



## Accuracy of radiographic estimation of small bowel dimensions in pediatric patients with short bowel syndrome



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### ABSTRACT

**Background:** The decision to perform autologous intestinal lengthening in patients with short bowel syndrome (SBS) depends on total bowel length and the diameter and length of dilated segments. This study evaluated the accuracy of radiologic measurements of intestinal length and diameter.

**Methods:** Patients who underwent an intestinal lengthening procedure with preoperative upper gastrointestinal study (UGI) were identified from 10/2012 through 1/2015. Measurements of total length and diameters and lengths of dilated segments on UGI were compared to intraoperative measurements using Spearman's rank correlation coefficients and Bland–Altman plots.

**Results:** Fourteen patients underwent 15 lengthening procedures. Median age was 3.6 years. Most common causes of SBS were complicated gastroschisis (43%) and small bowel atresia (36%). Intra-operative bowel lengths prior to performing lengthening procedures ranged from 21 to 170 cm. The median measurements of radiographic and operative measurements (respectively) were total bowel lengths 77 cm and 69 cm ( $r = 0.93$ ,  $p < 0.0001$ ), maximum diameters 7.7 cm and 7 cm ( $r = 0.86$ ,  $p = 0.001$ ), and lengths of dilated segments 13 cm and 14 cm ( $r = 0.41$ ,  $p = 0.36$ ).

**Conclusions:** The correlation between UGI and operative measurements suggests that prediction of total bowel length and maximum diameter of dilation is accurate and can assist with operative planning.

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Short bowel syndrome (SBS) is the most common cause of intestinal failure and is most commonly due to acquired foreshortening of the bowel through intestinal resection. Though the syndrome stems from loss of surface area and absorptive capacity, the sequelae of the disease and its management involves multiple systems. As such, many specialties are involved in the care of these patients. Recent work has shown that when these efforts are used in concert, outcomes for these patients are improved [1–3].

It is known that bowel length is associated with the ability to wean from total parenteral nutrition (TPN) and maintain enteral autonomy [4]. As part of the process of intestinal adaptation following bowel resection, the bowel will often lengthen and dilate. The process of dilation can exceed physiologic adaptation and proceed into pathologic dilation, whereby the segment loses coordinated motility which in turn interferes with enteral feeding tolerance or contributes to bacterial overgrowth [5]. These patients are then considered for autologous surgical lengthening procedures such as longitudinal intestinal lengthening

and tapering (LILT, Bianchi procedure) or serial transverse enteroplasty (STEP). The evaluation process for these procedures usually includes radiographic evaluation of the dilated segment including assessments of bowel length, diameter, and motility with an upper gastrointestinal series with small bowel follow through (UGI). The UGI can provide significant information to aid in preoperative planning; however the accuracy of an UGI to measure bowel dimensions has not been well studied. There are a few studies evaluating the accuracy of radiographic measurement of adult bowel length [6–8], but none describing the accuracy of an UGI to measure bowel dimensions in children with SBS.

The multidisciplinary intestinal failure team at our institution includes a dedicated radiologist who performs all scheduled UGI studies in our short bowel patients. Each patient is reviewed individually by the entire team including group discussion of UGI findings which are relied upon for operative planning. Incorporation of a dedicated radiologist has led to the provision of specific bowel measurements on the UGI, including the total bowel length, the length of any dilated segments and the maximum diameter of the dilated segment. The purpose of this study is to evaluate the accuracy of the UGI measurements of total bowel length, diameter of the dilated segments, and length of the dilated segments as compared to intraoperative measurements (OR) among pediatric patients with SBS.

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## 1. Methods

### 1.1. Study Design

This was a retrospective cohort study of pediatric patients with SBS at a single institution. Patients were identified who had SBS and underwent autologous intestinal lengthening procedure from 10/2012 to 1/2015. Charts were reviewed to evaluate for a preoperative UGI. The UGI examinations were all read by a single pediatric radiologist (GB) and operations were performed by a single surgeon (PM).

The UGI reports included detailed best estimates of total bowel length, length of any dilated segments, and the maximum dilation of the dilated segments. The same measurements were extracted from the operative reports for comparison. For cases where a single patient had multiple dilated segments, each dilated segment was treated as an independent entry for analysis of the dilated segment length and maximum diameter. Any episodes of missing data from the UGI or operative report were excluded.

### 1.2. Statistical analysis

Demographic and clinical characteristics were summarized using medians and interquartile ranges for continuous variables, and frequencies and percentages for categorical variables. To examine the degree of association between the radiographic and operative measurements, Spearman's rank correlation coefficients and intra-class correlation coefficients were used. Paired t-test was also used to detect systematic differences between the means of the two measurements. Linear regression plots of radiographic measurement vs. operative measurement were constructed for total bowel length and lengths of dilated segments. A p-value less than 0.05 was considered statistically significant. Agreement between radiographic and operative measurements was assessed using Bland–Altman (BA) plots. The BA plots were used to determine differences against the average between the radiographic and operative measurements, with calculated mean  $\pm$  SD and 95% limits of agreement (with 95% confidence intervals of the limits) for raw differences between the two methods of measurement. All analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, NC). This study was approved by the Institutional Review Board.

## 2. Results

There were 14 patients who underwent 15 intestinal lengthening procedures during the study period, each with a preoperative UGI. The average age of patients at the time of operation was 3.6 years and most patients were white, male, and born preterm (Table 1). The most common diagnosis associated with SBS was complicated gastroschisis (43%), followed by intestinal atresia (36%). Seven of the 15 patients had undergone a previous intestinal lengthening procedure. For their

current operation, 13 of the operations were a STEP procedure and 2 patients underwent LILT. The total bowel length after intestinal lengthening procedures increased from a mean of 86 cm to 110 cm for an average of 24 cm (39% increase). For patients who underwent transverse enteroplasty, an average of 6.9 enteroplasties was performed per operation.

There were 13 patients with both the UGI and OR measurements (one surgical measurement was unable to be obtained due to limited bowel visibility from adhesive disease and one UGI had uncertain radiographic length due to multiple areas of overlapping bowel). Sample images of the measurements taken on UGI to assess bowel length are shown in Fig. 1. The radiographic total length ranged from 29 to 142 cm with a median of 77 cm. The included OR lengths (prior to completion of lengthening) ranged from 21 cm to 170 cm with a median of 69 cm. The total bowel length showed strong correlation on linear regression between UGI and operative measurements (Fig. 2a,  $R = 0.93$ ,  $p < 0.001$ ). The differences from UGI to operative measurements were well balanced between over and underestimation with an average difference of 1.8 cm underestimation in total bowel length on UGI (Fig. 2b).

There were 17 dilated segments identified, of which 11 had complete data on UGI and OR measurements (six missing operative measurements). The maximum dilation on UGI ranged from 4.5 to 12 cm with a median of 7.7 cm as compared to OR measurements ranging from 5.8 to 10 cm with a median of 7 cm. These showed a strong linear correlation (Fig. 3a,  $R = 0.86$ ,  $p = 0.001$ ). The difference from UGI to OR measurement showed minimal average overestimation of 0.25 cm by UGI (Fig. 3b).

The estimation of the length of the dilated segment had more missing data, with only 7 events with both UGI and OR measurements out of 17 dilated segments identified with several missing measurements on UGI, OR, and/or both. The dilated segment lengths showed a median of 13 cm on UGI and 14 cm on OR measurements, but these failed to show a statistically significant linear correlation ( $R = 0.41$ ,  $p = 0.36$ ). The difference in measurements showed a larger relative difference with an average overestimation of 2.4 cm by UGI.

## 3. Discussion

This study demonstrates a high degree of accuracy of UGI radiographic measurements of bowel dimensions in pediatric SBS patients when evaluated by a radiologist who specializes in this patient population. Bowel length and diameter are important pieces of information in the medical and operative management of SBS patients. The measurement of total bowel length can help estimate the severity of the disease and the patient's ability to eventually attain enteral autonomy [4,9]. In addition, accurate estimation of the diameter and length of dilated segments of bowel can assist with medical decision making such as instituting therapy for bacterial overgrowth, and timing of surgical interventions.

Estimation of bowel length based upon planar imaging has the potential to be confounded by a number of anatomic, physiologic and geometric factors. In-plane movement of the bowel on the 2-dimensional radiograph would result in underestimation of bowel length, which has been suggested to be a more significant problem for longer bowel lengths [8]. Muscular contraction has been shown to vary the measured length of bowel in cadaver studies, which highlights the ability of bowel contraction to alter dimensions on static images and could result in a discrepancy when comparing unanesthetized UGI measurements to anesthetized intraoperative measurements [7,10]. Furthermore, many of these patients have had previous lengthening procedures, especially transverse enteroplasty, which creates areas of abrupt transitions that could create in-plane movement or unrecognized overlap that would result in UGI underestimation of length. Similarly adhesions between bowel loops are taken down prior to the intra-operative measurement and these can impact the difference between the radiographic and

**Table 1**  
Baseline characteristics for included patients.

Characteristic	N (%) or Median (IQR)
Male	10 (67)
Age (years)	3.6 (0.6–7.0)
Gestational age at birth (weeks)	34.9 (33–37)
White race	11 (79)
Diagnosis for previous resection	
Complicated gastroschisis	6 (43)
SB atresia	5 (36)
Necrotizing enterocolitis	1 (7)
Volvulus	1 (7)
Meconium ileus	1 (7)
Previous surgical lengthening procedure	
Bianchi	2 (13)
Serial Transverse Enteroplasty (STEP)	2 (13)
Multiple	3 (20)

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