The application of nutritional science to clinical practice

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Nutritional science consists of multiple overlapping disciplines: agricultural science including animal husbandry; food science; public health; nutritional physiology; and therapeutic or clinical nutrition. The application of nutritional science to clinical practice has undoubtedly resulted in improved survival and improved quality of life in certain groups of patients. It has also resulted in new concepts that are not only of fundamental importance to physiology and human biology, but also to the development of new therapeutic strategies. Several of these new concepts have arisen from three interrelated areas that are essentially unique to human and veterinary clinical nutrition. These are: (1) the consequences of bypassing the gut, which occurs during intravenous nutrition; (2) the effects of administering nutrients in quantities and proportions that are not normally possible with normal diets; (3) the effects of using continuous feeding over 24 h rather than intermittent feeding.

BYPASSING THE GUT

Bacteriological, metabolic and clinical consequences

Mammals have evolved complex biochemical, immunological and mechanical defence systems that are located at the interfaces between the external environment and their own tissues, i.e. the integument, the gastrointestinal tract and the respiratory tract. The administration of feeds directly into central veins bypasses all these defences, making infection much more likely. Indeed, in the early 1970s, just a few years after the first successful use of prolonged parenteral nutrition in man (Dudrick et al. 1968) was hailed as one of the most important advances in nutritional support for decades, serious infections, mainly in the form of catheter-related sepsis, became a major problem. Catheter-related sepsis occurred in as many as 25–30% of patients being fed parenterally. In the late 1970s the incidence of catheter-related sepsis was reduced to about 5% in many centres, because the central line came to be regarded as a ‘lifeline’ for administration of feed only and not for the convenience of administering blood products, drugs and fluids, or for withdrawing blood, especially by individuals not employing strict aseptic techniques. In the 1980s the incidence of catheter-related sepsis was reduced further to about 3% through the use of polyurethane catheters which replaced the older more ‘adhesive’ and thrombogenic polyvinyl catheters which were more likely to predispose to bacterial seeding. In the 1990s new catheters coated with silver sulpha-
diazine have become commercially available in an attempt to reduce the incidence of catheter-related sepsis even further. However, their value still remains to be proven, especially since there is concern about the development of antibiotic resistance by bacteria. In general, the introduction of nutrition teams (Elia, 1993) has probably been the most important factor in reducing the incidence of catheter-related sepsis, emphasizing the value of implementing strict protocols that employ aseptic techniques.

A different concept relating to the infectious complications of parenteral nutrition was that the parenteral nutrition might act as a form of iatrogenic immunosuppression (Alverdy & Burke, 1992), a possibility raised in 1970 (Boeckman & Krill, 1970). Several years later (Dionigi et al. 1977) it was noted that intravenous nutritional support in malnourished dogs could restore body composition and restore a number of immunological abnormalities, but it could not restore to normal some of the lymphocyte function tests. In the 1980s a series of studies involving septic models of injury reported that parenteral nutrition modified the metabolic response to sepsis and adversely affected outcome.

Peterson et al. (1981) and Kudsk et al. (1981) reported that the mortality of orally-fed depleted rats suffering from experimentally-induced Escherichia coli peritonitis was about 50%, in contrast to a mortality of more than 90% (P<0.01) in depleted rats given parenteral nutrition for 1 week before the peritonitis. Similar results were reported later in normal rats (Kudsk et al. 1983). Normally-nourished rats fed by gastrostomy had about 40% mortality 2 d after E. coli peritonitis, whilst those fed by parenteral nutrition for 1 week before the peritonitis had about 80% mortality.

Saito et al. (1987) complemented the previously described observations by demonstrating that in rats the metabolic response to 30% burns was exaggerated in parenterally-fed rats compared with gastrostomy-fed rats. Thus, the plasma cortisol and glucagon concentrations and urinary vanillyl mandelic acid (VMA) excretion were substantially greater in those fed parenterally, from day 1 through to day 14 after the burn. Human studies also complemented the previously described observations (Fong et al. 1989; Lowry, 1990). In the study of Fong et al. (1989) normal subjects were fed either orally or intravenously for a period of 1 week before being challenged with an intravenous dose of endotoxin. The subjects fed parenterally had a greater stress hormone response (cortisol, adrenaline), a greater acute-phase protein response (C reactive protein), which is used as an index of the severity of injury response, and a greater cytokine (TNF) response.

In clinical practice morbidity is a more important outcome variable than biochemical variables. Clinical trials attempting to assess outcome are often difficult to interpret, especially in heterogeneous groups of critically ill patients who are treated in different ways. Nevertheless, there is some evidence that parenterally-fed patients suffering from the effects of abdominal injury and laparotomy have a greater risk of developing septic complications (e.g. abdominal abscess, pneumonia) than those fed enterally. Apart from one small study (Adams et al. 1986), which reported no advantage of enteral over parenteral feeding, there is remarkable consistency in the results of three other studies, in that the incidence of septic complications was two- to tenfold lower in patients fed enterally than those fed parenterally (Moore & Jones, 1986; Moore & Moore, 1991; Kudsk et al. 1992; Moore et al. 1992). This effect seemed to be independent of the presence or absence of catheter sepsis, as shown by the largest and most recent study (n 235) which was essentially a meta-analysis of eight smaller studies (Moore et al. 1992).
and by the study of Kudsk et al. (1992) which analysed the incidence of individual septic complications (abscess, pneumonia, catheter-related sepsis). Although criticisms can be raised against individual studies, all the results taken together suggest an advantage of enteral nutrition over parenteral nutrition at least in subjects who have sustained abdominal injuries and have had a laparotomy.

If this conclusion is accepted there is a need to establish a mechanism by which enteral nutrition protects against sepsis. About 85 years ago Eli Metchnikoff (1908), the father of the phagocytic theory of immunity, suggested that the passage of bacteria and toxins from the gastrointestinal tract into the body (translocation) was an important cause of morbidity and premature death. Today translocation has become a prominent area of research in clinical nutrition. The barrier that keeps bacteria and toxins in the lumen of the gastrointestinal tract appears to break down after a variety of systemic insults (burn, trauma, haemorrhage, endotoxin; Border et al. 1987; Alverdy et al. 1988; Inoue et al. 1989; Alexander, 1990; Dietch et al. 1990; Dietch, 1992; Fukushima et al. 1992; Troche, 1993), especially if there is associated protein malnutrition. This means that bacteria and toxins pass to the mesenteric nodes and subsequently to the blood and other organs causing septicaemia and abscesses. Under normal circumstances mesenteric lymph nodes from guinea-pigs are essentially sterile, but 24–48 h after severe injury, e.g. 50% burns, most of them can become culture positive with intestinal organisms (Inoue et al. 1989). A proportion of bacteria escape the mesenteric lymph nodes, to find their way into the blood (septicaemia) and a variety of organs (where they may cause abscesses). Translocation is also enhanced by parenteral nutrition. In the study of Alverdy et al. (1988) about two-thirds of mesenteric lymph nodes from rats fed parenterally were culture positive compared with none in those given a normal oral diet. Other studies (see Troche, 1993) have confirmed that parenteral nutrition increases bacterial ‘translocation’ to the mesenteric nodes of rats.

The cause of the increased ‘translocation’ during parenteral nutrition is uncertain (Alverdy & Burke, 1992), but a number of processes have been implicated. The absence of luminal nutrition causes the following: decreased production of mucous, which acts as a barrier to bacterial penetration across mucous membranes (Parsons et al. 1979); decreased secretion into the lumen of the gut of immunoglobulin A (IgA), which binds to bacteria (Alverdy et al. 1985); decreased secretion of bile, which is not only the major source of intestinal IgA in the rat (Jones, 1984) but also the source of bile acids which may bind to endotoxin to prevent its translocation. In addition ‘bowel rest’ may decrease peristalsis, which favours bacterial overgrowth. The absence of luminal nutrition also causes mucosal atrophy, loss of gut-associated lymphocytes, and reduced blood flow, all of which may be important in the translocation process.

Apart from translocation, other factors can be suggested to explain the increased incidence of septic complication in the subjects receiving parenteral nutrition after abdominal injury and laparotomy. It is possible that the parenteral nutrition mixtures may be lacking in some immunomodulatory nutrient that is normally present in oral diets (see p. 7). Alternatively, since in some of the clinical studies there was a tendency for more nutrients to be administered during parenteral nutrition than during enteral tube feeding, it can be postulated that excess administration was responsible for the increased incidence of infection. For example, in the study of Moore et al. (1992) the excess administration of intravenous nutrition compared with enteral nutrition was associated with greater hyperglycaemia, which predisposes to infection and bacterial proliferation.
The high incidence of pneumonia during parenteral nutrition in some of the previously mentioned clinical studies may be due to aspiration of bacteria from the upper gastrointestinal tract, especially since lack of peristalsis and lack of upper gastrointestinal tract secretions favour bacterial overgrowth, which is common in critically-ill patients (Moulin et al. 1982).

Although there is some uncertainty about which of the mechanisms predominates, several of the previously mentioned observations on sepsis rates have reinforced the old adage that the gastrointestinal tract should be used for feeding whenever it is available, and that parenteral nutrition should only be used when the gut is not available. In some centres there has been a trend in providing small and tolerable amounts of enteral nutrition to parenterally-fed patients, based on the belief that a small or even minimal amount of enteral feeding is sufficient to maintain gastrointestinal integrity and provide mucosal protection (Lucas et al. 1986; Elia et al. 1987; Inoue et al. 1989).

**Effect on trace element requirements and toxicity**

Apart from microbiological protection, the gastrointestinal tract provides protection against toxicity from a variety of substances that may be present in the diet, including protection against the toxicity of some trace elements. For some trace elements, such as Se, F and I, there is little, if any, regulation over absorption. The absorption of these trace elements is almost complete (≥80%) irrespective of dietary intake over a wide range. For other trace elements such as Zn, Cu, Fe and Mn, which have a lower and more variable fractional absorption, there are important regulatory intestinal processes that prevent excessive uptake when their dietary intake is excessive. Indeed, for some trace elements such as Fe (McCance & Widdowson, 1943) the gut essentially provides the only defence against excess accumulation within the body. There is no effective way of disposing of excess Fe once it has entered the body, e.g. by repeated blood transfusions or in patients with haemochromatosis, who have an intestinal defect leading to increased Fe absorption. The Fe progressively accumulates within tissues until clinical symptoms occur (e.g. cirrhosis, bronze diabetes and infertility which are all features of haemochromatosis).

When it comes to parenteral nutrition it is important to remember that the recommended intake of trace elements may be substantially lower than that for normal oral intake (Elia, 1990), particularly for those trace elements such as Cr and Mn that are normally absorbed to the extent of less than 5% (Cr <3%, Mn 3–4%; National Academy of Sciences, 1980, 1989). If these considerations are ignored potential problems may arise. For example, since the normal intake of Mn is about 4 mg (80 μmol)/d (National Academy of Sciences, 1989; Department of Health, 1991) and its absorption is 3–4% (Greenberg et al. 1943), it can be calculated that the amount required for intravenous nutrition is only 120–150 μg (about 3 μmol/d). However, apart from contamination of parenteral nutrition fluids with Mn (Jetton et al. 1976; Hankins et al. 1979; Phillips & Garnys, 1981; Kurkus et al. 1984) the additional supplementation of Mn from commercial trace element ampoules (e.g. Adamel, Kabi Vitrum) may provide an additional 40 μmol/d, which is about half the normal oral intake. In patients on long-term parenteral nutrition the plasma Mn concentration is related to the quantity of added Mn; the mean value for those receiving 20 μmol/d is greater than that for those receiving <20 μmol/d. The highest plasma levels, which may be up to tenfold greater than the upper limit of...
normal, occur in patients receiving the highest supplemental dose (about 40 μmol/d), as reported by Shenkin et al. (1986). High levels are particularly likely to occur in patients with hepatobiliary disease, since Mn is mainly excreted in bile. If excessive Mn is infused over prolonged periods of time, possible toxicity from an overload syndrome might be anticipated, by analogy with the chronic Fe overload syndrome.

The first report of Mn toxicity from excess parenteral intake was that of Couper (1837). This did not involve intravenous administration of Mn but its inhalation by subjects working in Mn mines. Several subsequent reports confirmed and extended the information about Mn toxicity (Mena et al. 1967; Cotzias et al. 1968; Mena, 1981). In Chile, where Mn was actively mined, the symptoms were referred to as 'locura manganica', or 'manganic madness'. They consisted of behavioural and psychomotor symptoms (Mena et al. 1967; Mena, 1981), including a type of Parkinson's disease which is normally associated with damage to the basal ganglia in the brain.

Recent studies have shown that administration of excess Mn to monkeys, either by inhalation or intravenously, leads to abnormal magnetic resonance imaging (MRI) brain scans (Newland et al. 1989). The abnormalities were particularly prominent in the region of the basal ganglia, which had been shown previously to be depleted of dopamine and serotonin as a result of excess Mn administration (Bird et al. 1984). The monkeys also exhibited behavioural abnormalities with the higher cumulative doses. Prospective studies in patients on long-term parenteral nutrition (with a supplemental Mn intake of only about 6 μmol/d and an uncertain additional contamination of parenteral nutrition solutions) have also implicated Mn in an overload syndrome. In one prospective study of nine patients, five of whom had neurological symptoms (either due to the underlying disease, or to other factors such as possible Mn toxicity), striking abnormalities due to the presence of a paramagnetic substance were obtained from the basal ganglia, especially the globus pallidus, and subthalamic nuclei (Mirowitz et al. 1991; Mirowitz & Westrich, 1992). One patient who had the typical abnormalities on the MRI scans, after receiving parenteral nutrition for 3 years, showed resolution of the abnormalities during the subsequent year when Mn was removed from the regimen whilst the other constituents remained unaltered (Mirowitz & Westrich, 1992). Abnormalities in the basal ganglia have been demonstrated in MRI scans in patients with liver disease. Since Mn is almost exclusively excreted in bile, it is possible that some of the abnormalities may be due to Mn (Inoue et al. 1991). These observations as well as others relating to other trace elements (e.g. Al toxicity in renal dialysis patients) emphasize the potential problems of bypassing the gut, and the need to have strict and sound regulatory processes that prevent trace element mixtures intended for intravenous nutrition from becoming available commercially.

CONSEQUENCES OF CONTINUOUS 24 H FEEDING

The common practice of infusing nutrients continuously over 24 h, either nasogastrically or intravenously, may have important biochemical and clinical consequences. An insight into these effects can be obtained by considering essential fatty acid deficiency. This was first described in rats by Burr & Burr (1929), and biochemical evidence for its existence in children was obtained in the 1950s (Hansen & Wiese, 1954; Wiese et al. 1954; Adam et al. 1958; Hansen et al. 1958), when diets deficient in essential fatty acids were administered. The first report of essential fatty acid deficiency in adults was that of
Collins et al. (1971). This report described the biochemical and clinical features in two adults, one of whom had received parenteral nutrition. Several reports followed in subjects given fat-free parenteral nutrition (e.g. Paulsrud et al. 1972), partly as a reaction to the earlier experiences of toxicity from cotton-seed oil and other intravenous fats (Wretlind, 1992).

The development of essential fatty acid deficiency is likely to arise much earlier during continuous fat-free feeding than during intermittent fat-free feeding (Wene et al. 1975). During continuous fat-free feeding the percentage contribution of the essential fatty acid linoleic acid to total fatty acid concentration in various circulating lipid fractions (triacylglycerols, phospholipids, free fatty acids) decreases severalfold within a matter of only a few days to 1 week (Wene et al. 1975). The availability of free non-esterified linoleic acid may decrease even more because the total circulating concentration of non-esterified fatty acids decreases as a consequence of hyperinsulinaemia, which is associated with high-carbohydrate (fat-free) feeding. Apart from the major reduction in the availability of linoleic acid, the other classic biochemical stigmata of essential fatty acid deficiency, including an increase in triene:tetraene, develop within only a few days to 1 week (Wene et al. 1975). However, there is an apparent paradox because a man with about 15 kg fat has about 1-5 kg linoleic acid which is sufficient to supply the essential fatty acid needs of the body for about a year. Why then should biochemical evidence of essential fatty acid deficiency occur within 1 week? There is another apparent paradox: the absence of dietary intake during prolonged experimental starvation in man has not resulted in essential fatty acid deficiency.

These observations can be reconciled by considering the availability of fatty acid from adipose tissue. During starvation, adipose tissue releases various fatty acids including essential fatty acids, and their circulating concentration increases (Gray et al. 1991). There is, therefore, no shortage of essential fatty acids during starvation. In contrast, fat-free feeding (high-carbohydrate feeding) suppresses the release of fatty acids by adipose tissue; and if the feeding is continuous, the suppression is also continuous. Therefore, in this situation there is deficiency in the midst of plenty. In the subjects studied by Wene et al. (1975) a single day’s starvation after 7 d fat-free feeding was sufficient to double the percentage contribution of linoleic acid to some circulating lipid fractions (the actual increase of free linoleic acid is likely to be even greater because the circulating concentration of non-esterified fatty acids (NEFA) increases during starvation). Furthermore, when the 1 d period of starvation was followed by intermittent fat-free feeding, the percentage contribution of linoleic acid to the total fatty acid content of various circulating lipid fractions did not decrease, presumably because adipose tissue was intermittently releasing its fatty acids that were stored as triacylglycerols.

The mode of feeding (continuous instead of intermittent) has potential as a therapeutic strategy in patients with disease. For example, changes in the composition of membrane lipids, produced by feeding diets of specific fatty acid composition, can modify the metabolic response to injury and endotoxin in animals and man (e.g. Cook et al. 1981; Kinsella et al. 1990; Pomposelli et al. 1991; Grimble, 1992), and alter mortality in animal studies (e.g. Mascioli et al. 1989), presumably by mediating prostaglandin and leukotriene synthesis, and modifying the activity of membrane receptors such as the insulin receptor, as suggested by a recent study of insulin resistance in man (Borkman et al. 1993). However, the problem is the time required to achieve changes in the composition of membrane lipids. Intermittent feeding may take more than 2 weeks, or even months,
to produce major and significant changes in membrane composition. This is because of
the large 'buffering' effect of adipose tissue which takes up fatty acids part of the time
and releases its own endogenous fatty acids (stored as triacylglycerols) the other part of
the time. On the other hand, recent studies suggest that continuous 24 h feeding can
produce major changes in the composition of membrane lipids of animals and man within
a few days to 1 week (Adams et al. 1993; Palombo et al. 1993). This means that it may
become possible to modify the response to stress by beginning a short period of
continuous feeding (using formulas of specific fatty acid composition) before an elective
form of stress (e.g. elective surgery), or even after an injury has occurred.

MISSING NUTRIENTS

The concept that deficiency of nutrients can occur in the midst of plenty is not restricted
to adipose tissue. For example, Rudman et al. (1975) provided a high-energy intravenous
feeding regimen to depleted patients with and without phosphate. In the presence of
phosphate the subjects were in substantial positive N balance. When phosphate was
removed from the feed for a period of 6 d the N balance became negative. On
reintroduction of the phosphate the N balance became positive again. During the
intermediate period, the phosphate present within lean tissues was not available for
synthesis of new tissue, and the circulating phosphate concentration decreased, partly as
a result of hyperinsulinaemia, which favours uptake of both glucose and phosphate into
cells (Sitrin & Wood, 1983). Reductions in circulating phosphate concentrations have
also been implicated in causing sudden death (Weinsier & Krumdiek, 1981) from cardiac
causes and in adversely affecting skeletal muscle function to the extent that they
precipitate respiratory failure, making artificial ventilation necessary (Newman et al.
1977). However, for decades clinicians who have administered peripheral fluids lacking
in phosphate have not been troubled by such problems, presumably because lean tissue
breakdown releases phosphate and increases its availability. On the other hand during
intravenous phosphate-free feeding of malnourished patients, who have marked anabolic
potential, important clinical problems may occur, especially when the pharmacist or
clinician forgets to add phosphate to those commercial intravenous feeds that lack it.

Another example of how dietary manipulations can affect substrate availability
involves amino acids during the feeding–fasting transition (Ozalp et al. 1972). For
example, diets lacking in individual essential amino acids such as isoleucine do not result
in a significant change in circulating isoleucine concentrations after an overnight fast,
presumably because the missing amino acids are released from lean tissues. However,
abnormalities become strikingly apparent in the fed state. Although under normal
circumstances the concentration of isoleucine increases 30–40% after a meal, adminis-
tration of an isoleucine-free meal results in a severalfold reduction in its circulating
concentration (Ozalp et al. 1972).

Such observations would seem to have little clinical significance because general
purpose commercial amino acid formations include all the essential amino acids.
However, in clinical practice the distinction between essential and non-essential amino
acids is not always clear. Some of the amino acid solutions used in parenteral nutrition
lack tyrosine and cystine/cysteine, partly because of their poor solubility/instability, and
partly because of the belief that they can be synthesized in adequate quantities from their
precursors (tyrosine from phenylalanine, and cysteine from methionine), which are
included in the amino acid mixtures. Indeed, administration to normal subjects of solutions containing phenylalanine and no tyrosine or methionine and no cystine results in an increase in the plasma concentration of all these amino acids. However, administration of such solutions to some patients with liver disease may result in a marked reduction in the plasma concentration of tyrosine (and cystine) to values below normal, in association with an exaggerated rise in the plasma phenylalanine (and methionine) concentration (Rudman et al. 1981). In this situation there seems to be a metabolic block in the conversion of phenylalanine to tyrosine and possibly methionine to cystine. Thus, when tyrosine plus cystine were added to the parenteral feed of these depleted patients with cirrhosis, the N balance, which was persistently close to zero before the addition, became markedly positive. It seems that tyrosine and/or cystine could not be synthesized in adequate quantities from their precursor amino acids as in normal subjects and, therefore, they had become conditionally essential.

Arginine is another amino acid that is normally classified as non-essential for man, although in some circumstances it may become conditionally essential. In carnivores it has long been classified as an essential amino acid. Indeed, a single meal lacking in arginine, which is a urea-cycle intermediate, may be sufficient to cause death in cats within 1–4 h (MacDonald & Rogers, 1984; Anon, 1985; Rogers & Phang, 1985). This is associated with a rise in blood NH₃ concentration which is toxic, decreased excretion of urea which is partly replaced by orotic acid, and low hepatic concentrations of urea-cycle intermediates (arginine, citrulline and ornithine). Administration of arginine, citrulline and ornithine can prevent or correct the metabolic defect and symptoms. Thus, the absence of dietary arginine impairs the activity of the urea cycle and, therefore, results in decreased urea production, whilst the plasma NH₃ concentration rises to toxic levels. Some of the excess NH₃ is channelled towards synthesis of orotic acid which is excreted in increased quantities.

In the fasting state arginine is available from breakdown of lean tissues, but in the fed state (after an arginine-free meal) it becomes ‘trapped’ in peripheral lean tissues and, therefore, is unavailable for the urea cycle which operates in the liver. Other urea-cycle intermediates such as ornithine can compensate for this defect, but in the cat the activity of the enzyme responsible for the synthesis of ornithine from glutamate, a process which occurs in the gut, is very much weaker than that in several other mammals (MacDonald & Rogers, 1984; Anon, 1985; Rogers & Phang, 1985).

Administration of some commercial amino acid solutions deficient in arginine to some babies (prematurity is more likely to be associated with immature enzyme systems) who could not synthesize sufficient arginine (or other urea-cycle intermediates) endogenously resulted in a biochemical profile similar to that of the cat (Winters et al. 1983). The abnormalities were reversed by adding arginine to the parenteral feed. Since these studies the composition of intravenous feeds has changed to take into consideration the potential problems of arginine deficiency.

**PRECURSOR SUBSTRATES**

The absence of arginine in some of the early commercial intravenous amino acid solutions was not due to pharmacological constraints, but to a conceptual problem based on the erroneous belief that arginine can always be synthesized in sufficient quantities by
the human body to meet requirements. However, for other nutrients there are pharmacological constraints. For example, tyrosine is poorly soluble and glutamine is unstable. Heat sterilization quickly destroys glutamine, which explains why all commercial intravenous amino acid solutions lack free glutamine (Elia, 1992). The amounts of Ca and phosphate that can be added to parenteral nutrition solutions are also limited because of the potential problems of precipitation of CaP04, especially in the intravenous feeds of growing babies who have high requirements for these nutrients and who, at the same time, are fluid-restricted because of their clinical condition. These problems may be overcome by administering precursor substrates that are stable, soluble and less likely to interact with other feed constituents. Phosphate has been administered as organic phosphate (glucose phosphate, fructose phosphate, fructose biphosphate, glycerol phosphate; for example, see Hanning et al. 1991) because this does not precipitate with the Ca that is also present in the feed. Once it is within the body it is hydrolysed to yield free phosphate. Indeed, the routine use of such organic phosphate has proved effective. Tyrosine, cystine and glutamine may be given as components of synthetic dipeptides or as acetyl derivatives of amino acids (e.g. glycyl-tyrosine, n-acetyl-tyrosine, alanine-cystine, alanine-glutamine, glycy1-glutamine, n-acetyl-glutamine) which are hydrolysed within the body to release their constituent amino acids. In this way feeds that were lacking or deficient in specific amino acids may now include them in large quantities. For example, glutamine has become the dominant amino acid in some recent clinical trials involving parenteral nutrition (Ziegler et al. 1993).

NUTRITION OR PHARMACOLOGY?

The practice of clinical nutrition has introduced unphysiological and unconventional approaches to feeding (e.g. bypassing the gut, continuous instead of intermittent feeding and unusual combinations and quantities of individual nutrients). This raises the question of whether nutritional support should be regarded as a form of pharmacology. Support for this concept comes from the inclusion of drugs and bioactive substances in the nutrition regimen, in an attempt to improve utilization of nutrients and improve tissue structure and function. Some experience has been obtained with human bioactive recombinant proteins that may have general effects (e.g. growth hormone, insulin-like growth factors) or more specific effects (e.g. erythropoietin which stimulates haemoglobin synthesis). Growth hormone and insulin-like growth factors (IGF), either alone or in combination, have been used in an attempt to improve N balance in a variety of states in which catabolism and/or malnutrition are likely to occur. e.g. low-energy dieting, elective surgery, corticosteroid-induced catabolism, burns, AIDS and chronic obstructive airways disease (Manson & Wilmore, 1986; Dahn et al. 1988; Snyder et al. 1988; Belcher et al. 1989; Jiang et al. 1989; Horber & Haymond, 1990; Chwals & Bistrian, 1991; Pape et al. 1991; Kupfer et al. 1993; Mjaaland et al. 1993). The use of such agents in normal subjects can result in positive N balances in the face of a negative energy balance (Manson & Wilmore, 1986; Kupfer et al. 1993), a situation which is very unusual. The link between fat and lean tissue accretion, therefore, can be broken and manipulated. Furthermore, recent reports, which suggest that the use of such agents results in improved muscle strength after surgery (Jiang et al. 1989), improvement in respiratory muscle function in patients with chronic obstructive airways disease (Pape et al. 1991), and improvement in intestinal function in patients with the short bowel syndrome (in this
case growth hormone in conjunction with glutamine and fibre; Byrne et al. 1992), are of immense clinical interest.

The clinical use of recombinant human erythropoietin emerged from the severe anaemia associated with end-stage renal failure. The commonest cause of this anaemia, especially in the absence of AI toxicity, is lack of erythropoietin, which is produced by the kidney. Since erythropoietin stimulates the impaired erythropoiesis of end-stage renal failure, its administration might be expected to improve the anaemia and result in clinical benefit. There is usually no shortage of available Fe in end-stage renal failure, especially in patients who have had recurrent transfusions, but there is a problem with Fe utilization as a result of a lack of an erythropoietic stimulus. Several clinical trials with recombinant human erythropoietin have now been undertaken (Winearls et al. 1986; Eschbach et al. 1987; Rao et al. 1993), including a large multicentre study (Eschbach et al. 1989). All these show improvement in haemoglobin and packed cell volume, which may change from about 0.22 to about 35 (Eschbach et al. 1989). The dose of erythropoietin required to produce the same effect in different patients varies (Eschbach et al. 1989; Rao et al. 1993) depending on the extent of myelofibrosis (Rao et al. 1993), which effectively reduces the available space for erythropoiesis. However, one of the benefits of this form of therapy is the major reduction in transfusion requirements. Indeed, it has been estimated that the routine use of erythropoietin in end-stage renal failure will result in a financial saving of 0.5 million units blood/year in the USA. At the same time it will reduce hospitalization, reduce the risk of infection associated with the administration of blood (e.g. HIV) and reduce the risk of Fe overload. As far as the patient is concerned administration of erythropoietin results in improved quality of life (Karnofsky Scale and Nottingham Health Profile, and subjective feelings of activity level and energy level; Eschbach et al. 1989). The results of a study by the Canadian Orthopedic Perioperative Erythropoietin Study Group (1993) in patients undergoing hip replacement suggest that erythropoietin (administered for 1 week before and 4 d after surgery) can significantly reduce the incidence of postoperative anaemia (46% v. 23% with haemoglobin <80 g/l) and the percentage of patients requiring blood transfusions (26 v. 3). It is clear that there is likely to be a need for large-scale production of recombinant bioactive human substances, so that they will become more readily available for clinical use.

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