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Small Bowel Dilatation Predicts Prolonged Parenteral Nutrition and Decreased Survival in Pediatric Short Bowel Syndrome

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Objective: To analyze risk factors and prognostic significance of small bowel (SB) dilatation in children with short bowel syndrome (SBS).

Background: In SBS, the remaining SB may dilate as part of intestinal adaptation. The impact of dilatation on parenteral nutrition (PN) dependence and survival has not been studied systematically.

Methods: SB diameter of SBS children (n = 61) was measured in contrast SB series (n = 169, median age 0.94, range 0.32–2.7 years) during 2002 to 2015, and expressed as millimeters (SB width) and as ratio to L5 vertebra height (SB diameter ratio). Linear regression was used to examine risk factors for dilatation. PN weaning and survival were analyzed with Cox proportional hazards regression.

Results: Maximal SB diameter ratio during follow-up was predicted by PN dependence and SB atresia, while maximal absolute SB width by birth weight, age, PN duration, and remaining bowel length. Weaning off PN was 14-fold more likely in patients with maximal SB diameter ratio <2.00 compared with >3.00 ($P = 0.005$), and 5.4-fold more likely when maximal SB width was <20 mm compared with >30 mm ($P = 0.023$). After adjustment for age, remaining SB length, and the presence of ileocecal valve, both estimates of maximal SB dilatation remained significant independent predictors for weaning off PN. When all measurements were included, the cumulative survival was worse if SB diameter ratio exceeded 2.00 ($P = 0.002$–0.042).

Conclusions: SB dilatation predicts prolonged PN duration and decreased survival in SBS children. Measurement of maximal SB diameter standardized to L5 vertebra height may be a valuable objective tool for patient follow-up and assessment of prognosis.

Keywords: short bowel syndrome, small bowel dilatation, tapering surgery

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Intestinal failure (IF) occurs when insufficient bowel absorptive capacity leads to requirement of long-term parenteral nutrition (PN) to maintain adequate nutrition, weight, as well as growth in children.[1,2] In pediatric population, the most common reason for IF is short bowel syndrome (SBS) due to extensive bowel resection.[1,3] Despite recent progress in the field, SBS continues to carry significant morbidity and mortality.[1–3] Children are considered to have better intestinal adaptive capacity than adults, and with appropriate nutritional, medical, and sometimes also surgical management, most pediatric SBS patients are eventually able to wean off PN. Remaining small bowel (SB) length >40 cm, intact ileocecal valve (ICV), and preserved colon improve the chances of reaching enteral autonomy.[2–6]

Following resection, the bowel undergoes both structural and functional changes to optimize its absorptive capacity, including increased villus height and crypt length, enhanced transporter expression, and slowed transit time.[3,7,8] In some patients, the adaptive increase of absorptive surface encompasses excessive dilatation of the remaining SB. Dilated SB loops may become dysmotile and promote bacterial overgrowth (BO), thereby increasing the risk for septic infections, D-lactate acidosis, poor enteral tolerance, malabsorption, and prolonged PN duration.[9,10] Bowel dilatation can be demonstrated in SB series by monitoring the follow-through of contrast medium with repeated images. SB diameter perpendicular to bowel longitudinal axis exceeding 4 to 5 cm is considered clearly pathological.[11] Surgical tapering procedures such as serial transverse enteroplasty (STEP) and longitudinal intestinal lengthening and tapering to alleviate bowel dysfunction are often considered in PN-dependent pediatric SBS patients when bowel dilatation exceeds 3.5 to 4 cm.[12,13] Despite rapidly increasing popularity of tapering surgery in the treatment of SBS,[5,6,11–13] the actual prognostic significance of SB dilatation as well as the threshold for pathological bowel dilatation remains unclear. Moreover, no established reference values for SB width exist, and the changes occurring in normal SB width relative to growth have not been analyzed earlier.

As risk factors for bowel dilatation have not been studied previously, it remains unknown which SBS patients are susceptible to dilatation. The impact of SB dilatation on the most important outcome measures of SBS; PN dependence and survival, is also unclear. Finally, no standardized measure to estimate the degree of SB dilatation in children exists. To meet these challenges, we aimed to analyze which patient characteristics associate with SB dilatation, whether the degree of SB dilatation relates with PN dependence and survival, and whether individually standardized SB diameter measured as a ratio to fifth lumbar vertebra height reflects the degree of dilatation and outcome better than the absolute SB width in a population of SBS children.

METHODS

Patients

This was a retrospective follow-up study including all patients with IF due to SBS treated by our intestinal rehabilitation program during 2002 to 2015 (n = 61). Inclusion criteria were SB resection >50% of age-adjusted reference value, or lesser SB resection if related to duration of PN for over 2 consecutive months.[14–16] Patients with other etiology of IF such as primary motility disorders (n = 25), mucosal enteropathies (n = 3), and lymphatic disorders (n = 1) were excluded. Medical records were reviewed for SBS etiology,

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gestational age and weight, duration of PN, operative treatment, and intestinal anatomy. Small bowel and colon length were expressed both as absolute values and as percentage of age-adjusted reference values[15] while the presence of ICV and ileum was recorded as absent or present. Our management protocol for SBS has been described in detail previously.[17]

Contrast Small Bowel Series

Contrast SB series were performed using either barium or water-soluble, iso-osmolar iodixanol. The examination was performed either when dysmotility, BO, or other complications of SB dilatation were suspected based on clinical symptoms, or as part of the follow-up program every 6 to 24 months in patients receiving PN or recently weaned off PN. During 2002 to 2015, 48 patients underwent altogether 169 contrast SB series. Each patient underwent median 3 (range 1–5) investigations, while no contrast SB series were performed on 13 patients. Pulsed fluoroscopy was routinely applied and fluoroscopic images were stored to reduce radiation dose. Mechanical intestinal occlusion was ruled out by confirming distribution of contrast material throughout the intestine.

Small Bowel Width and Small Bowel Diameter Ratio

Maximal SB width perpendicular to the longitudinal axis of the bowel and the height of fifth lumbar vertebra were measured in each contrast SB series by the primary researcher in cooperation with an experienced pediatric radiologist (R.K.). The width of the largest SB segment was expressed both as millimeters (SB width) and as internally standardized ratio to the height of the fifth lumbar vertebra (SB diameter ratio).

Statistical Methods

Data are presented as medians with interquartile ranges or frequencies. Spearman rank correlation was used to examine associations between variables. Mann–Whitney *U* test was used to compare continuous variables and Fisher exact test to compare frequencies between subgroups. We used simple linear regression to test the relationships between other variables, SB width, and SB diameter ratio. For this analysis, the maximal SB width and maximal SB diameter ratio during follow-up (the highest values) were chosen for each patient to avoid having multiple measurements per patient. In addition to statistically significant variables from the univariate model, variables considered important according to earlier research were chosen for the multiple linear regression analysis.

To analyze the cumulative survival rates and weaning from PN in relation to the degree of SB dilatation, patients were divided into 3 subgroups according to both maximal SB width (<20 mm, 20–30 mm, >30 mm) and maximal SB diameter ratio (<2.00, 2.00–3.00, >3.00). The predictive value of maximal SB width, maximal SB diameter ratio, and other variables of interest were tested by generating hazard ratios (HR) with 95% confidence intervals (CI) with Cox proportional hazards regression analysis. Variables showing statistically significant univariate associations with PN weaning rates and survival were included in the multivariate model. In addition, according to earlier research suggesting preserved ICV relates with good prognosis,[3,4,18–21] the presence of ICV was included in the multivariate analyses. Finally, receiving operating characteristic (ROC) curves and areas under ROC curves were used to evaluate the accuracy of SB diameter ratio in the prediction of PN dependence at the time of contrast SB series. The optimal cutoff values were calculated using the maximum sum of specificity and sensitivity. The level of significance was set at $P < 0.05$ and all analyses were carried out with SPSS version 22.

Ethics

The study protocol was approved by the hospital ethical committee.

RESULTS

Patient Characteristics

In total, we identified 61 patients with IF due to SBS (males 59%, n = 36). At the time of study, intestinal continuity had been reestablished in all and none had an enterostomy. Baseline diagnoses were necrotizing enterocolitis (NEC) (n = 31), midgut volvulus (n = 13), small bowel atresia (SBA) (n = 13), and gastroschisis (n = 4). Four patients with both SBA and gastroschisis were analyzed in the SBA group. Median residual small bowel length was 40 (25–60) cm while colon length 32 (24–41) cm, corresponding 25 (17–44)% and 95 (61–100)% of age-adjusted reference values, respectively.[15] The ICV was missing in 28 (46%) and no ileum was remaining in 27 (44%). Median gestational age was 32 (27–36) weeks and birth weight 1765 (760–2880) g, and both were significantly lower in NEC than other patients (27 vs. 36 weeks; 760 vs. 2560 g, $P < 0.001$ for both). Altogether 17 patients underwent tapering procedures during the follow-up, including STEP (n = 16), longitudinal intestinal lengthening and tapering (n = 2), tapering enteroplasty (n = 4), and resection of dilated SB (n = 2). Median age was 0.94 (0.32–2.74) years at the time of contrast SB series while 4.70 (2.15–8.80) at the end of the follow-up. Patients who underwent no contrast SB series (n = 13) were comparable to others in relation to baseline diagnosis, percentage and length of remaining SB and colon, PN duration, PN weaning and survival rates, gestational age, birth weight, and the presence of ICV (P = ns for the difference between subgroups for all variables).

Predictors of Absolute Small Bowel Width

Maximal SB width correlated positively with age ($r = 0.532$, $P < 0.001$) and duration of PN ($r = 0.615$, $P < 0.001$) at the time of contrast SB series, with gestational age ($r = 0.646$, $P = 0.023$) and birth weight ($r = 0.608$, $P = 0.036$), and negatively with the percentage ($r = -0.431$, $P = 0.002$) and absolute length ($r = -0.606$, $P = 0.022$) of remaining SB. Maximal SB width was shorter in NEC versus other patients [26 (21–32) vs. 37 (24–46) mm, $P = 0.035$], while longer in patients who had undergone tapering surgery compared with those without surgery [41 (37–56) vs. 25 (20–30) mm, $P < 0.001$] and in patients with resected versus preserved ICV [36 (25–43) vs. 26 (20–32) mm, $P = 0.015$].

According to univariate linear regression, the percentage of remaining SB, the absence of ICV, age, duration of PN at the time of contrast SB series, gestational age, and birth weight were associated with maximal SB width. In the multiple regression analysis, only gestational age retained a statistically significant association with maximal SB width (Table 1).

Predictors of Small Bowel Diameter Ratio

Maximal SB diameter ratio was greater in patients currently on PN versus patients weaned off PN at the time of contrast SB series [3.00 (2.37–3.72) vs. 1.77 (1.25–2.82), $P = 0.007$] and in patients who had undergone tapering surgery compared with those without surgery [3.64 (2.30–4.04) vs. 2.74 (2.08–3.17), $P = 0.035$]. Maximal SB diameter ratio correlated negatively with age at contrast SB series ($r = -0.376$, $P = 0.008$).

In univariate regression analysis, SBA etiology, age, and PN dependence at the time of contrast SB series showed significant associations with maximal SB diameter ratio. In multiple regression analysis, only the association between SBA etiology and SB diameter ratio remained statistically significant (Table 2).

TABLE 1. Associations Between Maximal Small Bowel (SB) Width (mm) (n = 48) and Different Variables Assessed With Simple Linear Regression and Multiple Regression Adjusted for Percentage of Remaining SB, the Presence of ICV, PN Duration and Age at Contrast SB Series, and Gestational Age

	Simple Regression		Multiple Regression	
	β (95% CI)	*P* Value	β (95% CI)	*P* Value
SBA vs. other etiology	0.77 (−0.47–2.00)	0.217		
NEC vs. other etiology	−0.94 (−1.92–0.03)	0.058		
Remaining SB (%)	−0.02 (−0.04–0.00)	0.044	0.07 (−0.04–0.18)	0.172
Remaining SB length (cm)	−0.02 (−0.04–0.1)	0.010		
Remaining colon (%)	−0.01 (−0.03–0.02)	0.570		
ICV preserved	−1.25 (−2.20–0.29)	0.012	−2.82 (−5.83–0.20)	0.061
Weaned off PN at contrast SB series	0.30 (−0.73–1.34)	0.559		
Age at contrast SB series	0.19 (0.12–0.25)	<0.001	−0.04 (−0.21–0.28)	0.713
Duration of PN at contrast SB series	0.02 (0.01–0.04)	0.012	0.11 (−0.06–0.29)	0.158
Gestational age	0.32 (0.05–0.59)	0.023	0.32 (0.04–0.61)	0.034
Birth weight*	0.001 (0.00–0.002)	0.022		

Birth weight was omitted for the multivariate analysis because of high correlation with gestational age ($r = 0.920$, $P < 0.001$).

β indicates unstandardized coefficient; CI, confidence interval; ICV, ileocecal valve; NEC, necrotizing enterocolitis; PN, parenteral nutrition; SB, small bowel; SBA, small bowel atresia.

Predictors of Weaning Off Parenteral Nutrition

By the end of the follow-up, 80% (n = 49) of patients had weaned off PN after 7.3 (3.7–12.6) PN months. Compared with them, patients still receiving PN had a longer total PN duration [15.3 (8.1–46.4), $P = 0.025$] and a shorter remaining SB [17 (6.5–23) vs. 26 (19–48)%, $P = 0.010$].

Univariate Cox regression models suggested the percentage of remaining SB and maximal SB diameter ratio <2.00 compared with >3.00 as significant predictors for weaning off PN (Table 3). Patients with maximal SB diameter ratio >3.00 were 14.3 times less likely to wean off PN than patients with maximal SB diameter ratio <2.00. The median SB width corresponding to SB diameter ratios 2.00, 2.00 to 3.00, and >3.00 were 19 (16–32), 26 (20–33), and 30 (21–40) mm, respectively. Importantly, after adjustment for age, percentage of remaining SB, and the presence of ICV, categorized maximal SB diameter ratio remained a highly significant predictor of weaning off PN (Fig. 1A, Table 3). Maximal SB diameter ratio analyzed as a continuous variable was also predictive of weaning from PN (Table 3) and the result remained statistically significant after adjustment for age, percentage of remaining SB, and the presence of ICV [HR 0.39 (95% CI 0.16–0.92), $P = 0.031$)].

Based on areas under ROC curves analyses, the best SB diameter ratio cutoff value for being off PN at the time of contrast SB series was 1.77 (sensitivity 0.82, specificity 0.59) when all measurements were included in the analysis, and 2.17 (sensitivity 0.88, specificity 0.67) when only maximal SB diameter ratio for each patient was taken into account (Fig. 2).

Maximal absolute SB width was also significant, although a less powerful predictor of weaning off PN than SB diameter ratio. Compared with maximal SB width >30 mm, patients with maximal SB width <20 mm or 20 to 30 mm were more likely to wean off PN (Table 3). After adjustment for age, percentage of remaining SB, and the presence of ICV, SB width 20 to 30 mm compared with >30 mm remained a predictor of weaning off PN with borderline significance [HR 4.17 (95% CI 1.05–16.46), $P = 0.042$] while the HR for SB diameter <20 mm was no longer statistically significant [1.91 (95% CI 0.15–24.28), $P = 0.619$] (Fig. 1B). For SB width as a continuous variable, the multivariate model adjusted for age, percentage of

TABLE 2. Associations Between Maximal Small Bowel (SB) Diameter Ratio (n = 48) and Different Variables Assessed With Simple Linear Regression and Multiple Regression Adjusted for Baseline Diagnosis, Percentage of Remaining SB, and PN Dependence and Age at Contrast SB Series

	Simple Regression		Multiple Regression	
	β (95% CI)	*P* Value	β (95% CI)	*P* Value
SBA vs. other etiology	0.86 (0.11–1.60)	0.026	0.79 (0.05–1.53)	0.036
NEC vs. other etiology	−0.20 (−0.83–0.45)	0.554		
Remaining SB (%)	−0.01 (−0.02–0.01)	0.302	−0.01 (−0.02–0.00)	0.162
Remaining SB length (cm)	−0.01 (−0.02–0.00)	0.207		
Remaining colon (%)	−0.01 (−0.02–0.01)	0.386		
ICV preserved	−0.34 (−0.98–0.30)	0.290		
Weaned off PN at contrast SB series	−1.01 (−1.69–0.32)	0.005	−0.62 (−1.44–0.21)	0.140
Age at contrast SB series	−0.06 (−0.23–0.01)	0.030	−0.03 (−0.09–0.03)	0.337
Duration of PN at contrast SB series	−0.00 (−0.02–0.01)	0.623		
Gestational age	0.03 (−0.09–0.15)	0.602		
Birth weight	0.00 (–)	0.500		

β indicates unstandardized coefficient; CI, confidence interval; ICV, ileocecal valve; NEC, necrotizing enterocolitis; PN, parenteral nutrition; SB, small bowel; SBA, small bowel atresia.

TABLE 3. Hazard Ratios (HR) With 95% Confidence Intervals (CI) for Weaning Off Parenteral Nutrition

	Univariate		Multivariate	
	HR (95% CI)	*P* Value	HR (95% CI)	*P* Value
Maximal SB diameter ratio				
<2.00	14.33 (2.60–79.14)	0.005	17.74 (2.44–129.2)	0.005
2.00–3.00	0.59 (0.11–3.20)	0.544	0.27 (0.42–1.73)	0.167
>3.00	1.00 (ref)		1.00 (ref)	
Maximal SB diameter ratio (cont.)	0.38 (0.18-0.83)	0.015		
Maximal SB width				
<20 mm	5.40 (1.26–23.0)	0.023		
20–30 mm	3.56 (1.29–9.7)	0.014		
>30 mm	1.00 (ref)			
Maximal SB width (cont.)	0.69 (0.49–0.99)	0.047		
SBA vs. other etiology	3.28 (0.42–25.6)	0.257		
Remaining SB (%)	1.05 (1.02–1.08)	0.002	1.08 (1.03–1.13)	0.002
Remaining SB length (cm)	1.04 (1.01–1.06)	0.002		
Remaining colon (%)	1.01 (0.98–1.05)	0.503		
ICV preserved	2.01 (0.66–6.69)	0.211	5.32 (0.94–30.15)	0.059
Age at contrast SB series	1.06 (0.99–1.13)	0.136	1.02 (0.92–1.13)	0.745
Gestational age	0.89 (0.70–1.13)	0.329		
Birth weight	1.00 (-)	0.437		
Tapering surgery	0.47 (0.14–1.59)	0.226		

Results are obtained from Cox proportional hazards regression model. Maximal SB diameter ratio as a categorical variable, age at contrast SB series, percentage of remaining SB, and the presence of ICV are included in the multivariate model. Total n = 61.

cont indicates continuous; ICV, ileocecal valve; SB, small bowel; SBA, small bowel atresia.

remaining SB, and the presence of ICV resulted in an HR of 0.59 (95% CI 0.38–0.91) ($P = 0.018$).

Predictors of Survival

Overall survival was 92% (n = 56). Patients who died were PN dependent at the last follow-up more frequently than survivors (80% vs. 14%, $P = 0.004$). None of the patients with maximal SB diameter ratio <2.00 died during follow-up (Fig. 3A). When all contrast SB series were included in the analyses, a higher SB diameter ratio was observed in patients who died during follow-up compared with survivors [2.58 (2.29–3.11) vs. 2.07 (1.56–2.71), $P = 0.012$]. However, no statistically significant predictors of survival were identified in the Cox models; the HRs for the percentage and length of remaining SB, the presence of ICV, total duration of PN, maximal SB ratio, maximal SB width, or other tested variables were nonsignificant. When all measurements were included in the analysis, the cumulative probability of survival was worse if SB diameter ratio was 2.00 to 3.00 or >3.00 compared with <2.00 (Fig. 3B). The results did not remain statistically significant after adjustment for age, the percentage of remaining SB, and the presence of ICV (Table 4).

DISCUSSION

Survival and weaning off PN are the main objectives and the most important outcome measures in the management IF children.[1] This study demonstrates that SB dilatation is a major negative predictor of enteral autonomy and survival in SBS children. While both maximal SB diameter ratio and absolute SB width independently predicted weaning off PN after adjustment for patient age, remaining SB length, and the presence of ICV, maximal SB diameter ratio was also predictive of increased mortality.

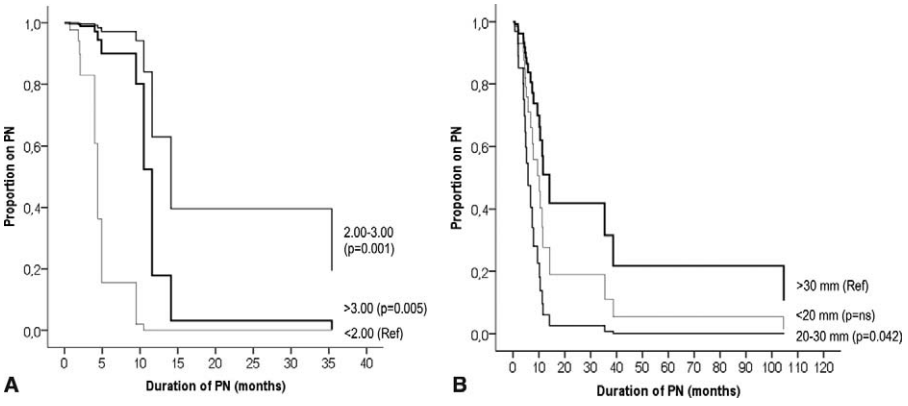

FIGURE 1. Cumulative parenteral nutrition (PN) weaning rates according to (A) maximal SB diameter ratio (n = 47*) and (B) maximal SB width (n = 47*). Results obtained from Cox proportional hazards regression model adjusted for age, percentage of remaining SB, and the presence of ICV.ns indicates nonsignificant; Ref, reference group. *PN weaning date missing for 1 patient.

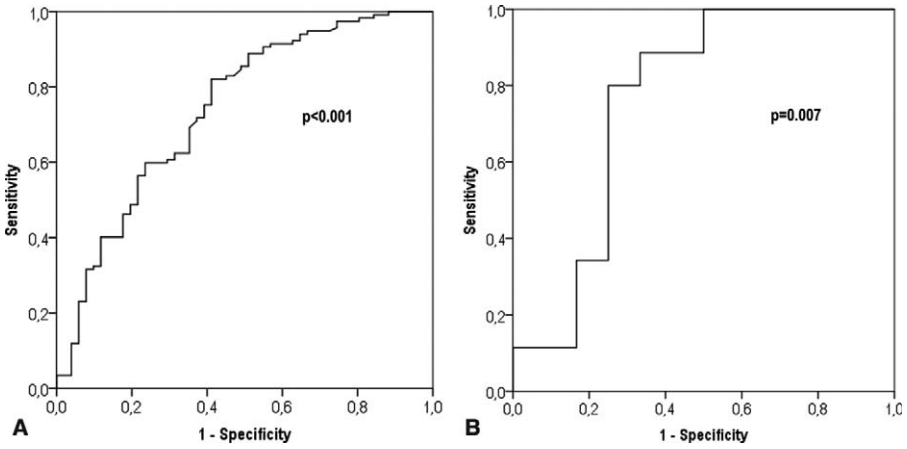

FIGURE 2. The ROC curves for PN dependence at the time of contrast SB series for (A) SB diameter ratio (n = 168*) and (B) maximal SB diameter ratio (n = 47*). The areas under the ROC curve were 0.74 (95% CI 0.66–0.83) and 0.76 (95% CI 0.56–0.96). *PN weaning date missing for 1 patient.

Although contrast SB series is commonly used to study bowel anatomy and function in pediatric SBS patients, previous reports on its use for evaluation of SB dilatation are few.[22] In small patient samples, the measurements of bowel width and length made in contrast SB series correspond well to those confirmed intraoperatively.[22,23] Unsurprisingly, absolute SB width related strongly with age, birth weight, and gestational age, which may compromise its accuracy in the evaluation of the degree of pathological SB dilatation particularly in infants, thereby reducing its prognostic value. More accurate recognition of pathological dilatation in contrast SB series may be possible by using a measure normalized to patient size. With a markedly higher hazard ratio for reaching enteral autonomy, weaker correlation with age, and with no direct association with birth weight or gestational age, SB diameter internally standardized to vertebral height seems a more useful measure of bowel dilatation in children. Although patients experiencing symptoms of dysmotility or BO likely underwent contrast SB series more frequently than asymptomatic ones, this should not have influenced our results as the main analyses were performed by using only 1 measurement for each patient.

The main mechanisms through which SB dilatation is considered to impede the achievement of enteral autonomy are associated dysmotility and BO. Dilatation and dysmotility may reduce effective mixing of intestinal contents and mucosal contact of nutrients, while altered microbiota in the intestinal lumen has potential to promote malabsorption and epithelial inflammation by deconjugating bile acids and producing toxic metabolites.[9,10] BO worsens the preexisting dysmotility[24,25] and likely predisposes to septic infections by promoting bowel permeability and bacterial translocation.[26–29] In studies analyzing predictors of BO, the only established risk factor has been current PN administration while the significance of both PN duration and the length of remaining SB remains controversial.[10,27,30] Although the ICV has been thought to prevent overgrowth of colonic bacteria in the small intestine, its presence has been unrelated with BO in both clinical and experimental studies.[10,27,30,31] Our finding that patients with the shortest remaining SB and missing ICV had wider SB than others suggests that loss of the distal small intestine together with ileocecal region may be mechanistically important in development of SB dilatation.[21] Whether objectively measured SB dilatation associates with altered intestinal microbiota or disrupted signaling by mediators whose expression is restricted to the ileocecal region such as glucagon like peptide 2 or farnesoid X receptor requires further research.[27,30]

Gastroschisis and SBA are predominant etiologies in STEP and other tapering cohorts, suggesting that such patients may be more prone to SB dilatation than those with NEC or midgut volvulus.[11–13,32,33] Accordingly, we found SBA etiology predictive for an increased SB diameter ratio. Possibly due to the small number of gastroschisis patients without associated SBA, instead, patients with isolated gastroschisis showed no tendency toward SB dilatation.

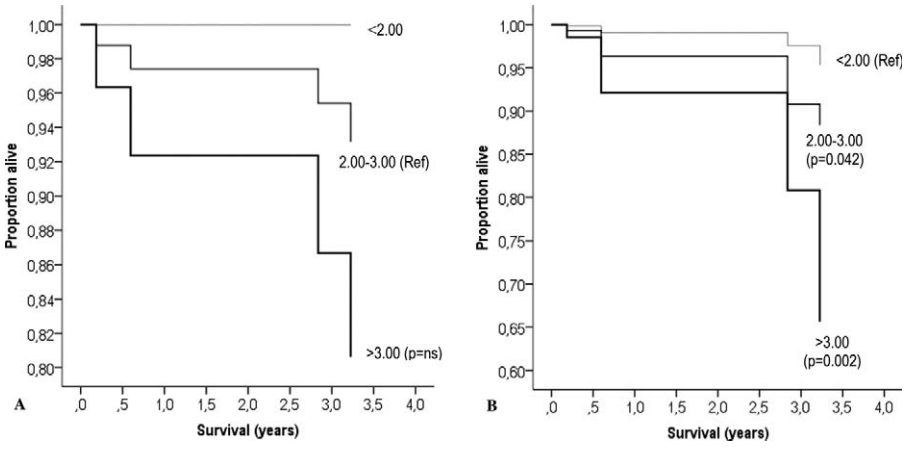

FIGURE 3. Cumulative survival according to (A) maximal SB diameter ratio (n = 48) and (B) SB diameter ratio by taking into account all measurements (n = 169) during follow-up. Maximal SB diameter ratio <2.00 was omitted from the analyses because all cases in the subgroup were censored. ns indicates nonsignificant; Ref, reference group.

TABLE 4. Hazard Ratios (HR) With 95% Confidence Intervals (CI) for Death During Follow-Up

	Univariate		Multivariate*	
	HR (95% CI)	*P* Value	HR (95% CI)	*P* Value
Maximal SB diameter ratio				
<2.00	1.00 (ref)		1.00 (ref)	
2.00–3.00	3.98 (1.05–15.02)	0.042	1.77 (0.44–7.13)	0.141
>3.00	8.75 (2.17–35.23)	0.002	4.00 (0.92–17.50)	0.065
Maximal SB diameter ratio (cont.)	1.83 (1.16-1.87)	0.009	1.59 (0.89–2.90)	0.118
Maximal SB width				
<20 mm	0.87 (0.23–3.25)	0.837	0.26 (0.07–1.03)	0.055
20–30 mm	1.54 (0.50–4.72)	0.448	0.66 (0.21–2.07)	0.472
>30 mm	1.00 (ref)		1.00 (ref)	
Maximal SB width (cont.)	0.85 (0.55-1.32)	0.470	1.55 (0.88–2.73)	0.131

All contrast SB series measurements (n = 169) are included in the analysis. Results are obtained from Cox proportional hazards regression model.
*Multivariate models adjusted for age at contrast SB series, the percentage of remaining SB, and the presence of ICV.
cont indicates continuous; ICV, ileocecal valve; SB, small bowel.

In SBA, the SB proximal to the obstruction dilates and promotes persisting stasis due to its defective intramural neuronal and muscular elements.[34,35] Both pathologies present often in combination and arise during fetal development, which probably results in more severe dysmotility compared with conditions occurring postnatally.[34–38] Indeed, dysmotility caused by the ischemic bowel injury present in NEC is seldom as difficult as in SBA and gastroschisis.[26] Our finding that NEC patients had narrower SB than others simply reflects their lower birth weight and younger gestational age, as no lower SB diameter ratio among them was observed. Despite these differences in SB width and SB diameter ratio, however, PN weaning rates were comparable among SBS subgroups, suggesting that SBS prognosis is largely independent of baseline diagnosis when intestinal rehabilitation is carried out appropriately.

The length of the remaining SB, preserved ICV, and intestinal continuity are known predictors of survival and weaning off PN in children with IF.[3,4,18–21] Also in our patients, the percentage of remaining SB was related to PN dependence, while possibly due to small number of patients who died, no association with survival was observed. Importantly, this study demonstrates that SB dilatation is a major risk factor for prolonged PN dependence and decreased survival. In fact, categorized SB diameter ratio surpassed all other predictors of PN dependence in the multivariate analysis, including remaining SB length, which is the most significant overall predictor of enteral autonomy.[3,4,18–21] Moreover, increased SB diameter ratio was the only identified risk factor for decreased survival in this cohort of SBS children. Based on these findings, screening for dilatation in PN-dependent SBS children seems meaningful. We found current PN dependence probable when SB diameter ratio exceeded 1.77, on the other hand, the chances of weaning off PN were reduced and mortality increased when SB diameter ratio exceeded 2.00. Patients with such dilatation require active intestinal rehabilitation and careful follow-up, while some may also benefit from tapering surgery. The corresponding median SB width was below 3 cm in all SB diameter ratio subgroups, demonstrating that even such SB width may be disadvantageous in small children. However, many patients with an increased maximal SB diameter ratio eventually weaned off PN without tapering surgery. As children can reach enteral autonomy even after having been PN dependent for several years, tapering surgery should be spared to those in whom the adaptation process stagnates or who develop serious complications during PN.[2–5,21]

In conclusion, SB diameter measured as ratio to fifth lumbar vertebra height predicts poor survival and prolonged duration of PN in pediatric SBS patients. Compared with absolute SB width, SB diameter ratio is affected less by patient age and size and may be a stronger predictor of SBS prognosis. PN dependence and the etiology of SBS influence the degree of SB dilatation measured as SB diameter ratio. Further research is warranted to establish the prevalence, risk factors, and prognostic significance as well as the pathophysiological mechanisms of SB dilatation in pediatric SBS population.

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REFERENCES

1. Goulet O, Olieman J, Ksiazyk J, et al. Neonatal short bowel syndrome as a model of intestinal failure: physiological background for enteral feeding. *Clin Nutr.* 2013;32:162–171.
2. Squires RH, Duggan C, Teitelbaum DH, et al. Natural history of pediatric intestinal failure: initial report from the pediatric intestinal failure consortium. *J Pediatr.* 2012;161:723–728.
3. Amin SC, Pappas C, Iyengar H, et al. Short bowel syndrome in the NICU. *Clin Perinatol.* 2013;40:53–68.
4. Quiros-Tejeira RE, Ament ME, Reyen L, et al. Long-term parenteral nutritional support and intestinal adaptation in children with short bowel syndrome: a 25-year experience. *J Pediatr.* 2004;145:157–163.
5. Sudan D, Thompson J, Botha J, et al. Comparison of intestinal lengthening procedures for patients with short bowel syndrome. *Ann Surg.* 2007;246:593–604.
6. Hukkinen M, Merras-Salmio L, Sipponen T, et al. Surgical rehabilitation of short and dysmotile intestine in children and adults. *Scand J Gastroenterol.* 2015;50:153–161.
7. McDuffie LA, Bucher BT, Erwin CR, et al. Intestinal adaptation after small bowel resection in human infants. *J Pediatr Surg.* 2011;46:1045–1051.
8. Tappenden KA. Intestinal adaptation following resection. *JPEN J Parenter Enteral Nutr.* 2014;38:23S–31S.
9. Quigley EM, Quera R. Small intestinal bacterial overgrowth: roles of antibiotics, prebiotics, and probiotics. *Gastroenterology.* 2006;130:S78–90.
10. Dibaise JK, Young RJ, Vanderhoof JA. Enteric microbial flora, bacterial overgrowth, and short-bowel syndrome. *Clin Gastroenterol Hepatol.* 2006;4:11–20.
11. Jones BA, Hull MA, Potanos KM, et al. Report of 111 consecutive patients enrolled in the International Serial Transverse Enteroplasty (STEP) Data Registry: a retrospective observational study. *J Am Coll Surg.* 2013;216:438–446.
12. Mercer DF, Hobson BD, Gerhardt BK, et al. Serial transverse enteroplasty allows children with short bowel to wean from parenteral nutrition. *J Pediatr.* 2014;164:93–98.

13. Wester T, Borg H, Naji H, et al. Serial transverse enteroplasty to facilitate enteral autonomy in selected children with short bowel syndrome. *Br J Surg*. 2014;101:1329–1333.
14. Avitzur Y, Grant D. Intestine transplantation in children: update 2010. *Pediatr Clin North Am*. 2010;57:415–431.
15. Struijs MC, Diamond IR, de Silva N, et al. Establishing norms for intestinal length in children. *J Pediatr Surg*. 2009;44:933–938.
16. D'Antiga L, Goulet O. Intestinal failure in children: the European view. *J Pediatr Gastroenterol Nutr*. 2013;56:118–126.
17. Merras-Salmio L, Pakarinen MP. Refined multidisciplinary protocol based approach to short bowel syndrome improves outcomes. *J Pediatr Gastroenterol Nutr*. 2015;61:24–29.
18. Khan FA, Squires RH, Litman HJ, et al. Predictors of enteral autonomy in children with intestinal failure: a multicenter cohort study. *J Pediatr*. 2015;167:29–34e1.
19. Spencer AU, Neaga A, West B, et al. Pediatric short bowel syndrome: redefining predictors of success. *Ann Surg*. 2005;242:403–412.
20. Sondheimer JM, Cadnapaphornchai M, Sontag M, et al. Predicting the duration of dependence on parenteral nutrition after neonatal intestinal resection. *J Pediatr*. 1998;132:80–84.
21. Pakarinen MP. Autologous intestinal reconstruction surgery as part of comprehensive management of intestinal failure. *Pediatr Surg Int*. 2015;31:453–464.
22. Lodwick D, Dienhart M, Ambeba E, et al. Accuracy of radiographic estimation of small bowel dimensions in pediatric patients with short bowel syndrome. *J Pediatr Surg*. 2016. DOI: 10.1016/j.jpedsurg.2016.02.059. [Epub ahead of print].
23. Shatari T, Clark MA, Lee JR, et al. Reliability of radiographic measurement of small intestinal length. *Colorectal Dis*. 2004;6:327–329.
24. Stotzer PO, Bjornsson ES, Abrahamsson H. Interdigestive and postprandial motility in small-intestinal bacterial overgrowth. *Scand J Gastroenterol*. 1996;31:875–880.
25. Vantrappen G, Janssens J, Hellemans J, et al. The interdigestive motor complex of normal subjects and patients with bacterial overgrowth of the small intestine. *J Clin Invest*. 1977;59:1158–1166.
26. Dicken BJ, Sergi C, Rescorla FJ, et al. Medical management of motility disorders in patients with intestinal failure: a focus on necrotizing enterocolitis, gastroschisis, and intestinal atresia. *J Pediatr Surg*. 2011;46:1618–1630.
27. Gutierrez IM, Kang KH, Calvert CE, et al. Risk factors for small bowel bacterial overgrowth and diagnostic yield of duodenal aspirates in children with intestinal failure: a retrospective review. *J Pediatr Surg*. 2012;47:1150–1154.
28. D'Antiga L, Dhawan A, Davenport M, et al. Intestinal absorption and permeability in paediatric short-bowel syndrome: a pilot study. *J Pediatr Gastroenterol Nutr*. 1999;29:588–593.
29. Cole CR, Frem JC, Schmotzer B, et al. The rate of bloodstream infection is high in infants with short bowel syndrome: relationship with small bowel bacterial overgrowth, enteral feeding, and inflammatory and immune responses. *J Pediatr*. 2010;156:941–947.
30. Kaufman SS, Loseke CA, Lupo JV, et al. Influence of bacterial overgrowth and intestinal inflammation on duration of parenteral nutrition in children with short bowel syndrome. *J Pediatr*. 1997;131:356–361.
31. Asensio AB, Garcia-Urkia N, Aldazabal P, et al. Incidence of bacterial translocation in four different models of experimental short bowel syndrome. *Cir Pediatr*. 2003;16:20–25.
32. Almond SL, Haveliwala Z, Khalil B, et al. Autologous intestinal reconstructive surgery to reduce bowel dilatation improves intestinal adaptation in children with short bowel syndrome. *J Pediatr Gastroenterol Nutr*. 2013;56:631–634.
33. Pakarinen MP, Kurvinen A, Koivusalo AI, et al. Long-term controlled outcomes after autologous intestinal reconstruction surgery in treatment of severe short bowel syndrome. *J Pediatr Surg*. 2013;48:339–344.
34. Masumoto K, Suita S, Nada O, et al. Abnormalities of enteric neurons, intestinal pacemaker cells, and smooth muscle in human intestinal atresia. *J Pediatr Surg*. 1999;34:1463–1468.
35. Masumoto K, Suita S, Taguchi T. The occurrence of unusual smooth muscle bundles expressing alpha-smooth muscle actin in human intestinal atresia. *J Pediatr Surg*. 2003;38:161–166.
36. Auber F, Danzer E, Noche-Monnery M, et al. Enteric nervous system impairment in gastroschisis. *Eur J Pediatr Surg*. 2013;23:29–38.
37. Zani-Ruttenstock E, Zani A, Paul A, et al. Interstitial cells of Cajal are decreased in patients with gastroschisis associated intestinal dysmotility. *J Pediatr Surg*. 2015;50:750–754.
38. Sala D, Chomto S, Hill S. Long-term outcomes of short bowel syndrome requiring long-term/home intravenous nutrition compared in children with gastroschisis and those with volvulus. *Transplant Proc*. 2010;42:5–8.