

LONG-TERM PARENTERAL NUTRITIONAL SUPPORT AND INTESTINAL ADAPTATION IN CHILDREN WITH SHORT BOWEL SYNDROME: A 25-YEAR EXPERIENCE

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Objective To analyze the outcome of children with short bowel syndrome (SBS) who required long-term parenteral nutrition (PN).

Study design Retrospective analysis of children (n = 78) with SBS who required PN >3 months from 1975 to 2000. Statistics: univariate analysis, Kaplan-Meier method, and Cox proportional regression model were used.

Results We identified 78 patients. Survival was better with small bowel length (SBL) >38 cm, intact ileocecal valve (ICV), intact colon, takedown surgery after ostomy (all $P < .01$), and primary anastomosis ($P < .001$). PN-associated early persistent cholestatic jaundice ($P < .001$) and SBL of <15cm ($P < .01$) were associated with a higher mortality. Intestinal adaptation was less likely if SBL <15 cm ($P < .05$), ICV was removed, colonic resection was done (both $P < .001$), >50% of colon was resected ($P < .05$), and primary anastomosis could not be accomplished ($P < .01$). Survival was 73% (57), and 77% (44) of survivors had intestinal adaptation.

Conclusions SBL, intact ICV, intestinal continuity, and preservation of the colon are important factors for survival and adaptation. Adaptation usually occurred within the first 3 years. Need for long-term PN does not preclude achieving productive adulthood. Patients with ICV even with <15 cm of SBL and patients with SBL >15 cm without ICV have a chance of intestinal adaptation. (*J Pediatr* 2004;145:157-63)

In 1880, Koeberle performed the first reported massive small bowel resection (>200 cm) in a patient who ultimately survived.¹ In 1937, Haymond reported that if >50% of the small bowel was resected the mortality was extremely high.² During the late 1960s, parenteral nutrition (PN) became available, improving dramatically the management and outcome of patients with short bowel syndrome (SBS).³ In 1972, Wilmore's review suggested that without the ileocecal valve (ICV), a jejunoileal segment of ≥ 38 cm was needed for intestinal adaptation, and if the ICV was preserved, this might happen with ≥ 15 cm of a jejunoileal segment.⁴

Today, prolonged survival has allowed us to better understand the adaptation process by the residual small bowel. On the other hand, long-term PN support has brought new clinical and physiological challenges. PN-related morbidity and mortality have been major concerns since the initiation of its use.⁵

To learn more about the clinical outcome of children with SBS who required long-term PN support and about their intestinal adaptation, we analyzed the subjects recruited in our 25-year-old home PN program.

METHODS

We analyzed the complete charts of all children who required PN support at UCLA for more than 3 months from January 1975 to April 2000 (n = 875). We defined SBS as

CVC	Central venous catheter	SBS	Short bowel syndrome
ESLD	End-stage liver disease	SBL	Small bowel length
ICV	Ileocecal valve	SSB	Short small bowel
NEC	Necrotizing enterocolitis	USSB	Ultra short small bowel
PN	Parenteral nutrition	VSSB	Very short small bowel

See editorial, p 147.

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a residual jejunoileal segment of ≤ 75 cm secondary to a surgical resection or congenital malformation.⁴ Children were subdivided into three groups according to their jejunoileal segment: (1) Short small bowel (SSB), >38 cm; (2) Very short small bowel (VSSB), 15 to 38 cm; and (3) Ultra short small bowel (USSB), <15 cm. The cited small bowel lengths (SBLs) are the measurements along the antimesenteric border from the ligament of Treitz that were made at the time of surgery; colonic resection and remaining length were obtained from the operative report measurements and descriptions. Intestinal adaptation was defined as the ability to maintain normal growth and fluid and electrolytes balance without the need for PN support.

The following data were collected from each patient: sex; date of birth; gestational age; birth weight; PN starting date; proportion of caloric support (enteral versus parenteral); date when PN was stopped; date when central venous catheter (CVC) was placed and removed; cause of SBS; SBL left; resection or not of the ICV; colonic resection; length of colon left; primary anastomosis versus ostomy; date of takedown surgery; date of gastrostomy tube placement and removal; cholecystectomy; evidence of bone disease; CVC-related sepsis; evaluation of sepsis; PN-associated complication (cholestatic jaundice, gallstones, cholecystitis, end-stage liver disease [ESLD], nutritional deficiencies, chronic anemia, deep vein thrombosis or embolus, pancreatitis, diabetes, and muscle cramps); level of education reached; developmental evaluation; marital status; working status; occupation; growth charts; liver function tests; renal function tests; iron studies; complete blood count and differential; electrolytes including calcium, magnesium and phosphorus, albumin, and prealbumin; cause of death; date of death; need for liver/small bowel transplantation; and other comorbidities. Cholestatic jaundice was defined as conjugated bilirubin ≥ 2.0 mg/dL (or ≥ 34.2 $\mu\text{mol/L}$).

Home PN support, usually cycled at night over 10 to 14 hours, was provided through indwelling Broviac catheters. Catheter insertion and care are standardized, as we previously described.⁶ In the adapted children, CVC was usually left for 3 to 6 months after discontinuation of PN, in anticipation of problems that may develop with enteral feeding.

The PN solutions, infusion principles, outpatient management, and changes done in our home PN support program at UCLA have been previously described.^{7,8} The proportions of nonprotein calories (dextrose and fat emulsion) were customized to individual requirements and tolerance. A comprehensive training period in the hospital was given to parents or guardians because they would be assuming full care and responsibility for CVC and PN at home. The major nutritional criterion for discharge from the hospital was evidence of steady weight gain on cycled PN and, in most instances, some enteral feedings.

In all children, the nutritional management includes the establishment of enteral feedings as soon as possible. Even though, the nature of elemental formulas has changed over the past 25 years; the main principle has been the use of a dilute elemental formula or breast milk continuously infused via nasogastric or gastrostomy tube.⁹ As intestinal adaptation or

decreased stool output occurs, the elemental formula is increased in amount and concentration, and gradually the feeding is changed to boluses.⁸ PN is decreased accordingly as growth is closely monitored to ensure a normal pattern. When growth is supported mainly by enteral nutrition, the PN is stopped. About 10% weight loss is accepted during the few months after stopping PN as long as weight is regained and normal growth ensues. Initial enteral nutritional support was defined as the percentage of calories originated from elemental formula in relation to the total amount of calories provided to the child by 2 weeks after the initial surgery.

For CVC-related sepsis, we followed our definition and protocol as described.¹⁰ In short, it was defined as an infection where an organism was identified through blood culture from the CVC and other potential sources of infection were ruled out by appropriate tests.¹⁰

Statistics

Values are given in percentage, median (range), and mean \pm SD. Mean z score for weight and height were calculated to control for age and sex. We performed a univariate analysis of all the variables using χ^2 test methods or two-sample t test. The significance of differences in all binary variables in the time to death (death rate) or intestinal adaptation (adaptation rate) was also assessed using the nonparametric log rank test. Survival and intestinal adaptation probabilities were calculated using the Kaplan-Meier method in those variables that were statistically significant. A Cox proportional hazards regression model, after adjusting for highly correlated variables, was used with parameters that were statistically significant after the univariate analysis. A P value $< .05$ was considered statistically significant.

RESULTS

We identified 78 patients. Forty-nine were male. PN was started at the median age of 0.6 months (0.1-152 months). In **Table I** we compared the characteristics of survivors versus nonsurvivors. We found better survival with SBL >38 cm, intact ICV, whole colon left, primary anastomosis, and takedown surgery after an initial ostomy. Early persistent cholestatic jaundice and SBL <15 cm were associated with higher mortality. These results were duplicated when all binary variables were analyzed by determining the death rate (deaths per 100 person-years) in each category. The only difference was that the diagnosis of necrotizing enterocolitis (NEC) became statistically significant (7.7 ± 2.9 vs 2.6 ± 0.7 deaths per 100 person-years; $P < .05$). The Kaplan-Meier method was used to analyze these statistically significant variables and two of these variables are presented in **Figure 1**.

We analyzed survivors who had intestinal adaptation versus the ones who did not (**Table II**). Intestinal adaptation was less likely if SBL <15 cm, ICV was removed, colonic resection was done, $>50\%$ of the colon was resected, and primary anastomosis could not be accomplished. The incidence of PN-associated gallstones/cholecystitis with subsequent

Table I. Characteristics of patients with SBS and PN support (survivors vs nonsurvivors)

Background information	Survivors (n = 57)	Nonsurvivors (n = 21)	P value
Sex (M)	63%	62%	NS
Birth weight (kg)	2.5 ± 0.7	2.4 ± 1.2	NS
Prematurity (<37 wk GA)	47%	67%	NS
Age when PN was started (mo)*	9.4 ± 26.4	9.1 ± 25.9	NS
Initial enteral nutritional support (mean %) [†]	23%	12%	NS
Primary diagnosis			
NEC	16% (9)	33% (7)	NS
Congenital malrotation/volvulus	21% (12)	14% (3)	NS
Small bowel atresia	26% (15)	19% (4)	NS
Gastroschisis	21% (12)	19% (4)	NS
Others [‡]	16% (9)	14% (3)	NS
SBL			
>38 cm	58%	24%	< .01
15-38 cm	28%	33%	NS
< 15 cm	14%	43%	< .01
Patients with ICV	58%	29%	< .01
Colonic resection >50% of colonic length resected	46% (11/24)	47% (7/15)	NS
Primary anastomosis	40%	10%	< .001
Takedown surgery after ostomy	94% (32/34)	58% (11/19)	< .01
Cholecystectomy [§]	18%	38%	NS
Gastrostomy tube placed	63%	67%	NS
PN-associated complications	42%	90%	< .001
PN-associated early persistent cholestatic jaundice	9%	62%	< .001
Infections per year on PN	1.1 ± 1.5	1.3 ± 1.0	NS

GA, Gestational age; NEC, necrotizing enterocolitis; NS, Not statistically significant.

Values are given in mean ± SD or percentage. Statistically significant: $P < .05$.

*Median age was 0.6 months for both groups.

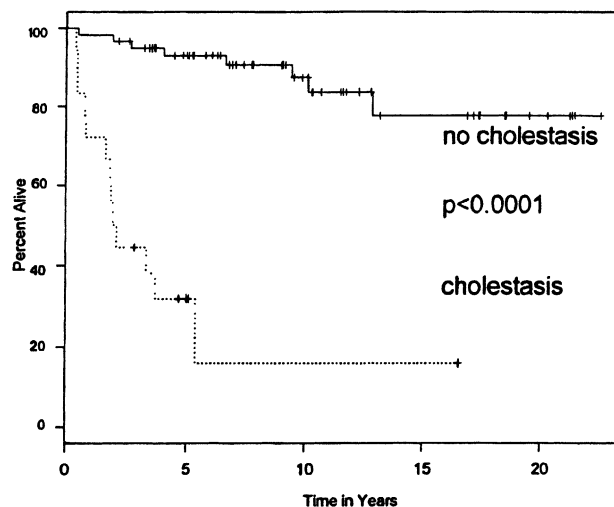
[†]Established by 2 weeks after first surgery.

[‡]Omphalocele(3), post-surgical intestinal obstruction (3), congenital SBS (3), abdominal trauma (2) and small bowel lymphoma (1).

[§]Secondary to gallstones and/or cholecystitis.

^{||}Early persistent cholestatic jaundice = cholestatic jaundice that started within the first 3 months on parenteral nutrition and lasted for more than 3 months.

A



B

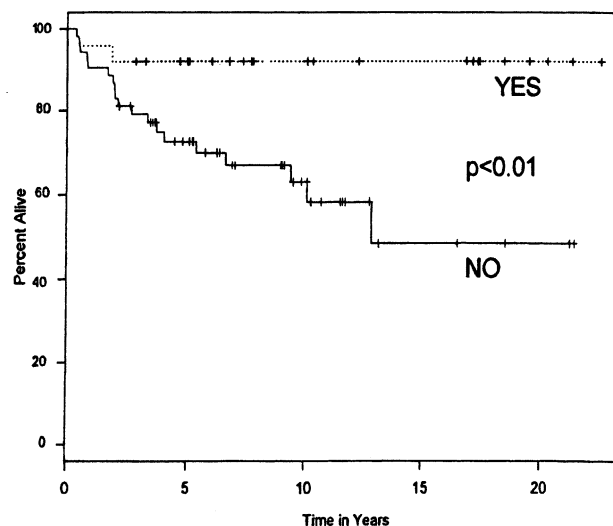


Fig 1. Probability of survival in 78 children with SBS based on (A) early persistent cholestatic jaundice and (B) primary anastomosis.

cholecystectomy was higher in children who did not have adaptation. When all binary variables were analyzed by determining the adaptation rate (adaptations per 100 person-years) in each category, the same parameters were statistically significant except SBL >38 cm that became statistically significant (54 ± 10.2 versus 8.7 ± 2.2 adaptations per 100 person-years; $P < .001$). The Kaplan-Meier method was used to analyze these statistically significant variables, and two of them are represented in Figure 2. The shortest SBL of a patient who adapted was 10 cm with ICV. Patients who did not adapt had fewer episodes of CVC-related sepsis per year than the ones who adapted (Table II) even though, as expected, their time on PN support was longer.

Table II. Characteristics of patients with SBS and PN Support (adapted vs nonadapted)

Background information	Adapted (n = 44)	Nonadapted (n = 13)	P value
Age (y)	10.3 ± 5.8	11.8 ± 7.4	NS
Sex (M)	66%	54%	NS
Birth weight (kg)	2.5 ± 0.7	2.6 ± 0.8	NS
Prematurity (<37 wk GA)	50%	38%	NS
Age when PN was started (mo)*	10.3 ± 29	6.3 ± 15.6	NS
Initial enteral nutritional support (mean %) [†]	24%	20%	NS
Primary diagnosis			
NEC	18% (8)	8% (1)	NS
Congenital malrotation/volvulus	23% (10)	15% (2)	NS
Small bowel atresia(s)	25% (11)	31% (4)	NS
Gastroschisis	23% (10)	15% (2)	NS
Others	11% (5)	31% (4)	NS
SBL			
>38 cm	64%	38%	NS
15-38 cm	30%	23%	NS
<15 cm	7%	38%	<.05
Patients with ICV	68%	23%	<.001
Colonic resection	32%	77%	<.001
>50% of colonic length resected	29% (4/14)	70% (7/10)	<.05
Primary anastomosis	48%	15%	<.01
Takedown surgery after ostomy	96% (22/23)	91% (10/11)	Ns
Time from first surgery to ostomy takedown (mo)	6.2 ± 7.7	21.3 ± 35.6	NS
Cholecystectomy [‡]	11%	38%	<.05
Gastrostomy tube placed	61%	69%	NS
PN-associated complications	36%	62%	NS
Infections per year	1.3 ± 1.6	0.5 ± 0.5	<.01
Time on PN (y)	2.0 ± 2.7	11.2 ± 7.4	<.001
Mean z score for weight	-0.6 ± 1.5	-0.3 ± 0.8	NS
Mean z score for height	-0.9 ± 1.7	-1.19 ± 1.2	NS
Special education	28%	18%	NS

GA, Gestational age; NEC, necrotizing enterocolitis; NS, not statistically significant.

Values are given in mean ± SD or percentage. Statistically significant: $P < .05$.

*Median age was 0.5 months for adapted versus 0.6 months for nonadapted.

[†]Established by 2 weeks after first surgery.

[‡]Secondary to gallstones/cholecystitis.

There was no statistical difference in intestinal adaptation between patients with SSB and VSSB with or without ICV, whereas patients with USSB were less likely to adapt if the ICV was resected (Table III). In addition, children with SBL >38 cm spent less time on PN support than the ones with SBL <38 cm (1.1 ± 1.3 years vs 3.6 ± 3.8 years; $P = .01$). For the patients with SBL >38 cm, this time was not affected by having or not having an intact ICV (1.2 ± 1.3 years versus

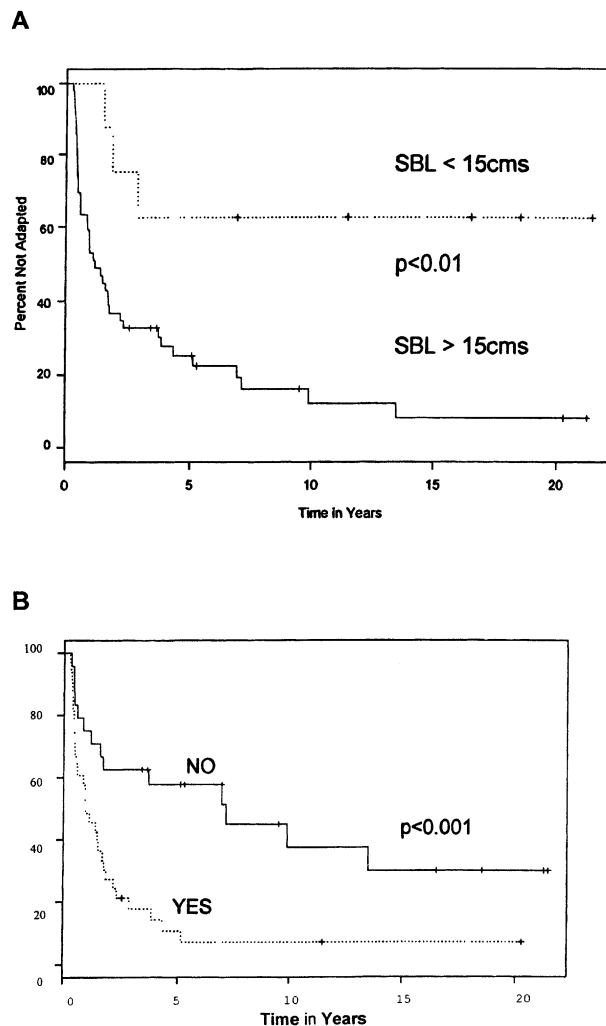


Fig 2. Probability of being PN-dependent in 57 children with SBS based on (A) SBL and (B) ICV status.

1.0 ± 1.2 years; $P = .82$), whereas ICV status was statistically significant for the subjects with SBL <38 cm (1.8 ± 1.1 years with ICV versus 6.7 ± 4.7 years without ICV; $P = .02$). Children with SBL >38 cm adapted faster than their counterparts regardless of ICV status, whereas time on PN was significantly affected by ICV status if children's SBLs were <38 cm. These results demonstrated that having an intact ICV became more crucial for intestinal adaptation as the SBL decreased.

In children with ICV who adapted (30/33), 90% (27/30) were adapted by 3 years and the other 3 children were adapted by 5 years postsurgery. In children without ICV who had intestinal adaptation (13/24), 69% (9/13) adapted by 3 years and 1 adapted by 4 years, whereas the other 3 needed more than 5 years of PN before adapting (7.1, 9.9, and 13.5 years). These last 3 children had VSSB. Intestinal adaptation happened in most of these children by 3 years.

The following group of children had statistically significant decreased survival rates by Cox proportional hazard regression model: SBL <15cm ($P < .05$), lack of primary anastomosis ($P < .05$), absence of takedown surgery ($P < .01$),

and evidence of PN-associated early persistent cholestatic jaundice ($P < .0001$). When the same Cox model was used to analyze intestinal adaptation we learned that children with SBL $>38\text{cm}$ ($P < .01$) and with intact ICV ($P < .001$) were more likely to have intestinal adaptation. Patients with SBL $<15\text{cm}$ and who underwent cholecystectomy ($P < .01$) were less likely to adapt. In both models, survival and intestinal adaptation, ICV resection was highly correlated with colonic resection.

Fifty-seven patients (73%) are alive at a median age of 9.5 years (2.1-24.3 years) after a median follow-up of 9 years (2.1-23.1 years). PN was discontinued in 44 patients (56%) after a median time of 1 year (0.4-13.5 years) at a median age of 1.5 years (0.4-14.8 years). Thirteen patients (17%) are still on PN after a median time of 9.5 years (2.5-23.1 years) at a median age of 9.6 years (2.6-23.3 years). The main causes of death were sepsis (8), liver disease (6), posttransplant complications (2), pneumonias (2), renal disease (1), heart disease (1 who had Down syndrome and congenital heart disease), and unknown etiology (1). Sepsis and liver disease composed 67% of all deaths. One patient had liver transplantation and 2 had combined liver/small bowel transplantation as a result of ESLD. No patient died as a direct consequence of thrombosis and/or lack of venous access.

Eleven subjects reached adulthood and 4 of them are still on PN. One patient died as an adult secondary to ESLD. Nine adults finished high school. Four graduated from college, 2 are still in college, and 4 are employed. One adult is married. Concerning the 4 patients on PN: 2 had bone disease, 3 underwent cholecystectomy secondary to symptomatic gallstones, 2 had deep vein thrombosis, and all had normal renal function. Two adults had mild portal fibrosis in their liver biopsy at the time of the cholecystectomy. One patient had abnormal liver function tests. Their mean CVC-related sepsis was 0.2 ± 0.1 episodes per year. The mean z score for height was -0.9 ± 1.7 and the mean z score for weight was -0.4 ± 1.1 for the adapted adults versus a mean z score for height of -1.4 ± 0.9 and a mean z score for weight of -0.6 ± 0.2 for the patients on PN ($P = .55$ and $P = .73$, respectively).

DISCUSSION

The main goal of treatment in SBS is intestinal adaptation while optimizing weight gain and linear growth while trying to maximize enteral nutrition while minimizing parenteral support. This is as much an art as it is a science. Since the late 1960s, PN has had an enormous impact on the accomplishment of these goals. After small bowel resection, the residual intestine becomes dilated, and crypt depth along with villus height increases by mucosal hyperplasia. The overall outcome is an increase of the absorptive capacity of the remaining small intestine.^{5,11} The magnitude of the hyperplastic response is directly proportional to the SBL that has been resected.¹²

Establishing elemental enteral feedings or feeding with breast milk as soon as possible has been widely accepted as one important controllable variable that may help intestinal

Table III. Adaptation of survivors based on SBL and presence or absence of ICV

SBL	Survivors' adaptation		P value
	With ICV	Without ICV	
$>38\text{ cm}$	20/21	8/12	NS
15-38 cm	7/8	5/8*	NS
$<15\text{ cm}$	3/4	0/4	$< .001$

NS, Not statistically significant.

Statistically significant: $P < .05$.

*A sixth patient came off PN after a liver/small bowel transplantation.

adaptation.^{8,9,13,14} Unfortunately, in our study too few children were on only breast milk to be able to compare with children on elemental formula. Moreover, the composition of elemental formulas that are available has changed over the past 25 years, which makes this group less homogeneous. In our series, the mean percentage of calories through enteral feeding accomplished by 2 weeks after the first surgery was similar for nonsurvivors or survivors who adapted or not. One problem could be that we look at enteral feedings at one point in time and not continuously. In addition, enteral feeding is not the only variable that affects survival and adaptation because the impact of intraluminal nutrients depends not only on the percentage of calories but also on the ability to maintain enteral nutrition continuously and progressively.^{9,14}

We found that not only survival but also adaptation are greatly affected by SBL and ICV status. In our series, patients with SBL $>38\text{ cm}$ are more likely to survive or adapt with or without ICV. The major impact of an intact ICV is appreciated if the SBL is $<15\text{ cm}$. SBL has been consistently an important factor to predict intestinal adaptation,^{4,8,13-15} whereas the presence of an intact ICV has been a predictor^{4,8,15,16} or not a predictor^{5,13,14} of who will be able to discontinue PN. What makes the evaluation of the impact of ICV resection so difficult is that it is usually done along with colonic and terminal ileum resections. This was seen in our Cox models, for survival and intestinal adaptation, where ICV and colonic resections were highly correlated. In adults the critical SBL for adaptation is 100 cm, which is different from that for children.¹⁷ Even though, intestinal adaptation is a complex phenomenon; in children the increase of SBL by normal growth, which enhances the capacity for intestinal adaptation, is a crucial factor. This is more significant from birth through aged 3 to 4 years.¹⁸

Ileal resection appears detrimental for the adaptation process. Intestinal adaptation seems to be greater after proximal rather than distal resection.¹⁹ This may be related to a greater adaptive capacity of the ileum, to intrinsic structural and functional differences, or to regional differences in motor and hormonal function such as enteroglucagon.²⁰ In addition, the transit time of the chyme through the ileum is longer than that through the jejunum because of less vigorous motility that increases the opportunity for nutrients to be absorbed during the adaptation process.²¹ Another factor affected by ileal resection is gastric emptying. When the ileum

is resected, the rate of gastric emptying is shortened as a result of the loss of the ileogastric reflex that normally slows it down, diminishing the opportunity for nutrients to be absorbed.²² This may explain why the children in our study with an intact ICV and part of the terminal ileum tended to adapt better.

The role of the colon in intestinal adaptation is an important one. In our study, we found that patients with an intact colon or with >50% of colon were more likely to adapt. In patients with SBS, when undigested nutrients reach the colon it may induce changes that allow the colonic mucosa to enhance its capacity of water and electrolyte absorption as well as modifications that allow absorption of nutrients such as short- and medium-chain fatty acids.²³⁻²⁵ As more intact nutrients reach the colon, trophic hormones such as enteroglucagon may be stimulated, contributing to the intestinal adaptation process.^{26,27}

When intestinal continuity is preserved through a primary anastomosis, this colonic exposure to undigested nutrients will take place. As we appreciated in our series, children with primary anastomosis were more likely to adapt. This may be secondary to improvement of water and electrolyte absorption as continuity is conserved and also may be a result of the increased absorptive role that the colon may play after small bowel resection. Increased colonic capacity of water and electrolytes absorption has been demonstrated after jejunal and ileal resection secondary to mucosal hyperplasia.^{12,28}

In our study, survival was adversely affected by PN-associated early persistent cholestatic jaundice. PN-associated cholestasis will affect the nutritional support because it will enhance nutrient malabsorption precluding advancement of enteral feeding. Furthermore, liver dysfunction and portal hypertension have been shown to be detrimental to the intestinal adaptation process.²⁹ Even though PN-associated cholestasis is multifactorial, it also could be the consequence of the inability for early restoration of intestinal continuity, which correlates with less severe liver disease.¹³

Our study showed that intact ICV was associated with better survival and adaptation rates. The main function of the ICV is to regulate the passage of contents from the small bowel to the cecum and to prevent bacterial reflux from the colon.^{30,31} The distal ileum, ICV, and cecum work together as a unit to accomplish this role.³¹ By resection of the ICV, malabsorption will occur as a result of alteration of these two mechanisms, causing shortened transit time of nutrients through the small bowel and bacteria overgrowth.³⁰ The bacterial overgrowth theory has been supported by the use of artificial ICV in enterectomized dogs, causing decrease of the bacterial counts in the small bowel with subsequent improvement of weight loss and dehydration.³²

There was a tendency for more symptomatic gallstones with subsequent cholecystectomy in children who did not adapt. Long-term PN support in association to prolonged periods of fasting and/or ileal resection will cause distorted bile composition and gallbladder stasis, predisposing to gallstone formation.³³ Because pancreato-biliary secretions directly affect the size of the intestinal villi, a decrease in them will

diminish the hyperplastic response by the remnant intestinal mucosa, causing further malabsorption and affecting the ability of the small intestine to adapt.³⁴

Our experience has shown that CVC care improves with time as the CVC may stay in place for more than a decade without major complications.³⁵ This may explain why the incidence of CVC-related sepsis was lower in patients who did not adapt, since they had a longer overall time on PN. Even though intestinal translocation may account for some CVC septic episodes in children with SBS,³⁶ our belief is that CVC care is the greatest controllable variable that may be affected by a standard protocol and good technique of CVC care.^{10,35,37}

Our study showed that need for long-term PN does not preclude achieving productive adulthood with normal heights and weights. Most of our long-term PN patients went through a normal education process. This is consistent with our previous report, where long-term PN children attended normal school and even a school for the mentally gifted.³⁸

In summary, our overall survival was 73%, with 77% of survivors having intestinal adaptation. SBL, intact ICV, intestinal continuity and preservation of the colon are important factors for survival and adaptation. Adaptation usually occurred within the first 3 years but may take as long as 13.5 years. Early persistent cholestatic jaundice is a predictor of poor outcome. Chronic intestinal failure was present in patients with USSB without ICV. Small bowel transplantation should be considered if such patients develop liver failure or loss of vascular access. Patients with ICV even with USBS and patients with >15 cm of SBL without ICV have a chance of intestinal adaptation.

REFERENCES

1. Koeberle E. Resection de deux metres d'intestine grele guerison. *Bull Acad Med* 1881;8:249-50.
2. Haymond HE. Massive resection of the small intestine: an analysis of 257 collected cases. *Surg Gynecol Obstet* 1935;61:693-705.
3. Dudrick SJ, Wilmore DW, Vars HM, Rhoads JE. Long-term total parenteral nutrition with growth, development and positive nitrogen balance. *Surgery* 1968;64:134-42.
4. Wilmore DW. Factors correlating with a successful outcome following extensive intestinal resection in newborn infants. *J Pediatr* 1972;80:88-95.
5. Cooper A, Floyd TF, Ross AJ 3rd, Bishop HC, Templeton JM Jr, Ziegler MM. Morbidity and mortality of short-bowel syndrome acquired in infancy: an update. *J Pediatr Surg* 1984;19:711-8.
6. Fonkalsrud EW, Berquist WE, Burke M, Ament ME. Long-term hyperalimentation in children through saphenous central venous catheterization. *Am J Surg* 1982;143:209-11.
7. Cannon RA, Byrne WJ, Ament ME, Gates B, O'Connor M, Fonkalsrud EW. Home parenteral nutrition in infants. *J Pediatr* 1980; 96:1098-104.
8. Dorney SA, Ament ME, Berquist WE, Vargas JH, Hassall E. Improved survival in very short small bowel of infancy with use of long-term parenteral nutrition. *J Pediatr* 1985;107:521-5.
9. Christie DL, Ament ME. Dilute elemental diet and continuous infusion technique for management of short bowel syndrome. *J Pediatr* 1975;87:705-8.
10. Buchman AL, Moukarzel A, Goodson B, et al. Catheter-related infections associated with home parenteral nutrition and predictive factors for need for catheter removal in their treatment. *J Parenter Enteral Nutr* 1994;18:297-302.
11. Dowling RH. Small bowel adaptation and its regulation. *Scand J Gastroenterol* 1982;74(suppl):53-74.

12. Williamson RC, Bauer FL, Ross JS, Malt RA. Proximal enterectomy stimulates distal hyperplasia more than bypass or pancreaticobiliary diversion. *Gastroenterology* 1978;74:16-23.
13. Andorsky DJ, Lund DP, Lillehei CW, et al. Nutritional and other postoperative management of neonates with short bowel syndrome correlates with clinical outcomes. *J Pediatr* 2001;139:27-33.
14. Sondheimer JM, Cadnapaphornchai M, Sontag M, Zerbe GO. Predicting the duration of dependence on parenteral nutrition after neonatal intestinal resection. *J Pediatr* 1998;132:80-4.
15. Goulet OJ, Revillon Y, Jan D, et al. Neonatal short bowel syndrome. *J Pediatr* 1991;119:18-23.
16. Mayr JM, Schober PH, Weissensteiner U, Hollwarth ME. Morbidity and mortality of the short-bowel syndrome. *Eur J Pediatr Surg* 1999;9: 231-5.
17. Messing B, Crenn P, Beau P, Boutron-Ruault MC, Rambaud JC, Matuchansky C. Long-term survival and parenteral nutrition dependence in adult patients with the short bowel syndrome. *Gastroenterology* 1999;117:1043-50.
18. Siebert JR. Small-intestine length in infants and children. *Am J Dis Child* 1980;134:593-5.
19. Hanson WR, Osborne JW, Sharp JG. Compensation by the residual intestine after intestinal resection in the rat, I: influence of amount of tissue removed. *Gastroenterology* 1977;72:692-700.
20. Thompson JS, Quigley EM, Adrian TE. Factors affecting outcome following proximal and distal intestinal resection in the dog: an examination of the relative roles of mucosal adaptation, motility, luminal factors, and enteric peptides. *Dig Dis Sci* 1999;44:63-74.
21. Summers RW, Kent TH, Osborne JW. Effects of drugs, ileal obstruction, and irradiation on rat gastrointestinal propulsion. *Gastroenterology* 1970;59:731-9.
22. Nylander G. Gastric evacuation and propulsive intestinal motility following resection of the small intestine in the rat. *Acta Chir Scand* 1967;133:131-8.
23. Jeppesen PB, Mortensen PB. The influence of a preserved colon on the absorption of medium chain fat in patients with small bowel resection. *Gut* 1998;43:478-83.
24. Jorgensen J, Holtug K, Jeppesen PB, Mortensen PB. Human rectal absorption of short- and medium-chain C2-C10 fatty acids. *Scand J Gastroenterol* 1998;33:590-4.
25. Sidhu GS, Narasimharao KL, Rani VU, Sarkar AK, Chakravarti RN, Mitra SK. Morphological and functional changes in the gut after massive small bowel resection and colon interposition in rhesus monkeys. *Digestion* 1984;29:47-54.
26. Jacobs LR, Bloom SR, Dowling RH. Response of plasma and tissue levels of enteroglucagon immunoreactivity to intestinal resection, lactation and hyperphagia. *Life Sci* 1981;29:2003-7.
27. Miazza BM, Al-Mukhtar MY, Salmeron M, et al. Hyperenteroglucagonaemia and small intestinal mucosal growth after colonic perfusion of glucose in rats. *Gut* 1985;26:518-24.
28. Nundy S, Malamud D, Obertop H, Szerban J, Malt RA. Onset of cell proliferation in the shortened gut: colonic hyperplasia after ileal resection. *Gastroenterology* 1977;72:263-6.
29. Weber TR, Keller MS. Adverse effects of liver dysfunction and portal hypertension on intestinal adaptation in short bowel syndrome in children. *Am J Surg* 2002;184:582-6.
30. Gazet JC, Kopp J. The surgical significance of the ileocecal junction. *Surg* 1964;56:565-73.
31. Quigley EM, Borody TJ, Phillips SF, et al. Motility of the terminal ileum and ileocecal sphincter in healthy humans. *Gastroenterology* 1984;87:857-66.
32. Ricotta J, Zuidema GD, Gadacz TR, Sadri D. Construction of an ileocecal valve and its role in massive resection of the small intestine. *Surg Gynecol Obstet* 1981;152:310-4.
33. Pitt HA, King W 3rd, Mann LL, et al. Increased risk of cholelithiasis with prolonged total parenteral nutrition. *Am J Surg* 1983;145:106-12.
34. Altmann GG. Influence of bile and pancreatic secretions on the size of the intestinal villi in the rat. *Am J Anat* 1971;132:167-77.
35. Moukarzel AA, Haddad I, Ament ME, et al. 230 patient years of experience with home long-term parenteral nutrition in childhood: natural history and life of central venous catheters. *J Pediatr Surg* 1994;29:1323-7.
36. Kurkchubasche AG, Smith SD, Rowe MI. Catheter sepsis in short-bowel syndrome. *Arch Surg* 1992;127:21-4.
37. Maas A, Flament P, Pardou A, Deplano A, Dramaix M, Struelens MJ. Central venous catheter-related bacteraemia in critically ill neonates: risk factors and impact of a prevention programme. *J Hosp Infect* 1998;40:211-24.
38. Vargas JH, Ament ME, Berquist WE. Long-term home parenteral nutrition in pediatrics: ten years of experience in 102 patients. *J Pediatr Gastroenterol Nutr* 1987;6:24-32.