plasma may rise during trauma and sepsis, peripheral tissues are relatively resistant to the effects of insulin and blood sugar concentration rise. Thus plasma insulin is inappropriately low for the blood sugar concentration and for the glucagon level. Hence there is insulin insensitivity and a low insulin:glucagon ratio. Substrates for gluconeogenesis are hepatic glycogen (initially), lactate, pyruvate, glycerol, alanine and glutamine. The latter amino acids are released from muscle in large amounts during trauma and sepsis, not only by breakdown of muscle protein directly, but by synthesis within muscle from C_3 fragments made available by gluconeogenesis. Glucose pool size and glucose turnover are increased, energy being derived more extensively from anaerobic glycolysis than glucose oxidation. There is insensitivity to insulin in peripheral tissues and liver, probably due largely to the influence of antagonists to its action, such as catecholamines, α-adenergic activity, glucagon, adrenal cortical steroids, growth hormone, etc. Infusion of glucose solutions or insulin can modify many of these metabolic changes but much less readily than in normal subjects or during starvation (Long *et al.* 1976; Burke *et al.* 1979; Elwyn *et al.* 1979). The alanine–glucose and glutamine–glutamate shunts, as well as providing the liver with precursors for gluconeogenesis, act as a convenient way to shuttle N from the catabolic muscle to the liver where the majority is converted to urea.

The only store of carbohydrate which is available for gluconeogenesis is liver glycogen (muscle glycogen can provide glucose-6-phosphate within the muscle cytosol, but cannot act as a source of glucose because muscle lacks glucose-6-phosphatase (*EC* 3.1.3.9)). Hepatic glycogen is extensively depleted by starvation for 1 or 2 d and its exhaustion is probably accelerated by sepsis, which provides an actively-glycogenolytic environment. Thereafter the fuel requirements of the body are met by glucose from gluconeogenesis (but largely by anaerobic glycolysis), by proteolysis within muscle which produces oxaloacetate and α-keto acids, by branched-chain amino acids within muscle and by oxidation of fatty acids liberated from triglyceride stores within adipose tissue. Fat constitutes about 20% of the weight lost by patients with trauma and sepsis and protein about 10% (Kinney, 1978); the proportions indicate the importance of fat as a fuel under these conditions. This conclusion is supported by studies employing indirect calorimetry (Duke *et al.* 1970; Stoner *et al.* 1983) and constant infusion of [U-^{14}C]glucose (in dogs; Shaw & Wolfe, 1985) and by the demonstration of high levels of circulating free fatty acids and glycerol. Lipolysis results from increased activity of lipase under the influence of cyclic AMP which is stimulated by catecholamines, and is favoured by peripheral resistance to insulin.

The severity of trauma or sepsis influences metabolic interrelations. Stoner *et al.* (1983), using a classification of sepsis which they had developed, showed that with increasing severity, fatty acids became increasingly dominant as a fuel source and glucose progressively less important. When multi-organ failure becomes established, the overall rate of metabolism may decline and some of these changes become reversed. A recent study of patients with severe, 'hypometabolic' septic

states, showed that utilization of oxygen by forearm muscle was low, arterial concentrations of free fatty acids and ketones were depressed and lactate production was lower than in post-operative patients (Hartl *et el.* 1984). The alanine–glucose cycle appeared to be working at a lower rate and glucose oxidation accounted for 80% of muscle O_2 uptake. These were clearly very ill patients being maintained by inotropic support. Despite the characterization of traumatic and septic states by hyperglycaemia, low blood sugar levels occur in overwhelming sepsis, although they may be masked by infusion of glucose solutions. This reversal is explained by the failure of the hepatocyte to continue gluconeogenesis.

Energy expenditure in trauma and sepsis. The accelerated loss of body tissue which accompanies trauma and sepsis should result in a rise of energy expenditure by the body. This has been confirmed by studies in which energy expenditure was measured by indirect calorimetry. This technique, which calculates metabolic expenditure from analysis of expired air, is more appropriate to the study of seriously ill patients than direct calorimetry. It has been shown that O_2 consumption correlates closely with heat production measured by direct calorimetry (Jéquier, 1985). During starvation, when there is conservation of reserves, energy expenditure falls, partly due to reduction in lean body mass and partly due to 'adaptation' to starvation. Minor trauma or sepsis have little effect on energy expenditure but more-severe conditions increase it, the magnitude of the rise being dependent on the type and severity of the event, the age of the patient and the 'starting point'. Thus if significant sepsis or trauma occurs in a normally-nourished individual, the resting metabolic expenditure will be raised compared with the predicted value for that individual based on age, sex, weight and height (Cuthbertson, 1932). However, if trauma or sepsis follows a period of starvation or weight loss, the resulting rise in energy expenditure over the predicted value is much less or even non-existent. It is rarely possible to obtain measurements of energy expenditure before trauma or sepsis of major severity (these are usually unexpected events) and the value of predictions is that they enable the energy expenditure of the patient to be compared with 'normal'. Major trauma or severe sepsis have been reported to increase energy expenditure to 120–140% of the predicted value and major burns by as much as 180–200% (Kinney, 1974; Wilmore *et al.* 1974). Recent evidence suggests that patients with severe trauma or sepsis and incipient or developed multiple organ failure have energy expenditures which are only slightly raised or even lower than those predicted (Askanazi *et al.* 1980; Quebbeman *et al.* 1982; Mann *et al.* 1985). This apparent contradiction might be related in part to differences in the technique of indirect calorimetry, and in part to a decline in energy expenditure when cellular 'failure' develops.

Hyperenergetic feeds for the patient with trauma or sepsis. Consideration of energy balance and N balance are of fundamental importance to the logical nutrition of patients with sepsis and trauma. If the energy and N losses are interpreted as 'requirements' then it is logical that administration of energy and N should equal or exceed the losses so that the nutritional status of the patient is maintained or replenished. Bartlett *et al.* (1982) studied metabolic expenditure and

nutritional intake of a group of fifty-seven patients who were sufficiently ill to require ventilation on a surgical intensive care ward. Cumulative energy balances at the time of discharge from the intensive care ward, or death, were calculated. Fifteen patients had a positive cumulative non-protein energy balance and four died (24% mortality); twenty-eight patients had a cumulative negative energy balance of less than 41·84 MJ (10 000 kcal) and eleven died (39% mortality); and fourteen patients had a cumulative negative energy balance of more than 41·84 MJ (10 000 kcal) and twelve died (86% mortality). Intensive nutritional support was given to three patients when it became apparent that a deficit of 41·84 MJ (10 000 kcal) had developed, and two survived. The authors concluded that 'it is much better to err on the side of hypercaloric feeding than caloric deficit', even though they observed that 'this type of hypercaloric feeding brings the risk of hypervolemia, dilutional anaemia and hypoproteinaemia, hyperosmosis, catheter complications and increased CO_2 load. It may even increase the metabolic rate somewhat'. An alternative view is that trauma and sepsis induce a state of obligatory 'negative energy balance' which is directly related to the magnitude of the sepsis or trauma and thus also to the magnitude of the more widely acknowledged 'negative N balance'. The term 'obligatory', is probably accurate for the early stages of severe trauma and sepsis, but as the flow phase gives rise to convalescence, it is less appropriate because reversal becomes progressively more easy. Thus the association between death and high cumulative negative energy balance probably implies more-severe and prolonged sepsis and trauma rather than higher nutritional 'needs'. Little conclusion can be drawn from attempts to reverse negative balances in three patients. The potential dangers that result from hyperenergetic feeding may well outweigh its advantages. Perhaps it is the more anabolic metabolism of the recovering patient which makes for a reduction in negative energy balance, a response which could be obtained with more modest energy supplies and with fewer hazards. Askanazi *et al.* (1980) have found considerable increases in energy expenditure (mean 29%) when an amino acid and glucose solution providing energy to a level of 1·35–2·25 times the 'starvation' energy expenditure was given intravenously to patients recovering from trauma or sepsis. We have also recorded increases of energy expenditure of more than 20% when large amounts of glucose were given intravenously to stable surgical patients (McMahon *et al.* 1984). This effect might be due, at least in part, to increased noradrenaline secretion (Elwyn *et al.* 1979). Hence, hyperenergetic feeding appears to induce a rise in energy expenditure and thus the 'requirement' for even more energy if nutritional balance is to be achieved, i.e. 'chasing one's tail'.

Similar arguments apply to the provision of protein or amino acids to patients with trauma or sepsis. Positive N balance can be achieved for long periods of time in depleted patients, reflecting repletion of lean body mass (Shaw *et al.* 1983). Even after major burns, feeding which was commenced 1 week after injury achieved positive N balance (Thomsen & Sørensen, 1984). Caution needs to be used in the interpretation of results from N balance studies. Expansion of amino acid pool size during the acute stages of sepsis and trauma may reduce negative

balance independent of influences on protein synthesis. Moreover, errors in the record of nutrient input and collection of specimens all bias the results towards more positive balance (Hegsted, 1978), and accurate collections may be difficult in the severely ill patient. Wolfe *et al.* (1983) showed that in patients with severe burns fed mainly by the intravenous route, 2·2 g protein/kg per d (0·35 g N/kg per d) achieved no greater net protein synthesis than 1·4 g/kg per d (0·22 g N/kg per d) when synthesis and breakdown were calculated from infusions of [^{15}C]urea or [1-^{13}C]leucine. At the higher level of intake, both synthesis and breakdown were stimulated. Results for N excretion, however, showed increased N retention when the high N regimen was administered.

Can positive N balance be achieved if hyperenergetic feeds are used? Provision of 'non-protein' energy produces N sparing up to a level of administration approximately equal to measured resting energy expenditure (Dinarello & Bernheim, 1981), but higher levels of glucose infusion do not spare more N (Elwyn *et al.* 1979).

Thus it remains uncertain that the administration of energy in amounts greater than the patient's expected energy expenditure, and of N in amounts greater than 0·25 g/kg per d convey benefit to the patient. In the previously fit, robust young adult with trauma or sepsis, feeding with about 10·46–12·552 MJ (2500–3000 kcal)/d and 18 g N/d might be appropriate, but I regard these as ceiling levels. In other patients, who may be older, and starvation-adapted, much lower levels are probably appropriate. I subscribe to the view that it is better to underfeed a little than to create complications by attempting to force metabolism with hyperenergetic regimens and high N loads. In the 'catabolic' stages of trauma and sepsis maintenance of the nutritional *status quo* is an acceptable aim, repletion of body composition being accomplished as the anabolic phase gains ascendency. When this stage is reached, fuel energy is efficiently utilized and large amounts are not needed.

Cellular effects of trauma and sepsis

Mediators of the response to trauma and sepsis. The mechanisms which lead to the metabolic changes which characterize trauma and sepsis have not been completely elucidated. There is undoubtedly a switch to a catabolic hormonal profile but other factors may be equally important. Mediators of the host response to infection or trauma are liberated from traumatized or infected tissues (e.g., histamine, serotonin, lysosomal hydrolase, etc.) and also, more remotely, from phagocytes which have ingested bacteria or tissue debris.

A group of similar or identical substances which are released from leucocytes during infection or trauma (interleukin-1, endogenous pyrogen, leucocyte pyrogen, leucocyte endogenous mediator) have been shown to induce fever by stimulation of arachidonic acid release and thus synthesis of prostaglandin E_2 in the hypothalamus (Dinarello & Bernheim, 1981), the synthesis of acute-phase proteins by the liver (Sztein *et al.* 1981), and the proliferation of subpopulations of lymphocytes (Beer *et al.* 1982). Interleukin 1 is also a powerful stimulant of protein

breakdown in muscle but has no effect on protein synthesis (Baracos *et al.* 1983). Interleukin 1 has a molecular weight of approximately 15 000 daltons, but a smaller molecule (probably a cleavage fragment of interleukin 1) of about 4500 daltons has been shown to have similarly powerful effects on the breakdown of skeletal muscle (Clowes *et al.* 1983). The relative contribution of hormonal changes, factors released from damaged tissue and infective organisms (such as gram negative endotoxin), and interleukin 1 to the metabolic response to trauma and sepsis in different clinical settings remains to be established. If many of these agents are an expression of the toxicity of a disease process rather than a mechanism by which the body regulates metabolism in order to survive, it is illogical to regard the catabolic and febrile consequences which result as an indication of the body's nutritional requirements. It remains to be determined to what extent exogenous or endogenous mediators can be blocked or neutralized by hormonal, pharmacological or nutritional manipulations, and whether reversal of their effects is beneficial to recovery from sepsis or trauma.

Cell damage during trauma and sepsis. During severe haemorrhagic or septic shock, studies in animals have shown that there is progressive depolarization of the cell membranes, probably due to failure of the energy-dependent sodium ion–potassium ion pump. The cells swell, take up Na and chloride and lose K. There is a reduction of total cellular energy levels in many organs (Chaudry *et al.* 1981) but preservation of cellular levels of ATP and creatine phosphate in skeletal muscle has been reported in severe septic states (in rabbits; Illner & Shires, 1981), perhaps because decline in production of ATP and creatine phosphate were paralleled by a decline in utilization. Mitochondria have a reduced capacity to synthesize ATP and may swell and burst (Baue *et al.* 1974). Failure of membrane function and active transport systems during sepsis and trauma lead to leakage of electrolytes in and out of the body cells, intercompartmental fluid shifts and escape of albumin from the plasma to the often expanded extracellular fluid. Mobilization of protein from extracellular fluid may be hampered by functional inadequacy of the reticuloendothelial system (Lanser & Saba, 1982).

Immune competence, as judged by the response to dermal antigens and lymphocyte activity, is impaired in patients with severe sepsis and trauma (Maclean *et al.* 1975), T lymphocytes are depressed (Bauer *et al.* 1978), and the ability to combat infections compromised (Bjornson *et al.* 1978). Starvation also depresses immune competence, and the patient who has lost weight as well as sustaining trauma or sepsis may be at particular risk. Feeding can correct the immunological deficiencies caused by starvation, and there is evidence to suggest that the same is true for patients with burns, as long as the traumatic–septic insult has been overcome (Alexander, 1974).

Clinical benefit of nutritional support in the patient with trauma and sepsis

Effect on survival. Analysis of information from intensive care wards has not demonstrated an improvement in survival during the course of the last 15 years (Searle, 1985). There are, however, many possible reasons why benefits from

advances in treatment such as nutritional support may be concealed. The spectrum of patients and their diseases may have changed, and criteria for entry to intensive care may have 'hardened' as calls on the service have increased, etc. To hope that the effect of improved nutritional care can emerge from the vast heterogeneity of clinical variants which are included under the heading of 'trauma and sepsis' is clearly unrealistic. Consideration of information from more homogeneous groups of patients might be of more value. Alexander (1980) reported a randomized study in which children with burns who were given 4·9 g protein/kg per d survived better than those given about 3·8 g protein/kg per d. However, the children who were given the higher-protein diet were able to take a greater proportion of the diet orally, and may have been less severely burned.

Nutritional depletion is common in patients with severe pancreatitis. Recent reports have suggested that a combination of nutritional support (parenteral or jejunostomy) and opportune surgical intervention can reduce mortality and maintain nutritional status (Blackburn *et al.* 1976; White & Heimbach, 1976; Grant *et al.* 1984). The hypothesis, that by inhibiting the exocrine secretion of the pancreas the course of acute pancreatitis can be attenuated, has not been proven (Goodgame & Fischer, 1977; Grant *et al.* 1984).

To the clinician, one of the most dramatic effects of careful nutritional support for the patient with sepsis of trauma, is the ability to 'buy' time whilst healing and recovery take place. No longer is the 'leak' after a gastrectomy usually fatal, and if a necrotic pancreas is allowed to mature for 1 month in order that the dead tissue can be removed more safely from the thick-walled, granulating cavity, the patient is not so weakened by starvation that he is unable to recover from the operation. The outlook for patients with septic complications of gastrointestinal surgery has probably been transformed by the availability of parenteral and enteral nutrition, but verification of this opinion by clinical trials is neither practical nor ethical. Thus the proof of efficacy that would be required to license a new drug is unlikely to be forthcoming for nutritional treatment of critically ill patients. A recent study of patients who sustained a fracture of the upper femur identified undernutrition as a risk-factor (Bastow *et al.* 1983*a*) and showed clinical benefits of enteral nutrition in the undernourished patients (Bastow *et al.* 1983*b*). This was a large and well-planned study, which focused on a single type of injury in a relatively homogeneous group of patients. Attempts to define the role of nutrition in other groups of patients with trauma or sepsis are hampered by the fact that aspects of the illness which are unrelated to nutrition frequently outweigh nutrition as a determinant of outcome.

The grading of sepsis and trauma. Burn injury is graded according to the extent of the burn in both thickness and surface area. The extent of the latter has been correlated with many of the clinical responses to burning, including the degree of disturbance of energy expenditure (Wilmore *et al.* 1974). A grading system for severe trauma was established more than a decade ago (Baker *et al.* 1974), but it is only recently that systems to grade the severity of sepsis have emerged (Knaus *et al.* 1981, 1984; Elebute & Stoner, 1983; Stevens, 1983). In a comparison of the fate

of intensive care patients in the USA and France, one of these systems has shown its value by demonstrating that French patients with gastrointestinal disease admitted to the intensive care ward fared less well than their American equivalents (Knaus *et al.* 1982). The most likely reason for this difference was a routine of early surgical intervention for acute pancreatitis in France. It is to be hoped that refinement of severity scoring systems, perhaps modified according to the cause of sepsis, will enable a clearer understanding of the metabolic perturbations which characterize trauma and sepsis, and thus enable treatment to be applied with greater precision.

Feeding patients with trauma and sepsis

Which route? There is little difficulty in making this decision in most patients. If the alimentary tract is functionally available, then enteral feeding is usually appropriate via a fine-bore nasogastric tube. A pump is helpful to maintain a slow and constant rate of infusion, and due care should be taken to prevent retention of fluid in the stomach with the risk of vomiting and inhalation of vomit. Gastric emptying is often impaired after trauma, even when it is localized to a site remote from the abdomen, as with a head injury. If gastrointestinal function is impaired, or if it is desired to 'rest' part of the gastrointestinal tract as, for example, in a patient with pancreatitis or an enterocutaneous fistula, then intravenous feeding can be used. In order that the most appropriate route is used, it is important that both enteral and parenteral feeding can be supplied easily and safely. In my view, automatic recourse to enteral feeding wherever possible because it is technically easier to administer and safer than intravenous feeding is erroneous in the patient with trauma and sepsis; the more unstable the patient the more I prefer the greater precision of the intravenous route. Whichever route is used, feeding must be nutritionally effective and must not compromise other modalities of treatment. I favour the use of an infusion pump and mixture of all nutrients in a single 'bag'.

When to feed? As a general rule, I do not commence feeding until about 5 d have elapsed from the time of trauma in previously well-nourished patients. If the traumatic–septic episode is very severe, the patient is usually very unstable during this time and optimal management of fluid, electrolytes, etc. is helped if nutrition can be ignored. If trauma or sepsis is less severe, it may become apparent after this period of time has elapsed that specialized nutritional support is unnecessary. If the patient was previously undernourished, feeding may be appropriate at an earlier stage. In patients who undergo operations with a relatively high complication rate, such as oesophagectomy or pancreatectomy, I prefer to commence (or recommence) intravenous nutrition about 48 h after operation in order that nutritional status is maintained and a complication, should it arise, is less devastating to the patient.

How much to feed? From previous considerations, I aim to maintain nutritional status by feeding patients with trauma and sepsis, not to attempt to suppress or reverse the catabolic response to the insult, nor to replete the patient; that can be achieved more easily during the convalescent stage. My preference is to aim for a

'non-protein' energy supply of 146–167 kJ (35–40 kcal)/kg per d, as recommended by Jeejeebhoy (1985). The choice of energy supply for patients receiving intravenous nutrition has been a subject of great controversy. Patients with sepsis and trauma use fat as a fuel and display glucose intolerance. Using fat (lipid emulsion) to provide 50% or more of the energy supply achieves a similar degree of protein-sparing in the patient with trauma or sepsis as a regimen providing all 'non-protein' energy as glucose (Baker *et al.* 1984). Furthermore, the use of lipid emulsion enables many of the metabolic and respiratory consequences of high-glucose loads to be avoided. Because clearance of lipid emulsion from plasma is reduced in patients with severe trauma or sepsis (Lindholm & Rossner, 1982) and agglutination of lipid emulsion and consequently microembolus formation have been reported in acutely ill patients, in the presence of high plasma concentrations of C-reactive protein (Hulman *et al.* 1982), I prefer to limit lipid emulsion to 50% of the energy supply. The use of insulin (with glucose and K) may improve the haemodynamic status of patients with 'septic shock' (Bronsveld *et al.* 1985) and enhance the N-sparing effect of glucose in patients with trauma or burns (Long *et al.* 1977; Woolfson *et al.* 1979), but I use it only to maintain blood glucose concentrations within the range of 5–10 mmol/l. The role of glycerol, ketoacids and medium-chain triglycerides as fuel sources for septic patients remains to be elucidated.

N administration of 0·2–0·25 g/kg per d means that most patients are given 10–18 g/d, which is readily available as 1 litre intravenous amino acid solution from several suppliers. A reduction in N supply may be needed in patients with renal impairment, but the presence of renal failure does not reduce the importance of nutritional therapy and is not an indication for omission of amino acids from the feed. Whether enrichment of amino acid solutions with essential or branched-chain amino acids confers clinical benefit to patients with trauma and sepsis is a matter of controversy but expense mitigates against the use of such solutions until their advantages can be clearly demonstrated.

The author is grateful to Miss J. T. Karamatsu for help with the preparation of this paper.

REFERENCES

Alexander, J. W. (1974). *Surgery* **75**, 934–946.
Alexander, J. W. (1980). *Annals of Surgery* **192**, 505.
Almond, D. J., Burkinshaw, L. & McMahon, M. J. (1985). *British Journal of Surgery* **72**, 400.
Almond, D. J., King, R. F. G. J., Burkinshaw, L. & Oxby, C. B. (1984). *British Journal of Surgery* **71**, 385.
Askanazi, J., Carpentier, Y. A., Elwyn, D. H., Nordenström, J., Jeevanandam, M., Rosenbaum, S. H., Gump, F. E. & Kinney, J. M. (1980). *Annals of Surgery* **191**, 40–46.
Baker, J. P., Detsky, A. S., Stewarts, S., Whitwell, J., Marliss, E. B. & Jeejeebhoy, K. N. (1984). *Gastroenterology* **87**, 53–59.
Baker, S. P., O'Neill, B., Haddon, W. & Long, W. B. (1974). *Journal of Trauma* **14**, 187–196.
Baracos, V., Rodemann, H. P., Dinarello, C. A. & Goldbert, A. L. (1983). *New England Journal of Medicine* **308**, 553–558.

Bartlett, R. H., Dechert, R. E., Mault, J. R., Ferguson, S. K., Kaiser, A. M. & Erlandson, E. E. (1982). *Surgery* **92**, 771–778.
Bastow, M. D., Rawlings, J. & Allison, S. P. (1983*a*). *Lancet* **i**, 143–146.
Bastow, M. D., Rawlings, J. & Allison, S. P. (1983*b*). *British Medical Journal* **287**, 1589–1592.
Baue, A. E., Chaudry, I. H., Wurth, M. A. & Sayeed, M. M. (1974). *Angiology* **25**, 31–42.
Bauer, A. R., McNeil, C., Trentelman, E., Swift, S. A. & Mason, J. D. (1978). *American Journal of Surgery* **136**, 674–680.
Beer, D. J., Dinarello, C. A., Rosenwasser, L. J. & Rocklin, R. E. (1982). *Journal of Clinical Investigation* **70**, 392–400.
Beisel, W. R. & Wannemacher, R. W. (1980). *Journal of Parenteral and Enteral Nutrition* **4**, 277–285.
Birkhahn, R. H., Long, C. L., Fitkin, D., Geiger, J. W. & Blakemore, W. S. (1980). *Surgery* **88**, 294–299.
Birkhahn, R. H., Long, C. L., Fitkin, D., Jeevanandam, M. & Blakemore, W. S. (1981). *American Journal of Physiology* **241**, E64–E71.
Bjornson, A. B., Altemeier, W. A. & Bjornson, H. S. (1978). *Annals of Surgery* **188**, 102–108.
Blackburn, G. L., Williams, L. F., Bistrian, B. R., Stone, M. S., Phillips, E., Hirsch, E., Clowes, G. H. A. & Gregg, J. (1976). *American Journal of Surgery* **131**, 114–124.
Bronsveld, W., Van Den Bos, G. C. & Thijs, L. G. (1985). *Critical Care Medicine* **13**, 566–570.
Burke, J. F., Wolfe, R. R., Mullany, C. J., Mathews, D. E. & Bier, D. M. (1979). *Annals of Surgery* **190**, 274–285.
Chan, S. T. F., Johnson, A. W., Moore, M. H., Kapadia, C. R. & Dudley, H. A. F. (1982). *Clinical Nutrition* **36**, 223–232.
Chaudry, I. H., Clemens, M. G. & Baue, A. E. (1981). *Archives of Surgery* **116**, 1309–1317.
Clague, M. B., Keir, M. H., Wright, P. D. & Johnston, I. D. A. (1983). *Clinical Science* **65**, 165–175.
Clowes, G. H. A., George, B. C., Villee, C. A. & Saravis, C. A. (1983). *New England Journal of Medicine* **308**, 545–552.
Cuthbertson, D. P. (1932). *Quarterly Journal of Medicine* **1**, 233–246.
Cuthbertson, D. P., Fell, G. S., Smith, C. M. & Tilstone, W. J. (1972). *British Journal of Surgery* **59**, 925–931.
Dinarello, C. A. & Bernheim, H. A. (1981). *Journal of Neurochemistry* **37**, 702–708.
Duke, J. H., Jørgensen, S. B., Broell, J. R., Long, C. L. & Kinney, J. M. (1970). *Surgery* **68**, 168–174.
Elebute, E. A. & Stoner, H. B. (1983). *British Journal of Surgery* **70**, 29–31.
Elwyn, D. H., Kinney, J. M., Jeevanandam, M., Gump, F. E. & Broell, J. R. (1979). *Annals of Surgery* **190**, 117–127.
Feller, J. H., Brown, R. A., Toussaint, G. P. M. & Thompson, A. G. (1974). *American Journal of Surgery* **127**, 196–201.
Goodgame, J. T. & Fischer, J. E. (1977). *Annals of Surgery* **186**, 651–658.
Grant, J. P., James, S., Grabowski, V. & Trexler, K. M. (1984). *Annals of Surgery* **200**, 627–631.
Hartl, W., Günther, B., Wicklmayr, M., Teichman, R. & Dietze, G. (1984). *Clinical Nutrition* **3**, 221–226.
Hegsted, D. M. (1978). *American Journal of Clinical Nutrition* **31**, 1669–1677.
Hulman, G., Fraser, I., Pearson, H. J. & Bell, P. R. F. (1982). *Lancet* **ii**, 1426–1427.
Illner, H. P. & Shires, T. (1981). *Archives of Surgery* **116**, 1302–1305.
Jeejeebhoy, K. N. (1985). In *Substrate and Energy Metabolism*, pp. 93–101 [J. S. Garrow and D. Halliday, editors]. London: John Libbey.
Jeejeebhoy, K. N., Baker, J. P. & Wolman, S. L. (1982). *American Journal of Clinical Nutrition* **35** (Suppl.), 1117–1127.
Jéquier, E. (1985). In *Substrate and Energy Metabolism*, pp. 82–89 [J. S. Garrow and D. Halliday, editors]. London: John Libbey.
Kinney, J. M. (1974). *Anaesthesiologica Scandinavica* **55** (Suppl.), 15–20.
Kinney, J. M. (1978). In *Advances in Parenteral Nutrition*, pp. 511–518 [I. D. A. Johnston, editor]. Edinburgh: Churchill Livingstone.
Knaus, W. A., Drapper, E. A., Wagner, D. P. & Zimmerman, J. E. (1984). *Critical Care Medicine* **12**, 213.
Knaus, W. A., Legall, J. R., Wagner, D. P. & Draper, E. A. (1982). *Lancet* **ii**, 642–646.
Knaus, W. A., Zimmerman, J. E., Wagner, D. P., Draper, E. A. & Lawrence, D. E. (1981). *Critical Care Medicine* **9**, 591–597.

Lanser, M. E. & Saba, T. M. (1982). *Annals of Surgery* **195**, 340–345.
Lindholm, M. & Rossner, S. (1982). *Critical Care Medicine* **10**, 740–746.
Long, C. L., Birkhahn, R. H., Geiger, J. W. & Blakemore, W. S. (1981). *American Journal of Clinical Nutrition* **34**, 1087–1093.
Long, C. L., Kinney, J. M. & Geiger, J. M. (1976). *Metabolism* **25**, 193–201.
Long, M. J., Wilmore, D. W., Mason, A. D. & Pruitt, B. A. (1977). *Annals of Surgery* **185**, 417–422.
Maclean, L. D., Meakins, J. L., Taguchi, K., Duignan, J. P., Dhillon, K. S. & Gordon, J. (1975). *Annals of Surgery* **182**, 207–217.
McMahon, M. J., King, R. F. G. J., Almond, D. J. & Zeiderman, M. R. (1984). *Journal of Parenteral and Enteral Nutrition* **8**, 89.
McNeill, K. G., Mernagh, J. R., Jeejeebhoy, K. N., Wolman, S. L. & Harrison, J. E. (1979). *American Journal of Clinical Nutrition* **32**, 1955–1961.
Mann, S., Westenskow, D. R. & Houtchens, B. A. (1985). *Critical Care Medicine* **13**, 173–177.
Moore, F. D. (1959). *The Metabolic Care of the Surgical Patient.* Philadelphia and London: W. B. Saunders.
Moore, F. D. & Ball, M. R. (1952). *The Metabolic Response to Surgery.* Springfield, Illinois: Charles C. Thomas.
Popp, M. B. & Brennan, M. F. (1983). In *Surgical Nutrition*, pp. 479–513 [J. E. Fischer, editor]. Boston and Toronto: Little Brown and Company.
Quebbeman, E. J., Ausman, R. K. & Schneider, T. C. (1982). *Annals of Surgery* **195**, 282–286.
Searle, J. F. (1985). *Annals of the Royal College of Surgeons of England* **67**, 187–189.
Shaw, J. H. F. & Wolfe, R. R. (1985). *Metabolism* **34**, 442–449.
Shaw, S. N., Elwyn, D. H., Askanazi, J., Iles, M., Schwarz, Y. & Kinney, J. M. (1983). *American Journal of Clinical Nutrition* **37**, 930–940.
Stevens, L. E. (1983). *Archives of Surgery* **118**, 1190–1192.
Stoner, H. B., Little, R. A., Frayn, K. N., Elebute, A. E., Tresadern, J. & Gross, E. (1983). *British Journal of Surgery* **70**, 32–35.
Sztein, M. B., Vogel, S. N., Sipe, J. D., Murphy, P. A., Mizel, S. B., Oppenheim, J. J. & Rosenstreich, D. L. (1981). *Cellular Immunology* **63**, 164–176.
Thomsen, M. & Sørensen, K. I. (1984). *Scandinavian Journal of Plastic Reconstruction Surgery* **18**, 81–85.
Tomkins, A. M., Garlick, P. J., Schofield, W. N. & Waterlow, J. C. (1983). *Clinical Science* **65**, 313–324.
White, T. T. & Heimbach, D. M. (1976). *American Journal of Surgery* **132**, 270–275.
Wilmore, D. W., Long, J. M., Mason, A. D., Skreen, R. W. & Pruitt, B. A. (1974). *Annals of Surgery* **180**, 653–669.
Wolfe, R. R., Goodenough, R. D., Burke, J. F. & Wolfe, M. H. (1983). *Annals of Surgery* **197**, 163–171.
Wood, C. B., Goumas, W., Pollard, M. & Brinker, J. E. (1984). *Journal of Parenteral and Enteral Nutrition* **8**, 665–667.
Woolfson, A. M. J., Heatley, R. V. & Allison, S. P. (1979). *New England Journal of Medicine* **300**, 14–17.

Printed in Great Britain