

ENTERAL NUTRITION FOR THE SURGICAL PATIENT

by

KIRSTEN EICH

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Department of Foods and Nutrition

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Approved by:

*Beth Fryer*

Major Professor

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## INTRODUCTION

The beginnings of enteral nutrition (tube feeding) go back to the end of the 16th century when the gastrointestinal tract (GI tract) was first reported to be used for feeding via tube. Since then advances in enteral nutrition (EN) have occurred periodically throughout history (1). In 1858 Busch used direct intrajejunal feeding to support a malnourished patient in the preoperative state and in 1878 the first jejunostomy was performed (2). Between 1930 and 1950 jejunostomy feedings had their greatest use as gastrectomy was being performed extensively for patients with cancer and peptic ulcer, even if they were dehydrated and/or malnourished. The importance of hypoproteinemia and malnutrition on postoperative morbidity and mortality had already been established. In the 1950s when intravenous therapy (parenteral nutrition) became safe and familiar to the surgeon, the interest in enteral nutrition decreased (2).

Total parenteral nutrition (TPN) consists of feeding a person totally by infusing nutrients directly into the blood. It has been widely used since its introduction in the early 1970s. However, administration of TPN is technically demanding and expensive, so that the possibilities of enteral nutrition have been rediscovered in the last few years. New technologies and formulas have been

found, and enteral nutrition has become more and more important in the nutritional support system (2,3).

During the last 5 to 10 years, various studies have provided new information about the use of EN for the surgical patient. In general, the well-nourished and otherwise healthy patient has sufficient body fuel reserves to withstand an uncomplicated major surgical procedure. However, adequate nutritional support may become very important for those preoperative surgical patients who are chronically debilitated from their disease or malnourished, or for those patients who cannot maintain adequate caloric and protein intake because of drastically increased metabolic demands caused by trauma, infections and surgical complications (4,5). Furthermore, central depression of the appetite center may occur in those patients and worsen their nutritional situation (4). Therefore, special tube feeding techniques and EN formulas are needed in such situations.

In this report the metabolic changes that occur in the postoperative period will be reviewed. The advantages and disadvantages of using EN to provide energy and nutrients to the surgical patient in the postoperative or posttraumatic phase during recovery also will be discussed.

### BASICS OF ENTERAL NUTRITION

In specific illnesses, EN is used as nutritional support to avoid malnutrition in the patient. Grant (6) has defined malnutrition as "the state induced by alterations in dietary intake resulting in changes in subcellular, cellular and/or organ function which expose the individual to increased risks of morbidity and mortality and which can be reversed by adequate nutritional support". To reduce the number of complications and rates of infections, as well as to improve wound healing and speed recovery in general, sufficient nutritional support is necessary.

EN is defined as the provision of liquid formula diets by tube or mouth into the GI tract (7). This method of nutritional support is preferred over TPN if the gastrointestinal tract can be used safely and effectively (presence of intestinal function and absence of conditions of dysfunction). If oral nutrient intake is inadequate, the use of a feeding tube will become essential.

#### Tube Feeding Techniques

A variety of tube feeding techniques are available for enteral nutrition support including nasogastric and nasojejunal feeding techniques as well as esophagostomy, gastrostomy and jejunostomy (Fig 1.)

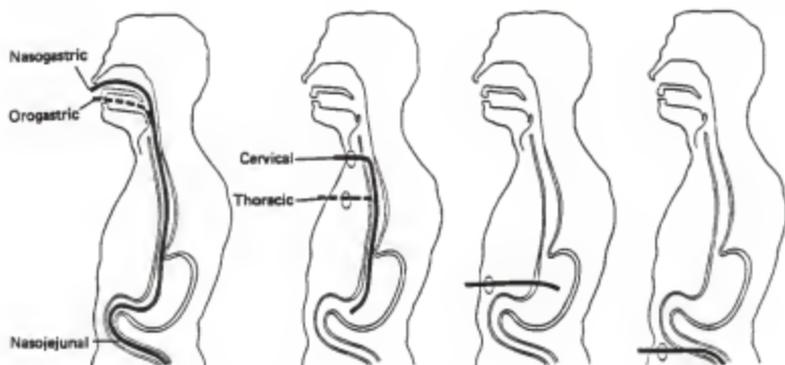


FIGURE 1 Various tube feeding techniques (8).

Nasogastric tube feeding. Intubation by the nasogastric route is the simplest and most commonly used technique. Soft, small-bore, plastic or silastic catheters which are well tolerated by patients have been developed. In combination with a larger tube (e.g. Levin tube), the feeding tube is passed through the nose into the stomach or through the pylorus into the upper small bowel (extra length and weighted end needed). The larger tube is then withdrawn leaving the smaller feeding tube in place (9). The risk of aspiration which may result in pulmonary complications is minimized when the feedings are given by pump or drip and the tube is passed beyond the pylorus into the upper jejunum (4,10).

Pharyngostomy and Esophagostomy These two techniques are used for patients undergoing major oropharyngeal surgical procedures for trauma, tumor removal, or correction of congenital maxillofacial anomalies (4). The tip of the tube is inserted into the pharynx through a small skin incision and then directed down the esophagus into the stomach (11). The tube can be retained for a long time period since the tubes are well tolerated (9).

Gastrostomy Gastrostomy is an excellent method for feeding patients with obstructing lesions of the head, neck and esophagus and also is applied in gastric decompression. Either a temporary serosa-lined tube (Stamm or Witzel gastrostomy) or a permanent mucosa-lined tube (Depage-Janeway gastrostomy) can be constructed (9).

Jejunostomy Early jejunostomy techniques such as the "Witzel" jejunostomy or the "Stamm" jejunostomy have long been used in surgical practice. A recent modification of the "Witzel" jejunostomy which combines the advantages of simplicity and safety is the needle catheter jejunostomy (NCJ) introduced by Delany and colleagues in 1973 (12). As shown in Fig.2 a loop of the proximal jejunum is isolated and a seromuscular suture is placed on the antimesenteric border of the intestine. Then a fine needle and an

intravenous catheter are passed through the wall of the intestine before being placed in the lumen. Feeding may be started immediately after closing the abdomen.

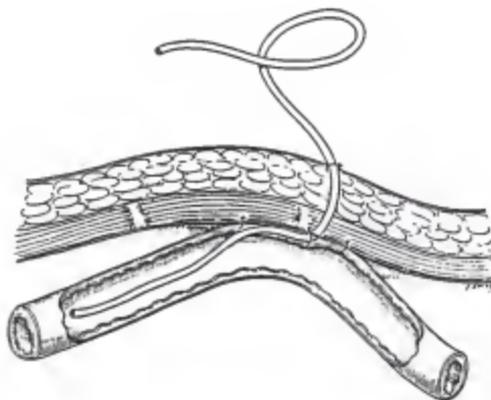


FIGURE 2 The needle catheter jejunostomy (12).

NCJ is recommended for use in cases of surgery on the esophagus, stomach, liver or pancreas, if postoperative chemotherapy or radiotherapy is planned or under the circumstances of a second laparotomy or laparotomy for multiple trauma (2). Jejunostomy also might be a good alternative for selected patients on long-term enteral tube feeding or for patients with extensive lung disease when morning vomiting often occurs after prolonged coughing (13).

Gastrostomy Versus Jejunostomy. The advantage of feeding by gastrostomy over feeding by jejunostomy is that relatively large boluses can be administered. A greater tolerance to the diets (e.g. osmolarity) can be shown due to the reservoir and mixing function of the stomach and the total small bowel absorptive surface can be used (2). However, the risk of gastro-esophageal reflux and aspiration is greater with gastrostomy than with jejunostomy, but pulmonary infection is less common with a gastrostomy than with a nasogastric tube (14). Gastric atony, stomal inflammation and stasis can occur due to gastrostomy so that jejunostomy should be the preferred technique in upper abdominal operations. A combination of gastrostomy (for gastric decompression) and jejunostomy (nutritional support) may be used in the early postoperative state (2).

Recent technological advances have led to the development of percutaneous endoscopic gastrostomy (PEG) or jejunostomy, which can be carried out under local anaesthesia (12). Various studies demonstrated that PEG is safer, faster and much less expensive than operative gastrostomy (15-17).

### METABOLISM IN SURGICAL PATIENTS (POSTAGGRESSION METABOLISM)

Metabolic and hormonal changes which occur in the surgical patient as a response to injury are a dynamic process. The metabolic response which is activated by an aggression (traumatic event), tends to be highest at 48 to 72 hours postinjury and diminishes during the next 3 to 4 days (18,19). A complication (usually infectious) can occur when the response continues. If the response is controlled, it again abates. However, organ failure can lead to death (Fig. 3).

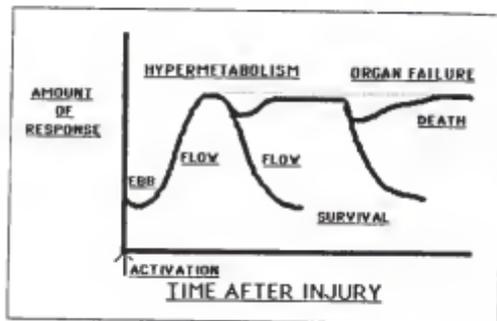


FIGURE 3 The time course of the hypermetabolism and organ failure response (19).

The activating events (e.g. dead or injured tissue, infection, severe perfusion) are translated into a metabolic response by the mediator system which consists of three major components: the central nervous system (CNS), the

endocrine system, and the cell-cell mediator system (18,19). Effects of mediators on metabolic pathways, following trauma or starvation are summarized in Table 1.

TABLE 1

Effects<sup>1</sup> of mediators on metabolism (modified from 19).

Characteristics	Trauma	Starvation
Resting energy expenditure (REE)	++	-
Respiratory Quotient (RQ)	0.8 - 0.85	0.7
Primary fuel	mixed	fat
Proteolysis	+++	+
Protein synthesis - hepatic	+++	+
- total body	--	-
Amino acid oxidation	+++	+
Ureagenesis	+++	+
Gluconeogenesis	+++	+
Ketone production	+	++++
Rate of development of malnutrition	+++	+

<sup>1</sup> - = effects reduced; + = effects increased

Starvation adaptation with lowered "stress hormone" levels occurs when hormonal alterations associated with the onset of metabolic stress abates (20). The hormonal milieu during the postoperative period favors proteolysis, hepatic protein synthesis, amino acid oxidation, ureagenesis and glucogenesis (19).

Due to the metabolic alterations, the energy expenditure in the surgical patient is increased in relation to the severity of injury or major trauma (Table 2).

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TABLE 2

Alterations in energy expenditure due to metabolic stress  
(modified from 21)

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Stress level	Energy expenditure (BEE) <sup>1</sup> (kcal/kg body wt/d)
normal	25 - 30
moderate catabolism (trauma, burns I and II degree, postoperative phase, infection)	40 - 50
high catabolism (severe trauma and major surgery, burns III degree, sepsis)	50 - 85

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<sup>1</sup>BEE = Basal Energy Expenditure

However, loss of body weight is not only due to the hypermetabolic state of the traumatized patient but occurs as the sum of changes in fat, protein and water (22). The body composition of a normal individual (70 kg man) is given in Fig. 4.

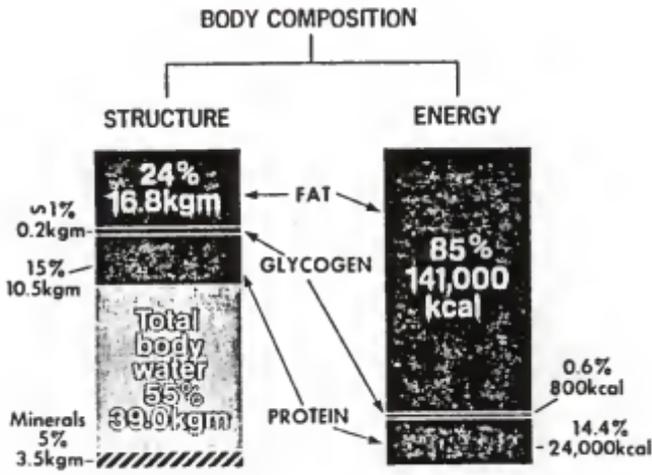


FIGURE 4 Body composition may be viewed as structure that has the potential for conversion to energy. The traumatized patient, during the acute phase, has an expanded glucose space and converts protein into glucose. As starvation adaptation occurs, the large potential source of energy, fat, becomes the primary source of energy (20).

### Energy Metabolism

Protein catabolism is one of the major problems occurring in the postoperative state since it causes decreased wound healing and a higher infection risk. Independent of the severity of injury, the nonprotein calorie to N ratio is 100:1 (19). Body protein (38% of the organic material) has various functions with different turnover rates (Table 3).

The fundamental metabolic response to injury in reference to the protein metabolism is the translocation of amino acids (AAs) from muscle to viscera (23) which varies with the nutritional state, level of muscle activity and hormonal status (24). The rapid and progressive loss of body protein after major trauma can be tremendous (>30 g N/d) and is mainly derived from muscle tissue. This can be supported by clinical observations as well as by experimental data. The postoperative increase in urinary 3-methyl-histidine excretion reflects the increased rate of muscle catabolism and posttraumatic hypermetabolism (23-26). In addition to catabolic losses, erythrocyte and plasma protein (35-40 g/l blood) can be lost directly due to hemorrhage and wound exudates (23).

TABLE 3

Categories of protein in the human body (modified from 22).

% of TBP <sup>1</sup>	Characteristic	Turnover rate
45	supporting structure	slow
40	muscle protein	intermediate
15	visceral	high

<sup>1</sup>TBP = total body protein, 38 % of the organic material.

The branched chain amino acids (BCAA) are of high interest in postoperative metabolism, since they can be oxidized extrahepatically without intervention of glucose and, thus, serve as a fuel source primarily for the skeletal muscle as substrates for gluconeogenesis through alanine and glutamine (N-sparing effect) and are one factor in the regulation of muscle protein degradation and synthesis (26,27). The first breakdown products of the BCAA are their keto acids (BCKA), which show highest serum levels after a fasting period of 60 hr. The nitrogen-sparing effect of the BCKA, especially of  $\alpha$ -ketoisocaproic acid, which was demonstrated in 21 patients undergoing a 72-hr fasting period after major abdominal surgery, may be related to the

increased ketosis, to suppression of protein degradation, or to an effect on liver protein turnover. Serum glucagon and  $\beta$ -hydroxybutyrate levels increased and glucose concentration decreased (28).

Injury results in marked hormonal changes during the initial phase of recovery, depending on the severity of surgery, type of trauma and other factors (hypoxia, sex, age). These alterations include suppression of insulin secretion and/or increase in insulin resistance, as well as an increase in catecholamines, glucocorticoids and glucagon, so that the postoperative hormonal environment is a stimulus to glycogenolysis, gluconeogenesis and lipolysis (20,27). Thus, the peripheral substrate release is increased. There is an accelerated uptake of alanine and lactate by the liver, and their conversion to glucose is favored. The increase in hepatic gluconeogenesis, which largely depends on the peripheral amino acid release, is associated with an elevated output of glucose from the liver and results in hyperglycemia. Besides increased hepatic gluconeogenesis, both oxidative and nonoxidative glucose metabolism and turnover rate of glucose are elevated (22). Amaral et al. (29) observed that wounded tissue can oxidize lactate in a dose dependent manner and may substitute it for glucose.

Not only during starvation but also in the postoperative period most of the energy is provided from endogenous fat sources. Indirect calorimetry in surgical patients who did not receive any nutritional support indicated that 75-90% of the caloric needs are met by the oxidation of fat which also is expressed in a low RQ (18,22). Due to the increased mobilization of free fatty acids from adipose tissue and uptake by the liver, the blood ketone body concentration is expected to be higher than normal, since ketone bodies are formed by partial oxidation of these free fatty acids. However, depending on the nutritional status, those fatty acids can also be esterified to triglycerides, so that hyperketonemie does not occur in all surgical patients. In comparison to the normoketonemic group, hyperketonemic patients have slightly increased levels of blood fatty acids and lower levels of blood glucose and insulin but a higher glucose/insulin ratio. It was suggested that higher insulin levels in the normoketonemic patients inhibit mobilization of stored fat (30).

Fig. 5 shows the changes in liver metabolism after major surgery in 14 patients with alcoholic cirrhosis. Due to an increased metabolic rate, the liver releases a higher amount of glucose and ketone bodies to the bloodstream

during the postoperative period. The sum of the caloric value of glucose and ketone bodies is raised from 638 kcal/d/1.73m<sup>2</sup> to 793 kcal/d/1.73m<sup>2</sup>, which is an increase of 26% (31).

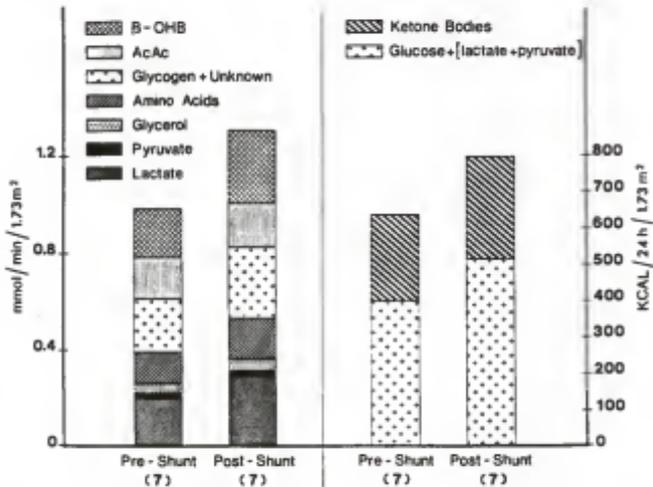


FIGURE 5 Net glucose and ketone body release rates, gluconeogenic precursor extraction rates, and caloric equivalents in cirrhotic patients before and after portosystemic shunting following an overnight fast (31).

### Changes in GI Functions after Surgery

A major problem after abdominal surgery is the occurrence of the postoperative "ileus" which was believed to obstruct the whole GI tract. However, it now has been proven that small bowel function is not impaired after surgery so that postoperative feeding is possible immediately when the stomach is bypassed. The diet can be infused directly into the small intestine either using a nasojejunal tube or performing a NCJ or PEJ. After 3 to 5 days when the stomach and colon have regained function, oral feedings may be started (32,33).

## ENTERAL FORMULATIONS

### Types of Diets

Besides choosing the right feeding technique, it is also very important to administer the enteral diet which is most beneficial for the patient. Today a multitude of enteral formulas are available commercially which can be classified into one of 4 major categories (Table 4).

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TABLE 4

Categorisation of enteral diets (modified from 34).

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Type	Comment
1. Polymeric diets	Whole protein N-source: for use in patients with normal or near normal GI function
containing fiber	indications are still under investigation
2. Elemental diets	Predigested chemically defined: most diets have a low fat content for use in patients with severely impaired GI function
3. Specially formulated predigested diets	Indications are still disputed
4. Nutrient modules	

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Polymeric diets. These are nutritionally complete formulas containing whole protein as a nitrogen source, and complex carbohydrates and fat as energy sources. They have wide application in enteral nutrition support in patients with normal GI functions (3). Indications for polymeric diets with additional fiber content are still under investigation (35).

Elemental formulas. These formulas were first developed to be used by astronauts on prolonged space voyages because of storage, ingestion and disposal problems (36) The so called "space diets" were formulated synthetically out of known predigested nutritional compounds. Since these nutrients can be individually added, predefined mixtures can be produced which today are known as "chemically defined" diets and widely used for nutritional support in patients with particular absorption problems.

Special enteral formulations. Predigested diets have been created for nutritional support in certain specific diseases, like hepatic insufficiency, acute renal failure and severe states of metabolic stress. Depending on the disease in which enteral feeding is used, the formulas are rich in branched-chain amino acids and low in aromatic amino acids (cirrhosis, portosystemic encephalopathy), or rich in essential amino acids (renal failure) or may contain more

than 1 kcal/ml (metabolic stress) (3,34).

Nutrient modules. Formulas of protein, carbohydrate, fat (corn oil), medium chain triglycerides (MCT oil), trace minerals and vitamins are available commercially. They can be formulated for the individual needs of each patient or be given as supplements to oral intake as well as to other enteral diets (3).

### Ingredients of Enteral Diets

Carbohydrates. Polymeric diets contain complex carbohydrates, whereas chemically defined diets contain predigested carbohydrates so that the carbohydrate source is the reason for the usually higher osmolality seen in chemically defined diets.

Hyperosmolar diets have been proposed as a cause of diarrhea and abdominal discomfort. Therefore in some formulas, glucose and disaccharides are replaced by hydrolysed corn starch which consists of a very heterogenous mixture of glucose polymers.

The intestinal absorption and mucosal hydrolysis of a partial and a complete  $\alpha$ -amylase hydrolysate of corn starch were studied in normal human volunteers in the absence of luminal  $\alpha$ -amylase activity, using a steady state jejunal perfusion technique (37). The higher molecular weight

fraction of the partial amylase hydrolysate of corn starch (containing >10 glucose molecules) was more slowly hydrolysed than was the lower molecular weight fraction. Since the glucose uptake from the partial starch hydrolysate was not significantly different from that of free glucose, Jones et al. (37) suggested that the slower absorption rate of the high molecular fraction was counterbalanced by maltose and the oligosaccharides in the 3-10 glucose molecule range. The hypothesis that low molecular weight oligosaccharides confer a kinetic advantage on glucose absorption was confirmed in a later experiment, when glucose was absorbed faster from the complete amylase hydrolysate than from free glucose (Table 5). But only the 1-4 linked oligosaccharides were absorbed from the jejunum more efficiently than glucose since hydrolysis was the rate limiting factor for 1-6 linked oligosaccharides.

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TABLE 5

Glucose absorption (mmol/h/25 cm  $\pm$  SEM) (37).

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Partial amylase hydrolysate of starch vs 140 mM glucose	Complete amylase hydrolysate of starch vs 140 mM glucose
60.8 $\pm$ 3.8	81.8 $\pm$ 4.8
vs	vs
53.3 $\pm$ 5.6	55.8 $\pm$ 4.9

---

The advantage of using glucose polymers was shown by McArdle et al. (38). After replacing a 25% dextrose solution with a glucose polymer solution consisting of 50% polyose, the osmolarity decreased from 1,750 mosmol to 800 mosmol. The enteral feeding solution then was tolerated well by all patients. The osmolarity of some carbohydrate substrates commonly used in enteral nutritional formulas are reviewed in Table 6.

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TABLE 6  
Osmolalities of carbohydrate substrates (33)

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Substrate (100 g/kg H <sub>2</sub> O)	Osmolality (mosmol/kg) (freezing point depression)
Glucose	569
Maltose	270
Caloreen <sup>1</sup>	92
Polycose <sup>1</sup>	116
Maxijoule <sup>1</sup>	111
Maltodextrins (Vivonex) <sup>1</sup>	104
>G10 polymer mixture	18

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<sup>1</sup>Partial amylase hydrolysate of starch

Caloreen is a starch hydrolysate and consists of a 1-4, 1-6 glycosidically linked  $\alpha$ -D-glucose polymer mixture with a minority of 1-6 branch points (37).

In Blacks, Orientals, Indians and other racial groups lactase deficiency occurs in up to 60-100%. Lactase deficiency results in a reduced lactase ( $\beta$ -galactosidase) activity which is seen only in 5 - 15% of the white European or American population. However, illness or gastric resection results in unphysiological high stress for the small intestine. In such cases people who originally have not suffered from lactase deficiency can become temporarily or even permanently lactose intolerant (39). The main GI side effect due to lactose deficiency is diarrhea (40). Ingested lactose cannot be hydrolysed to glucose and galactose when the activity of the  $\beta$ -galactosidase is reduced so that the unabsorbed lactose then occurs in lower parts of the intestine. Due to the microbial activity lactose is broken down to carbon dioxide, lactic acid and acetic acid leading to a higher osmotic pressure. The water secretion and increased peristalsis then will cause diarrhea (39).

In malnourished black lactose intolerant patients, a lactose-containing enteral diet was bolus fed and caused GI complications (mainly diarrhea and abdominal cramps) in 50% of the patients on a half-strength diet and in 94% of the

patients on a full-strength diet (150g lactose/2000ml/day) (40). However, no symptoms were developed in patients with lactase deficiency when the lactose-containing diet was constantly infused (nasogastric tube) over 24 hours (20.9 + 5.3 g lactose/24 hr). In this case, the load of lactose administered per unit time was low and, therefore, well tolerated (41).

Since the enzyme activity is only reduced, but not absent, in patients suffering from lactase deficiency, these studies confirm that the incidence of GI side effects associated with that enzyme effect mainly depends on the load (concentration x rate) of lactose given.

Fat. Elemental diets usually contain only small amounts of fat, whereas polymeric diets are mostly medium-fat diets. An important, sometimes sole fat source in both types of formulations are vegetable oils (corn oil, safflower oil, sunflower oil) which are high in essential fatty acids. However, a fat content of <2 g/l as seen in some elemental diets is insufficient to prevent essential fatty acid deficiency during long-term enteral feeding (42).

Enteral formulations high in fat can cause diarrhea (43) which might be due to the increased bile salt excretion after a high-fat diet. Bile salts, mainly dihydroxy bile salts induce water and electrolyte secretion into the human colon and increase the colonic motility (44). In a recent

study (45) 9 patients were nasogastrically fed after ileal resection in random order with the following diets: a polymeric medium-fat diet (34 g/1000 kcal), an elemental peptide diet (11 g/1000 kcal) and a polymeric low-fat diet (4 g/820 kcal). The bile salt excretion (sum of cholate and desoxycholate) was found to be 13-17% lower ( $p < 0.05$ ) on the low fat diets than on the medium fat diet, whereby the cholate excretion was 14-20% lower. However, no difference between the diets could be seen in the chenodesoxycholate excretion. The protein source, whether whole protein or peptides, did not influence the bile acid secretion. Bosaeus et al. (45) confirmed that bile salt excretion is influenced by the level of dietary fat in jejunostomy patients and seems to influence the incidence of diarrhea. These results can possibly also be extrapolated to patients suffering from other diseases.

### Protein

The source as well as the content of protein in the enteral diet is of particular concern for the surgical patient. Protein serves as a source of essential amino acids and provides nitrogen for the synthesis of other amino acids as well as for other nitrogen-containing compounds (nucleic acids, neurotransmitter, glutathione and creatine). Protein requirement increases due to metabolic stress (injury, surgery, trauma, burn).

Polymeric diets containing whole protein as their nitrogen source should be administered to patients with normal intestinal functions, since the infusion (via nasogastric tube) of a more expensive elemental diet was not of greater benefit than a polymeric diet in patients with normal GI functions (46). The diets tested contained 31 g free amino acids/l (4.8g N) versus 30 g whole protein/l (4.8g N). However, elemental formulations containing free amino acids or partially hydrolyzed protein (mixture of amino acids and peptides) have been preferred for patients with impaired GI functions for early postoperative jejunal feeding (47).

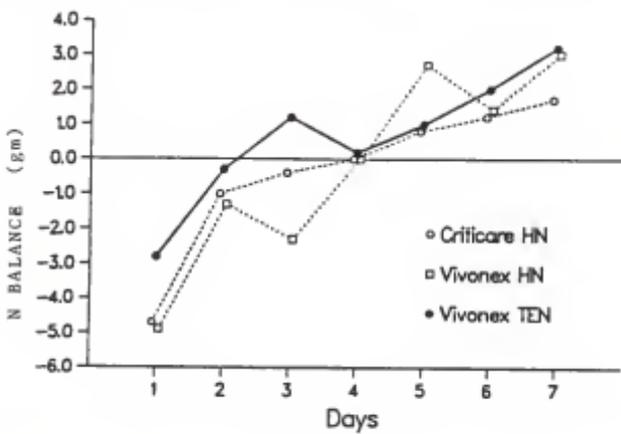
Rees et al.(48) demonstrated that the jejunal nitrogen absorption is influenced by the peptide chain length. Using an in vivo jejunal perfusion technique in normal human subjects, three different ovalbumin hydrolysates containing peptides with a chain length varying from 1 to 5 amino acids were prepared as isotonic test solutions and infused in random order. Since the nitrogen absorption was significantly lower from the medium-chain preparation (68% of amino acids were 3-5 amino acid residues) than from the short chain preparations, it was found that only slight increases in peptide chain length are sufficient to slow down the absorption rate of amino acid nitrogen and that the optimum absorption occurs from partial enzymic

hydrolysates if they predominantly contain di- and tripeptides (48). Moreover, the absorption rate of amino acid nitrogen is higher from partial protein hydrolysates than from equivalent equimolar free amino acid solutions (34). Therefore, mixtures of di- and tripeptides seem to be the best choice as the protein source in elemental diets.

Branched chain amino acid (BCAA) enriched enteral diets are of high interest for use in surgical patients in the postoperative state. Increased muscle protein catabolism occurs in such patients due to metabolic stress, and the BCAA are proposed as anticatabolic amino acids.

Cerra et al. (49) demonstrated that postoperative patients receiving high-BCAA solutions return to a positive nitrogen balance more rapidly than those receiving a standard solution, whereas the cumulative nitrogen balances were the same over 6 days. Andrassy et al. (50) described 20 patients undergoing extensive intraabdominal surgery fed via NCJ with a BCAA-enriched solution (33% BCAA) and compared the results to patients supported with a 21% or 15% BCAA containing diet. The patients receiving the high BCAA diet showed increased but still normal BCAA blood levels and went into a positive N-balance sooner. However, this difference never approached significance (Fig. 6). The increase in the levels of nutritional markers (total lymphocyte count, transferrin and prealbumin levels) were similar in all

groups. The effects of utilization of leucine and N-balance seem to depend on the type of patient and the degree of injury (50). Other studies did not show any difference in protein metabolism and N-balance when feeding an BCAA-enriched or normal enteral diets (35). To confirm any potential clinical benefits of BCAA-enriched diets over normal enteral diets, more studies are necessary.



**FIGURE 6** Comparison of the nitrogen balance among groups when Vivonex TEN is the BCAA enriched elemental formula (50).

Electrolytes.

Electrolyte and water absorption during enteral feeding is of great importance since impaired absorption or increased secretion (inflow of water and mainly sodium into the jejunum) can cause diarrhea which is a common GI side

effect in enteral fed patients. To demonstrate that diets have a secretory effect on the normal human jejunal mucosa, Jones et al. (51) perfused 25 cm of proximal jejunum with two different types of diets. Water absorption was stimulated by a whole protein based diet (Ensure), whereas an isotonic elemental diet (Vivonex HN) caused water secretion; both diet solutions stimulated sodium secretion (Table 7). Despite similar sodium contents in the diets, sodium secretion was greater after Vivonex perfusion than after Ensure perfusion. This was explained by the fact that the whole protein diet stimulates water absorption which is linearly related to the net absorption of osmotically active particles and, therefore, decreases the net sodium secretion (51).

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TABLE 7

Influence of enteral diets on human jejunal mucosa water and sodium absorption and secretion (modified after 51).

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Enteral Diet	Water absorption <sup>1</sup> (ml/25 cm/h±SEM)	Sodium absorption <sup>2</sup> (mmol/25cm/h±SEM)
Vivonex HN	-60.05 ± 8.4	-37.4 ± 3.0
Ensure	+130.00 ± 24.3	-22.0 ± 1.2

---

<sup>1</sup>(p <0.001), <sup>2</sup>(p <0.01)

There was also a linear correlation between initial sodium concentration and net sodium absorption. Comparing 9 enteral formulations, a net sodium absorption was seen if the initial sodium concentration exceeded 90 mmol/l, whereas sodium was secreted by the jejunal mucosa when the initial sodium concentration was below 90 mmol/l. The results of these jejunal perfusion experiments lead to the conclusion that jejunal sodium secretion may occur with any low-sodium diet (52).

Metabolic complications related to electrolyte imbalances mainly include hyper- and hypokalemia. Almost half of 70 patients with normal GI functions became hypokalemic when fed with the elemental diets Vivonex HN (53% of patients) and Clinifeed 400 (47% of patients) over a mean period of 15 days. The occurrence of hypokalemia was evenly distributed in the two groups despite the different potassium content (Vivonex HN, 13 mmol/l, Clinifeed 400, 25 mmol/l) (46). In the study of Doelp et al. (53) a potassium infusion of 60 mmol/d during postoperative enteral feeding was not sufficient to cover the potassium needs of all patients. Hypocalemia also can occur secondary to diarrhea. To patients suffering from diarrhea, liquid potassium supplements may be given (54). Such supplements are generally well tolerated, if they are diluted in the feeding formula and slowly administered (55). Hyperkalemia can occur

if risk factors such as renal insufficiency, anabolic process and excess levels of potassium in the enteral formulation are present (54). Thus, the potassium content of the enteral formulation is very important to meet the potassium requirements and avoid hypokalemia, as well as hyperkalemia. Hypophosphatemia seems to be related to the phosphate content of the diet, since it occurred more often in patients fed on a diet low in phosphate (Vivonex HN 190 mg/l) than in those fed with Clinifeed 400 (460 mg/l) (46).

Vitamins and trace elements. The vitamin and trace element contents of enteral formulations are based mainly on the RDA (Recommended Dietary Allowances). However, these recommendations are given for healthy persons so that they may not cover the possible increased requirements for vitamins and trace elements in illness, and they may not account for the effect of pharmaceutical preparations. For example, problems have occurred in some patients who were anticoagulated with warfarin when they were fed with an enteral diet high in vitamin K (56). General agreement exists that the vitamin B and C requirements are increased after surgery due to hypermetabolism and collagen synthesis (vitamin C) (57).

The hypothesis that the vitamin activity in enteral feeding solutions might be lost to a certain degree during storage in polyvinyl chloride (PVC) or polyethylene bags could not be confirmed (58). Additionally, the stability of vitamin A, vitamin E and riboflavin (B2) was not affected by freezing.

Iron (Fe), copper (Cu) and zinc (Zn) seem to be of particular interest for the surgical patient, since wound healing is impaired in Zn-deficiency and Fe and Cu are necessary for a normal heme production and hemoglobin synthesis. However, several commercially available enteral formulations provide less than the RDA and SADI (Safe and Adequate Ranges of Daily Dietary Intake) values for Fe, Cu, Zn and manganese (Mn). Additionally, a great discrepancy between the levels stated by the manufacturers and the analyzed values has been demonstrated (59). The same problems exist for the essential trace element selenium (Se). Most formulas, besides those which are based on egg albumin, provided less Se than recommended by the SADI (60).

Dietary fiber. Recently dietary fiber has become of high interest because many physiological functions have been discovered (see Table 8), and some polymeric diets containing fiber have been developed.

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TABLE 8

Physiological effects of dietary fiber (modified after 61).

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- the feeling of satiation due to increased gastric filling is intensified
  - the rate of gastric emptying is slowed down
  - the rate of resorption is diminished
  - the stool volume is increased
  - the transit time is decreased
  - the colon contact is decreased
- 

In normal male volunteers, 40 g fiber/day added to a polymeric diet ensured normal bowel function and stool weights (62). Although Patil et al. (63) suggested that a dietary fiber-containing diet, because of its increased viscosity, might be more difficult to infuse through a small-bore feeding tube. No problems occurred when intensive care patients were continuously fed with such a diet via nasogastric infusion (64). The diet containing 1 g fiber/100 ml generally was tolerated well. The daily stool frequency was 1.2, and the feces were of soft consistency. The blood glucose lowering effect of dietary fiber could not be demonstrated in the study of Rothe et al. (64) since most

patients became hyperglycemic. Metabolic changes occurring in the postaggressionmetabolism, including a "relative insulin" resistance and increased levels of insulin antagonists (catecholamines) were supposed to be the reason for this phenomenon. In contrast, Patil et al. (63) found that both daily stool weights and frequency as well as the incidence of GI-side effects remained unchanged in patients receiving 24 g carrot fiber in addition to a polymeric diet. More studies seem to be necessary to confirm a positive effect of dietary fiber additions to enteral diets.

### COMPLICATIONS IN ENTERAL NUTRITION

In general, nutritional support via the enteral route is regarded as being safer than intravenous infusion of TPN. An excellent tolerance of the diet was shown in a variety of surgical patients when EN was provided in the postoperative state either by NCJ or nasogastric or nasojejunal tube (50,53,64,65). However, in contrast to these positive results other studies report complications occurring during EN support.

#### Mechanical and infectious complications

The most serious complications that occur in patients fed nasogastrically are feed aspiration and regurgitation (43,54). Aspiration of feed into the lungs may cause pulmonary infections and indicate treatments with antibiotics. The large-bore tubes used for nasogastric feeding can produce irritation and inflammation along their course and may increase the risk of gastric reflux that is favored by the reduced competency of the esophagastric sphincter. Most of these problems can be avoided by using a fine-bore tube, since fine-bore tubes may collapse with negative pressure and prevent aspiration of the gastric residual. However, fine-bore tubes show a tendency to dislodge or to become occluded. Leakage of gastric contents leading to skin erosion and wound infection are the most

critical complications in enterostomy feeding. Peritonitis and again aspiration occur most often as complications in gastrostomy feeding. The problem of aspiration can be met by feeding beyond the pylorus. However, jejunal feedings are associated with small bowel obstructions (43,54).

#### GI Side-Effects

The most commonly reported complications during EN-support are GI side-effects. Diarrhea, vomiting and abdominal distention occur most frequently, but also nausea, inadequate gastric emptying and more serious complications (very rare) as GI bleeding, and small bowel infarction can become a problem (54,66-68).

Moderate diarrhea occurred during feeding in 9 of 26 patients (34%) who were fed with an elemental diet via NCJ starting immediately after surgery (69). Sagar et al. (70) reported that 2 out of 15 patients developed diarrhea and nausea in the initial phase of their trial. In both studies diarrhea was directly related to the rate of feeding, since those complications could be avoided by reducing the rate and concentration of the elemental diet or starting with half strength solutions (0.5 ml/min) (69,70). Since hyperosmolality of the undiluted diet seems to be the major factor in the inducement of GI side effects, "starter

regimens" are used widely (71). The diet is diluted with sterile water, and the concentration and tonicity are increased gradually over the first 3 or 4 days of feeding before the full-strength diet is administrated.

However, for polymeric diets the usefulness of diluted starter or isotonic regimens was not reported. Keohane et al. (72) randomly allocated 118 patients (40 surgery or trauma, 30 neurosurgery) with normal GI function to one of 3 feeding regimens including a hypertonic diet (430 mmol/kg), the same diet with a "starter regimen" (over the first 4 days the osmolality increased from 145 to 439 mmol/kg) and an isotonic diet (300 mmol/kg). All diets were the sole nutritional support and administered by nasogastric infusion. Patients with a restricted fluid intake of less than 2.5 l/d (cardiorespiratory or renal failure and others) were excluded from the study. The side effects related to the diet are summarized in Table 9. There was no difference in the incidence of GI-side effects between an undiluted hypertonic polymeric diet, a "starter regimen" or isotonic diet. Keohane et al. (72) concluded that diarrhea was significantly associated with the concurrent treatment with broad spectrum antibiotics (ampicillin alone or in combination with flucloxacillin, gentamicin or metronidazole during enteral feeding, since all 17 patients who developed diarrhea belonged to the antibiotic treatment group (35

TABLE 9

GI complications during EN support (modified from 72).

Patients <sup>1</sup>	Nausea, bloating cramps	Diarrhea
Group I (n= 40)	4 (10.0%)	2 ( 5.0%)
Group II (n= 39)	6 (15.4%)	8 (20.5%)
Group III (n= 39)	6 (15.4%)	7 (18.0%)
total (n=118)	16 (13.5%)	17 (14.4%)

<sup>1</sup>Group I = undiluted hypertonic polymeric diet, Group II = hypertonic polymeric diet with an "starter regimen", Group III = isotonic polymeric diet.

patients). In cardiac surgery patients, diarrhea also occurred due to antibiotic therapy (66). The mechanism whereby antibiotics induce diarrhea is still not clear, but antibiotics do cause changes in the normal intestinal flora. Rapid infusion of hypertonic formula may happen accidentally if enteral pumps are not available and contribute to diarrhea, vomiting and abdominal distention (66). In addition, bolus feeding methods, gastric hypersecretion, lactose intolerance and contaminated enteral formulae cause GI disturbances (43,54). Moderate symptoms of diarrhea, nausea, vomiting, or abdominal cramping usually are treated

by discontinuing the infusion for 8 to 12 hr and then restarting it at a lower infusion rate. Codeine phosphate is given in some cases (67).

As summarized in Table 10, a variety of mechanical and GI complications occur during enteral feeding. Those disturbances may differ in frequency and severity. Some of the complications associated with NCJ are related to the additional surgery which is necessary for this technique. However, the major advantage of NCJ is the absence of tube-induced discomfort. Almost 20% of the patients fed nasojejunally in 2 different studies (66,73) accidentally removed their tubes. This technique is most suitable for short-term feeding, whereas NCJ is preferred when the nutritional support is of longer duration. In regard to GI side-effects, both techniques seem to induce almost the same problems. Some patients suffered from more than one GI side effect. Side effects include moderate diarrhea, vomiting and abdominal distention which usually do not respond to discontinuing the nutritional enteral support. In a recent study (68), however, enteral feeding had to be switched to TPN when severe GI-disturbances occurred. Those complications included 4 patients with severe diarrhea, 2 patients with aspiration, and 5 patients with small bowel infarction. Patients with diminished mesenteric blood flow

TABLE 10

Complications of immediate postoperative jejunal enteral feedings in the literature

References	Method	Patients	Mechanical	Complications			
				diarrhea	vomiting	abd. dis.	other
Hoover et al. (59)	NCJ	26	1 (4)	9 (35)	.....	1 (4)	.....
Bagar et al. (70)	naje	15	.....	1 (6)	.....	.....	1 (6)
Takala et al. (73)	naje	120	31 (26)	29 (24)	17 (14)	.....	41 (34)
Smith et al. (74)	NCJ	25	5 (20)	.....	.....	.....	36 (30)
Hayashi et al. (47)	NCJ	20	.....	.....	.....	.....	13 (65)
Haitzberg (56)	naje	70	20 (29)	29 (41)	15 (21)	6 (9)	.....
Daly et al. (57)	NCJ	22	.....	.....	.....	.....	311 (55)
Smith-Choban (58)	NCJ	129	17 (13)	38 (29)	2 (2)	17 (13)	5 (4)

NCJ = Needle catheter jejunostomy, naje = nasojejunal feeding.  
 Abd. dis. = abdominal distension.  
 Total GI complications.  
 Values in parentheses are percentages.

are at higher risk for the latter complication (68). GI bleeding and renal failure occurred in relation to enteral feeding (using a mixed-fuel polymeric diet) in 26% of cardiac surgery patients who were evaluated for nutritional support because of postoperative complications (mainly dysfunction of CNS) (66). Enteral nutrition had to be discontinued and TPN was initiated. GI bleeding usually requires enteral feedings to be discontinued (54).

#### Metabolic Complications

Besides mechanical, infectious, and GI complications metabolic disturbances also can occur due to enteral nutritional support. Metabolic side effects including dehydration, hyperglycemia, electrolyte abnormalities, or vitamin and trace element deficiencies were discussed under "enteral nutrition formulas".

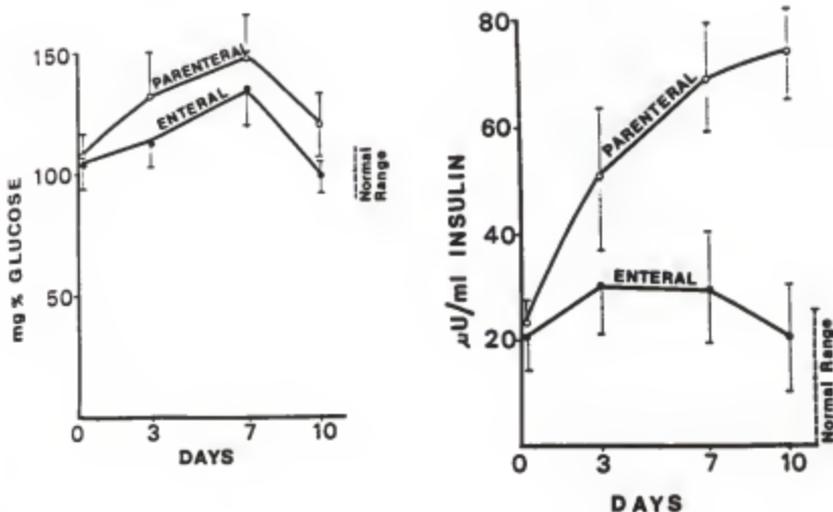
Although the previous discussion may give the impression that a variety of complications occur during EN, this method of nutritional support generally is safe for most patients. Cataldi-Betcher et al. (54) reported that out of 253 patients (with various diseases) who were supported with EN via tube, only 11.7% showed GI, 6.2% mechanical and 3.5% metabolic complications. Other workers (50,53,65) did not observe any complications.

## ENTERAL NUTRITION VERSUS TOTAL PARENTERAL NUTRITION

In former times TPN was the only choice for immediate postoperative feeding since it was generally accepted that postoperative ileus impairs the entire GI tract. However, recent studies demonstrated that the motility and absorptive capacity of the small bowel is not affected after surgery. Therefore, enteral feeding solutions can be administered almost immediately after surgery and is an alternative to TPN today (2). Several studies (38,55,65) were carried out to compare the benefits of enteral feeding solutions versus total parenteral nutrition as the choice of nutritional support in the early postoperative period.

McArdle et al. (38) reported that the blood glucose levels remained almost normal in a TPN-fed group, as well as in an enteral-fed group. However, the insulin levels were markedly and continuously increased after TPN (Fig. 7). Thus, in the TPN-fed group, the blood glucose levels were kept in an almost normal range only due to the enormous increased insulin levels which, on the other hand, turned off lipolysis, so that the serum free fatty acid level dropped down to 0 within a week. In contrast, the blood glucose levels were controlled by normal insulin levels in the enteral feeding group and the serum free fatty acids did not disappear ( $0.33 \pm 0.2$  Eq/l). The different insulin levels found in the enteral and parenteral groups probably

can be explained by the different handling of the glucose and insulin by the liver (38).



**FIGURE 7** Blood glucose and serum insulin levels in the parenteral and enteral-fed groups (38).

In 19 patients undergoing abdominal surgery, the mean N balance and the mean urinary excretion of 3-methylhistidine was almost parallel in a TPN-fed group and in the group fed via NCJ with an elemental diet (Vivonex HN). A positive N

balance occurred only on day 5 in both groups (65). The high incidence of GI disturbances in the EN group was probably due to a high infusion rate, since immediate postoperative enteral feeding was well tolerated in other studies. Doelp et al. (55) also demonstrated a similar N balance after TPN and EN feeding, whereby the N balance remained negative (-2g N/d) over 6 days. In contrast, the N balance was greater in the TPN (positive by day 2) than in the NCJ group (positive by day 4) in 20 patients. These results are probably due to the greater N intake in the TPN group ( $202.54 \pm 15.27$  mg/kg/d) than in the NCJ group ( $108.11 \pm 18.17$  mg/kg/d).

## SUMMARY AND CONCLUSION

A variety of tube feeding techniques (nasogastric, nasojejunal, esophagostomy, gastrostomy and jejunostomy, as well as percutaneous endoscopic gastrostomy and jejunostomy) have been developed. Jejunal feeding techniques usually are preferred in patients undergoing abdominal surgery. Feeding can be started almost immediately after surgery, since the small bowel function is not impaired. As a response to injury, metabolic and hormonal changes occur which primarily cause protein catabolism and an increase in energy expenditure. A nutritionally complete chemically defined (elemental) diet that is easily administered through small-bore tubes should be the choice for postoperative jejunal feeding. To avoid diarrhea, the osmolarity of the diet should not exceed 500 - 600 mosmol/l. This osmolarity can be ensured by substituting oligosaccharides for glucose and using more complex protein or protein hydrolysates instead of free amino acids, since amino acids are most rapidly absorbed as di- and tripeptides. The benefit of BCAA-enriched solutions over normal chemically defined diets still has to be confirmed. To meet the increased energy requirements in moderately hypermetabolic patients, the diet should contain 1.5 kcal/ml. Polymeric diets can be administered to those postoperative patients who can be fed

via nasogastric tube and have normal GI functions. For all patients with impaired GI functions, chemically defined diets should be the choice. Enteral nutrition often is preferred over TPN because it can be administered more safely, avoids GI atrophy and is much less expensive.

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ENTERAL NUTRITION FOR THE SURGICAL PATIENT

by

KIRSTEN EICH

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Department of Foods and Nutrition

KANSAS STATE UNIVERSITY  
Manhattan, Kansas

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A variety of tube feeding techniques (nasogastric, nasojejunal, esophagostomy, gastrostomy and jejunostomy, as well as percutaneous endoscopic gastrostomy and jejunostomy) have been developed. Jejunal feeding techniques usually are preferred in patients undergoing abdominal surgery. Feeding can be started almost immediately after surgery, since the small bowel function is not impaired. As a response to injury, metabolic and hormonal changes occur which primarily cause protein catabolism and an increase in energy expenditure. A nutritionally complete chemically defined (elemental) diet that is easily administered through small-bore tubes should be the choice for postoperative jejunal feeding. To avoid diarrhea, the osmolarity of the diet should not exceed 500 - 600 mosmol/l. This osmolarity can be ensured by substituting oligosaccharides for glucose and using more complex protein or protein hydrolysates instead of free amino acids, since amino acids are most rapidly absorbed as di- and tripeptides. The benefit of BCAA-enriched solutions over normal chemically defined diets still has to be confirmed. To meet the increased energy requirements in moderately hypermetabolic patients, the diet should contain 1.5 kcal/ml. Polymeric diets can be administered to those postoperative patients who can be fed

via nasogastric tube and have normal GI functions. For all patients with impaired GI functions, chemically defined diets should be the choice. Enteral nutrition often is preferred over TPN because it can be administered more safely, avoids GI atrophy and is much less expensive.