COLLECTIVE REVIEW

Current Surgical Options in Short Bowel Syndrome

Bianchi technique

STEP
Serial Transverse Enteroplasty

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Current surgical options in Short Bowel Syndrome

Definition

Intestinal failure (IF) was firstly defined in 1981 by Fleming and Remington as “a reduction in the functioning gut mass below the minimal amount necessary for adequate digestion and absorption of food”\(^\text{(1)}\).

The European Society for Clinical Nutrition and Metabolism defined intestinal failure (IF) as “the reduction of gut function below the minimum necessary for the absorption of macronutrients and/or water and electrolytes, such that intravenous supplementation is required to maintain health and/or growth”\(^\text{(2)}\), in which short bowel syndrome is its most frequent cause.

Short bowel syndrome (SBS) is a malabsorptive condition that is caused by congenital defect or an acquired shortage of small bowel length

- surgical resection of the small intestine
- disease-associated loss of absorption

and is characterized by the inability to maintain protein-energy, fluid, electrolyte, or micronutrient balances when on a conventionally accepted, normal diet\(^\text{(3),(4)}\).

The classification based on functional outcome was introduced by Shaffer in 2002\(^\text{(13)}\)

- **Type I IF** an acute, short-term and usually self limiting condition, commonly occurring in the peri-operative setting and/or in association with critical illnesses, and requiring IVS for a few days or a few weeks
• **Type II IF** a prolonged acute condition, often in metabolically unstable patients, such as those with an intra-abdominal catastrophe, enterocutaneous fistulae, or acute mesenteric ischemia, requiring complex multi-disciplinary care and intravenous supplementation over periods of weeks or months.

• **Type III IF** a chronic condition, in metabolically stable patients, who require intravenous supplementation over months or years. It may be reversible or irreversible.

The latest revision has been made recently by Pironi et al. (see table 1)\cite{4,11-12}.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Anatomical and functional classification of short bowel syndrome.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Anatomical</strong></td>
</tr>
<tr>
<td>Type I</td>
<td>End-jejunostomy</td>
</tr>
<tr>
<td>Type II</td>
<td>Jejunocolonic continuity, ileocaecal valve not present</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Type III</td>
<td>Jejunoileal anastomosis, ileocaecal valve present</td>
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</tbody>
</table>

The anatomical classification was derived from Feldman et al.\cite{12}, the functional classification was derived from Pironi et al.\cite{11}.

• type I: represents the potentially severest condition being an end-jejunostomy

• type II: there is jejunocolic continuity but there is no ileocolic valve present

• type III: there is a jejunoileal anastomosis and the ileocecal valve is preserved.
The prognostic factor in short bowel syndrome are the age of the patient, diagnosis of an intrinsic bowel disease [Crohn’s], systemic disease, the presence of duodenum, IC valve, the colon length, and the length of remnant small bowel. (shown in the table 2)

### Table 2
Prognostic factors for short bowel syndrome.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Favourable</th>
<th>Unfavourable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Young</td>
<td>Extremely young or old</td>
</tr>
<tr>
<td>Systemic disease</td>
<td>Not present</td>
<td>Present</td>
</tr>
<tr>
<td>Intrinsic Bowel Disease</td>
<td>Not present</td>
<td>Bypassed or (partially) resected</td>
</tr>
<tr>
<td>Duodenum</td>
<td>Complete</td>
<td>Present</td>
</tr>
<tr>
<td>Length small bowel</td>
<td>&gt;150 cm</td>
<td>ileum</td>
</tr>
<tr>
<td>Part resected</td>
<td>Jejunum</td>
<td>Not present</td>
</tr>
<tr>
<td>Ileocecal valve</td>
<td>Present</td>
<td>Not present</td>
</tr>
<tr>
<td>Colon</td>
<td>Present</td>
<td></td>
</tr>
</tbody>
</table>

**Epidemiology**

The Retrospectice cohort study in Canada showed the overall incidence of short bowel syndrome is 24.5 per 100,000 live births. The incidence is much greater in premature live births. The Canadian incidence of SBS is approximately 85 cases annually[^5].

The incidence and prevalence of short bowel syndrome have increased over the past decades. In Europe, the estimated incidence and prevalence is 2-3 per million and 4 per million, respectively[^6][^8].

**Etiology**

Short Bowel Syndrome is the predominant cause of intestinal failure in children and is related to congenital causes such as atresias, gastroschisis or acquired conditions including volvulus, and necrotizing enterocolitis[^7].

The main causes of SBS[^1][^4] in children remain congenital and perinatal diseases, such as intestinal atresia, abdominal wall defects (gastroschisis), malrotation/volvulus, and extensive Hirschsprung’s disease.

In the non-neonatal population; the volvulus, trauma and Crohn’s disease are the leading etiologies.
The etiologies of short bowel syndrome are presented in Table 3.

<table>
<thead>
<tr>
<th>Etiology</th>
<th>Prenatal</th>
<th>Neonatal</th>
<th>Postnatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atresia (unique or multiple)</td>
<td>Midgut volvulus (midgut or segmental)</td>
<td>Midgut volvulus (malrotation, bands, or tumor)</td>
<td></td>
</tr>
<tr>
<td>Apiepel syndrome</td>
<td>Necrotizing enterocolitis</td>
<td>Complicated intussusception</td>
<td></td>
</tr>
<tr>
<td>Midgut volvulus (malrotation)</td>
<td>Arterial thrombosis</td>
<td>Arterial thrombosis</td>
<td></td>
</tr>
<tr>
<td>Segmental volvulus (with omphalomesenteric duct or intra-abdominal bands)</td>
<td>Venous thrombosis</td>
<td>Inflammatory bowel disease</td>
<td></td>
</tr>
<tr>
<td>Abdominal wall defects</td>
<td></td>
<td>Postruption resection</td>
<td></td>
</tr>
<tr>
<td>Gastrochisis &gt; Omphalocoele</td>
<td></td>
<td>Extensive angioma</td>
<td></td>
</tr>
</tbody>
</table>

From the table 3 can be concluded, the etiology of SBS results from bowel resection for ischemia or bowel injury.

**Embryology**

At the end of the 6th week GA, the intestinal loop herniates through the umbilicus and rotates 90 degrees counterclockwise around the SMA (A,B). The small intestine (prearterial) elongates and forms the jejunoileal loops. During the 10th week, the jejunoileal loops retract into the abdominal cavity, and rotate an additional 180 degrees counterclockwise (C), makes a total of 270 degrees. The postarterial loop will form the colon, remains relatively straight. As the midgut completes its return, the cecum lies in the RUQ (D). The mesenteries become adherent to the parietal
peritoneum. The cecum separates the liver, the increasing distance becomes occupied by the lengthening ascending colon. Finally, the liver position is in RUQ and the cecal position is in RLQ (E).[9]

The small bowel is completely formed by 20 weeks of gestation. Most of its growth occurs in the 3rd trimester gestation and increases to approximately 250 cm with a diameter of 1.5 cm after 35 weeks of gestation[10]. The mucosal surface area increases with age; an average infant's intestine is about 950 cm$^2$ compared with an adult intestine of 7500 cm$^2$.

**Pathophysiology**

Intestinal failure can be classified into 5 major pathophysiological conditions, which may originate from various gastrointestinal or systemic diseases (show in table 4[11]):

<table>
<thead>
<tr>
<th>Condition</th>
<th>Primary mechanism of intestinal failure</th>
<th>Concomitant mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short bowel</td>
<td>Reduced absorptive mucosal surface</td>
<td>• Increased intestinal losses of fluids and electrolytes (adjunctive mechanism in the case of end jejunostomy)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Restricted oral/enteral nutrition, loss of intestinal mass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Disease related hypophagia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lack of adaptive hyperplasia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Accelerated gastrointestinal transit time</td>
</tr>
<tr>
<td>Intestinal fistula</td>
<td>By pass of large areas of absorptive mucosal surface</td>
<td>• Small bowel bacterial overgrowth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increased intestinal losses of fluids and electrolytes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Disruption of the entero-hepatic cycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Restricted oral/enteral nutrition or total fasting (bowl rest) to decrease fistula output</td>
</tr>
<tr>
<td>Intestinal dysmotility</td>
<td>Restricted oral/enteral nutrition or total fasting from intolerance due to feeding related exacerbation of digestive symptoms or to episodes of non-mechanical intestinal obstruction</td>
<td>• Malabsorption due to small bowel bacterial overgrowth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increased intestinal secretion of fluids and electrolytes in the obstructed segments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increased intestinal losses of fluids and electrolytes due to vomiting, gastric drainage and/or diarrhoea</td>
</tr>
<tr>
<td>Mechanical obstruction</td>
<td>Incomplete or total fasting (bowl rest)</td>
<td>• Increased intestinal secretion of fluids and electrolytes in the obstructed segments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increased intestinal losses of fluids and electrolytes due to vomiting or gastric drainage</td>
</tr>
<tr>
<td>Extensive small bowel mucosal disease</td>
<td>Inefficient absorptive and/or nutrient losing mucosal surface.</td>
<td>• Increased intestinal losses of fluids and electrolytes due to vomiting or gastric drainage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Restricted oral/enteral nutrition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Disease-related hypophagia</td>
</tr>
</tbody>
</table>

1. Short bowel:

A short bowel may be the result of extensive surgical resections or of congenital diseases of the small intestine. The primary pathophysiological mechanism is the reduced intestinal absorptive surface area.
The likelihood of developing an SBS-associated IF depends on the residual small bowel length in continuity and on several “concomitant mechanisms” related to the anatomy, integrity, function and adaptive potential of the small bowel remnant as well as to the underlying clinical condition \[^{15}\]. The post-resection intestinal adaptation is a spontaneous process that attempts to ensure a more efficient absorption of nutrients per unit length of the remaining bowel. This occurs partly by increasing the absorptive area (structural adaptation) and/or by slowing the gastrointestinal transit (functional adaptation). It is promoted by the presence of nutrients in the gut lumen, by the pancreatic and biliary secretions and by gut hormones mainly produced by the ileum and colon, and usually takes place over 1 or 2 years. Post-operative intestinal adaptation appears to be absent or impaired in the presence of an end-jejunostomy\[^{15}\].

Other mechanisms contributing to IF may be, excessive fluid and electrolyte intestinal losses in the presence of an end jejunostomy, restriction of oral nutrient intake in an attempt to decrease the intestinal losses, reduced oral intake because of underlying disease-related hypophagia and failure to develop the post-resection adaptive hyperphagia.

SBS-associated IF may be reversible because of the intestinal adaptation process and/or intestinal rehabilitation programs based on medical and surgical treatments\[^{16}\].

2. **Intestinal fistula**

Abnormal communications between 2 parts of the gastrointestinal tract, between the gut and the other organs, or between the gastrointestinal tract and the skin (enterocutaneous fistulas, EC)\[^{17}\].

In EC fistulas, the enteric content is prematurely lost from the small bowel lumen. The primary mechanism of IF is the bypass of a large area of intestinal absorption surface, a condition resembling a short bowel\[^{17}\]. The onset of an EC fistula is often an acute event, associated with intra-abdominal abscess collection, systemic sepsis and the related metabolic derangement, as well as with high intestinal fluid and electrolyte losses with the fistula effluent. Concomitant pathophysiological mechanisms contributing to EC fistula-associated IF may be the impairment of gastro-intestinal motility and the metabolic alterations associated with systemic sepsis or intra-abdominal inflammation, the excessive intestinal losses of fluids and electrolytes, the disruption of the entero-hepatic cycle of bile acids, and the restricted or abolished ("bowel rest") oral/enteral nutrition to decrease the fistula output and/or to favor spontaneous fistula closure\[^{11\,11\,11\,18}\].

3. **Intestinal dysmotility**

The presence of disorders of the propulsion of the gut content in the absence of fixed occluding lesions. It may be locoregional, affecting only one bowel segment, as in achalasia, gastroparesis, colonic obstruction and Hirschprung's disease, or multi-regional, involving more than one part of the GI tract, especially the small bowel. Acute intestinal
dysmotility is the primary pathophysiological cause of type I IF due to post-operative or acute critical illness associated ileus, and a frequent concomitant cause of type II IF, due to the impaired gastrointestinal motility associated with systemic or intra-abdominal inflammation. Permanent intestinal dysmotility is termed chronic intestinal pseudo-obstruction (CIPO), where the modifier “pseudo” is used to underline the absence of occluding lesions\(^\text{[11],[19]}\).

In intestinal dysmotility, the primary pathophysiological mechanism is intolerance to oral or enteral nutrition resulting in inadequate nutritional intake. The mucosal surface is generally intact. “Secondary mechanisms” include nutrient malabsorption due to small bowel bacterial overgrowth, and increased intestinal secretion and/or losses of fluids and electrolytes, occurring in the dilated bowel segments, or after intestinal resection and venting or end-ostomy performed to relieve symptoms. CIPO-associated IF represents approximately 20% of both adults and children on HPN for type III chronic IF. The reversibility of IF in patients with CIPO is lower than that reported in SBS, having been reported in 25–50% in adults and 25–38% in children, with a 78% 5 year survival probability for adults on HPN\(^\text{[20]}\).

4. Mechanical obstruction

Mechanical obstruction results from a physical abnormality affecting the intestine, which may be intraluminal, intrinsic or extrinsic, of benign or malignant origin. It may be an acute event encompassing a feature of type I IF, that resolves in a few days through conservative medical treatment or a surgical procedure. It may also be a prolonged feature, determining a type II or III IF, as in patients with extensive adhesions (“frozen abdomen”), or in those with peritoneal carcinomatosis associated with late-stage intra-abdominal malignancy.

The primary pathophysiological mechanism of IF in obstruction is the spontaneous or prescribed (“bowel rest”) abolished oral or enteral nutrition. Secondary mechanisms include the increased intestinal secretion of fluids and electrolytes in the obstructed segment, and increased intestinal losses of fluids and electrolytes with vomiting or NG drainage.

5. Extensive small bowel mucosal disease

Extensive small bowel mucosal disease is an intact or almost intact, although inefficient, mucosal surface\(^\text{[20-22]}\). The reduction of nutrient absorption and/or the loss of nutrients through the intestinal mucosa to the point where the body’s requirements are no longer met, are the most frequent primary mechanisms of IF. Rarely, increased intestinal secretion of fluids and electrolytes can be present as a concomitant mechanism. Extensive small bowel mucosal disease has been reported to be the cause of CIF in about 25% of children and 5% of adult patients on long term HPN. In adults with type III IF due to extensive mucosal disease, weaning from HPN rarely occurs\(^\text{[20]}\).
<table>
<thead>
<tr>
<th>Condition</th>
<th>Most frequent underlying diseases</th>
</tr>
</thead>
</table>
| Short bowel                       | Extensive surgical resection for:  
  - Mesenteric inflammation (arterial or venous thrombosis)  
  - Crohn's disease  
  - Radiation enteritis  
  - Surgical complications  
  - Intestinal volvulus  
  - Familial polyposis  
  - Abdominal trauma  
  - Intestinal angiofoliosis  
  - Necrotizing enterocolitis  
  - Complicated intussusception  
  - Congenital  
  - Gastrostomy  
  - Intestinal stricture  
  - Intestinal malformation  
  - Omphalocele  |
| Intestinal fistula                 | Inflammatory (Crohn's disease, diverticular disease, pancreatic disease, radiation enteritis)  
  - Neoplastic (colon cancer, ovarian cancer, small bowel malignancy)  
  - Iatrogenic (operation, percutaneous drainage)  
  - Infectious disease (tuberculosis, actinomycosis)  
  - Trauma  
  - Foreign body  |
| Intestinal dysmotility             | Acute postoperative, systemic inflammatory or neurological reaction associated with critical illnesses;  
  Ogilvie syndrome (acute colonic non-mechanical obstruction)  
  Chronic intestinal pseudo-obstruction (obstructive symptoms for at least 6 months):  
  - Primary/idiopathic (with no underlying disorder)  
    - Neuropathic: inflammatory or degenerative injury to the enteric nervous system (ENS)  
    - Myopathic: damage of the smooth muscle (congenital, familial, or sporadic), familial visceral myopathy is classified as type 1 (autosomal dominants), type 2 (autosomal recessive with associated prions and ophthalmoplegia), or type 3 (autosomal recessive with the presence of gastrointestinal tract dilatation)  
    - Mesenchymopathy: injury to the intestinal cells of Cajal  
  - Secondary (due to an underlying disorder): may be also classified as neuropathy, myopathy or mesenchymopathy  
    - Collagen vascular diseases: primary systemic sclerosis, systemic lupus erythematosus, dermatomyositis, polymyositis, parietal bone, rheumatoid arthritis, mixed connective tissue disorders, Ehlers-Danlos syndrome  
    - Endocrine disorders: diabetes, hypothyroidism, hyperparathyroidism  
    - Neurologic disorders: Parkinson disease, Alzheimer disease, Shy-Drager syndrome, Chagas disease, Hirschsprung disease (intestinal hypoganglionosis), dystonia (familial or sporadic), Von Recklinghausen's disease  
    - Medication associated: tricyclic antidepressants, anti-cholinergic agents, ganglionic blockers, anti-Parkinsonian agents, clonidine, phenothiazines  
    - Pancreatic: central nervous system neoplasms, lung micromyoma, brosal cancer, leptomeningomas, carcinoid, thymoma  
    - Miscellaneous: celiac disease, infiltrative disorders (amyloidosis, lymphoma), alcohol abuse, post-infectious processes (viral, bacterial, parasitic), radiation, vascular insufficiency, metabolic (hyperkalemia, hypomagnesemia), postsurgical, post-organ transplant, mitochondrial disorders |
| Mechanical obstruction             | Obstruction (polypoid tumors, intussusception, gallstones, foreign bodies, bezoars, feces)  
  - Intestinal bowel lesions (stenosis or strictures: neoplastic, inflammatory bowel disease, chemical, axenomosis) |

Table 5 (continued)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Most frequent underlying diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive small bowel mesenteric</td>
<td></td>
</tr>
</tbody>
</table>
  disease  
  - Microvillous inclusion disease (or microvillous atrophy)  
  - Tolking enteropathy (or intestinal epithelial dysplasia)  
  - Tricho-basal enteric syndrome (or syndromic diarrhea or phenotypic diarrhea)  
  - Intractable diarrhea of infancy  
  - Severe food allergy in children  
  - Autoimmune enteropathy  
  - Intestinal lymphangiectasia  
  - Waldman disease and other protein-losing enteropathies  
  - Common variable immunodeficiency  
  - Crohn's disease  
  - Celiac disease  
  - Radiation enteritis  
  - Chemotherapy related enteritis  
  - Congenital diseases (such as glucose-galactose malabsorption, congenital defects of glycosylation, primary bile acid malabsorption, chloride diarrhea, sodium diarrhea) |

Table 5 [11]
**Imaging Studies**

1. Film abdomen
2. UGI study
3. CT whole abdomen
4. Endoscopy or Colonoscopy

**General Management Scheme**

**Intestinal adaptation**

Intestinal adaptation is the process following intestinal resection whereby the remaining bowel undergoes macroscopic and microscopic changes that serve to increase its absorptive ability. Adaptation is highly variable and usually occurs during the first two years following intestinal resection in adults and for longer and perhaps more vigorously in children. Adaptive changes are usually most prominent in the ileum and to a lesser extent, in the jejunum and colon. These changes are mediated by a variety of internal and external stimuli including nutrients, gastrointestinal secretions, hormones, and growth factors and other genetic and biochemical factors. In particular, adaptation depends upon the nutrient components of the diet and on influences from the remaining segments of the intestine.

Both structural and functional changes can occur:

- **Structural adaptive changes** include dilation and elongation of the remnant bowel, an increase in intestinal wet weight, protein and DNA content, villus lengthening, expansion in microvilli, and an increase in crypt cell depth and enterocyte number. These morphologic changes in the mucosa are driven by a proliferative stimulus that affects cellular progression along the crypt-villus axis, resulting in an increase in mucosal weight and enlargement in mucosal folds. Adaptation of the gut muscle layers also takes place, leading to an increase in muscle thickness, circumference, and length.

- **Functional adaptive changes** occurring include modifications of the brush border membrane enzyme activity, fluidity and permeability, up- or downregulation of carrier-mediated transport (eg, upregulation of Na+/glucose cotransporters, Na+/H+ exchangers, and other enzymes involved in digestion and absorption) and a slowing in
the rate of transit, allowing more time for absorption to occur\textsuperscript{[49-50]}. Adaptive changes in gut microbiota, motor activity, and barrier and immune functions after massive intestinal resection are poorly understood.

Animal models of SBS provide insight into the adaptive process. After bowel resection, epithelial hyperplasia is seen within 24 to 48 hours\textsuperscript{[51-56]}. The length of villi and intestinal absorptive area increases and digestive and absorptive function gradually improve. These morphologic changes are associated with changes in expression of a variety of genes\textsuperscript{[57-59]}, some of which are known mediators of intestinal growth. These adaptive changes are more apparent in the animal models compared with humans with SBS. Furthermore, most studies investigating the process of adaptation have utilized animal models with a jejuno-ileo-colonic anastomosis, a relatively uncommon bowel anatomy in humans with SBS. Thus, the physiologic and structural changes that occur in the animal models are of unclear clinical relevance.

**Ileal versus jejunal adaptation** — The ileum is capable of undergoing marked adaptation after small bowel resection, with significant growth in villus surface area, as well as increases in intestinal length, diameter, and motor function\textsuperscript{[60-61]}. These structural changes are primarily responsible for enhancement of nutrient uptake in a given segment of bowel\textsuperscript{[62]}. However, there is also some evidence for functional improvement of absorption through upregulation of transporters and of brush border enzymes. These adaptive changes lead to a gradual improvement in macronutrient absorption during the first one to three years after jejunal resection\textsuperscript{[63]}. The jejunum exhibits more modest adaptive changes in response to intestinal resection, and most of these changes are functional (changes in transport and enzyme activity) rather than structural (changes in absorptive area)\textsuperscript{[63]}. Jejunal adaptation appears to depend on influences from other remaining segments of the bowel; patients with a jeuno-colic anastomosis demonstrate functional small bowel adaptation, whereas those with an end-jejunostomy show little to no adaptation. Despite limited evidence, similar effects would be expected in those with colon-in-continuity versus those whose colon remains but is not in continuity, given the lack of nutrient exposure to the excluded colon. This reinforces the importance of the colon in the prognosis of the patient with SBS.
Medical management

Early management — During the first few months after intestinal resection, the predominant goals are maintenance of good nutritional status through administration of parenteral nutrition (PN) and prevention of fluid and electrolyte abnormalities.

Parenteral nutrition — In this early phase, the major portion of energy is delivered through PN, but enteral nutrition should be initiated promptly to support intestinal adaptation. The principles of prescribing PN to infants and children are discussed in detail in a separate topic review. In patients who will likely require PN for more than three weeks, we commonly restrict soy-based intravenous lipids solutions to a dose of 1 gm/kg/day in order to reduce the risk of intestinal failure-associated liver disease (IFALD). Infants with SBS are at particular risk of developing IFALD and therefore should be monitored carefully for this condition.

Fluid management — Large-volume fluid losses from gastric or proximal small bowel secretions are common in the early phase. As a result, patients require rigorous replacement of fluids with sodium, potassium, chloride, and magnesium.

Fluid and electrolyte losses through an enterostomy or in the feces (if these are >2 mL/kg/hr) should be measured and replaced. Most of the chronic fluid replacement usually can be supplied through PN using a solution that is tailored to the patient's fluid and electrolyte needs. Acute increases in enteral losses may warrant immediate replacement. This should be done with a solution separate from the parenteral nutrition, to allow timely and accurate replacement of the losses. High output ostomy or stool losses can also be replaced with appropriately formulated oral rehydration solutions. These solutions generally contain a suitably designed mix of water, electrolytes, and carbohydrate to replace diarrheal losses.

Acid suppression — Patients with SBS often exhibit hypersecretion of gastric acid and fluids, which reduces pH below the optimal level needed for fat absorption (by inactivating pancreatic lipase and deconjugating bile salts), alters enteral drug absorption, and increases intestinal fluid losses.

Histamine 2 receptor antagonists (eg, ranitidine) and proton pump inhibitors (PPIs; eg, omeprazole) inhibit excessive gastric secretion. Routinely administration the acid suppression to patients during the early phase of SBS after intestinal resection, when gastric hypersecretion is most common. Acid blockade decreases the acid load delivered to the duodenum and may be particularly helpful in managing gastrointestinal outputs in patients with extensive ileal resection.
**Growth Goals** — The resting energy expenditure in infants with SBS is similar to that in healthy controls\[^{64}\]. However, because of malabsorption, patients with SBS typically require 30 to 70 percent more calories if they are fed enterally compared with their energy needs from PN\[^{65}\]. Growth is monitored by assessing whether increases in weight are proportional to linear growth, using standard growth curves for infants, with adjustment for premature birth until two years of age.

**Enteral Feeding** — Enteral feeding is a central goal in management of a patient with SBS. Enteral feeds should be introduced early, and advanced carefully but persistently, as rapidly as tolerated by the patient. Enteral feeding is important for several reasons:

- The presence of nutrients in the intestinal lumen is essential to promote intestinal adaptation, and appears to be more effective if enteral feeds are initiated early\[^{66-68}\]. This effect occurs even when only small amounts of feeds are given (sometimes termed "trophic feeds"). Absence of enteral feeding may induce atrophy of the mucosa\[^{69}\].
- As enteral feeds are increased, parenteral nutrition (PN) can be decreased, reducing the risk for complications of long-term PN such as intestinal failure-associated liver disease (IFALD) and metabolic bone disease.
- Some oral feeding is important in infants in order to avoid feeding aversion.

**Surgical approaches**

The initial goal of management in patients with intestinal failure is to wean parenteral nutrition and minimize parenteral nutrition associated comorbidities.

Timing is an essential consideration when considering a surgical intervention for intestinal rehabilitation. Early surgery may be an unnecessary, as bowel adaptation and lengthening may prevent the need for long term TPN. Late surgery exposes the patient to additional TPN-related costs and complications.
Phase of treatment

Surgical options in patients with long-term intestinal failure fall into 4 main categories as shown in Table 6:

1. Operations to Correct Slow Transit

   Slow transit in SBS is relatively rare and should trigger a search for strictures, partial obstructions or blind loops, and enteroenteric fistulas. These are often sequelae of the underlying disease leading to SBS, such as Crohn’s disease, and often require meticulous investigation to diagnose and treat appropriately. A high index of suspicion regarding patients whose clinical behavior is at odds with their underlying anatomical characteristics should permit the discovery and satisfactory resolution of such cases.

2. Operations to Improve Intestinal Motility in Cases of Dilated Bowel

   Rapid intestinal transit is a nearly universal clinical challenge in SBS and should elicit prompt investigation into underlying structural causes. Segmental bowel dilatation with poor peristalsis is a frequent finding in patients with SBS and rapid transit, and it often results in clinical features of small bowel bacterial overgrowth.

3. Operations to slow intestinal transit in the absence of bowel dilatation

   - **Segmental reversal of the small bowel (SRSB)** is a procedure that is designed to slow transit in the absence of bowel dilatation. SRSB creates an antiperistaltic segment of bowel approximately 10–12 cm in length, located ~10 cm proximal to an end-stoma or the small bowel-colon anastomosis. Of 38 patients undergoing SRSB over a 25-year period at a single center, 17 (45%) achieved complete independence from PN. Among patients who were not weaned, PN requirements were decreased by a median 3 days per week. A shorter interval between enterectomy and SRSB, an SRSB >10 cm, and an extended stay with the nutrition unit were significantly associated with enteral autonomy.
Operations to increase mucosal surface area

Although the creation of neomucosa remains an elusive goal, use of sequential lengthening procedures and controlled tissue expansion (CTE) before bowel lengthening may have immediate, albeit limited, clinical application. The theoretical basis for the strategy of CTE of non-dilated bowel in preparation for definitive intestinal lengthening was laid out in experimental work on pigs by the demonstration of mucosal hypertrophy and gain in length and diameter of partially obstructed intestine[39]. More recent experience from the Ann Arbor group suggests that redilation after prior lengthening may be an overall poor prognostic sign and merits caution[40].

Surgical options

1. Non-intestinal transplantation
   a. Increase transit time
   b. Enhance adaptation

2. Intestinal transplantation

1. Non-intestinal transplantation

a. Increase transit time

- A simple tapering enteroplasty is most easily managed the excessive intestine in which a strip of intestine along the antimesenteric border of dilated bowel is removed using a mechanical stapling device[26]. This procedure is most applicable when bowel length is considered adequate and when loss of surface area is an acceptable tradeoff for better prograde peristalsis.
- Reversing intestinal segments: interposition of a reversed, antiperistaltic segment of bowel creates a “physiologic” valve
- Intestinal Valve: Partially obstructing intestinal valves have traditionally employed for patients with short intestinal length and normal caliber, but who are also hampered by rapid transit. The simplest techniques include the placement of sutures or an external Teflon collar around the circumference of the bowel
- Colon interposition: used consists of interposing of a segment of colon between two limbs of small bowel in patients with rapid intestinal transit

b. Enhance adaptation
The longitudinal intestinal lengthening and tailoring (L.I.L.T) procedure, originally described by Bianchi [25] (A) accomplishes intestinal tapering without loss of surface area used in cases where bowel length is critical. 

**Figure 2** The longitudinal intestinal lengthening and tailoring (L.I.L.T) procedure, originally described by Bianchi [25] (A) Creation of the avascular space along the mesenteric border of a dilated loop of bowel, (B) view of avascular space, (C) splitting of the bowel lengthwise; (D) view of newly created herni-loops; (E) isoperistaltic anastomosis of herni-loops. Reproduced with permission from Bianchi A. Intestinal loop lengthening—a technique for increasing small intestinal length. *J Pediatr Surg.* 1986;21(3):147.

- The longitudinal intestinal lengthening and tailoring (L.I.L.T) operation first described by Adrian Bianchi [25] accomplishes intestinal tapering without loss of surface area used in cases where bowel length is critical.
The LILT procedure are

1. An avascular space is created longitudinally along the mesenteric border of a dilated loop of bowel.
2. The bowel is then split lengthwise, taking care to allocate alternating blood vessels to each side.
3. Each side of the split bowel is then tubularized, generating 2 “hemi-loops” that are anastomosed end to end in “isoperistaltic fashion” (Figure 2).

When completed, LILT creates a loop of bowel that is twice the length of the original and half the original diameter; no new bowel is created. The decrease in bowel diameter accomplished without loss of surface area is likely more important than the gain in length.

Anatomical criteria for LILT are
1. Intestinal diameter > 3 cm
2. Residual bowel length > 40 cm
3. A length of dilated bowel loops > 20 cm

LILT can lead to less bacterial overgrowth and stasis. Bianchi has described a protocol for the management of SBS with an important role for intermittent clamping of the tube jejunostomy to expand the diameter of the small bowel.

Bianchi’s early personal experience with the procedure in 20 children resulted in 7 of 9 survivors attaining enteral autonomy from PN at a mean follow-up of 6.4 years. The LILT should be applied with extreme caution in patients with ultrashort bowel and in the presence of liver disease. However, notwithstanding the need for cautious patient selection, we have reported on functional liver recovery even in the presence of moderate to advanced liver disease in carefully chosen patients following autologous gut salvage. Based on a recent report, outcomes following autologous gastrointestinal reconstruction are improving with accumulating experience. Of 27 children undergoing various autologous procedures for SBS, including 19 LILT procedures, overall survival was 92%, and >90% of survivors achieved independence from PN.

Complications – Initially, the reported complication rate was high with anastomotic stenosis (18%), staple line leakage (13%), interloop abscess (7%), and fistula formation (7%). Mortality in these series resulting from intra-abdominal sepsis and liver failure were around 30%. However recent series show that with more surgical experience an acceptable complication rate and no surgical related mortality can be achieved. Survival after LILT is comparable to other AIR procedures between 87 and 95%.
The serial transverse enteroplasty (STEP) procedure described by Kim et al. in 2003 is a tapering without loss of surface area. It is accomplished effectively and relatively simply.

STEP is based on the anatomical principle of the vessels rising from the mesenteric border and enfolding the bowel perpendicularly to the long axis of the bowel. There is no lower limit in bowel length to perform STEP, but a minimal luminal diameter of 3.5–4 cm is required.

The STEP procedure are:

1. The luminal channel is placed with the staples in zig-zag pattern
2. The luminal is narrowed by firing a series of staples perpendicular to the long axis of the bowel in a zig-zag pattern without interfering with the blood supply of the bowel (Figure 3).

Figure 3: In the serial transverse enteroplasty (STEP) procedure, staples are fired perpendicular to the long axis of the bowel in a zig-zag pattern to make and close incisions and thereby reduce lumen diameter and lengthen the bowel. The (A) first and (B) second staples are placed, (C) with the appropriate placement of multiple staples, the bowel is extended and tapered. Reproduced with permission from Kim et al. Serial transverse enteroplasty (STEP): a novel bowel lengthening procedure. J Pediatr Surg. 2003;38(3):426.
In a long-term study of 12 pediatric patients who underwent STEP, 8 (67%) patients remained alive and transplant-free at a median follow-up of 5.7 years. Of those 8 patients, 7 achieved independence from PN. In addition, the dilated segment showed an 87% increase in median length and a 67% decrease in mean internal diameter\(^{[33]}\). A recent retrospective observational study of 111 consecutive patients enrolled in the international STEP registry provides additional impetus for more serious consideration of the appropriateness of the STEP procedure in suitable patients\(^{[35]}\). Of 97 patients for whom complete data were available, 11 patients died and 5 required intestinal transplantation. In a multivariate analysis, risk of progression to transplantation or death was greater among patients with shorter bowel length before surgery and higher conjugated bilirubin levels.

The choice of lengthening procedure between the Bianchi LILT and the technically simpler STEP remains somewhat unclear and until recently seemed related to surgeon preference. In a retrospective, uncontrolled, single-center study, Sudan et al\(^{[34]}\) reported outcomes of 64 patients who underwent a total of 43 LILT and 34 STEP procedures over a 24-year period. Overall survival was 91% at a median follow-up of 3.8 years. Enteral autonomy was achieved by 69% of PN-dependent patients, and liver disease was reversed in >80% of affected patients. Differences between the 2 procedures were small, although nonsignificant trends were documented for a lower rate of weaning from PN, longer time to PN discontinuation, and a higher incidence of complications requiring reoperation after LILT than after the STEP procedure. Of note in this series, 14% of patients underwent intestinal transplantation at a median of 2.9 years. Transplantation was required more often following LILT than after the STEP procedure (18.6% vs 5%, respectively; \(P = .03\),
although this difference may be due in part to the longer follow-up time for patients receiving LILT (5.9 vs 1.7 years for STEP)\textsuperscript{[34]}.

- **Spiral intestinal lengthening and tailoring (SILT)** was introduced in 2011 by Cersni et al. in an experimental animal model as a possible alternative and additive to STEP and LILT\textsuperscript{[47]}.

1. The incisions in the mesentery are made carefully without damaging any vessels
2. The intestinal wall is cut spirally in angle to the longitudinal axis

The total length will increase and its diameter is reduced by stretching the bowel over a tube preserving the adjust luminal diameter (Figure 6)\textsuperscript{[48]}.

Fig. 6 A model of the SILT technique: (A) The bowel is cut spirally in an angle to the longitudinal axis. (B) Maintaining orientation by using a silicon catheter, the bowel is stretched. (C) When adjusted to the right length and diameter, the lumen is closed by suturing. (D) The bowel in a longer and narrower shape (Adapted to Cersni et al. \textsuperscript{[81]}).

An advantage of SILT is the mild alteration of the position of the intestinal muscle fibres and therefore should influence peristalsis less. A major disadvantage of SILT is the requirement to open the lumen completely, whereas in a STEP procedure the lumen remains closed, reducing bacterial contamination. Thereto, in an experimental model a modified SILT procedure was developed where the mucosa is remained intact with incisions made only in the muscular and submucosal layer so that the lumen is only opened on the outer ends\textsuperscript{[81]}.
Table 7 shows the comparison of technique and outcome of the Intestinal lengthening procedure.

**2. Intestinal Transplantation**

For patients in whom all attempts at intestinal rehabilitation have failed and who are at risk of life-threatening complications of PN, intestinal transplantation has emerged as the standard of care. The US Centers for Medicare and Medicaid Services (CMS) approved intestinal transplantation for patients with irreversible IF and PN-related complications in 2000 and extended the approval to multivisceral transplantation the following year. The CMS definition of PN failure includes the following:

1. Presence of PN-associated liver disease
2. Loss of central venous access (i.e., loss of 3–6 central venous access sites in children or 2–4 central venous access sites in adults)
3. Recurrent catheter-related sepsis or a single episode of fungal sepsis
4. Recurrent bouts of severe dehydration or metabolic abnormalities

**Absolute Contraindications to Intestinal transplantation**

1. Active infection
2. Malignancy
Relative Contraindications to Intestinal transplantation

1. Severe neurodevelopmental disability
2. Psychosocial factors

In the absence of liver disease, isolated intestine transplantation, often including the right colon, is the procedure of choice. For patients with moderate biochemical and histologic liver disease, we have demonstrated that successful isolated intestinal transplantation results in biochemical improvement of liver function and may also allow histologic liver recovery[^42][^43].

Transplantation of the intestine may be performed alone (i.e., isolated intestine transplantation) or in combination with the liver (i.e., a combined liver/intestine or multivisceral transplantation).

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[^42]: Reference 42
[^43]: Reference 43
Figure 8 demonstrates details of the surgical technique of isolated intestine transplantation with replacement of the entire jejunum and ileum. A combined liver/intestine transplantation is performed in patients with advanced liver disease and occasionally in patients with mesenteric or pancreatic neoplasms (most commonly en bloc with the duodenum and pancreas to maintain the donor hepatic hilar structures undisturbed). Figure 9 depicts details of the liver/bowel or multivisceral operative technique.

Small bowel transplants alone are offered to patients with

1. intestinal failure that cannot be managed on total parenteral nutrition (vide supra) and/or
2. mild to moderate liver dysfunction due to total parenteral nutrition.

Combined bowel-liver transplants are offered to patients with

1. intestinal failure and advanced, irreversible liver failure due to total parenteral nutrition and
2. intestinal failure due to a hypercoagulable state associated with enzyme deficiencies that can be corrected by a liver graft (e.g., mesenteric vascular thrombosis secondary to protein C or S deficiency).

Complications

1. Immunologic complications
   - Rejection and graft-versus-host disease

   Clinical rejection symptoms (including abdominal pain and distention, tenderness on palpation, ileus, increased fecal volume and stomal output, diarrhea) are unspecific and appear often late - after rejection is already apparent on histology. Therefore, biopsy evaluation is - as for all other solid organ grafts - the gold standard for the diagnosis of intestinal rejection. Surveillance intestinal (transstomal) biopsies are obtained twice weekly for the first 2 months, then weekly for the following 4 months, and monthly thereafter. Endoscopic biopsies must be taken from all areas of the graft (because intestinal rejection can be confined to specific bowel segments) and should always include ileal specimens (because rejection is more frequently observed in the ileum than in the jejunum and colon).

   Clinically relevant graft-versus-host disease is - in contrast to the findings of many experimental studies - relatively rare.
- Posttransplant lymphoproliferative disease

The PTLD incidence in intestinal recipients (ranging from 15% in adults to up to 25% in children) is higher than in other solid organ recipients. Most PTLDs are EBV virus infection-associated and have a deleterious overall effect on graft and patient survival. PTLD therapy includes reduction or cessation of immunosuppression, antiviral therapy with acyclovir and ganciclovir, administration of α-interferon, and chemotherapy. However, these interventions result frequently in rejection episodes and graft losses. More recently, strategies have been focused on surveillance for, and early diagnosis of, EBV infections using molecular biology techniques (polymerase chain reaction). But the impact of therapeutic interventions based on these more refined screening and diagnostic methods is presently unknown and awaits further study.

2. Infectious complications
   - Bacterial and fungal infections

   Breakdown of the mucosal barrier of intestinal grafts (e.g., during rejection episodes) can cause bacterial and fungal translocation into the mesenteric lymph nodes and into the portal and systemic circulation, presenting clinically as sepsis. Thus, treatment of translocation-associated infections due to rejection includes both antimicrobial and antirejection therapy. Prophylactic interventions, such as systemic and local (selective gut decontamination) administration of antimicrobial agents have proven ineffective, leading instead to the emergence of multiresistant organisms.

   - Viral infections

   The cytomegalovirus is the clinically most significant viral pathogen in intestinal transplant recipients. CMV infections still cause considerable morbidity and have been associated with increased mortality, in spite of the availability of effective antiviral therapy (e.g., ganciclovir). At highest risk are CMV-seronegative intestinal recipients of organs from CMV-positive donors. This has led to the recommendation that only seronegative donors be used for seronegative recipients - at least for bowel alone-recipients, since recipient candidates with concomitant liver failure may not survive a prolonged waiting period for a suitable seronegative donor.

   The 1-year graft and patient survival rates for transplants done in the current era were respectively 55% and 69% for intestinal grafts, 63% and 66% for bowel-liver grafts, and 63% and 63% for multivisceral grafts. Of all intestinal recipients alive as of 1997, over 75% were off total parenteral nutrition after successfully resuming an oral diet.
Despite a trend for earlier consideration of intestinal transplantation, >50% of patients listed for intestinal transplantation are simultaneously listed for liver replacement \textsuperscript{[44]}. The mortality rate on the liver-intestine transplant waiting list can reach 30%, compared with a 9% mortality rate on the isolated intestine transplant list \textsuperscript{[45]}. Thus, early referral of patients who are failing PN may increase the rate of isolated intestinal transplantation and thereby reduce the significant mortality associated with waiting list placement. Patient and graft survival rates at 1 year are 89% and 79%, respectively, following isolated intestinal transplantation and are 72% and 69%, respectively, following combined liver-intestine transplantation \textsuperscript{[44]}. The relative tolerogenic capacity of liver-derived lymphocytes compared with intestine-derived lymphocytes may explain the immunoprotective effects of combined liver-intestinal transplants compared with isolated intestinal transplants \textsuperscript{[46]}. It is hoped that newer strategies to improve human leukocyte antigen matching and to account for the possible role of B lymphocytes in long-term graft survival may allow us to translate improved early outcomes into prolonged gains.
Table 1. Different operative approaches for SBS including advantages and limitations of the different techniques

<table>
<thead>
<tr>
<th>AGIR procedure</th>
<th>colon interposition: iso- or antiperistaltic</th>
<th>Bianchi LILT</th>
<th>STEP lengthening</th>
<th>others: intestinal valves, tapering, and plication</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indications</strong></td>
<td>adequate small bowel length with or without remnant colon but with rapid transit and diarrhoea or increased ileostomy output due to absence of ileocecal valve</td>
<td>i) rapid transit time with any length of remnant small bowel but with adequate colon length ii) USBS</td>
<td>i) dilated small bowel &gt;5 cm in diameter, &gt;20 cm in length, with length of residual small bowel &gt;40 cm i) preferred initial lengthening option</td>
<td>i) dilated remnant small bowel &gt;3-4 cm in diameter ii) presence of foreshortened mesentry (duodenum) iii) with prior abdominal surgeries without preservation of both leaves of the mesentery iv) dilated segments shorter than 20 cm v) when re-dilatation occurs</td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>slows the transit and enhances nutrient absorption by: i) partial mechanical obstruction ii) delay of distal segment myoelectric activity</td>
<td>i) no use/loss of precious small bowel length ii) can be applied to the colon as well</td>
<td>i) doubles length of the original small bowel segment ii) can be repeated post STEP or LILT</td>
<td>valves: increased transit time = improved enteral absorption tapering: optimizes bowel caliber and effective peristalsis return placement: optimizes bowel caliber without long suture line and preserves mucosal mass</td>
</tr>
<tr>
<td><strong>PN weaning</strong></td>
<td>Paris-Thompson 75%</td>
<td>Glick 50%</td>
<td>Bianchi 75%, Weber 100%, Thompson 53%</td>
<td>Sudan 88%, STEP Registry 48%</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>i) risk of obstruction with longer reversed segments ii) cannot be used when remnant bowel length is &lt;25 cm iii) loss of bowel length if unsuccessful</td>
<td>i) fatal/fatal obstruction ii) enterocolitis in the transposed segment iii) colonic dilatation iv) unpredictability</td>
<td>i) needs uniformly dilated bowel segment ii) one-time surgery, cannot be duplicated on the same bowel loop following re-dilatation iii) risk of necrosis with mesenteric damage iv) morbidity 15% v) mortality: Bianchi 45%, Holsie 10-20%</td>
<td>valves: i) intussusception ii) obstruction and bacterial overgrowth iii) sacrifice of valuable bowel length if unsuccessful tapering: i) loss of significant mucosal absorptive surface ii) long suture line with risk of leak placement: i) obstruction ii) re-dilatation due to unraveling from suture breakdown</td>
</tr>
</tbody>
</table>

AGIR = Autologous gastrointestinal reconstruction; STEP = serial transverse enteroplasty; LILT = longitudinal intestinal lengthening and tailoring; USBS = ultra-short bowel syndrome; PN = parenteral nutrition.
References


53. Hanson WR, Osborne JW. Epithelial cell kinetics in the small intestine of the rat 60 days after resection of 70 per cent of the ileum and jejunum. Gastroenterology 1971; 60:1087.


