Artificial Nutrition: Principles and Practice of Enteral Feeding

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ABSTRACT

Enteral feeding is a commonly used form of nutritional supplementation for patients with intestinal failure, both in hospitals and in the community. This article concentrates on the basic principles of enteral feeding, including the physiological effects of feeding into the intestinal tract. It covers the indications for enteral feeding, the different methods of supplying enteral feeds to the gastrointestinal tract, and the potential complications. There is also a discussion of the indications for and practice of home enteral nutrition.

KEYWORDS: Nutrition, enteral feeding, enteral access, complications

Objectives: Upon completion of this article, the reader should have a working understanding both of the principles of enteral nutrition and of the basic practical issues related to this area of nutritional support.

Nutrition needs to be supplied to patients by the simplest and most cost-effective means acceptable. Unquestionably, the optimal method for delivering nutrition to a patient with a functioning gastrointestinal tract is by the oral route. Most patients in hospital have a short hospital stay and are managed with hospital food. The 20 to 40% of patients who are undernourished may benefit from supplements of food, liquid feeds, or specific nutrients or micronutrients. For those who cannot eat enough for more than a few days, sip feeds become essential. Sip feeds have been shown to improve nutritional intake, reduce weight loss, and reduce complications in patients after abdominal surgery.[1] These benefits have been shown to extend beyond discharge in patients who were initially malnourished.[2] An important observation is that sip feed supplementation does not suppress spontaneous food intake significantly.[3]

However, for reasons that are discussed here, it is sometimes necessary to provide nutrition to hospitalized patients with a functioning, or partially functioning, gastrointestinal tract by nonoral routes. This is achieved by means of specialized artificial tubes inserted into various parts of the intestine. This article focuses principally on the provision of "tube feeding" to the gastrointestinal tract by the array of nonoral routes.

The concept of artificial tube feeding is not a new one. In the 19th century it was a relatively common practice to feed inmates of asylums through rubber or gum elastic tubes inserted either into the esophagus or rectally. However, the theory and practice of what would be considered to be modern enteral nutrition have been developed only over the last 30 years. One of the first descriptions of the provision of a specialized liquid diet through a feeding tube was published in 1976 by Dobbie

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and Hoffmeister.[4] Since then, rapid advances have been made and enteral nutrition is now commonplace in hospitals and increasingly in the community.

Enteral feeding is preferred to parenteral feeding as it is more physiological and has fewer complications. Continued supply of nutrition to the gut is believed to help prevent mucosal atrophy,[5] decrease endotoxin translocation, and maintain gut barrier function, which may become compromised in patients receiving parenteral nutrition.[6,7] The relationship of parenteral feeding with intestinal bacterial translocation remains debatable in human compared with animal studies. Enteral feeding also avoids the abnormalities of liver and biliary function seen with parenteral feeding. However, if adequate feeding cannot be provided through the intestine, or if intestinal feeding is intolerable or undesirable, parenteral nutrition is required.

PHYSIOLOGICAL EFFECT OF FEEDING ON THE INTESTINE

Although the exact response of the intestine to feeding is not well understood, a basic understanding of gut physiology is useful when considering the principles of enteral feeding. The rate of gastric emptying varies with the volume of feed, its energy density, and its fat content.[8] Little is known about how continuously infused liquid feeds are emptied from the stomach. Preliminary studies using electrical impedance tomography (C. Soulsby, unpublished data) show that the stomach remains essentially empty in normal subjects with continuous feeding. When food enters the stomach the fasting phase I, II, and III patterns of the small intestinal migrating motor complex, which act to propel debris through the small intestine, give way to a disorganized-looking fed pattern.[9] This disorganized fed pattern of activity delays small intestinal transit time, effectively aiding nutrient digestion and absorption. The intestinal response to feeding is dependent upon whether a meal is solid or liquid, with the fasting pattern returning much quicker if a liquid meal is ingested.

Continuous intragastric infusion of feed usually initially results in cessation of the fasting pattern of small bowel motility; however, phase III contractions may return after a few hours and then, despite continuous feeding, a fasted pattern may be mimicked.[10] Return to phase III activity is quicker if a liquid feed is ingested but is delayed the larger the caloric load of a meal.[11] These effects may be related to the speed of gastric emptying and the effect of this on the concentration of nutrients arriving in the duodenum. Intraduodenal infusion appears to preserve a fed pattern of intestinal motility. Studies of intestinal motility and colonic fluid inflow during gastric and intraduodenal tube feeding show that although cecal inflow is less with intragastric than with intraduodenal feeding, the incidence of diarrhea is higher, and that this may be related to failure to stimulate the colonic absorptive response.[12]

Normal gut motility is affected by a range of pathological processes, and this has a significant impact on enteral nutrition. For example, in the critical care scenario, fasting patients undergoing mechanical ventilation and receiving morphine analgesia have shortened migrating motor complexes; during intragastric infusion of feed, intestinal manometry patterns may not change to the fed state until morphine is discontinued.[13] Bowel surgery and bowel resection also have significant effects on gastric emptying and intestinal motility. Although phase III motor activity returns within hours of surgery, contraction amplitude is markedly attenuated for up to 72 hours.[14] Small bowel motility recovers earlier than gastric emptying, which may provide a rationale for intrajejunal rather than intragastric infusion of feeds in the early postoperative period.[15]

Patients with a “short bowel” and end jejunostomy have large-volume stomal outputs that may be related to rapid gastric emptying; gastric emptying in patients in whom the jejunum is in continuity with colon is normal. It has been suggested that this is related to low fasting levels of peptide YY (PYY) and lower increments in this peptide after feeding in the patients with end jejunostomies.[16] This may form a part of the basis of the “colonic brake.” PYY is also thought to slow small bowel transit times and reduce pancreatic secretions. Interestingly, PYY is increased by intraduodenal but not intragastric feeding; this may, in part, explain the higher incidence of diarrhea seen with intragastric feeding compared with intraduodenal feeding.[17]

Another physiological difference between intragastric feeding and feeding into the small intestine is the effect on pancreatic secretion. This is of relevance in the management of acute pancreatitis. Studies have shown that infusions of liquid feeds into either the stomach or the duodenum stimulate pancreatic secretion; however, infusion of feed into distal jejunum does not stimulate pancreatic secretion.[18] This difference appears to be mediated by changes in the secretion of gastrin and cholecystokinin (CCK) in response to feeding. After intragastric feeding, plasma levels of gastrin and CCK rise significantly. In patients fed into the jejunum there was no significant rise in plasma gastrin levels, and the increase in CCK levels was delayed and attenuated.[17]

INDICATIONS FOR ENTERAL FEEDING

Enteral tube feeding is frequently used to deliver nutrition to patients who are unconscious or who have clouded consciousness (Table 1). This is very common in the critical care scenario. Tube feeding can also be used to provide nutrition to a specific point in the upper gastrointestinal tract. This is especially useful in patients who cannot initiate swallowing or who have dysphagia,

Table 1 Indications for Enteral Feeding

Reduced level of consciousness
Impaired swallow
Cannot initiate swallow
Esophageal obstruction
Esophageal dysmotility
Impaired gastric emptying
Gastroparesis
Gastric outlet obstruction
Nutritional supplementation
Inadequate oral intake
Moderate intestinal failure
Postoperatively
In critical care
Acute pancreatitis
Anorexia
Physiological (e.g., liver failure)
Psychological

whether this is due to a mechanical obstruction or dysmotility. In these cases, feeding can be provided directly into the stomach, thereby bypassing the esophagus. Similarly postpyloric feeding can often be successfully provided in patients with gastric outlet obstruction and gastroparesis.

In the care of postoperative patients, early enteral feeding has also been shown to be beneficial when compared with prolonged "nil by mouth" regimens. In a meta-analysis of postoperative feeding following gastrointestinal surgery, the results of 11 studies involving more than 800 patients were pooled.[15] Early enteral feeding (within 24 hours of surgery) was compared with "standard" postoperative care; six studies provided nutrition via postpyloric feeding tubes and five studies provided oral sip feeding. The meta-analysis showed that early enteral feeding reduced the risk of infection (relative risk 0.72) and shortened hospital stay; in addition, there was a trend toward a reduction in anastomotic dehiscence (relative risk 0.53). The only significant disadvantage of early enteral feeding was an increased risk of nausea and vomiting. Perioperative enteral feeding also compares favorably with parenteral feeding, with an approximately 30% reduction of infective complications,[19] although the mechanism of this is uncertain.

Enteral feeding can be use to supplement nutrition in patients with moderately severe intestinal failure. Tube placement allows patients to receive supplemental feeding (usually overnight) to increase the supply of nutrients to the gastrointestinal tract and counter the effects of malabsorption. In patients with short bowel syndrome it is estimated that an enteral feeding regimen can provide adequate nutrition as long as there is more than about 100 cm of jejunum.[20] With this length of jejunum approximately 50% of the calories supplied to the gut are utilized, the remaining 50% being wasted. In patients with between 70 and 100 cm of jejunum, nutritional requirements can usually be met with enteral feeding regimens but parenteral fluid replacement may be required. The importance of an intact colon is discussed subsequently.

Finally, there has been renewed interest in the enteral feeding of patients with severe acute pancreatitis. Until the last decade the standard nutritional strategy was to feed such patients parenterally. However, jejunal feeding has been shown to avoid pancreatic stimulation.[21] Early enteral feeding has been shown to reduce pulmonary and renal complications, reduce the incidence of sepsis, and reduce mortality (from 26 to 6%) compared with "standard postoperative therapy" in a study of patients undergoing surgical intervention for severe acute pancreatitis.[22] In addition, a Cochrane meta-analysis has suggested that enteral feeding of patients with acute pancreatitis reduces markers of disease severity, morbidity, and mortality when compared with parenteral feeding,[23] although the pooled number of patients was only 70 and few of the trends reached statistical significance. Further work is needed on this topic and also on whether or not jejunal feeding has a significant advantage over gastric or oral sip feeding in patients with acute pancreatitis.

ROUTES OF ADMINISTRATION

Nasoenteral Tubes

Acute, short-term nutritional supplementation can be provided enterally using nasoenteral tubes—most commonly nasogastric tubes (Table 2). The commonest form of nasoenteric feeding is provided by fine-bore nasogastric tubes. The tubes are typically made of flexible polyurethane or silicone with a diameter of 1.4 to 4.0 mm (4–12 French). Before infusion of each feed, the tube position should always be checked by aspiration of gastric contents, confirmed by pH testing ($pH < 4$)[24]; it should be remembered that drugs such as proton pump inhibitors raise gastric pH. Auscultation is not a reliable method of assessing tube position. Similarly, radiography and endoscopy only confirm the position of a tube at the time of the procedure and may not reliably reflect the position of a tube at a later point in time.

Nasoduodenal and nasojejunal tubes allow postpyloric feeding. This is especially useful if there is impaired gastric emptying. In an intensive care unit (ICU) setting, jejunal feeding has been shown to provide a significantly greater percentage of target calorific intake compared with intragastric feeding.[25,26] However, nasoduodenal and nasojejunal tubes are more difficult to insert than nasogastric tubes, usually requiring either fluoroscopic or endoscopic guidance. This may lead to delays in initiating feeding, and a meta-analysis showed

Table 2 Routes for Enteral Feeding (most common methods in *italics*)

Nasoenteral tubes
Nasogastric
Nasoduodenal
Nasojejunal
Double-lumen tubes
Cervical pharyngostomy
Cervical esophagostomy
Gastrostomy
Surgical
Open
Laparoscopic
Percutaneous
Endoscopic (PEG)
Radiologically inserted (RIG)
Jejunostomy
Surgical
Open
Needle catheter
Percutaneous
Endoscopic
Direct
Through PEG

no overall mortality benefit of postpyloric feeding,[27] partly because of this. Clinical practice is likely to be dictated by local resources. Trials have repeatedly failed to show any advantage of using weighted tubes to assist blind insertion of feeding tubes into the duodenum or jejunum.[28]

Double-lumen nasoenteral tubes are available that have proximal ports to allow gastric aspiration and more distal ports for postpyloric feeding. These tubes allow simultaneous aspiration of gastric secretions and enteral feeding and are of most use in an ICU setting. However, tube insertion remains difficult and there is a significant risk of tube migration and subsequent malposition.

Long-Term Feeding Tubes

CERVICAL PHARYNGOSTOMY AND OESOPHAGOSTOMY

Enteral feeding tubes can be inserted directly into the esophagus either above (pharyngostomy) or below (esophagostomy) the cricoid cartilage. Historically, they were inserted by maxillofacial surgeons in the setting of oropharyngeal malignancy, but they are uncomfortable and hazardous to place and are now rarely employed.

GASTROSTOMY

Feeding tubes can be inserted directly into the stomach either surgically under direct vision (open or laparoscopic), endoscopically, or radiologically. Gastrostomy tubes allow the delivery of supplemental nutrition directly into the stomach and also provide a mechanism to drain gastric contents (e.g., in intestinal pseudo-obstruction). Although insertion techniques may differ, gastrostomy tubes share several common features including an internal fixation device (either a balloon or a flange) and an external fixation device, which together hold the tube in place and hold the anterior gastric wall against the anterior abdominal wall. An important difference between the different types of gastrostomy tube is that those held in position with a flange arrangement require endoscopic placement with the tube being pulled into the stomach through the mouth; this can be technically difficult if there is significant esophageal obstruction. Balloon gastrostomies are held in position by inflating a balloon and therefore can be inserted directly into the stomach through the anterior abdominal wall and easily removed by deflating the balloon.

Percutaneous endoscopic gastrostomy (PEG) tube insertion has been shown to be cost effective and safe compared with surgical gastrostomy placement. Several different insertion methods have been described including "direct stab," "pull," and "push through" techniques. Radiological gastrostomy insertion is usually performed under fluoroscopic (and occasionally ultrasound) guidance after first placing a nasogastric tube, which is used to inflate the stomach. Success and morbidity are similar to those with PEG insertion.[29] When the gastrostomy track has become established for a few weeks, a low-profile "button gastrostomy" can be inserted through the existing track. This lies flush with the skin and features an antireflux valve to prevent leakage. Button gastrostomies are more cosmetically acceptable than standard gastrostomy tubes and are often used in children and in patients receiving long-term home enteral feeding.

JEJUNOSTOMY

Long-term postpyloric feeding can be achieved by the insertion of a feeding tube directly into the lumen of the jejunum. This is most simply performed surgically under direct vision and is often performed at the time of upper gastrointestinal surgery when a period of postpyloric feeding is anticipated. Several different insertion methods have been described such as needle catheter jejunostomy insertion and a modified Witzel technique. Jejunostomy tubes can also be inserted percutaneously under endoscopic guidance. The technique is similar to that of PEG insertion, although a longer endoscope (usually a pediatric colonoscope) is required and radiological screening is sometimes employed to guide insertion. There is a theoretical risk that a balloon fixation device may cause small bowel obstruction, and if there is clinical suspicion the tube should be replaced. Jejunostomy tubes can also be placed through an existing gastrostomy, usually under either endoscopic or fluoroscopic guidance. Although technically easier to insert, these jejunal extension tubes have a high incidence of migration and frequently are displaced back into the stomach.[30]

CHOICE OF ROUTE

The type of feeding tube used to deliver enteral nutrition is influenced by the estimated duration of feeding. Nasoenteral feeding tubes are ideal for short-term feeding or to assess a patient's response to enteral feeding before a more permanent tube is sited. However, nasoenteral tubes are susceptible to accidental removal and blockage, and if it is thought that enteral nutrition is going to be required for more than a few weeks, a long-term feeding tube should be inserted.

The positioning of an enteral feeding tube should take into account the degree of gastric atony and delayed gastric emptying. Causes of delayed gastric emptying are shown in Table 3. Gastric atony and delayed emptying are common in the setting of critical care. Studies using electrical impedance tomography (Soulsby, unpublished data) suggest that, whereas normal subjects maintain an empty stomach with continuous infusion of liquid feed, some critically ill patients accumulate feed in the stomach. Several approaches can be used to overcome this problem. Prokinetic agents such as metoclopramide or intravenous erythromycin can be given as there is evidence that these promote gastric emptying and shorten the time to the initiation of nasogastric feeding.[31] Patients can be fed through a nasogastric tube and the stomach aspirated at regular intervals. The rationale behind this is that the presence of feed in the stomach encourages gastric emptying and regular aspiration reduces the risk of aspiration. An alternative approach is to feed postpylorically, usually with a nasojejunal tube. Studies have shown that, in a critical care setting, jejunal feeding delivers a greater percentage of the target intake compared with intragastric feeding.[25,26] However, jejunal feeding reduces gastric emptying and secretion,[20] and this can result in increased gastric aspiration volumes.[32] Nasojejunal tubes with a gastric aspiration port may be useful in such situations.

A specific concern with PEG insertion, during which the tube and flange are pulled through the upper gastrointestinal tract, is the potential for seeding of oropharyngeal tumors. There are several case reports of seeding having occurred, usually to the gastric mucosa.[33] Large oropharyngeal tumors may also make gastroscopy and the passage of a PEG tube through the oropharynx difficult. Because of these risks it is prudent to consider other techniques, such as direct gastric insertion under fluoroscopy, when placing a gastrostomy in patients with oropharyngeal malignancy.

Table 3 Causes of Delayed Gastric Emptying

Multiple trauma
Head injury
Cerebral palsy
Intra-abdominal sepsis
Postoperative, e.g.,
Major abdominal surgery
Multiple trauma
Neurosurgery
Impaired gastrointestinal motility, e.g.,
Chronic pseudo-obstruction
Neuromotor disorders
Neuromuscular blocking drugs
Ventilator-dependent patients
Diabetic neuropathy
Hypothyroidism
Senescence

TYPES OF FEED

Standard equations should be used to calculate energy and nitrogen requirements in patients receiving enteral nutrition. However, as mentioned earlier, the absorption of nutrients from the small intestine can be variable and may be significantly reduced in patients with reduced jejunal mucosal surface area, dysfunctional jejunal mucosa, or abnormal motility. Therefore, it may become necessary to provide nutrition in a form that is more effectively absorbed or more effectively emptied from the stomach. In addition, specific nutritional deficiencies such as B_{12} malabsorption after ileal resection may need to be addressed. The absorptive potential of the colon should not be underestimated. Bacterial fermentation of undigested carbohydrates in the colon produces short-chain fatty acids that can be absorbed and utilized by colonic enterocytes. Up to 1000 kcal/day can be absorbed in this fashion.[34] It must be remembered that the bacterial load in the colon and therefore bacterial fermentation are significantly impaired if patients are treated with broad-spectrum antibiotics.

Polymeric Versus Predigested and Elemental Feeds

Polymeric feeds contain carbohydrate, nitrogen, and lipid in the form of partially digested starch, whole protein, and triglycerides. Additional minerals, vitamins, and trace elements are added to this. Such feeds can be used in patients with near-normal gut function.

In patients with a degree of malabsorption, it may be helpful to provide nutrition in a form that can be digested and absorbed more easily. Indications for elemental and predigested feeds based on the mechanisms of malabsorption are shown in Table 4. The effects of

Table 4 Mechanisms of Malabsorption Necessitating Predigested Feeds

Reduced absorptive area
Small bowel resection
Impaired mucosal function
Crohn's disease
Celiac disease
Radiation enteritis
Pancreatic insufficiency
Chronic pancreatitis
Pancreatic malignancy
Cystic fibrosis
Fat malabsorption
Impaired biliary circulation
Chronic biliary obstruction
Primary biliary cirrhosis
Impaired fat transport
Lymphangiectasia
Abetalipoproteinemia

maldigestion and malabsorption on macronutrient economy are usually not great except in severe pancreatic insufficiency and short bowel syndrome.

Early elemental feeds were composed of nitrogen in the form of L-amino acids and energy in the form of glucose. The rationale behind this was the belief that protein was absorbed in the form of free amino acids. Elemental feeds are still widely used especially in the treatment of Crohn's disease, especially in children, where they (like polymeric feeds) have been shown to have significant therapeutic effect.[35]

Amino acids can also be absorbed rapidly as di- and tripeptides. Predigested feeds consist of protein in the form of partial hydrolysates and comprise a mixture of free amino acids, dipeptides, and tripeptides. Carbohydrate is provided as partially digested starch in which there are various chain lengths of glucose polymers (maltodextrins).

Neither elemental feeds nor predigested feeds contain a source of fiber, although there is evidence that the addition of pectin to predigested feeds can significantly reduce feed-related diarrhea.[36] Another potential disadvantage of enteral feeds, and to a lesser degree predigested feeds, is that they have a higher osmolarity. This may have an effect on bowel transit and fluid balance, especially in patients with short bowel syndrome.

Nonstarch Poly- and Oligosaccharides ("Fiber")

The first enteral feeds were developed for use by astronauts and contained no fiber. These feeds had the obvious advantage of reducing daily stool weights. The lack of fiber also resulted in low-viscosity feeds ideally suited to tube feeding. Recently, there has been much interest in the addition of various forms of nonstarch polysaccharides (NSP, fiber) to enteral feeds in an attempt both to normalize gut motility and to improve gut function. Simplistically, dietary NSPs can be split into soluble and nonsoluble fractions. Soluble fiber is readily fermentable to short-chain fatty acids by colonic bacteria; insoluble fiber is less completely fermented. The fermentation products depend on the exact NSP and usually consist of a mixture of acetate, propionate, and butyrate. Insoluble fiber consists of large polysaccharides, and the size of these increases the viscosity of liquid feeds. This limits the addition of insoluble fiber to enteral feeds. Feed viscosity may also affect the rate of gastric emptying and small bowel transit times. It has been hypothesized that soluble fiber could increase stool weight by encouraging bacterial load whereas insoluble fiber could increase stool weight by water trapping.

Mixed fiber supplements in enteral feeds have been shown to normalize whole-bowel transit times (measured using radiopaque pellets) in normal compared with fiber-free polymeric diets.[37] However, there is no increase in stool weight. Fiber supplementation may also improve gut barrier function, and some studies have shown a reduction in bacterial translocation in the gut with fiber supplementation.[38,39] Studies have shown that fructo-oligosaccharides have a prebiotic effect, favoring the colonization of the colon with lactobacilli and bifidobacteria.[40] A large number of animal studies have focused on the effects of short-chain fatty acids (derived from soluble fiber in the gut) on enterocyte function and proliferation. Luminal, but not parenteral, short-chain fatty acids (especially butyrate) have been shown to increase proliferation of colonic enterocytes, to speed wound healing, and to reduce wound dehiscence after bowel surgery in rats.[41] Infusions of short-chain fatty acids into the cecum have also been shown to reverse the secretion of water, sodium, and chloride by colonic enterocytes induced by intragastric feeding.[42] It should be remembered that antibiotic therapy reduces gut fermentation and hence short-chain fatty acid production and thus limits the benefit of soluble fiber supplementation.

The effect of fiber supplementation of enteral feed–related diarrhea has been extensively investigated. In animal studies, the short-chain fatty acids released in the colonic lumen increase colonocyte absorption of water and electrolytes[42,43] and improve mucosal integrity.[39] Although in theory these effects should combine to help prevent diarrhea, initial human studies of fiber supplementation of enteral feeds showed little significant effect on the incidence of diarrhea.[44,45] This may be related to the small particle size of fiber in enteral feeds and the lack of any bulking effect. More recent trials have shows significant benefit from fiber in the form of partially hydrolyzed guar gum.[46,47]

Immunomodulatory Feeds

The immune system is often suppressed in severe infection and inflammation, and there has been much interest in using nutrition to enhance immune function, especially in the setting of critical care (so-called immunonutrition). Studies have focused on supplementation with L-arginine, nucleotides, and omega-3 polyunsaturated fatty acids (Impact feed). Some meta-analyses have suggested that such supplements may reduce infection and hospital stay in critical care patients.[48,49] However, other authors argue that immune enhancement may worsen the systemic inflammatory response syndrome and thereby have a detrimental effect.[50] Current advice is to avoid arginine supplementation in critical care patients. One of the most impressive studies favoring the use of immunomodulation involved the use of a modified lipid, omega-3 fatty acid–supplemented, antioxidant-enriched feed in a multicenter randomized controlled trial in the context of acute respiratory distress syndrome (ARDS).[51] Patients receiving this feed had significantly shorter periods of ventilation, shorter intensive care stays, and lower occurrence of new organ failure.

Immunomodulation through both enteral and parenteral nutrition remains controversial. Antioxidant status is depleted during inflammation and sepsis and the role of antioxidant supplementation remains promising. Canadian practice guidelines suggest the use of omega-3 fatty acid and antioxidant supplementation in ARDS and glutamine supplementation in burns and trauma.[52] Omega-3/antioxidant supplementation has also been used to down-regulate components of the ubiquitin-proteasome proteolytic pathway in skeletal muscle that are overexpressed in cancer cachexia,[53] but so far clinical trials have been inconclusive.[54] Further research is needed in this growing field in human nutrition.

Glutamine is a nonessential amino acid that is an important substrate for enterocytes and cells of the immune system. It is a precursor for glutathione and nucleotide synthesis and is important in regulating intracellular hydration. In times of sepsis and metabolic stress, levels of glutamine fall such that glutamine is now considered to be a "conditionally essential" amino acid.[55] Glutamine supplementation may reduce infective complications in critical care patients.[56] Studies of glutamine supplementation (at supraphysiological levels) of parenteral feeds tend to show improved survival in critical care patients.[57,58] A randomized trial of glutamine supplementation of enteral feeds in patients with multiple trauma has shown a significant reduction in infective complications,[59] as have studies in patients with severe burns.[60,61] However, similar results were not seen in a larger Australian trial.[62] Intravenous glutamine appears, at present, in meta-analysis to be the most clearly effective approach in reducing septic complications and mortality in the critically ill and in reducing length of stay in surgical patients.[63]

DELIVERY OF FEED

Traditionally, patients were initially started on low-volume and diluted feeding regimens and gradually built up to a full-volume, full-strength feeding regimen. This was thought to reduce the incidence of bloating and abdominal pain. However such "buildup" regimens often serve only to provide inadequate nitrogen and energy.[64] Bolus feeding may cause more problems with bloating and diarrhea than continuous feeding, and therefore continuous infusion of enteral feeding is usually the recommended delivery method.[65] However, there is current renewed interest in the place of the older technique of bolus feeding, in the context of delayed gastric emptying. Continuous enteral feeding into the stomach raises gastric pH, and this can allow bacterial colonization of the stomach. A rest period from feeding of at least 90 minutes allows gastric pH to fall sufficiently to kill the majority of bacterial species that colonize the stomach.[66]

MONITORING

Initial records must document a minimum of usual weight, current body weight, and height, from which body mass index is calculated. Serum albumin is a useful predictor of outcome although its direct nutritional relevance is debatable. When weight or height cannot be measured, middle upper arm circumference can give a simple and useful guide to nutritional status and predicted outcome.[67] Patients receiving nutritional supplementation need to be monitored. The appropriate position of a temporary feeding tube should be checked before the start of *every* feed by pH testing of aspirate. A careful record must be kept of daily nutritional intake and urinary and intestinal excretion. Fluid balance should also be monitored where possible by regular weighing.

Biochemical monitoring of plasma urea and electrolytes, magnesium, and phosphate is necessary, especially in patients with significant weight loss. The refeeding syndrome is characterized by rapid falls of plasma phosphate, magnesium, and potassium as a result of rapid insulin-driven electrolyte uptake into cells. Measurement of plasma B_{12}, folate, and ferritin levels may be relevant, and plasma zinc can be low in patients with large intestinal losses, especially during refeeding. A 24-hour urine nitrogen or urea measurement may be useful to calculate nitrogen balance during prolonged feeding in catabolic patients. The importance of blood glucose monitoring in patients receiving nutritional support has also become apparent. Tight glycemic control has been shown to reduce mortality significantly in patients receiving nutritional support in critical care units,[68] and therefore blood glucose needs to be monitored carefully in all patients receiving aggressive nutritional supplementation.

PROBLEMS WITH ENTERAL FEEDING

There are several complications that can beset enteral feeding. These can be split into those related to the tube delivering the feed and those related to the effect of the feed itself.

Tube Related

INSERTION COMPLICATIONS

Insertion of nasoenteral feeding tubes is essentially a blind procedure, and as a result there is a risk of both insertion failure and misplacement. Tube placement into the bronchial tree can be fatal if feed is subsequently delivered into the lungs. It must be remembered that tubes may become displaced, especially after prolonged vomiting or upper gastrointestinal endoscopy. This reinforces the need to check tube position by aspiration before every feed is commenced. Patients with an altered level of consciousness or an impaired gag reflex are at particularly high risk of tube misplacement and some ICUs insert nasoenteral tubes under fiberoptic guidance. Nasoenteral tube insertion has been reported as a cause of esophageal perforation and pneumothorax although this is extremely rare. Complications related to the presence of the feeding tube in the esophagus such as severe esophagitis are also rare with fine-bore tubes (although higher with large-bore Ryle's tubes).

PEG tube insertion is now commonplace in most hospital endoscopy units. However, appreciable mortality and morbidity are still associated with the procedure. The 30-day mortality is in the region of 7 to 10%, although the majority of this is due to the underlying medical condition.[69,70] Common complications of PEG insertion include failure of insertion (because of inability to identify a suitable insertion site), peristomal infection, or leakage and hemorrhage. The risk of insertion site infection has been shown to be significantly reduced by the use of prophylactic broad-spectrum antibiotics[71] (e.g., co-amoxiclav). Other potentially serious complications include peritonitis, colonic perforation, and necrotizing fasciitis. The risks of peritonitis following gastrostomy placement are unacceptably high in patients with ascites or in those undergoing peritoneal dialysis. Overall procedure-related mortality is between 1% and 2%.[72] It should be remembered that a benign pneumoperitoneum is detectable on chest or abdominal radiography in 38% of patients after PEG insertion.[73]

ACCIDENTAL REMOVAL

One of the major problems associated with nasoenteral tubes is accidental removal or partial withdrawal. Nasoenteral feeding tubes are usually secured with adhesive tape to the patient's cheek. It is estimated that about 50% of all nasogastric tubes are removed accidentally either by patients or by staff. Complicated systems to secure nasoenteral feeds, such as "bridling," have been described but there is debate over the degree of patient's discomfort and as a result these systems are rarely used. Accidental removal is rare with gastrostomy and jejunostomy tubes.

TUBE BLOCKAGE AND DAMAGE

Enteral feeding tubes, especially fine-bore, postpyloric tubes (e.g., 7 and 9 French tubes) are prone to blockage, especially if crushed medications are administered through the tube. The proteins in polymeric enteral feeds may also precipitate, causing tube blockage. The risk of tube blockage can be reduced by regular flushing with sterile water. Pancreatic enzymes mixed with 8.4% sodium bicarbonate have been demonstrated to reduce tube occlusion by about 10-fold.[74]

Long-term gastrostomy and jejunostomy tubes have a wider bore than nasoenteral tubes and are therefore less likely to become blocked (although similar protocols should be used to avoid blockage). Gastrostomy tube flanges may become obstructed by an overgrowth of gastric mucosa—the so-called buried bumper syndrome. This complication may necessitate replacement of the gastrostomy tube, and it is often difficult to remove the buried bumper without resorting to surgery. With correct care, gastrostomy tubes last for in excess of 2 to 3 years. Once the tube track is established, replacing a damaged tube is a relatively simple endoscopic procedure.

OTHER TUBE-RELATED COMPLICATIONS

Enteral feeding tubes can cause erosion, ulceration, and tissue necrosis at any point along the insertion route. Fortunately, such complications are rare, especially with correct care. Although colonization of enteral tubes is common, clinically significant infection associated with an established tube is rare.

Gastrointestinal Complications

ASPIRATION

The delivery of a large volume of feed into the stomach through a nasogastric tube or gastrostomy may result in reflux of feed into the esophagus and ultimately in pulmonary aspiration. Patients with an altered level of consciousness, an impaired gag reflux, or other neurological problems have an especially high risk of aspiration, with studies citing an incidence of up to 30%.[75] The risk of aspiration can be reduced by keeping the patient's thorax at 30% or greater from the horizontal, by using iso-osmolar feeds (high-osmolar feeds reduce the rate of gastric emptying[76]), and by infusing slowly. Prokinetics have also shown to be effective in an ICU setting. Postpyloric feeding reduces the risk of aspiration, but not completely.[77] There is still significant esophageal reflux if a patient is fed into the upper duodenum, although this is reduced by feeding beyond the ligament of Treitz.

GASTROINTESTINAL SYMPTOMS

Nausea and abdominal bloating are common side effects of enteral feeding. Although the etiology is multifactorial, it is important to exclude any potentially reversible causes such as a mechanical obstruction. It has been suggested that feeding by continuous infusion causes fewer symptoms than bolus feeding, although this is not backed up by conclusive evidence.

ALTERED BOWEL HABIT

Although constipation may be seen in patients receiving enteral feeding, diarrhea is a more common complication. The cause of diarrhea in patients receiving enteral nutrition is unclear but it is likely to be multifactorial, with many of the principal reasons related to the underlying disease process rather than enteral feeding per se. Concomitant use of antibiotics is a major cause of diarrhea and combination with enteral feeding appears to potentiate this.[78] Antibiotics such as erythromycin have a direct action on gut motility, decreasing gut transit times. The majority of antibiotics disrupt normal gut flora. This may have several adverse effects including overgrowth of pathogenic bacteria (such as *Clostridium difficile*) and inhibition of bacterial production of short-chain fatty acids that in turn reduces water and electrolyte absorption by colonocytes.[79]

INFECTION

Enteral feeds are an excellent growth medium for a range of pathogenic bacteria, and although they are sterilized, contamination occurs rapidly once they are opened. An early study involving patients receiving continuous infusion of enteral feed reported a 36% incidence of contamination.[80] Enteral feeds and their infusion sets should be changed at least every 24 hours. Continuous feeding also raises gastric pH, thus increasing the risk of gastric colonization; a break in feeding of several hours each day may prevent gastric colonization.

METABOLIC (SEE ALSO MONITORING)

Refeeding syndrome and hyperglycemia have already been discussed. Other potential metabolic problems include overhydration or hypertonic dehydration, hyperglycemia, and electrolyte imbalance.

HOME ENTERAL NUTRITION

INDICATIONS, INCIDENCE, AND ROUTES OF ADMINISTRATION

Home enteral nutrition is mostly used to provide nutrition for patients who have a functional intestinal tract but who have a degree of oropharyngeal or esophageal failure. An ESPEN survey of home enteral nutrition in Europe[81] revealed that of all patients started on home enteral nutrition in 1998, 49% had underlying neurological problems (usually cerebrovascular accidents) and 27% had head and neck cancer; 85% of these patients had dysphagia. Home enteral nutrition can be used to supplement patients with borderline intestinal failure although such patients are more likely to require home parenteral nutrition. Home enteral nutrition is also sometimes used for the treatment of patients with anorexia (e.g., due to dementia or psychological disorders) and patients whose energy demands exceed their ability to take nutrition orally (e.g., acquired immunodeficiency syndrome).

The median incidence of patients starting home enteral nutrition in Europe in 1998 was 163 patients per million inhabitants per year.[81] More than 50% of patients were older than 65 years. The incidence of patients starting home enteral nutrition is over 10 times the incidence of patients starting home parenteral nutrition. The majority of patients receiving home enteral nutrition have long-term feeding tubes sited; in the European study, 58% of patients had feed delivered through a PEG tube and 29% of patients had nasoenteral tubes.[81]

PROBLEMS AND ETHICAL ISSUES

Compared with home parenteral nutrition, the complication rates for home enteral nutrition are low with hospital admission rates of 0.3 to 0.4 admissions per patient per year; this is half that of patients receiving home parenteral nutrition.[82] However, in contrast to that of patients receiving home parenteral nutrition, overall mortality in patients receiving home enteral nutrition is high and quality of life poor,[83] reflecting the underlying medical conditions, particularly cerebrovascular accidents and chronic neurological disorders.

The poor survival and poor quality of life recorded in patients receiving home enteral nutrition highlight the problems of selection of patients for long-term enteral feeding. These are often difficult ethical issues that need to be addressed before initiating home enteral feeding, and full and frank discussion with patient, family, and carers is essential. The overall aim must be to improve the quality of life of the patient, and this must not be allowed to become secondary to convenience for the carers, although this is also important.

SUMMARY

This article has covered the basic physiological principles that underlie enteral nutrition and has discussed the indications for enteral feeding and the different routes by which it can be delivered. Potential difficulties and complications have also been highlighted. The importance of adequate nutrition in hospital patients, especially critically unwell and surgical patients, is being increasingly recognized. A good understanding of enteral nutrition is therefore vital for all medical practitioners treating such patients.

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