



## Serial transverse enteroplasty is associated with successful short-term outcomes in infants with short bowel syndrome

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### Abstract

**Background:** The serial transverse enteroplasty (STEP) has been shown to improve nutritional indices in an animal model of short bowel syndrome. The aim of this study was to review short-term surgical and nutritional outcomes in the first cohort of infants to undergo the STEP procedure at our institution.

**Methods:** All patients who underwent the STEP procedure during a 26-month period from February 2002 to March 2004 were reviewed. Paired *t* tests were used for comparisons between values pre-STEP and post-STEP ( $P < .05$  deemed significant). Data are expressed as mean and range.

**Results:** The STEP was performed on 5 patients, including 1 newborn. The STEP was used as a primary lengthening operation in 4 patients. Intestinal length was significantly increased in all patients with 18 (10–26) stapler applications. There were no perioperative complications and no evidence of intestinal leak or obstruction on routine postoperative contrast study. Nutritional follow-up was available on 3 subjects at 17 (11–26) months post-STEP. Percentage of enteral nutrition was significantly increased in these subjects ( $P < .05$ ). One subject was fully weaned from total parenteral nutrition 6 weeks after the STEP, and bilirubin in another patient with profound cholestasis who had been listed for liver–small bowel transplant normalized after the STEP. An additional patient, with established cirrhosis before operation, underwent successful liver–small bowel transplantation 8 months after intestinal lengthening.

**Conclusion:** The STEP procedure is a simple bowel-lengthening procedure with promising early surgical and nutritional outcomes. Further data from a multicenter registry are needed to demonstrate its long-term efficacy.

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The management of short bowel syndrome remains a challenge for the pediatric surgeon. Recently, the serial transverse enteroplasty (STEP) was introduced as a novel

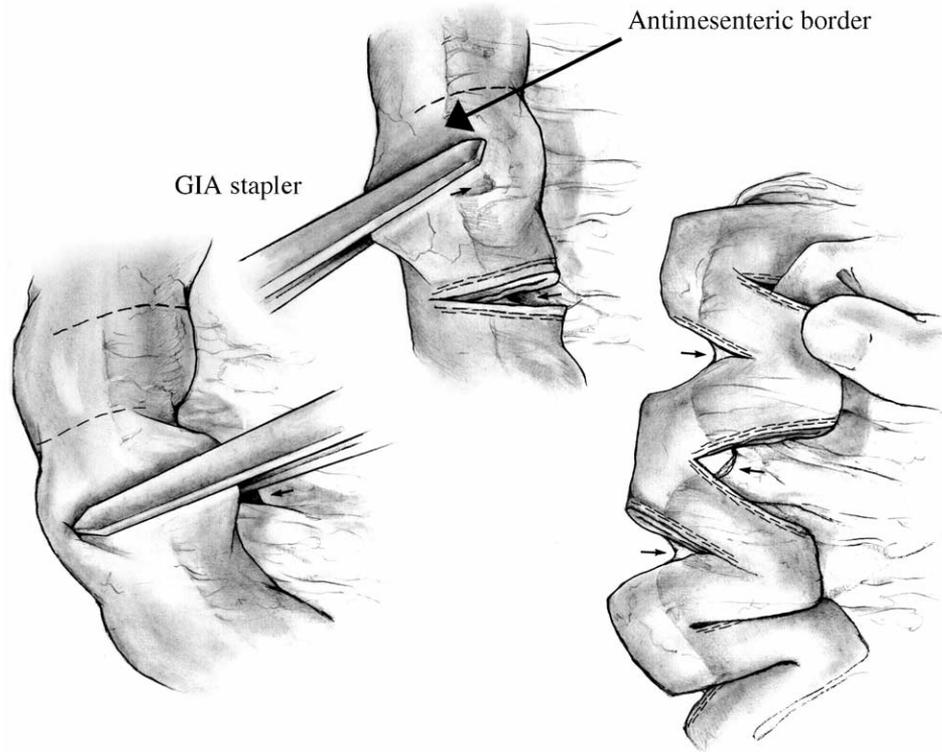
option for operative bowel lengthening in short bowel syndrome. The STEP procedure involves the sequential linear stapling of the dilated small bowel from alternating directions perpendicular to the long axis of the intestine (Fig. 1). In this way, all stapler applications are placed parallel to the direction of mesenteric blood flow so that the intestinal blood supply is not put at risk.

Since its introduction, the STEP has been shown to be an effective bowel-lengthening technique in an animal model

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**Fig. 1** The basic concepts of the STEP procedure. Serial applications of the linear stapler are used to create a zigzag-shaped channel of lengthened small bowel. The stapler is placed perpendicular to the long axis of the bowel, so that all stapler applications are parallel to the mesenteric blood supply.

of short bowel syndrome [1] and in select human case reports [2,3]. Recently, data have also demonstrated that the STEP may provide a nutritional benefit to animals with short bowel syndrome [4]. As experience with the STEP procedure continues to evolve, the operation is now being performed at multiple institutions worldwide. However, to date, an aggregate analysis of outcomes in patients who undergo the STEP procedure has not been performed. Therefore, the aim of this study was to measure and review the short-term surgical and nutritional outcomes of the first cohort of patients to undergo the STEP procedure for short bowel syndrome at our institution.

## 1. Methods

After approval from the Children's Hospital Boston Committee on Clinical Investigation (#M04-03-071), a retrospective chart review was performed on all patients who have undergone the STEP procedure at our institution. The period for data review was a 25-month period beginning in February 2002 (when the first STEP procedure was performed) and ending in March 2004. In addition to the patients' hospital medical records, data were collected from the Children's Hospital Boston Short Bowel Syndrome Clinic and from radiological imaging studies.

Data recorded by investigators included patient characteristics and medical history, intestinal length pre-STEP and

post-STEP, perioperative complications, and results of postoperative radiological imaging. Intraoperative intestinal length was measured along the antimesenteric border of the bowel. Weight parameters for each subject were assessed preoperatively and then at each postoperative clinic visit. For each subject, the degree of enteral intake was calculated as the percentage of total caloric intake derived from enteral administration, as measured by a study nutritionist. Serological liver function tests and levels of D-xylose were measured in the chemistry laboratory at Children's Hospital Boston both pre-STEP and at subsequent clinic visits postprocedure.

Paired *t* tests were used for statistical comparison of values pre-STEP and post-STEP.  $P < .05$  was deemed statistically significant. Unless otherwise indicated, all data are expressed as mean and range.

## 2. Results

Table 1 presents a summary of patient baseline data and results of operative bowel lengthening. In total, 5 patients underwent the STEP procedure during the 26-month study period. Mean age at time of STEP was 12 (range 0-23) months. The STEP was performed on 1 newborn infant with gastroschisis associated with intestinal atresia. The STEP was used as a primary bowel-lengthening operation in 4 of the 5 subjects in this cohort; the remaining patient

**Table 1** Baseline data from the STEP cohort

Subject	Age (mo)	Diagnosis	Pre-STEP bowel length (cm)	Post-STEP bowel length (cm)
1	23	Gastroschisis/volvulus	135	200
2	8	Gastroschisis/volvulus	27	59
3	14	Malrotation/volvulus/Hirschsprung disease	84	113
4	14	NEC	39	69
5	0	Gastroschisis/intestinal atresia	22	51
Mean	12		61	98

Baseline patient characteristics and results of operative bowel lengthening with the STEP procedure. All subjects underwent successful bowel lengthening with an average increase in small bowel length of 82%. There were no perioperative or short-term complications from the STEP procedure in this cohort. NEC indicates necrotizing enterocolitis.

had previously undergone a Bianchi isoperistaltic bowel-lengthening operation and subsequently developed recurrent small bowel dilatation 15 months later with inability to wean from parenteral nutrition (PN), thereby necessitating operative bowel lengthening with the STEP procedure [2].

Small bowel length was significantly increased from 61 (22-135) cm on initial measurement at laparotomy to 98 cm (51-200 cm,  $P < .01$ ) immediately post-STEP for an increase in small intestinal length of 82% (34%-132%, Table 1). An average of 18 (range 10-26) linear stapler applications were used to perform the operation. There were no perioperative complications in this cohort, and the length of in-hospital stay was 16 (11-20) days. All subjects underwent fluoroscopic small bowel transit study before enteral feeding, and no subject had evidence of intestinal leak, obstruction, or delay in bowel motility.

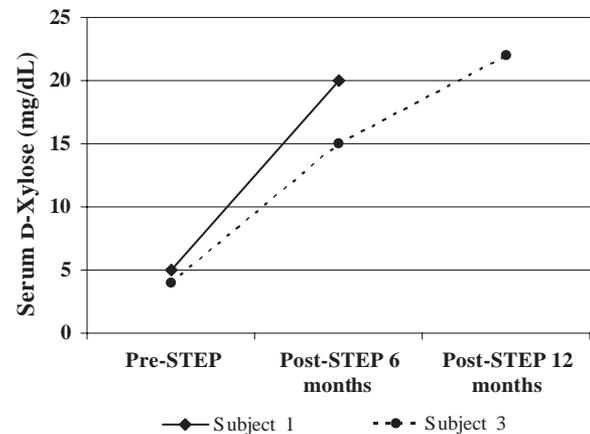
Subjects underwent serial outpatient evaluation at out institution's Short Bowel Syndrome Clinic. Average follow-up duration was 15 (range 1-26) months. During this period, there were no postoperative complications from the

**Table 2** Enteral nutrition after the STEP procedure

Subject	Follow-up interval (mo)	Percentage of enteral nutrition pre-STEP	Percentage of enteral nutrition post-STEP
1	26	10	60
3	15	60	80
4	11	70	100
Mean	17	49	80*

Percentage of total caloric intake as derived from enteral nutrition for the 3 subjects with short-term postoperative nutritional data. Subjects had a significant increase in the percentage of calories from enteral nutrition with an average follow-up of 17 months post-STEP. Subject 3 was weaned completely from PN within 6 weeks of the STEP procedure.

\*  $P < .05$ .



**Fig. 2** Levels of serum D-xylose pre-STEP and post-STEP. In 2 of the 3 subjects with postoperative short-term nutritional data, levels of D-xylose were abnormally low before STEP procedure. After STEP, both subjects demonstrated a substantial increase to normal levels of D-xylose. D-Xylose is a validated marker for small intestinal mucosal surface area and carbohydrate absorptive capacity [6].

STEP procedure. All subjects continued to gain weight throughout the follow-up period. Postoperative nutritional data were available on 3 of the 5 subjects at 17 (11-26) months post-STEP and are presented in Table 2. The percentage of enteral nutrition was significantly increased from time of STEP procedure (49%, range 10%-70%) to post-STEP follow-up (80%, range 60%-100%,  $P < .05$ ). One subject was fully weaned from PN within 6 weeks of the STEP procedure. Another subject, who had previously been listed for liver–small bowel transplantation with evidence of hepatic fibrosis on liver biopsy and a preoperative total bilirubin of 17 mg/dL, completely normalized his serological liver functions tests within 6 months of the STEP procedure.

Of the 3 subjects with nutritional data, 2 patients had abnormally low levels of serum D-xylose before STEP. Both subjects demonstrated normalization of serum D-xylose levels within 1 year of the STEP procedure (Fig. 2).

The sole subject in this cohort with established preoperative cirrhosis secondary to PN underwent a successful liver–small bowel transplant 8 months after the STEP procedure.

### 3. Discussion

The STEP was introduced in 2002 as a novel surgical option for short bowel syndrome [1]. The STEP lengthens the small intestine by using sequential applications of the linear stapler in alternating directions across the bowel and staying within a plane parallel to the mesenteric blood supply (Fig. 1). In this way, the STEP creates a zigzag-shaped bowel that is greater in length without putting the mesenteric blood supply at risk. In practice, the STEP is a simple and efficient technique for bowel lengthening,

particularly when compared with previously reported intestinal lengthening procedures such as the isoperistaltic technique described by Bianchi [5].

Previous reports have evaluated the STEP procedure in an animal model of short bowel syndrome. These studies have shown the STEP to be a feasible operation without prohibitive risk [1] and have demonstrated that the STEP may improve macronutrient indices and intestinal function [4]. Use of the STEP in human beings has been reported in select case reports only [2,3]. These communications have demonstrated that the STEP can be an effective bowel-lengthening procedure when used either as an adjunct to other bowel-lengthening techniques or as a primary bowel-lengthening operation. Given the novel nature of the operation, there has been no report to date of outcomes from a cohort of patients who have undergone the STEP procedure.

The purpose of the present study was to review the short-term outcomes in the first cohort of children to undergo the STEP procedure at our institution. In this small series of 5 subjects, all children underwent successful operations. There were no significant complications during the perioperative or follow-up periods, and the infants demonstrated an overall improvement in enteral intake. The data presented here suggest that the STEP is a safe and effective operation for children with short bowel syndrome who cannot be weaned from PN secondary to difficulties with small bowel length and absorptive capacity.

With an average postoperative follow-up period of 17 months, the STEP was also associated with significant improvements in nutritional indices. All subjects gained weight after the operation, and the 3 subjects with short-term nutritional data were tolerating significantly greater provisions of enteral nutrition after the STEP procedure ( $P < .05$ ). In fact, 1 child who could tolerate only 70% of feedings enterally was weaned completely from PN within 6 weeks of the operation. Although a definitive mechanism to explain the effects of the STEP on intestinal function continues to be studied, our animal investigations indicate that there is both improved nutrient absorption and an actual increase in intestinal mucosal surface area post-STEP. The latter is associated with a uniform and relatively rapid increase in bowel diameter within the lengthened bowel [1]. Indeed, in the 2 subjects with abnormally low preoperative levels of D-xylose, a serum marker for small intestinal passive absorption, the STEP was associated with a substantial increase and normalization in D-xylose levels within 1 year of the procedure [6]. These human data are consistent with previous data in an animal model of short bowel syndrome that suggest the STEP can improve intestinal macronutrient absorptive capacity when compared with animals who do not undergo operative bowel lengthening [4].

The effects of the STEP procedure on children with advanced PN-associated liver disease remain to be fully evaluated. In this series, 1 child who had been listed for liver–small bowel transplantation and had hepatic fibrosis

on preoperative pathology and severe hyperbilirubinemia completely normalized his liver function tests within 6 months of the operation. This child is now doing well and receiving greater than 80% of his nutritional intake through the enteral route. The second child to undergo the STEP had documented cirrhosis before the procedure (at 8 months of age), and the STEP was performed because nonoperative management of her short bowel syndrome was associated with worsening liver dysfunction. This patient's liver disease remained stable but did not improve after the STEP, and she ultimately underwent a successful liver–small bowel transplant 8 months after the STEP. Although the STEP did not avert the need for transplantation in this patient, the operation served as a bridge to successful transplantation at a more suitable and practical age. From these patients, we have learned that there is likely a point in the evolution of liver dysfunction at which the STEP will no longer result in improved liver function. A future challenge will be to identify which patients with PN-associated cholestasis will ultimately benefit from the operation.

The most recent subject to undergo the STEP procedure in this review was a newborn who was transferred to our institution with gastroschisis and an associated jejunal atresia. Upon exploration on day 1 of life, the child's proximal small bowel was found to be dilated, and the STEP procedure was performed to lengthen the bowel from 22 to 51 cm. This child has subsequently done well and is tolerating increasing provisions of enteral nutrition. This patient demonstrates that, in the proper candidate, the STEP procedure can be performed safely at the initial operation in a newborn with significant short bowel anatomy. Clearly, newborns who are in distress or who may have sufficient small bowel to eventually tolerate enteral nutrition may be better candidates for a delayed approach to operative bowel lengthening.

The present study is limited by its small scope and the fact that not all tests were performed on all subjects. We therefore cannot exclude the possibility of bias in the study's data. Although these data are encouraging, the present evaluation does not fully validate the STEP procedure as a successful bowel-lengthening operation. It is clear that further study of the STEP operation is needed to better define both the clinical outcomes of the procedure and its effects on the intestine at the cellular level. Longer term evaluation looking at growth indices and nutritional parameters is ongoing and will provide valuable information as to the ultimate effectiveness of the operation. With accumulating data from our institution and other pediatric tertiary centers, it may be feasible to compare the outcomes of the STEP procedure with alternative treatments. Ultimately, a coordinated, prospective, multicenter approach to the collection and analysis of outcomes from the STEP procedure is needed to objectively quantify the effectiveness of the operation. To that end, we have initiated a secure Web-based registry that may be accessed at [www.stepoperation.org](http://www.stepoperation.org). We invite all surgeons performing

the STEP operation to contribute their cases to this data repository. For now, we believe that the available data demonstrate the STEP to be a simple, safe, and effective option for operative management in the child with short bowel syndrome.

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## Discussion

*Mike Skinner, MD, FAAP (Durham, NC):* Have you seen any recurrence of dilation of the small bowel after you have done the procedure, and have you given any thought to how you are going to manage that when you do see it?

*Patrick J. Javid, MD (Boston, MA):* We have not seen recurrence at this point. In our animal model, at 6 weeks postoperatively, we did see the bowel dilate slightly, and this was associated with increases in D-xylose as well as citrulline, which is a marker of small bowel mucosal mass. So to some extent, the dilatation might be helpful because it is increasing the mass of mucosa to assist in enteral nutrient absorption, to date, although we have not seen any recurrent dilatation in human beings.

*Darrell Cass, MD (Houston, TX):* Can you tell us a little bit more about that 1 newborn patient with gastroschisis? If this operation was done in the newborn period, was there any peel, and how did it go? How is the child doing?

*Patrick J. Javid, MD (Boston, MA):* The child is doing well. The operation was a complicated one. The baby had been diagnosed preoperatively with this anomaly. What was fortunate for us was that at the time the bowel was significantly dilated as a result of both of these processes,

and there was not an apple peel abnormality, but there was basically a mass of bowel that was of questionable viability. The baby only had 22 cm of remaining bowel before the STEP operation. So it was decided at that time, because there was significant bowel dilatation and there would be so little bowel remaining if we did not lengthen the bowel, to perform the STEP operation on the initial operation on the first day of life. I think this is clearly an exception, and in most patients, there is either not going to be bowel dilatation or you would attempt conservative measures to optimize enteral nutrition before performing the STEP operation.

*Darrell Cass, MD (Houston, TX):* My concern is that the bowel would have been thickened in the presence of gastroschisis. How does the GIA stapler work for that thickened bowel?

*Patrick J. Javid, MD (Boston, MA):* At that time, the proximal bowel was not thickened to the point where we felt it would be risky to perform the stapler applications.

*Augustino Pierro, MD (London, UK):* One of the things that happens when you have a short bowel syndrome such as in the patient you have shown is bacterial overgrowth, and very often, this leads to infection and line sepsis possibly because of bacterial translocation. My question to you is that have you studied in your population if there was any difference in bacterial overgrowth in the bowel before and after the STEP procedure, and have you noticed any difference in infection rate?

*Patrick J. Javid, MD (Boston, MA):* We have data from an animal model where we specifically looked at the bacterial content. In that animal model, the STEP animals had no incidence of bacterial overgrowth using standard definitions, whereas in control animals, more than 50% of them did. In these patients, we are not looking for overgrowth routinely unless they present with clinical symptoms. One limitation of studies on bowel lengthening is that it is difficult to identify a control population either in children who had an alternative bowel-lengthening operation or in children who have not had bowel lengthening at all. So it is difficult to compare, but we do not see any increase in line sepsis or in incidence of bacterial overgrowth compared with children who are managed conservatively.

*Donna Caniano, MD, FAAP (Columbus, OH):* Can you give us some guidelines as to when the ideal time is to perform the STEP procedure and what the ideal patient would be?

*Patrick J. Javid, MD (Boston, MA):* I think that is a good question. The majority of patients on whom we performed this recently have had this as their primary bowel-

lengthening operation. The first child was a patient who had had a Bianchi bowel-lengthening procedure, who then redilated 2 years after the procedure, and we could not advance his enteral nutrition despite numerous attempts. I think in a patient such as that in whom you have exhausted all conservative measures, then the STEP procedure is an option. Before we use the STEP as the

primary bowel-lengthening procedure, our patients are worked up extensively in our multidisciplinary clinic. So when they are referred to us, we make several attempts through G tube feedings and, with continuous feedings, to try to advance enteral nutrition. When we are at a plateau of enteral nutrition that cannot be advanced further, we would consider the STEP operation.