Series Editor: Carol Rees Parrish, M.S., R.D., CNSD

Nutritional Management of Pediatric Short Bowel Syndrome

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Pediatric short bowel syndrome (SBS), usually caused by massive intestinal resection, presents a significant nutritional challenge to the pediatric clinician. The overall clinical course and nutritional outcomes of SBS are impacted by various factors including remaining intestinal length and site, functional differences between the proximal and distal small intestine, and the presence of the colon. Nutritional management of SBS can be variable from patient to patient and can be divided into three stages: parenteral nutrition, enteral nutrition, and introduction of solid foods. Optimization of parenteral nutrition with a balanced fuel mix of carbohydrate, protein and fat should be provided to meet energy needs and promote growth during the first few weeks of nutritional management. Following fluid and electrolyte stability and demonstrated growth on parenteral nutrition, enteral nutrition with semi-elemental or elemental formulas should be initiated in a timely manner to promote intestinal adaptation. Because electrolyte and fat-soluble vitamin loss can impair optimal growth, infants and children with SBS often require supplementation with sodium and pediatric multivitamins and also benefit from supplementation with fiber and glutamine. Introduction of age appropriate low simple carbohydrate, high protein foods using small frequent feedings during the day further promote intestinal adaptation as well as oral-motor skills. The following article will present a comprehensive overview of nutritional management in the pediatric patient with SBS with practical guidelines for the clinician.

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INTRODUCTION AND ETIOLOGY

Pediatric short bowel syndrome (SBS), a disorder characterized by diarrhea, malabsorption, fluid and electrolyte disturbances, and eventually malnutrition, is usually caused by massive intestinal resection (1–4). However, infants and children may exhibit malabsorption as well as the infectious and metabolic complications associated with SBS, even with minimal or relatively modest resections of the small bowel (2). As such, the overall functional prognosis and complications associated with SBS do not always strictly correlate with the length of the remaining small intestine. Additional factors such as the presence of the ileocecal valve, the presence or amount of remaining colon, and the physiological status of the remaining intestine significantly impact the overall management and functional status of the child with SBS (3,4).

Short bowel syndrome in neonates may be present at birth due to a congenital anomaly or may develop in older infants and children as a result of disease or trauma, occurring later in life. Infants may be born with intestinal atresias, which may occur along any portion of the small intestine within an isolated area or along multiple segments. The obstruction caused by the atretic portions of the gut can lead to gastrointestinal (GI) ischemia, necrosis and resection (3,5). Gastroschisis, which results from an abdominal wall defect, can result in significant bowel injury or ischemia, necessitating bowel resection (3). Infants who are born with normal GI anatomy may experience intestinal injury and resection as a result of necrotizing enterocolitis (NEC) (2), which usually occurs in the preterm infant. While the exact cause is unknown, the premature GI tract is more susceptible to intestinal hypoxic injury and ischemia (5,6). Additional factors such as the presence of pathogenic bacteria, aggressive feeding advancement with hyperosmolar formulations, and intrauterine cocaine exposure may also increase the risk of NEC (6). In older infants and children with normal GI anatomy, malrotation can lead to volvulus, resulting in occlusion of the mesenteric artery and ischemia (3,5). Additional conditions such as hernias and intussusception can lead to intestinal hypoxic injury and resection. Crohn's disease, abdominal tumors and radiation enteritis resulting from radiation therapy are also common causes of intestinal resection and SBS in older children and adults (3).

PATHOPHYSIOLOGY

A basic review of normal neonatal GI anatomy and physiology is essential to an understanding of the impact of intestinal resection on the clinical outcome and management of pediatric SBS. Both remaining intestinal length and functional differences between the proximal and distal small intestine have a major impact on the overall clinical course and nutritional management of SBS. In the term neonate, the small bowel is estimated to be 240 cm, while the colon is about 40 cm (7). The length of the jejunum, ileum and colon doubles in the last trimester of pregnancy, thus giving a preterm infant a better outcome potential in terms of gut growth (2). Good clinical outcome, which can be defined as being able to eventually meet nutrition and growth needs on enteral nutrition (EN), can be achieved with as little as 15 cm of jejunum and ileum with the presence of the ileocecal valve, but 40 cm without the presence of the valve (8). These outcomes, however, presume normal functioning of the remaining bowel.

The degree and extent of malabsorption and metabolic complications seen in SBS also depends on the site of intestinal resection. The jejunum, which has longer villi and a large absorptive surface area, has a high concentration of digestive enzymes as well as enzyme carrier proteins and is the site of greatest nutrient absorption. The duodenum and jejunum are the primary sites for carbohydrate, protein, fat, as well as mineral absorption. Although the ileum has shorter villi and less overall absorptive capacity than the jejunum, it is the only site for B_{12} and bile salt absorption through site specific receptor-mediated transport. While the ileum can adapt and compensate for jejunal loss, the duodenum and jejunum cannot take on the absorptive functions of the ileum. Ileal resection results in decreased enterohepatic circulation and vitamin B_{12} and bile salt malabsorption, impairing normal micelle formation and efficient fat and fat-soluble vitamin absorption. Ileal resection can also lead to an increased risk of renal oxalate stones, bilious diarrhea and an increased potential for cholelithiasis. Additionally, ileal resection impairs the normal regulation of gut motility, as the ileum is a site of GI hormone production, particularly those that affect small bowel motility such as enteroglucagon and peptide YY (4).

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Overall, gut adaptation and functional prognosis is more of a challenge following ileal resection compared to jejunal resection.

Resection of the ileocecal valve and length of the remaining colon also impact the course of nutritional management and overall clinical outcomes in pediatric SBS. As the ileocecal valve slows the emptying of chyme from the small intestine into the colon, its resection increases the emptying rate of small intestinal contents (5). Fluid and electrolyte loss are also increased due to rapid transit time. Bacteria can also migrate upward to the small intestine, resulting in small bowel bacterial overgrowth. Bacterial colonization of the small bowel leads to deconjugation of the remaining bile acids, altering micelle formation, and exacerbating steatorrhea (9). Furthermore, bacterial overgrowth can also result in D-lactic acid production, which cannot be metabolized by humans; consequently, D-lactic acidosis with neurological symptoms such as ataxia, dysarthria and confusion can result (10). When steatorrhea results from SBS, fluid and electrolyte homeostasis can be better maintained if the colon has been preserved. Energy balance can also be improved through colonic preservation as short chain fatty acids, a by-product of bacterial carbohydrate fermentation in the colon, can provide up to an additional 500 kcal/day (11).

NUTRITIONAL MANAGEMENT IN SHORT BOWEL SYNDROME

Nutritional management of SBS, which can be variable from patient to patient depending on a number of physiological and clinical factors, can generally be divided into three phases or stages (4, 5). Advancement from one stage to another is individualized depending on clinical course, and for pediatric patients, on the efficiency and quality of their growth. Stage 1, which generally lasts from one to three weeks, involves initial hydration and electrolyte management to achieve hemodynamic stability, and initiation of parenteral nutrition (PN) using the central venous route for optimal nutritional support. Stage 2, which is characterized by a reduction in diarrhea and improved intestinal adaptation, involves the judicious initiation of EN using a continuous feeding schedule, while gradually weaning PN delivery to achieve caloric and protein requirements. Successful PN weaning is predicated by EN tolerance, ostomy output and growth outcomes. Stage 3 of nutritional management is characterized as a period of complete bowel adaptation when EN is well tolerated and oral feedings can be initiated. The time required to arrive at stage 3 can take a few months to greater than a year, depending on the child's clinical course, extent of metabolic complications and growth outcomes.

Stage 1: Parenteral Nutrition

The initial mode of nutrition support for pediatric SBS is PN using the central venous route in order to meet caloric and nutrient requirements. Generally, a balanced fuel mix containing carbohydrate, protein and fat should be provided to meet caloric requirements and promote growth. In infants, dextrose should be started at 5–7 mg of glucose/kg/min and advanced by 1–3 mg of glucose/kg/min to an endpoint goal of 12–14 mg/kg/min of glucose (2). This stepwise advancement promotes the gradual response of endogenous insulin, thus preventing hyperglycemia and glycosuria (2–4). Furthermore, provision of adequate, but not excessive carbohydrate infusion, can help prevent immune dysfunction, hepatic steatosis, and excess CO_2 production and retention (4). Parenteral lipids can be initiated at 1 gm/kg/day and advanced by 1 gm/kg per day to an endpoint goal of 3 gm/kg in infants and 1–2 gm/kg/day in children. Generally, lipid provision should not exceed 30%–40% of total calories to minimize the potential for immune dysfunction and hyperlipidemia, particularly in small for gestational age or stressed neonates (13). Optimal fatty acid oxidation requires carnitine, which may become a conditionally essential amino acid in preterm and infants with SBS (14). Parenteral amino acids can be started liberally at 1.5–2 gm/kg/day and advanced to goal by day two or three of PN. Even in neonates, recent studies have clearly demonstrated that progressive protein initiation and advancement promotes improved nitrogen retention and is well tolerated (15, 16). Infants less than two years of age should be managed with a pediatric amino acid formulation such as TrophAmine (B.Braun, Irvine, CA, website: www.bbraunusa.com). Pediatric amino acid solutions provide numerous advantages in the management of infants with SBS including a reduction in the concentration of hepatotoxic amino acids while providing essential amino acids including taurine, tyrosine and histidine (17,18). The addition of 30–40 mg

of cysteine HCl per gram of amino acids, recommended for use with pediatric amino acid formulations, decreases the pH of the PN solution thus increasing calcium and phosphorus solubility. In addition, supplementation of cysteine, an essential amino acid in neonates, in PN solutions serves as a precursor to taurine production, leading to plasma concentrations in the neonatal target range (19).

Provision of adequate electrolyte, vitamin and mineral levels is essential for optimal parenteral nutrition support of the infant or child with SBS. Calcium and phosphorus delivery should be optimized as patients with SBS, particularly infants, have a higher requirement. Pediatric multivitamin solutions, which include vitamin K, and trace element solutions including copper, zinc, chromium, manganese, and selenium should be provided daily. As patients with SBS often have excessive zinc losses through ostomy output and diarrhea, an additional 10 mcg/mL of output is frequently recommended (2,3). In infants and children with cholestasis, however, copper and manganese should be reduced as these trace elements are excreted through the biliary route. Either decreasing the pediatric trace elements to 0.5 mL/day or holding them from the PN solution while adding the chromium and zinc as separate additives may accomplish this. Excessive fluid losses from diarrhea and ostomy output can also result in fluid and sodium deficits. Fluid and electrolytes may be repleted over and above what is provided in the PN using a separate intravenous solution. Often, sodium may need to be provided up to 8–10 mEq/kg/day depending on the degree of ostomy output and diarrhea.

The duration of, and continued reliance on, PN therapy in the management of SBS depends on a number of factors including physiological factors such as length and site of remaining bowel, presence of bacterial overgrowth, degree of hepatobiliary disease, ability to hydrate, tolerance to EN and quality of growth.

Stage 2: Enteral Nutrition

Once the patient is stable from a fluid and electrolyte perspective and growing on PN therapy, EN can be initiated to help promote intestinal adaptation and growth. Intestinal adaptation refers to the processes of cellular hyperplasia, villous hypertrophy, intestinal lengthening, and enhanced hormonal response, which result in increased absorptive surface area (5). Intestinal adaptation occurs sooner with earlier initiation of EN. The ileum has greater potential for adaptation than does the duodenum and jejunum (20). While the process of intestinal adaptation can begin as soon as 24 to 48 hours post-resection, the process can take over one year to occur depending on the course of EN therapy and clinical response based on numerous physiological and metabolic factors (2,3,5).

Enteral nutrition is best administered using continuous infusion, gradually advancing the rate based on a number of outcome indicators (4, 5). In general, continuous feedings are better tolerated and allow for better total nutrient absorption. Emesis, increased abdominal distention, and significant increases in ostomy output are also minimized with gradual advancements in the continuous feeding rate. As enteral calories are advanced, thereby increasing the intestinal load, additional adaptation is promoted which may reduce the duration of reliance on PN. However, a significant increase in stool output by more than 50 percent, or output significantly positive in reducing substances, is a contraindication to feeding advancement. Eventually, as continuous EN is tolerated, the PN delivery can be transitioned to a cyclic schedule, gradually increasing the time off of PN by 2 to 4 hour increments until PN is provided over an 8 to 12 hour nocturnal infusion schedule.

Controversy exists regarding the optimal enteral nutrition formula for use in infants and children with SBS. Historically, elemental, semi-elemental or peptide based formulas have been considered to be the products of choice for use in patients with SBS. In adult patients comparing these products to polymeric formulas have demonstrated similar caloric absorption with all products (21). Complex nutrients do appear to stimulate intestinal adaptation better than simple nutrients such as amino acids, peptides and monosaccharides, and is thought to be explained by the "functional workload" hypothesis, which essentially states that the greater the bowel must work to digest a nutrient, the greater the inducement to adapt (1). While in adults complex proteins are thought to promote better intestinal adaptation than amino acids, in infants and children, protein hydrolysate or even amino acid containing formulas are still predominantly used for a number of *theoretical reasons.* Allergic response is more prevalent in infants and children who have experienced a disruption of their mucosal barrier. Frequently, infants develop allergic

problems during the course of their management of SBS, particularly if exposed to macromolecules. Bacterial overgrowth, which is common in infants and children with SBS, also predisposes them to GI allergies (1). Enteral fats, particularly long chain fatty acids, have the greatest potential for exerting trophic effects in the promotion of intestinal adaptation (22,23). While medium chain triglycerides are more water soluble and have improved absorption in children with SBS, they also have a higher osmotic effect and less of a trophic effect on the gut (22). The provision of excessive levels of simple carbohydrates can have significant osmotic effects, exacerbating diarrhea. Optimally, no more than 40% of the total calories provided should be from carbohydrates, particularly in infants with SBS. In summary, the current standard of practice is to use either a protein hydrolysate formula, or on rare occasion for infants and children with persistent intolerance, an amino acid based formula with a high percentage of fat, mostly in the form of long chain fatty acids, as the optimal enteral feeding formula for infants and children with SBS.

Despite these established practice guidelines for enteral management of pediatric SBS, there is a lack of randomized clinical trials to support the practice of exclusively using semi-elemental or amino acid based formulas. A recent prospective, randomized, crossover, double-blind study in pediatric patients compared the effects of two formulas, differing only in their nitrogen source, on infants with SBS (24), a hydrolyzed and non-hydrolyzed protein source. The study concluded that intestinal permeability, weight gain and energy and nitrogen balance in the SBS patients did not differ between the formulas regardless of hydrolysis of enteral nitrogen source. Depending on the extent and site of intestinal resection and function of the remaining gut, some infants and children may be effectively managed with standard polymeric infant and pediatric formulas.

BREAST MILK AND ENTERAL FORMULAS

Although at first glance, breast milk (BM) may not be considered the enteral feeding of choice for infants with SBS as the nutrients are intact and not hydrolyzed, the literature indicates that the use of BM results in improved GI tolerance and reduced duration of PN in comparison to protein hydrolysate formulas (4,25). Andorsky, et al (25) concluded that several components of BM might have been responsible for these observations. Breast milk contains immunoglobulins as well as growth factors such as growth hormone and epidermal growth factor, which may result in improved intestinal adaptation.

Formulas used for the nutritional management of infants and children with SBS as well as formula cost and manufacturer are summarized in Table 1. Because of the semi-elemental nature of the protein and fat sources, the formulas, Pregestimil (Mead Johnson, Evansville, IN) and Alimentum (Abbott Laboratories, Ross Labs Division, Columbus, OH) are commonly used in the nutritional management of infants with SBS. Pregestimil and Alimentum contain casein hydrolysate with added amino acids as the protein source, and a blend of vegetable oils and MCT oil as the fat source. The carbohydrate in Pregestimil is provided by corn syrup solids (85 percent) and modified tapioca starch (15 percent), while Alimentum contains a blend of tapioca starch and sucrose. Alimentum is also corn free, which may be valuable in infants with multiple food allergies. At a concentration of 20 kcal per ounce, Pregestimil and Alimentum have osmolalities of 320 mOsm and 370 mOsm per kilogram, respectively, and cost more than twice that of standard infant formula. Both Pregestimil and Alimentum are available in powdered and ready-to-feed forms. Additionally, Pregestimil also makes a ready-to-feed 24 kcal per ounce formula for use in the hospital setting.

Infants with SBS who demonstrate persistent GI symptoms when managed with a casein hydrolysate formula may benefit from use of a purely elemental formula (26). NeoCate (SHS North America), which is available in powdered form, is comprised of 100% free amino acids, is lactose free, and has a blend of 5% MCT oil and 95% long chain fats from vegetable oil.

Pediatric patients over the age of one with SBS, who experience continued impaired GI function, or severe allergic complications may require EN support with a semi-elemental or elemental pediatric formula. Over the past 10 years, a variety of semi-elemental and elemental products have entered the medical nutritionals market. Semi-elemental pediatric formulas include Peptamen Junior (Nestle Clinical Nutrition) and Pepdite One +(SHS North America). Peptamen Junior contains

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Table 1.
Pediatric Elemental or Semi-Elemental Formulas for Management of Short Bowel Syndrome*

Product	*Kcal/cc*	*Description*	*Cost per 100 Kcal* **	*Manufacturer****
Infant Formulas (< 1 year old)				
Pregestimil	0.67	Semi-elemental: Peptides & amino acids Ready-to-feed and powdered form	$1.21 (powdered)	Mead Johnson
Alimentum	0.67	Semi-elemental: Peptides & amino acids Ready-to-feed and powdered form	$1.33 (ready-to-feed) $1.21 (powdered)	Ross Labs
Neocate	0.67	Elemental: free amino acids Powdered form	$1.71	SHS North America
Pediatric Formulas (1 year old)				
Peptamen Junior	1.0	Semi-elemental: 100% whey based peptides Ready-to-feed	$2.13 (unflavored) $2.42 (flavored)	Nestle
Pepdite One+	1.0	Semi-elemental: 56% soy hydrolysate peptides & 44% free amino acids Powdered form	$2.19	SHS North America
Neocate One+	1.0	Elemental: 100% free amino acids Powdered form	$1.90	SHS North America
EO28	1.0	Elemental: 100% free amino acids Ready to feed, flavored, available in tetrapacks	$1.50	SHS North America
Elecare	1.0	Elemental: 100% free amino acids Powdered form	$2.65	Ross Labs

*Used with permission from the University of Virginia Health System Nutrition Support Traineeship Syllabus (43)
**Cost based on pricing for October 2003. Price is highly variable among stores, however.

Manufacturer***	Phone Number	Website
Mead-Johnson	800/831-3959	*www.meadjohnson.com*
Nestle	800/776-5446	*www.nestleclinicalnutrition.com*
Ross Laboratory	800/544-7495	*www.ross.com*
SHS North America	800/365-7354	*www.shsna.com*

100% whey based peptides, while Pepdite One + contains 56% low molecular weight peptides from pork and soy hydrolysates and 44% free amino acids. Peptamen Junior provides 33% of the calories from fat with a 60:40 ratio of MCT to long chain triglycerides and an essential fatty acid content of 5% of total calories. Pepdite provides 46% of the calories from fat while providing a 35:65 ratio of MCT to long chain triglycerides. Both formulas are lactose free and sucrose free with corn syrup solids and/or maltodextrins comprising the carbohydrate source. These formulas may be indicated for pediatric patients with SBS who experience persistent intolerance to intact polymeric formulas. Elemental pediatric formulas such as Neocate One+ (SHS North America, Gaithersburg, MD), EleCare (Ross Division, Abbott Laboratories) and Vivonex Pediatric (Novartis Nutrition) are indicated for the child with SBS with severe protein allergy and unable to tolerate the hydrolysate formulas. While their indicated use may be rare, they are useful for the nutritional support of the child with persistent malabsorption and malnutrition. Neocate One+ and Pediatric EO28 (SHS North America), which are both 1 kcal per mL, contain 100% free amino acids and a 65:35 ratio of long chain triglycerides to MCT, providing 32% of the calories from fat. They are also lactose and fructose free with a blend of mal-

Table 2.
Pediatric Liquid Multivitamin Supplements*

Product and Distributor	*Dose*	*A (IU)*	*D (IU)*	*E (IU)*	*B_1 (mg)*	*B_2 (mg)*	*B_3 (mg)*	*B_5 (mg)*	*B_6 (mg)*	*B_{12} (mcg)*	*C (mg)*	*Folate (mg)*	*Fluo (mg)*	*Other Content*
Vi-Daylin Multivitamin Liquid (Ross)	1 ml	1500	400	5.5	0.5	0.6	8	0	0.4	1.5	35	—	—	—
Poly-vi-sol Multivitamin Liquid (Mead Johnson)	1 ml	1500	400	5.2	0.5	0.6	8	0	0.4	2	35	—	—	—
Poly-vi-Flor Multivitamin Liquid (Mead Johnson)	1 ml	1500	400	5	0.5	0.6	8	0	0.4	2	35	—	0.25	—
ADEK Pediatric Drops (Scandipharm) *www.axcanscandipharm.com*	1 ml	1500	400	40	0.5	0.6	6	3	0.6	4	45	—	—	0.1 mg K, 15 mcg biotin, 5 mg zinc
Baby Vitamin Drops (Goldline)	1 ml	1500	400	5.2	0.5	0.6	8	0	0.4	1.5	35			—
Multivitamins for Older Children														
Vi-Daylin Multivitamin Liquid (Ross)	5 ml	2500	400	15	1.05	1.2	13.5	0	1.05	4.5	60	—		—
Thera Multivitamin Liquid (Major)	5 ml	10000	400	0	10	10	100	21.4	4.1	5	200			—
ADEKs tablets (Scandipharm)	1 tab.	4,000	400	150	1.2	1.3	10	10	1.5	12	60	0.2	—	—

*Used with permission from the University of Virginia Health System Nutrition Support Traineeship Syllabus (43)
Note: Brand names are representative of products purchased by the University of Virginia.

todextrin and sucrose as the carbohydrate source. Neocate One+ is available in powdered form for use in tube feedings, while EO28 is flavored and packaged in tetrapacks for oral intake. EleCare, available in powdered form, also provides 100% free amino acids and contains a caloric distribution of 15% protein, 43% carbohydrate as corn syrup solids, and 42% fat in a 67:33 blend of long chain triglycerides and MCT.

ELECTROLYTE, VITAMIN AND MINERAL SUPPLEMENTATION

Excess sodium losses from excessive ostomy output or diarrhea may result in impaired growth despite adequate caloric intake and often requires sodium supplementation in the enteral formula. Infants may require up to 4–8 mEq/kg/day to achieve adequate growth (2–4). Infants who experience metabolic acidosis as a complication of bacterial overgrowth may also require supplementation with sodium bicarbonate.

Due to the loss of absorptive surface area and steatorrhea, children with SBS usually have impaired vitamin and mineral status. Fat-soluble vitamins A, D, and E should be supplemented daily using a pediatric multivitamin preparation (refer to Table 2). As intestinal bacteria primarily synthesize vitamin K, its deficiency is rare unless a child is on long term broad spectrum antibiotic therapy. Water-soluble forms of the fat-soluble vitamins are recommended for optimal absorption. Due to the potential toxicity of the fat-soluble vitamins, annual monitoring of levels is recommended for children with SBS. In children with ileal resection, monthly B_{12} injections are eventually needed to maintain optimal nutrient status.

SBS MANAGEMENT WITH FIBER AND GLUTAMINE

Fiber is now being successfully used in older infants and children with an intact colon as a valuable adjunct in the management of pediatric SBS. Water-soluble fibers, such as soy polysaccharide and pectin, can help lengthen transit time and thus may help increase absorption by enhancing nutrient contact time with the intesti-

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nal mucosa (2). An additional benefit of fiber for patients with a preserved colon is that the undigested fiber can be metabolized to short chain fatty acids by colonic bacteria. The short chain fatty acids induce a trophic effect on the colon and are also a primary energy source for colonocytes. Hawkins, et al (27) demonstrated a reduction in stool reducing substances, a reduction in fecal fat loss from 21% to 10% and a resolution in metabolic acidosis within two weeks of adding 1%–3% pectin to the semi-elemental formulas of former preterm infants following bowel resection. Liquid pectin may be added to formula using Certo Liquid Pectin (Kraft Foods, website: www.kraft.com). Feedings were also advanced more rapidly and both infants were able to maintain appropriate growth rates. Potential risks of exceedingly high fiber intake (greater than 0.5 gm/kg or upper limit of 35 gm) in children, however, include malabsorption of zinc, iron and magnesium.

Glutamine, the most abundant amino acid in the body, is considered to be an important fuel source for rapidly dividing cells such as the cells of the intestinal mucosa. While glutamine is not considered an essential amino acid, it may become conditionally essential in catabolic illness and in prematurity. Neu, et al (28) found that 24–32 week preterm infants fed preterm formula supplemented with glutamine tolerated enteral feedings better than unsupplemented infants. Additionally, as glutamine is absent from commercial PN formulations, it is believed that parenteral supplementation with glutamine may help intestinal adaptation in infants with intestinal immaturity or with short bowel syndrome (2). While diet modification with glutamine and growth hormone has been demonstrated to have positive effects on promoting intestinal adaptation in adults (29), this remains controversial. Similar studies have not been conducted in infants or children.

Stage 3: Introduction of Solid Foods

In infants with short bowel syndrome, solid foods should generally be introduced fairly early in their therapy, usually between 4 to 6 months of age or when the child is developmentally appropriate. Infants who are developmentally delayed and have problems with oral hypersensitivity and aversive feeding behaviors may require a feeding evaluation by an occupational therapist or a speech pathologist. When initiating solid foods or foods with high osmotic loads, those with high simple carbohydrate content should initially be limited. Generally, high protein, low to moderate fat foods (1), as tolerated, should be introduced before carbohydrates. While infants and children may continue to receive continuous nocturnal EN with an age appropriate semi-elemental formula, during the day they should receive small frequent meals and can be orally supplemented with the appropriate formula such as Pregestimil (Mead Johnson) or Peptamen Junior (Nestle Clinical Nutrition), which is available in vanilla flavor. Oral intake can be advanced gradually, as the child tolerates, to more polymeric supplements such as Kindercal (Mead Johnson) or more complex foods. The transition to complete oral feedings may take weeks, months or even years as intestinal adaptation occurs. Patients with intact colons are at risk for developing calcium oxalate renal stones. In the presence of steatorrhea, calcium binds to free fatty acids and forms insoluble soaps. Consequently, the unbound oxalate is absorbed by the colon and is excreted in the urine, potentially forming calcium oxalate renal stones (5). High oxalate foods including tea, colas, chocolate, nuts, green leafy vegetables, celery and strawberries should be limited in the diet and adequate fluid intake for optimal hydration should be emphasized. Refer to Table 3 for a summary of the guidelines for Stages 1 through 3 of the nutritional management of short bowel syndrome.

MEDICAL COMPLICATIONS OF SHORT BOWEL SYNDROME

The most common serious medical complication of SBS is central venous line (CVL) catheter infection, with *Staphylococcus* from the skin being the most common species. Dacron cuffs bonded to the CVL and placed subcutaneously serve as a barrier to migration of bacteria along the track. Complete subcutaneous placement of the injection hub also theoretically decreases bacterial access to the catheter. However, our experience has been that repeated needle sticks inevitably lead to infection with these catheters (30). Bacteria may also migrate from the intestine to the blood through bacterial translocation across the gut wall. Multiple factors such as cholestasis, pharmaco-

Table 3.
Summary of Nutritional Management of Pediatric SBS

Stage	*Nutritional Management Guidelines*
1. Parenteral Nutrition	• Stabilize fluid and electrolytes • Initiation of parenteral nutrition • Advancement of macronutrients to meet nutritional and growth goals *Carbohydrate* – Dextrose: begin at 5-7 mg/kg/min – Advance by 1 – 3 mg/kg/min – Endpoint: 12-14 mg/kg/min (neonates) – Older infants and children use appropriate calorie level *Protein* – Begin at 1 – 2 gm/kg/day – Advance to goal by Day 2 of PN – Use TrophAmine in infants < 2 years *Lipids* – Begin at 1 gm/kg/day – Advance by 1 gm/kg/day – Endpoint goal: 3 gm/kg/day (infants < 2 years) and 1.5 – 2 gm/kg/day (children >2 years)
2. Enteral Nutrition	• Initiate continuous enteral feeds with age appropriate formula; optimize gut trophic stimulation • Gradually wean parenteral nutrition • Begin small intermittent feedings by mouth and transition to nocturnal continuous feeding • Begin appropriate electrolyte, vitamin and mineral supplementation
3. Introduction of Solid Foods	• Initiation of age appropriate solid foods • Stress high protein, low to moderate fat, foods before introducing carbohydrates • Consider feeding evaluation by speech or occupational therapist • As oral intake improves may consider supplementation with semi-elemental or polymeric formulas by mouth.

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logic acid suppression, dysmotility, and absence of an ileocecal valve may accentuate small bowel bacterial overgrowth and facilitate bacterial translocation (31).

The second most common medical complication of SBS is large vessel thrombosis associated with CVL catheters. This is extremely common in children under 1 year of age, probably due to the relatively small vessel size. Repeated thrombosis can lead to superior vena cava syndrome and life-threatening difficulty with venous access (32).

Liver disease associated with SBS is most often cholestatic. Multiple factors are responsible, with decreased enteral intake and stimulation and associated increased PN use being the most common causes. Without enteral intake, gallbladder emptying is decreased and bile continues to be concentrated, eventually becoming viscid, forming sludge or stones, which can clog bile ducts (33). Absence of EN also may be partly responsible for inadequate stimulation of gallbladder emptying (34). In addition, small bowel bacterial overgrowth can lead to the formation of lithogenic bile salts through the action of bacterial hydroxylase on luminal bile salts, further diminishing

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the effective bile salt pool (35). Finally, documented bacterial sepsis is a significant adjuvant to the development of severe liver disease (36).

Intestinal dysmotility can be a vexing complication of SBS (37). Multiple resections can interfere with nerve propagation along the intestine. Inflammation at the sight of anastomoses can be severe. With sufficient time, strictures and adhesions may also contribute to a picture of dysmotility. Bacterial overgrowth, generally with anaerobic species, in the small intestine can potentiate dysmotility through inflammation of normal mucosal and anastomotic mucosal surfaces. Gastroschisis (38) and malrotation anomalies (39) of themselves may be associated with poor motility and are often associated with SBS. Surgical Nissen Fundoplications can lead to dysmotility particularly in the stomach where both dumping syndrome and outlet obstruction have been described (40). Occasionally, primary dysmotility (pseudoobstruction syndrome) is misdiagnosed and intestinal resection is performed which further antagonizes the underlying dysmotility of pseudoobstruction.

Ultimately, once diarrhea decreases in SBS, actual constipation may become a problem, especially in children with cerebral palsy and those who do not receive bolus feedings (which stimulate a gastrocolic reflex). Over reliance on refined enteral formulas, and inadequate fluid provision can also contribute to constipation. If actual fecal impaction occurs, secondary obstructive symptoms may be misinterpreted as proximal gut motility abnormalities, diverting the clinician away from the need for disimpaction prior to treatment or evaluation of proximal gut dysmotility (41).

Blood loss can be extreme in children with short bowel syndrome. This can occur along anastomotic lines or be due to bleeding at a gastrostomy site, mechanical erosion from indwelling enteric catheters or associated stress ulcers. Bacterial overgrowth (42) and potentially protein sensitive enteropathy can antagonize blood loss. The effects of anastomotic inflammation and bacterial overgrowth probably render the gut more susceptible to the development of protein sensitive enteropathy because they allow absorption of intact protein across the gut with consequent sensitization. Inadequate gut length for absorption of iron, folic acid, vitamin B_{12} and/or copper can hinder efforts to improve secondary anemia in short bowel syndrome.

CONCLUSION

The nutritional management of pediatric SBS presents numerous challenges for physicians and other health care professionals; however, with aggressive and timely medical nutrition therapy, most infants and children do well. Management goals should include appropriate and timely initiation of PN and EN to promote optimal intestinal adaptation and to promote continued growth and development. Timely initiation and advancement of EN with age appropriate specialized formulas, aimed at providing stimulation to the GI tract is of utmost importance. Minimizing fluid and electrolyte loss, supplementation with appropriate vitamin, mineral and other nutrients such as glutamine and fiber can play a pivotal role in preventing nutritional deficiencies and optimizing clinical outcomes. Careful monitoring of nutritional status and growth velocity on a long term basis are key components to success in nutritional and medical management. ■

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