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PII: S1521-6918(16)00022-6
DOI: 10.1016/j.bpg.2016.03.006
Reference: YBEGA 1417

To appear in: Best Practice & Research Clinical Gastroenterology

Received Date: 15 January 2016
Accepted Date: 5 March 2016


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Surgical Management and Autologous Intestinal Reconstruction in Short Bowel Syndrome

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Keywords:
Intestinal failure, short bowel syndrome, longitudinal intestinal lengthening and tailoring, serial transverse enteroplasty, spiral intestinal lengthening and tailoring, bariatric surgery

Total words used: 6861 (including abstract, summary bullet points, tables and figures)
A. Abstract

Short bowel syndrome (SBS) is a serious condition with considerable morbidity and mortality. When treatment with parenteral nutrition fails and life-threatening complications occur, autologous intestinal reconstruction (AIR) should be considered before intestinal transplantation (ITx). Single or combined ITx should be reserved for patients with severe liver disease and as last resort in the treatment of SBS. Longitudinal intestinal lengthening and tailoring (LILT) has proven its value in AIR, but its availability depends on the expertise of the surgeons. Serial transverse enteroplasty (STEP) has similar success rates as LILT and fewer patients progress to ITx. STEP is also applicable at small bowel dilatation in ultra-short bowel syndrome. The scope may be widened when duodenal dilatation can be treated as well. Spiral intestinal lengthening and tailoring (SILT) is a promising alternative. More research is needed to confirm these findings. Therefore we suggest an international data registry for all intestinal lengthening procedures.
A. Introduction

Parenteral nutrition (PN) is the standard treatment in short bowel syndrome (SBS). After its introduction in the late 1960’s (1), several important improvements in the treatment of PN have been introduced. Despite these improvements, PN-dependent patients are still prone to develop severe complications contributing to a high mortality (2–4). Intestinal transplantation is the standard treatment for patients with intestinal failure who develop severe complications from PN or experience a low quality of life (5). The accepted indications nowadays for intestinal transplantation (ITx) are recurrent catheter related infections, thrombosis of the central veins, alteration in growth and development of infants, severe dehydration with refractory electrolyte changes and liver failure and/or liver cirrhosis with portal hypertension (5). The first successful isolated transplantation of the intestine was performed in 1989 (6), 2 years after the first successful multivisceral transplantation in 1987 (7). Improvement in surgical techniques, novel immunosuppressive agents and advances in anaesthesia and critical care led to an overall increase of intestinal transplantations worldwide. However, after the initial enthusiasm it became evident that the long-term results were disappointing with a 5-year graft survival of only 50% for patients transplanted after 2000 (8). As a consequence, the number of intestinal transplantations has decreased from more than 200 procedures in 2008 to only 120 cases in 2012 (8). Given the severe complications and the disappointing survival of ITx and low quality of life of patients on PN, all efforts should be made to prevent a SBS. The ultimate goal of treating SBS is to achieve enteral autonomy through medical and
surgical intestinal rehabilitation. The aim of this review is to discuss the initial surgical management and autologous intestinal reconstruction (AIR) in patients with SBS.

A. Definition and aetiology of short-bowel syndrome

B. Definition

Short bowel syndrome (SBS) is a condition in which there is a congenital or an acquired shortage of small bowel length and thus a lack of absorptive small bowel surface. This leads to the incapability of retrieving enough nutrients, water and electrolytes to ensure growth in infants and body maintenance in adults and therefore requiring long-term administration of PN. The broader term ‘intestinal failure’ includes in addition to SBS, mechanical abnormalities and intrinsic bowel diseases. These patients have a normal bowel length, but experience severe bowel obstructions or functional problems caused by motility disorders or mucosal abnormalities (9,10). In this chapter, we will limit ourselves to SBS with an anatomical absence or loss of significant bowel length.

The total length of small bowel in a healthy person depends on the gestational age within a natural spread. The younger, the more growth potential there is. Loss of for instance 50 cm is clearly more severe in a premature born child then in a mature neonate (11). From the second year of life, bowel length does not significantly increase further and stays around 340 cm. However, the diameter of the intestinal lumen still increases with age (12).

There have been made functional and anatomic classifications, both in 3 types, which enables us to compare treatments of SBS. The classification based on functional outcome
was introduced by Shaffer in 2002 (13). The latest revision has been made recently by
Pironi et al (see Table 1): type I SBS being acute, short-term and usually self-limiting.
Type II stands for a prolonged acute condition, often in metabolically unstable patients
requiring complex multi-disciplinary care and intravenous supplementation over periods
of weeks or months and type III representing chronic intestinal failure in metabolically
stable patients, requiring intravenous supplementation over months or years; it may be
reversible or irreversible (10,14). In adults the minimal length needed for functional type
I or II SBS is at least 115 cm in patients with an endjejunostomy, 60 cm in case of a
jejunoileal anastomosis and 35 cm if a jejunoileal anastomosis with an intact colon is
present (Table 1 and Fig. 1) (15). Although the exact length is not part of the generally
accepted functional classification, we thus know that the remaining bowel length is an
important prognostic factor to estimate the amount of enteral autonomy that reasonably
can be expected. In addition, a detailed description of the remaining length of the
duodenum, jejunum, ileum and colon makes a comparison of the effectiveness of AIR
possible.
In the anatomical classification, type I represents the potentially severest condition being
an end-jejunostomy. In type II there is no ileocaecal valve present, but there is jejunoileal
continuity. In type III there is a jejunoileal anastomosis and the ileocaecal valve is
preserved (Fig. 1) (16).
It is clear from these classifications that small bowel length, presence of an ileocaecal
valve and colon length are important prognostic factors in SBS. Other factors that should
be taken into account are the age of the patient, diagnosis of an intrinsic bowel disease
like Crohn's disease or a systemic disease, the presence of duodenum and the length of the remnant bowel (see Table 2) (17).

**B. Aetiology**

The aetiology of SBS differs between children and adults. In children SBS is most often the result of extensive resections due to necrotizing enterocolitis (NEC), complicated gastroschisis and midgut volvulus resulting from malrotation and severe intestinal atresia (18). The most common causes of SBS in adults are bowel ischemia due to superior mesenteric artery thrombosis, Crohn's disease, volvulus and abdominal trauma (19). SBS as a complication of bariatric surgery is relatively upcoming and therefore we consider it worthwhile to include this in our review.

**A. Initial Surgical Management**

The initial management of SBS starts immediately after surgery. Abdominal sepsis and organ failure must be treated if present. Enteral nutrition has to be initiated as soon as possible to promote intestinal adaptation (20). Parenteral nutrition, management of bacterial overgrowth and treatment of PN associated liver disease are all essential in treating SBS patients, but are not within the scope of this chapter. All these aspects and possibilities should be discussed in a multidisciplinary team (21). Patients with intestinal failure must preferably be seen in an intestinal failure outpatient clinic by a dedicated gastroenterologist, gastrointestinal surgeon, dietician, stoma or wound nurse, psychologist and other specialists if necessary. A restorative surgical
procedure has to be discussed with the patient in order to restore the intestinal continuity. It is essential that the patient is in the best possible condition and that the surgical team is fully prepared by reviewing the surgery reports and radiographic imaging. Patients must be in a stable, anabolic state and infections and sepsis settled down. In a non-hostile abdomen it should be considered to restore continuity as early as possible (20). In addition, our own experience is that a relaparotomy performed more than 7-10 days after the initial abdominal exploration has a high change of iatrogenic bowel perforations and intra-operative complications. Most patients would benefit from a delayed intestinal reconstruction procedure performed at least 3 to 6 months after the last surgical procedure. Important principles of these operations are a complete adhesiolysis to get a good overview of the complete intestine and identify all internal fistulas. Also, resections have to be limited to a minimum with tension-free, well perfused anastomoses. All anastomoses have to be covered by peritoneum, omentum if present or at least the abdominal wall. Coverage of the intestine by abdominal wall reconstruction or biomesh interposition when necessary is essential after reconstructive surgery.

A. Intestinal Failure after Bariatric Surgery

B. Introduction in bariatric surgery

Currently, bariatric surgery is the most effective ultimate treatment for severe obesity (22). The dramatic increase in incidence of overweight, severe and morbid obesity worldwide is a well known ongoing trend. Consequently, bariatric surgery has become
one of the most performed abdominal surgical procedures worldwide. Two different mechanisms contribute to weight loss after bariatric surgery, being restriction and malabsorption, or a combination of both. Two restrictive procedures are commonly used: gastric banding and most often a sleeve gastrectomy. Nowadays, combined restrictive and malabsorptive surgery is most often performed. In this matter, the procedures of choice are the Roux-Y gastric bypass, distal gastric bypass and the biliopancreatic diversion with or without gastric sleeve (23,24).

**B. Complications can lead to SBS**

All these operation differ in effectiveness, but also in potential complications. The incidence of severe complications that can potentially lead to SBS is very low. However, due to the dramatic increase in the amount of procedures, complications of bariatric surgery have become an important cause of SBS. There are several mechanisms that can lead to intestinal failure after bariatric surgery. First of all, severe malnutrition from a very short common channel <50 cm can lead to dramatic weight loss that results in severe protein-caloric malnutrition, vitamin deficiencies and liver failure. The malabsorbtive procedure should partially be reversed by increasing the bowel length of the ‘common channel’ after a period on PN and before irreversible liver failure has occurred. Secondly, catastrophic gut loss is the most severe complication possible and can lead to permanent SBS. This may be the result of internal hernias and volvulus due to the altered anatomy, incarcerated incisional hernias, mesenteric ischemia, obstruction and necrosis due to severe adhesions. Finally, complications like anastomotic breakdown, perforations and fistulas can lead to gut loss (22).
Internal hernias are of specific concern after bariatric surgery. Internal hernias are difficult to recognize clinically and radiographically and require specific knowledge of the bariatric procedures (Fig. 2). Currently, most surgeons perform an antecolic gastric bypass, as there is evidence of a lower incidence of internal hernia’s than with a retrocolic gastric bypass (25). Although ischemia and necrosis from the herniated segment as well as the small bowel bordering the defect can occur. Early recognition, urgent laparoscopic exploration and closure of the defects are important aspects to the success of treatment. Also, mesenteric ischemia due to thrombosis following altered coagulation or a non-recognized clotting disorder can lead to dramatic gut loss (26).

B. Patient care

Patients should be referred to a centre with expertise in intestinal failure after the initial dramatic event. Obviously, these patients need a thorough and multidisciplinary evaluation. Clinical review of the patient medical history and operative notes are essential. The anatomy and residual length of the intestine should be confirmed with radiological studies and if necessary endoscopic evaluation. Malnutrition, electrolyte disturbances, metabolic and vitamin deficiencies should all be corrected. When indicated, coagulation blood testing, visceral angiograms and full liver function tests with or without a liver biopsy should be performed. As mentioned before, we recommend restorative surgery within 7-10 days or after 3 to 6 months. The aim of this procedure is restoring the nutritional anatomy, reverse stomas and fistulas and avoid the recurrence of severe obesity. In patients with critical bowel length, all efforts should be made to
minimize additional bowel resection. Reversing bypassed segments and an additional AIR can be offered if needed.

A. Antiperistaltic segments, colon interposition and nipple valve reconstruction

B. Antiperistaltic segments

In a select group of patients, interposition of an antiperistaltic segment might help to wean from PN. The indications for such procedures are rapid transit diarrhoea and/or a persistent high-output stoma despite conservative measures (27). The remaining bowel should be at least 25 cm. An important advantage of this procedure is that there is no need for a dilated bowel. Both the LILT and STEP procedure can only be performed on dilated segments of bowel. There are several options in implementing a reversed segment. The most used option is to reverse, thus not transposition, a 10-12 cm segment of terminal ileum and to anastomose the distal end to the terminal ileum and the proximal end to the colon (27). Another option is to isolate 10-12 cm of ileum and reverse transposition this between the proximal jejunum loops. Continuity is then restored with 3 end-to-end anastomoses. The reversed segment decreases transition time, reduces the myoelectric activity and consequently improves the absorption of nutrients. An important disadvantage is the risk for obstruction by isolating a segment that is too long. Also, reversed segments cannot be used in a very short remnant bowel (<15cm). Failure and complications can lead to loss of the reversed small bowel segment.
There are only a few series that describe the results of antiperistaltic segments in SBS. The largest study is a retrospective analysis of 38 patients from the group of Panis (28). After 5 years of follow-up 45% of their patients were completely weaned from PN. It has to be mentioned that all these procedures were combined with continuity restoration by stoma reversal, consequently inducing a significant gain in bowel length. Despite the encouraging results and acceptable complication rate this method has not gained much popularity (29,30).

**B. Colon Interposition and nipple valve construction**

The first publication on isoperistaltic colon interposition in dogs was done by Hutcher et al in 1971 (31). Only very few reports have been published about colon interposition ever since (32,33). Considered as important potential disadvantages are bowel obstruction, bacterial overgrowth and significant loss of bowel in case of complications. The interest in construction of artificial valves lies in the observation that a present ileocaecal valve has a positive influence on achieving enteral autonomy. An artificial valve is constructed at the intussusception of the distal ileum, thereby increasing the transit time and improving the enteral absorption. There are only very few cases known in literature, therefore we do not recommend to use this procedure as a treatment of SBS (34).

**A. Longitudinal Intestinal Lengthening and Tailoring**

**B. Introduction and technique**
In 1980, Bianchi described the first longitudinal intestinal lengthening and tailoring or LILT procedure in an experimental model using pigs (35). The first clinical application was performed one year after (36). Bianchi isolated a segment of dilated bowel from the rest of the bowel by dividing the proximal and distal end. Then, an avascular plane between the double leaflets of the mesentery is created. After confirmation of this double plane and having successfully separated these parts, the dilated bowel segment is divided using a linear stapling device. Three years later, Bianchi described an alternative for the stapling technique by cutting the bowel instead of stapling and close it afterwards with use of a hand-sewn technique, because of interloop fistulas which occurred frequently when the stapling technique was used (37). After creating an end-to-end anastomosis using a hand-sewn technique, the isolated bowel segment is connected proximally and distally to the small bowel or colon (Fig. 3). The net result is a doubling in length of the isolated bowel segment and a reduction of the diameter by half the size.

Anatomical criteria for LILT are an intestinal diameter >3 cm, residual bowel length of > 40 cm and a length of dilated bowel loops >20 cm (38). Significant more complications are described after performing a LILT in shorter bowel segments (39). LILT can lead to less bacterial overgrowth and stasis. Although, evidence on treating bacterial overgrowth with LILT is limited. 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 (40). Because the results of LILT are already well reviewed elsewhere, we will only give a brief description of the outcome and complications (40–42).
B. Enteral autonomy and survival

The degree of intestinal lengthening is significant after LILT. Although the isolated segment is doubled in length, the amount of intestinal lengthening of the entire bowel is reported 48-55% (41,42). The most recent series report a success rate of 37-91% for achieving enteral autonomy (40,43–45).

B. Complications

Initially, the reported complication rate was high with anastomotic stenosis (18%), staple line leakage (13%), interloop abscesses (7%) and fistula formation (7%)(21,42,46–50). 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 (45). It must be mentioned though that even the most recent series not always clearly describe postoperative morbidity (40,45,51). Survival after LILT is comparable to other AIR procedures between 87-95%. The need for ITx is relatively low between 10-26% after LILT.

B. Perspective

A disadvantage of LILT is that it cannot be applied when the vessels in one of the mesenteric leaves are compromised. Another limitation is LILT being a one-time surgery that cannot be repeated on the same intestinal segment, as the double leaves of the mesentery can only be separated once. LILT is considered a primary treatment in SBS and is usually performed prior to any other AIR procedure. However, recently it was
successfully applied in a 2-month old infant who experienced redilatation after a prior STEP. Without major complications reported, the patient weaned from PN, however, there is only a short-term follow-up of 7 months (52).

Due to the lack of expertise worldwide and upcoming alternative treatments, LILT is nowadays performed only sporadically. Nevertheless, it is the only lengthening procedure with over 30 years of clinical application in the field of SBS and novel treatments should therefore be compared to the results achieved with LILT.

A. Serial Transverse Enteroplasty

B. Introduction and technique

Serial transverse enteroplasty or STEP is a surgical technique to taper and lengthen the dilated small bowel. STEP was first described in 2003 in a porcine model as an alternative to LILT because of its minimal manipulation of the mesenteric vessels (53). That same year the procedure was performed at first in a 2-year old child with SBS (54). Nowadays, STEP is next to LILT one of the two mainly accepted surgical approaches for the treatment of SBS (40, 41, 55, 56) and congenital dilatation and atresia (57).

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. Therefore, there will remain no segments devascularized afterwards. With the use of a linear stapler, a zig-zag pattern is created with staples in opposite directions (Fig. 4), keeping a distance of 2 to 2.5 cm and maintaining a luminal diameter of approximately 2 cm dependent on the age and size of the patient (53). There is no lower limit in bowel length to perform
STEP, but a minimal luminal diameter of 3.5 to 4 cm is required (53,54). One of the characteristics of the procedure is a minimal manipulation of the mesentery. Also, because there are no anastomoses required, the intestinal lumen remains closed, consequently reducing bacterial contamination. STEP is considered to be a technically less challenging procedure in comparison to LILT and has the possibility to customize the tapering of the bowel (42,58), which is of importance when an asymmetrical dilatation of the bowel is present (53).

B. Indications

The aim of STEP is similar to that of general AIR procedure. STEP has been used to treat SBS caused by gastroschisis, proximal jejunal atresia, NEC and midgut volvulus (55,59,60). STEP has proven its value as primary therapy in neonates with congenital intestinal dilatation and atresia. It is possibly the only surgical intervention feasible for patients with ultra-short bowel syndrome (USBS) or SBS with a remnant bowel length of <20 cm (61–64). Also, STEP has successfully been performed in adult patients with a 90% survival rate and 47% of all patients who underwent STEP weaned from PN (44). Furthermore, STEP has a clear long-lasting influence on bacterial overgrowth and the associated D-lactic acidosis and therefore being a specific indication (65,66). STEP is preferred in particular as an additive to previous AIR procedures. It is important to realize that it is possible to perform STEP after LILT. Recently, Bueno et al reported a successful attempt to treat the dilated duodenum of 3 patients using a modified STEP procedure (67). To our knowledge, there are only few cases known where STEP was applied to the duodenum (66). Their promising findings may widen the scope of STEP,
whereas a significant amount of patients who underwent AIR still have to rely on PN (55,56,68,69). Studies in larger populations are needed to confirm these effects on dilatation of the duodenum.

B. Enteral autonomy

An important predictive factor for achieving enteral autonomy is the post-operative length of the small bowel (41,56,68,69). Multiple studies report the possibility of lengthening the small bowel over a 100% of its pre-operative length (56,60,61,69,70). In a systemic review of 109 patients who underwent STEP, a median percentage of 63% lengthening was reported (42). There is some variety in this finding, whereas other studies report a lengthening of 46-69% of the small bowel (41,55,71). The majority of patients who underwent STEP experience an overall improvement in nutritional status and a decrease in requirement for PN (60,70,72,73). These findings are supported with experimental evidence in animal and human studies. It is known that in patients with SBS, the intestine is able to adapt to enlarge the uptake of nutrients after resection (74). The absorption of xylose, which is a marker for the uptake of carbohydrates and mucosal integrity, generally improves after STEP as also the faecal fat content which is related to absorptive function of the bowel. Besides, motility patterns are preserved after STEP (65,75), with better bowel ratios and stool consistency and frequency improving (55). These improvements in absorption and function continue after both STEP and LILT and takes around 1 – 2 years (42), but can take years to reach a final plateau (55). If weaning from PN cannot be reached, STEP at least is able to postpone ITx (38). The number of
patients who receive ultimately an isolated or combined intestinal transplantation varies between 5% and 16% (41,42,73).

B. Survival and complications

Intestinal lengthening procedures of the last 15 years show a consistently high survival-rate with reports of 89% by the STEP Data Registry and up to 95% in a single-centre retrospective study. The main causes of death were liver failure and sepsis (41,42,58). Recent smaller studies report similar survival rates up to 100% (60,61,70,72,76).

It is known that complications are common in STEP procedures, with a chance of intestinal bleeding being up to 26%, which is higher compared to other lengthening procedures (41,77). A recent study also identified a rather high infectious burden of 39% in 14 patients who underwent STEP, which could be of importance considering that sepsis is the second cause of death after STEP (78). Further research is required to identify the relation between infection and STEP. Redilatation is considered a serious complication effecting the nutritional status of the patient causing a lower weaning rate and higher mortality (79). The exact mechanism behind redilatation is still unclear. In literature, rates of redilatation requiring a re-STEP procedure go from 25% up to 49% (42,58). Re-STEP is not an inevitable problem and has proven its feasibility in both animals (80) and humans (81) with up to 50% of the patients weaned from PN. The possibility of re-STEP is of specific importance in case of bacterial overgrowth which can occur frequently as a complication of AIR (79).

B. Long term outcome and perspective


Since the introduction in 2003, many studies have shown the positive effect of STEP. Determining the long term outcome has been difficult due to a limited follow-up time of only several years (41,42,55,70,82). More recently, Pakarinen et al reported the longest follow-up time to date with a median follow-up time of 9.7 years (4.9-14 years) of 8 patients (59). Indications for intestinal lengthening were intestinal failure due to SBS, dilated bowel segments and complications of bacterial overgrowth. Their conclusions support the previous findings with a survival rate of 90% and a promising weaning rate with 8 out of 9 patients remaining off PN at median 6.9 years after AIR. Interestingly, they found the same survival and weaning rate for children with SBS without AIR. These numbers and conclusions have to be interpreted carefully though, considering the sample size and retrospective character of this study. Therefore, larger population studies are needed, preferably including a control group, although due to ethical reasons such a study will probably not be conducted. However, the International STEP Data Registry (www.stepoperation.org) could confirm the promising findings with a next report (71).

The scope of STEP can possibly be widened further by using delayed primary STEP in children with USBS, which remains a challenging condition and still has a poor outcome (62). The principle of this approach rests in obstructing the small bowel intermediately and facilitate the dilatation of the bowel with sham feeds to optimize the bowel for STEP. This technique accelerates the growth potential of the bowel, with an observed increase of the small bowel length up to 294%. Controlled bowel expansion is not a novel concept, whereas it has already been applied previously in LILT (21,83–85). Further research is needed to confirm these promising results of delayed primary STEP as treatment for USBS and trace the mechanisms behind it.
A. Spiral intestinal lengthening and tailoring

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 (86). With SILT, incisions in the mesentery are made carefully without damaging any vessels. Next, the intestinal wall is cut spirally in an angle to the longitudinal axis. Basically, the total length will increase and its diameter is reduced by stretching the bowel over a tube preserving the adjust luminal diameter (Fig. 5) (87). SILT was then applied in vivo to porcine small bowel in which the jejunum was lengthened with 75% and the luminal diameter reduced by 56% (88) after inducing dilatation with controlled bowel expansion. 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 (89).

Recently, the first clinical application of SILT was successfully introduced on a 3-year old patient after initial controlled bowel expansion (90). In this case, the dilated segment was lengthened by 81% (from 11 to 20 cm) leading to an increase in total jejunal length by 41% and a reduction of the diameter by 50% to 2 cm. The patient was weaned from
PN 4 weeks after surgery and still is at 6 months follow-up. The second successful application on a 10-month old neonate led to a lengthening of 125% (from 4 to 9 cm) without controlled bowel expansion (91). This patient did not fully wean from PN, but did well with a PN requirement of 18% at 12 months after surgery. The indication for AIR in both cases was SBS due to midgut volvulus. In neither case serious complications were reported. These case reports prove that SILT has potential as treatment in SBS. Its remarkable technique is also already studied for other applications (92).

A. Patient selection and care

Specialized multidisciplinary programs to optimize the management of intestinal failure have irrefutable improved the outcomes in the last decade (93). The chance of weaning from PN and survival rates increased, whereas the cases of central line infections and intestinal failure associated liver disease decreased. Also, patient selection is an important key to successful intestinal lengthening procedures and to prevent unnecessary procedures in patients who could wean from PN without surgery (38). STEP can be performed at any age with cases in literature varying from the first day after delivery until adulthood (41,57). Performing LILT in neonates is not without controversy because of unfavourable outcome and complications (39), although LILT was performed successfully at the age of 6 weeks. For SILT however, no conclusions can be drawn yet due to its recent introduction.

Liver failure is an important contraindication to intestinal lengthening procedures (94). Patients with advanced liver disease are facing poor prognoses after AIR and may benefit
more from an isolated liver transplantation prior to AIR or a combined intestinal/liver transplantation if enteral autonomy is not expected after AIR. (41). Nevertheless, there is a lack of consensus in literature about when intestinal lengthening procedures can be performed in patients developing liver disease (55).

A. Discussion and Conclusion

SBS has a dramatic impact on the quality of life of a patient and is associated with significant morbidity and mortality. Therefore, it is obvious that every effort should be made to prevent SBS by limiting bowel resections to an absolute minimum and treat the underlying disease. Moreover, patient care for SBS must be optimized in a specialized multidisciplinary intestinal failure program to prevent complications of PN and contain intestinal failure associated liver disease, since this is associated with a higher morbidity and mortality. Therefore, one of the keys to success of AIR in SBS is patient selection. If AIR cannot lead to PN independence, it should be considered as an option to postpone intestinal or combined transplantation, which is currently the last resort for these patients. If AIR is indicated, the first step is restoration of small bowel continuity through relaparotomy in case of unused intestinal segments. In a non-hostile abdomen this can be done relatively early, meaning within 7-10 days, after the initial surgical procedure. The alternative approach is a relaparotomy 3 to 6 months later. AIR can be performed as well during this operation if the bowel is critically short. Important principles of AIR procedures are knowledge of the exact altered gut anatomy and a thoroughly performed adhesiolysis to recognize all fistulas, obstructions or strictures. Any anastomosis has to be
well perfused, tension free and covered with peritoneum, omentum and at least the abdominal wall.

As mentioned, AIR should be considered in every patient with SBS and persistent PN dependence who reached a plateau in their intestinal adaptation. Over the last decades several surgical procedures have been introduced. The least common performed procedures are antiperistaltic segments and colon interposition. Because of complications like obstruction, rapid transit time and disturbance of motility patterns, antiperistaltic segments and colon interposition did not find its way into the clinic, despite initially promising results. Generally, there are serious concerns on the effectiveness and complications of these procedures. Therefore, we cannot recommend this as therapeutic options in the treatment of SBS.

Since LILT is surgically a challenging procedure, the type of reconstruction will depend first of all on the experience of the surgeon. If the expertise is not present, STEP should be the first surgical treatment to consider. LILT doubles the length of the isolated segment, whereas in STEP the gained length depends on the extend of the dilated bowel. In clinical setting it is seen that with STEP more length is gained compared to LILT. Both procedures show good survival rates of around 90%. In studies with larger populations included, average rates are reported up to 69% for STEP vs. 55% for LILT. PN independence is achieved in both LILT and STEP in up to 55-60% of the patients, but there is a large spread of these numbers in literature, thus careful interpretation is therefore needed.
One should consider that after LILT, STEP can be performed relatively easy, but vice versa will be challenging. However, despite what is generally assumed, it is technically possible to perform a LILT procedure after STEP (52). Despite the short follow-up, this is an interesting finding which teaches us that SBS is a dynamic condition that requires a personalized medical and surgical approach.

Nevertheless, STEP remains the most performed AIR procedure nowadays, largely due to the technically difficulties of LILT. There are clear advantages of STEP compared to LILT (see Table 2). STEP is the only procedure where the lumen remains closed, potentially reducing the chance of complications. Consequently, (late) interloop fistulas, abscesses, necrosis and leakage are more often seen in LILT. This is of importance when taken into account that these complications could lead to further gut loss. However, the complications are, to our view, not always clearly described. Any postoperative complication or mortality should be clearly described in future publications to get a better view on what short and long term positive or side effects AIR procedures cause.

Furthermore, STEP has a wider scope whereas it can be applied to USBS tailored to asymmetrical dilated bowel segments and dilated duodenum. Also, STEP has a clear effect on bacterial overgrowth which is less seen after LILT. Despite this, redilatation is seen more often in STEP, although it is easily reproducible and after a second or third STEP >50% of the patients could still wean from PN after all or at least improve their nutritional status.

SILT is novel lengthening procedure with promising clinical results. In unpublished data, a lengthening of 75% is reported in three patients who all weaned from PN (91).
SILT has similar advantages as STEP compared to LILT, being a technically less challenging procedure with a minimal handling of the mesentery without compromising the blood supply. However, STEP is considered a technically less challenging and quicker procedure than SILT. With both SILT and STEP it is possible to reduce the luminal diameter more than 50%, (91) whereas in LILT the luminal diameter can only be reduced by half. Cserni et al state that in STEP the physiology of the muscle fibres is dramatically altered and reverses the role of longitudinal fibres to circular and vice versa, possibly compromising peristalsis (86,88,91). However, one could argue that experimental evidence showed that motility in STEP is preserved (65,75), therefore the relation between altered muscle fibres direction and peristalsis remains unclear and needs to be studied further. Finally, whereas STEP has the potential of treating duodenal dilatation (67), SILT could probably not be applied to the duodenum due to its relation with the pancreas. Nevertheless, SILT has an undeniably potential in the treatment of SBS. Promising results are encouraging further studies in a larger population to confirm the effects of SILT and determine the long-term outcome. Also, SILT needs to be compared to other AIR techniques like LILT and STEP. We are curious to see more data and maybe a prospective randomized controlled trial could be conducted between STEP and SILT in the future.

Based on the current literature, most patients who received AIR are treated with LILT or STEP. The results are relatively good, but the considerable morbidity remains a point of concern. Comparison between frequently used AIR procedures has been difficult due to discrepancy in follow-up times, methods and lack of control groups. Only recently, long-
term outcome of STEP has started to become clearer, but only in case reports or retrospective studies. Currently, a randomized controlled trial between LILT and STEP is in our opinion almost impossible to conduct due to the low patient numbers and limited surgical expertise in both AIR procedures. In our opinion it might be worthwhile to initiate a combined online data registry for all intestinal lengthening procedures, including LILT, STEP and possibly SILT. This will give us more insights in all aspects of the lengthening procedures.
Summary

In general, AIR should be considered in SBS patients who are dependent on long-term PN. Since there is no lengthening procedure without the risk of complications, all efforts should be made to limit bowel resection wherever possible and prevent complications of PN.

If AIR is needed after all, restoration of bowel continuity should be the first step. Currently, in clinical practice two mainly applied surgical interventions are available; being LILT and STEP. We think LILT, however being a technically difficult procedure demanding specific expertise, should be performed if possible. If not, STEP can be performed as both primary treatment and after prior AIR procedures. Of specific importance is the right assessment of the indication. STEP is superior to LILT in treating bacterial overgrowth and seems the only feasible option in treating USBS and duodenal dilatation. Also, complications leading to gut loss are seldom seen after STEP. If PN independence is not within reach, AIR can be considered as a bridge to intestinal transplantation. Novel techniques like SILT need to be further investigated before widespread clinical implication. Since there are no randomized controlled studies that confirm these conclusions and it is unlikely there is going to be one, it will be difficult to determine an evidence based ‘golden standard’ because of the spread in results in the currently available literature of the last decade. To create the best possible evidence based clinical guidelines, we suggest that an international online data registry for LILT, STEP and SILT should be founded.
Bullet points:

Research agenda

- SILT
- Found online data registry and compare outcomes.
- Treatment of duodenal dilatation with STEP.
- Combination of controlled bowel expansion and STEP.
- Determine an international accepted golden standard for the surgical management of short and ultra-short bowel syndrome.

Practice point

- If expertise is available, perform LILT as initial intestinal lengthening procedure.
- A second or third STEP can still lead to independence of PN for >50% of patients.
- STEP is the treatment of choice in bacterial overgrowth when medical management fails.
- STEP should be considered in persistent PN dependence ultra-short bowel syndrome without improvement.
- When PN independence is not to be expected, intestinal lengthening procedures should be considered a bridge to intestinal transplantation.

Conflict of interest statement
No conflict of interest has been declared by the authors.
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### Table 1. Anatomical and functional classification of short bowel syndrome

<table>
<thead>
<tr>
<th>Type</th>
<th>Anatomical</th>
<th>Functional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>End-jejunostomy</td>
<td>Acute, short-term, usually self limiting</td>
</tr>
<tr>
<td>Type II</td>
<td>Jejunocolonic continuity, ileocaecal valve not present</td>
<td>Prolonged acute condition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Often metabolically unstable patients</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Complex multidisciplinary care</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intravenous supplementation for weeks/months</td>
</tr>
<tr>
<td>Type III</td>
<td>Jejunoileal anastomosis, ileocaecal valve present</td>
<td>Chronic condition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metabolically stable patients</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intravenous supplementation for months/years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reversible or irreversible</td>
</tr>
</tbody>
</table>

The anatomical classification was derived from Feldman et al (16), the functional classification was derived from Pironi et al (10).
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>Present</td>
</tr>
<tr>
<td>Duodenum</td>
<td>Complete</td>
<td>Bypassed or (partially) resected</td>
</tr>
<tr>
<td>Length small bowel</td>
<td>&gt; 150 cm</td>
<td>&lt; 150 cm</td>
</tr>
<tr>
<td>Part resected</td>
<td>Jejunum</td>
<td>Ileum</td>
</tr>
<tr>
<td>Ileocaecal valve</td>
<td>Present</td>
<td>Not present</td>
</tr>
<tr>
<td>Colon</td>
<td>Present</td>
<td>Not present</td>
</tr>
</tbody>
</table>
Table 3
Comparison of technique and outcome of SILT, STEP and SILT.

<table>
<thead>
<tr>
<th></th>
<th>LILT</th>
<th>STEP</th>
<th>SILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesenteric handling</td>
<td>Significant No 20-40 cm</td>
<td>Minimum Any length</td>
<td>Minimum Any length</td>
</tr>
<tr>
<td>Apply to duodenum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bowel length limitation</td>
<td>Double leaflet present, dilated bowel</td>
<td>Dilated bowel, also asymmetrical</td>
<td>Dilated bowel</td>
</tr>
<tr>
<td>Anatomical criteria</td>
<td>Complex No</td>
<td>Low</td>
<td>Less complex Nihil</td>
</tr>
<tr>
<td>Surgical complexity</td>
<td>Considerable Opened</td>
<td>Low</td>
<td>Unknown Opened</td>
</tr>
<tr>
<td>Risk of necrosis</td>
<td></td>
<td>Low</td>
<td>Unknown</td>
</tr>
<tr>
<td>Lumen</td>
<td></td>
<td>Closed</td>
<td>Opened</td>
</tr>
<tr>
<td>Repeatable</td>
<td></td>
<td>Yes</td>
<td>Unknown</td>
</tr>
<tr>
<td>Complications</td>
<td>Bleeding, obstruction, leakage, intestinal necrosis, perforation, fistula, abscess</td>
<td>Bleeding, obstruction, leakage</td>
<td>Obstruction, leakage, bleeding, possibly fistula, abscess.</td>
</tr>
<tr>
<td>Average lengthening*</td>
<td>48 – 55%</td>
<td>43 – 69%</td>
<td>-</td>
</tr>
<tr>
<td>PN independence*</td>
<td>55 – 71%</td>
<td>48 – 60%</td>
<td>-</td>
</tr>
<tr>
<td>Estimated survival*</td>
<td>87-95%</td>
<td>77-89%</td>
<td>-</td>
</tr>
<tr>
<td>ITx needed*</td>
<td>10 – 26%</td>
<td>5 -8%</td>
<td>-</td>
</tr>
</tbody>
</table>

*average rates mentioned are based on recent systematic reviews (41,42,56,58,73).
Fig. 1. Classification of short bowel syndrome. (Type I) endjejunostomy. (Type II) jejunocolic continuity, no ileocecal valve present. (Type III) jejunoleal anastomosis, ileocecal valve present. (Freely adapted after Feldman, Friedman & Sleisenger (16))
Fig. 2. Internal hernia’s after Roux-Y gastric bypass. (1) Herniation of the small bowel through the opening in the mesentery of the jejunojejunostomy. (2) Herniation of the small bowel through the opening between the alimentary loop and the mesocolon (Petersen Hernia). (Obtained from Bakker et al. (95))
Fig. 3. Bianchi procedure or LILT. (A) separating the two leaves of the mesentery of the isolated small bowel segment. (B) Creating a funnel on the mesenteric site for dividing the small bowel. (C), (D) Separating the small bowel by introducing a surgical stapler. This can also be done by cutting the bowel half. (E) The two bowel loops are then anastomosed together in a isoperistaltic manner. (Obtained from Bianchi A. (35))
Fig. 4. Schematic view of STEP. Perpendicular to the longitudinal axis, a stapler line is made preserving a 2 cm luminal diameter. After multiple staples, the bowel is lengthened. (Adapted to Kim et al. (53))
Fig. 5. 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 Cserni et al. (90))