

Original Communication

Challenges to Optimal Enteral Nutrition in a Multidisciplinary Pediatric Intensive Care Unit

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Objective: To describe nutrient intake in critically ill children, identify risk factors associated with avoidable interruptions to enteral nutrition (EN), and highlight opportunities to improve enteral nutrient delivery in a busy tertiary pediatric intensive care unit (PICU). **Design, Setting, and Measurements:** Daily nutrient intake and factors responsible for avoidable interruptions to EN were recorded in patients admitted to a 29-bed medical and surgical PICU over 4 weeks. Clinical characteristics, time to reach caloric goal, and parenteral nutrition (PN) use were compared between patients with and without avoidable interruptions to EN. **Results:** Daily record of nutrient intake was obtained in 117 consecutive patients (median age, 7 years). Eighty (68%) patients received EN (20% postpyloric) for a total of 381 EN days (median, 2 days). Median time to EN initiation was less than 1 day. However, EN was subsequently interrupted in 24 (30%)

patients at an average of 3.7 ± 3.1 times per patient (range, 1–13), for a total of 88 episodes accounting for 1,483 hours of EN deprivation in this cohort. Of the 88 episodes of EN interruption, 51 (58%) were deemed as avoidable. Mechanically ventilated subjects were at the highest risk of EN interruptions. Avoidable EN interruption was associated with increased reliance on PN and impaired ability to reach caloric goal. **Conclusions:** EN interruption is common and frequently avoidable in critically ill children. Knowledge of existing barriers to EN such as those identified in this study will allow appropriate interventions to optimize nutrition provision in the PICU. (*JPEN J Parenter Enteral Nutr.* XXXX;XX:xx-xx)

Keywords: enteral nutrition; critical care; parenteral nutrition; pediatric intensive care units

The prescription of optimal nutrition support therapy during critical illness requires an individualized assessment of the risks and benefits associated with the timing, route, and quantity of nutrient intake. Enteral nutrition (EN) is the preferred mode of nutrient intake in critically ill patients with a functional gastrointestinal system because of its lower cost and complication rates when compared with parenteral nutrition (PN).¹ Early institution of EN is associated with beneficial outcomes in animal models and human studies^{2,3} and has been increasingly

implemented during critical illness, often using nutrition guidelines or protocols.^{4,5} However, subsequent maintenance of enteral nutrient delivery remains elusive, as EN is frequently interrupted in the intensive care setting for a variety of reasons, some of which are avoidable.^{6,7} Frequent interruptions in enteral nutrient delivery may affect clinical outcomes secondary to suboptimal provision of calories and reliance on PN.⁶ To realize the potential benefits of EN in the pediatric intensive care unit (PICU), both early initiation and maintenance of enteral feeding must be ensured.

Objective

The objective of this study was to identify risk factors associated with avoidable interruptions to EN in critically ill children admitted to a busy multidisciplinary PICU. We aimed to evaluate the frequency of avoidable EN interruptions, as well as their impact on nutrient delivery, and to identify those children who are at risk for such interruptions during critical illness. We hypothesized that

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EN is frequently interrupted following initiation and that a significant proportion of these interruptions are avoidable. Identification of high-risk subjects will allow educational interventions and practice modifications to be targeted, with the aim of decreasing the incidence of avoidable EN interruptions in the PICU.

Design, Setting, and Measurements

After obtaining approval from the institutional review board, we conducted a prospective, bedside evaluation of daily nutrition practice in a 29-bed medical and surgical PICU at Children's Hospital Boston. Patients with a PICU length of stay 24 hours or longer were eligible for data collection. Patients with PICU length of stay under 24 hours, those on end-of-life compassionate care, or those who were transferred from another intensive care facility were excluded from this study. In this nonintervention study, parenteral and enteral nutrient intakes were recorded daily by bedside nursing staff for all consecutive eligible patients admitted over a period of 4 weeks. Participating staff members reviewed the objectives of the study and were trained to complete the data collection tool before initiating the study. We used group discussions, information leaflets, and electronic dissemination of information during this training period. We also provided daily reminders to review and complete daily bedside recording and 24-hour access to the investigators to facilitate the completion of nutrition procedures at the bedside. The study was conducted by a multidisciplinary group of investigators, including an intensivist, nursing staff, nutritionist, gastroenterologist, and biostatistician.

Institutional Enteral and Parenteral Nutrition Guidelines

Nutrition therapy was provided according to existing institutional guidelines. EN is preferred as the mode of nutrition support in our PICU. Patients admitted to our PICU begin EN support as soon as possible after PICU admission. Patients with hemodynamic instability who require escalating vasoactive medication support, significant upper gastrointestinal bleeding, presence or high risk of necrotizing enterocolitis, postoperative ileus, intestinal obstruction, and graft-vs-host disease following allogeneic stem cell transplantation are not offered early EN. Enteral feeding is held for 6 hours before elective anesthesia for general surgery or sedation for procedures, and it is held for 4 hours before elective endotracheal intubation and extubation. The route of EN is determined on an individual basis. Oral feeding is preferred in unintubated patients who are alert with

optimal cough and gag reflexes. In intubated patients, gastric feeding is provided, usually as an intermittent bolus, unless concerns for the risk of aspiration are high, in which case continuous postpyloric feeding is administered. The type of formula for EN is selected by the dietitian, based on age, medical history, and nutrition assessment. The formula volumes and caloric goals are calculated for each patient, and a plan for EN initiation and advancement is prescribed. Following any interruption other than those for feed intolerance, feeding is restarted according to previously established feeding schedules and advanced as tolerated. PN is indicated when fasting (on minimal or no EN) is anticipated for 5 days or more.⁸ In cases of malnutrition, low birth weight, or hypermetabolism, PN is initiated if fasting is anticipated for 3 days or more.

Nutrition Data Collection

In patients who received at least 24 hours of EN during their PICU stay, we recorded the time of initiation of enteral intake, the route of enteral feeding, intolerance to EN, and any interruption to enteral nutrient intake. EN interruption was defined as an episode of stoppage for a period longer than 30 minutes in a patient in whom EN was previously initiated. Causes of EN interruption were categorized a priori into the following broad groups: (a) endotracheal intubation or extubation; (b) diagnostic tests or procedures in the radiology suite; (c) other procedures at the bedside; (d) surgical procedure in the operating room; (e) feeding intolerance (as determined by the healthcare team at the bedside); (f) feeding tube malfunction, malposition, or obstruction; and (g) other reasons not already specified. The reason(s) for interruption and the time of restarting EN were recorded for each episode.

All episodes of interruption to EN delivery were examined, and avoidable episodes were identified by consensus among the multidisciplinary group of investigators. An episode of EN interruption was deemed avoidable if the reason or duration of interruption was not in accordance with the institutional nutrition support guidelines described earlier. Nurses documented the nutrition record at least twice daily. These documents were examined at the end of each nursing shift to allow the capture of any missing data. The accuracy of the nutrition record was verified by a dietitian at regular intervals and also crosschecked with the existing electronic medical record. Data related to outcomes such as duration of mechanical ventilation support, length of PICU stay, and timing of achievement of caloric goal were abstracted retrospectively from patient charts following completion of enrollment and after the patient was discharged from the PICU.

Statistical Analysis

Distributions of all variables were examined for outliers or missing data and corrected upon chart review whenever possible. Patient characteristics were described using frequency tables for categorical variables and using measures of central tendency with spread for noncategorical variables. Variables that were reasonably normally distributed were described using mean (standard deviation [SD]), whereas those displaying a high degree of skew were characterized by their median and interquartile range (IQR). Comparisons in patient characteristics were made between those receiving and not receiving EN. In patients who received EN for at least 24 hours, clinical characteristics were compared between those with and without interruptions to enteral feeding. Tests of significance for 2-group comparisons included Fisher exact test for categorical variables, and Student *t* test and the Mann-Whitney rank sum test for normal and skewed distributions, respectively.

Logistic regression was used to determine predictors of all EN interruptions as well as predictors of avoidable EN interruptions among patients who received EN.⁹ Model selection proceeded by examining unadjusted results and then subsets of predictors until a parsimonious model was found based on clinical judgment and likelihood ratio tests. Estimates of coefficients and 95% Wald confidence intervals were expressed as odds ratios. The ability of the regression model to correctly predict interruption of EN was quantified by the C statistic associated with the area under the receiver operating characteristic (ROC) curve. For number of days of EN, an optimal cut point on the ROC curve was selected at which point the discriminatory power of the regression model for this predictor was maximized. Tests of significance were 2-sided, and all statistical analysis was conducted with SAS/STAT software (Version 9.1) of the SAS System for Windows (SAS Institute Inc, Cary, NC).

Results

A total of 117 patients admitted during the 4-week enrollment period were included in this study. Critical care nurses obtained a detailed daily record of nutrition practice at the bedside during 1,020 nursing shifts over 4 weeks. Clinical characteristics of this cohort are described in Table 1. Patients ranged in age at the time of admission from newborn to 36 years, with 20 (17%) patients being younger than 1 year. Both genders were equally represented. Total PICU length of stay ranged from 1 to 246 days, with a median of 2 days. Eighty (68%) patients received EN for at least 24 hours during their PICU course, accounting for a total of 381 EN days (median duration, 2 days; IQR, 1.0–6.5 days). Among patients receiving EN, median duration from PICU admission to EN initiation was 1 day (IQR, 0.0–3.5) with 75% of patients on EN by the end of day 3. Twenty percent

Table 1. Clinical Characteristics of the Cohort

Characteristic	All Patients ^a
Age at PICU admission, y, median (IQR)	7.2 (1.7–15.3)
Age <1 y, n (%)	20 (17)
Female gender, n (%)	60 (51)
PRISM 3 score (116 patients), median (IQR)	3.0 (0.0–5.0)
PICU length of stay, d, median (IQR)	2.0 (1.0–8.0)
Patients admitted to the medical service, n (%)	59 (50)
Respiratory failure, n	24
Seizures, n	8
Shock, n	4
Oncology/bone marrow transplant, n	7
Bronchiolitis, n	3
Reactive airway disease, n	2
Diabetic ketoacidosis, n	1
Anaphylaxis, n	1
Interventional radiology procedures, n	3
Patients admitted to the surgical service, n (%)	63 (54)
Neurosurgery, n	21
General surgery (laparotomy), n	13
Mediastinal surgery, n	2
Trauma, n	2
Plastic surgery, n	3
Oral and maxillofacial surgery, n	4
Orthopedic procedures, n	3
Renal transplant, n	4
Otolaryngology surgery, n	5
Patients on EN for at least 24 hours, n (%)	80 (68)
Days on EN (80 patients), median (IQR)	2.0 (1.0–6.5)
% PICU days on EN (80 patients), median (IQR)	77 (41–100)
Days from PICU admission to starting EN (80 patients), median (IQR)	1.0 (0.0–3.5)
Caloric goal reached during PICU course (80 patients on EN), n (%)	49 (61)
Days from PICU admission to reach caloric goal (49 patients), median (IQR)	4.0 (1.0–8.0)
Mechanical ventilation support during PICU course, n (%)	60 (51)
Patients on any PN during PICU course, n (%)	15 (13)
Days on PN (15 patients), median (IQR)	6.0 (3.0–10.0)
% PICU days on PN (15 patients), median (IQR)	41 (25–75)
Charge of PN per patient in U.S. dollars (15 patients), median (IQR)	987.00 (493.50–1645.00)

EN, enteral nutrition; IQR, interquartile range; PICU, pediatric intensive care unit; PRISM, pediatric risk of mortality;

^aN = 117, unless otherwise noted.

(16/80) of the patients received EN via the postpyloric route. The rest received EN orally, via gastric tube or through a gastrostomy tube.

Table 2. (a) Comparison of Patients With Any EN Interruption vs Those Without EN Interruption and (b) Comparison Between Patients With Avoidable EN Interruptions vs Those Without Avoidable EN Interruptions

Characteristic	(a) EN Interruption (All)			(b) EN Interruption (Avoidable)		
	No (n = 56)	Yes (n = 24)	P Value	No (n = 65)	Yes (n = 15)	P Value
Age at PICU admission, y, median (IQR)	9.5 (2.2–15.3)	1.4 (0.8–8.5)	.006	8.3 (2.1–15.2)	1.0 (0.5–10.2)	.02
Age <1 y, n (%)	5 (9)	10 (42)	.001	8 (12)	7 (47)	.006
Female gender, n (%)	24 (43)	16 (67)	.09	30 (46)	10 (67)	.25
PRISM 3 score, median (IQR)	2.5 (0.0–4.0)	3.0 (1.0–7.0)	.13	2.0 (0.0–4.0)	3.0 (1.0–7.0)	.08
Percent PRISM predicted mortality, median (IQR)	0.53 (0.23–1.11)	1.00 (0.76–2.49)	.008	0.60 (0.31–1.21)	1.00 (0.53–2.75)	.13
PICU length of stay, d, median (IQR)	2.0 (1.0–4.0)	18.0 (7.5–30.5)	<.0001	2.0 (1.0–6.0)	23.0 (11.0–69)	<.0001
Days from PICU admission to start EN, median (IQR)	1.0 (0.0–2.5)	4.0 (2.0–6.5)	<.0001	1.0 (0.0–3.0)	5.0 (2.0–8.0)	.003
EN duration, d, median (IQR)	1.0 (1.0–2.0)	11.0 (5.0–16.5)	<.0001	1.0 (1.0–3.0)	15.0 (8.0–17.0)	<.0001
Percent PICU days given EN, median (IQR)	100 (50–100)	57 (33–81)	.007	90 (46–100)	58 (25–78)	.03
Postpyloric feeds, n (%)	3 (5)	13 (54)	<.0001	7 (11)	9 (60)	.001
Mechanical ventilation, n (%)	21 (38)	23 (96)	<.0001	30 (46)	14 (93)	.001
Surgery, n (%)	28 (50)	10 (42)	.63	30 (46)	8 (53)	.78
PN administered, n (%)	6 (11)	7 (29)	.05	7 (11)	6 (40)	.01
PN days, median (IQR)	5.0 (2.0–7.0)	7.0 (5.0–12.0)	.40	7.0 (2.0–7.0)	8.0 (5.0–12.0)	.49
PN charge, U.S. dollars, median (IQR)	822.50 (329.00–1151.50)	1151.50 (822.50–1974.00)	.40	1151.50 (329.00–1151.50)	1316.00 (822.50–1974.00)	.49
Caloric goal reached, n (%)	28 (50)	21 (88)	.002	35 (54)	14 (93)	.007
Time to reaching caloric goal, d, median (IQR)	1.0 (1.0–4.0)	7.0 (4.0–11.0)	.0004	2.0 (1.0–6.0)	8.0 (5.0–11.0)	.002

EN, enteral nutrition; IQR, interquartile range; PICU, pediatric intensive care unit; PN, parenteral nutrition; PRISM, pediatric risk of mortality. *P* value from Fisher exact test or Mann-Whitney rank sum test.

Following initiation, EN was interrupted in 24 (30%) patients at an average of 3.7 ± 3.1 times per patient (range, 1–13), for a total of 88 episodes, accounting for 1,483 hours of EN deprivation. Fifty-one (58%) episodes of EN interruption in 15 patients in our study were deemed as avoidable (Figure 1). The characteristics of patients with avoidable interruptions have been described in Table 2. Feeds were stopped for a variety of reasons, including: (a) fasting for extubation or intubation; (b) intolerance to EN for gastric residuals, abdominal discomfort, or distension; (c) mechanical problems with postpyloric feeding tubes; and (d) procedures in the operating room, in the radiology suite, or at the bedside. Figure 1 shows the proportion of episodes that were avoidable in each of these categories.

Thirty-seven (32%) patients in our study did not receive any EN during their PICU course. There were no significant differences between patients in this group and

those in the EN group, except for a much shorter PICU length of stay. The median PICU length of stay for patients who did not receive any EN was 1 day (IQR, 1.0–2.0) compared to 4 days (IQR, 1.0–10.5) in patients who received some EN ($P < .0001$). Length of PICU stay was less than 3 days in 31/37 (84%) patients who did not receive EN. PN was used in 3/37 (8%) patients in the group deprived of any EN, accounting for a total of 12 PN days. Twenty-four (65%) patients who did not receive EN were on the surgical service, including 6 patients who underwent thoracoabdominal surgeries. Postoperative ileus and hemodynamic instability were the most common reasons for withholding EN in this group. Mechanical ventilatory support was required for 10/37 patients (including 3 patients on noninvasive respiratory support).

Table 2 shows unadjusted comparisons in patients who received EN: (a) between patients with at least 1 EN interruption and the rest and (b) between patients who

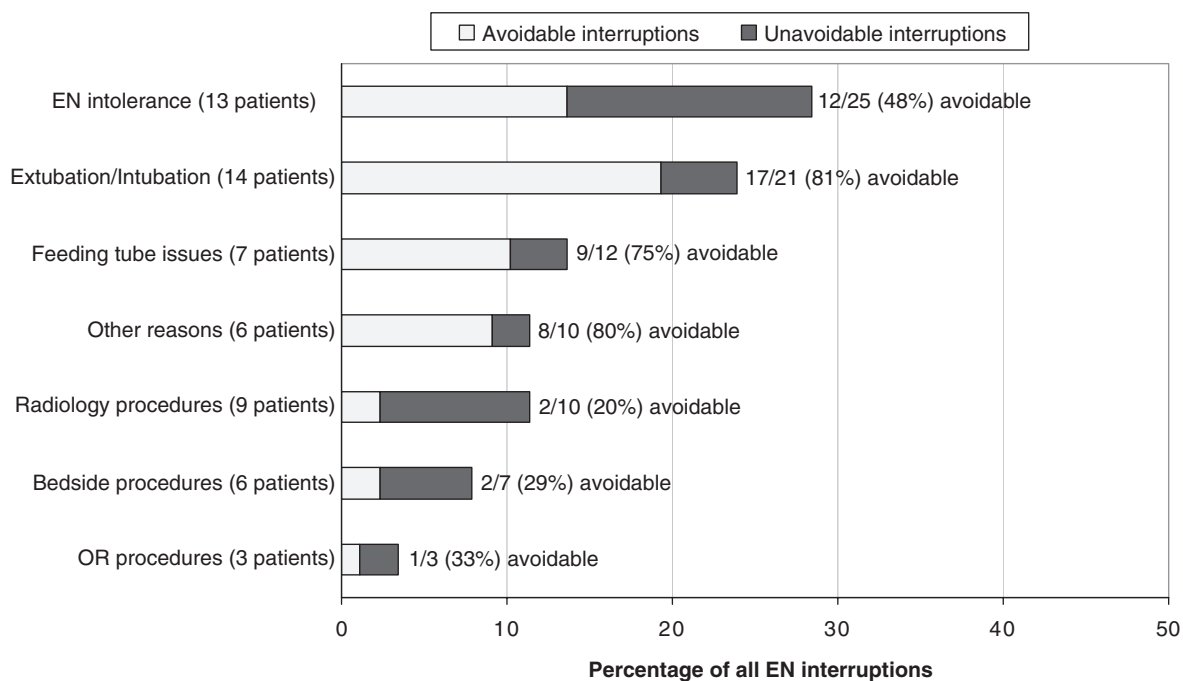


Figure 1. Reasons for EN interruption. EN, enteral nutrition; OR, operating room.

had at least 1 avoidable EN interruption and the rest. Patients with episodes of avoidable EN interruption were younger (47% younger than 1 year compared with 12%, $P = .006$), were more likely to have postpyloric feeds (60% vs 11%, $P = .0001$), and had a higher likelihood of requiring mechanical ventilation (93% vs 46%, $P = .001$). Patients with longer PICU stay, delayed initiation of EN, and increased EN exposure were more likely to have interruptions ($P < .01$ for each). Furthermore, patients with avoidable EN interruptions had more than a 3 times higher likelihood of PN use and required a significantly longer period to reach their prescribed caloric goal.

In patients with any EN interruption (avoidable and unavoidable), multivariable logistic regression showed that each additional day of EN was associated with increased odds of EN interruption of 1.43 (95% confidence interval [CI], 1.18–1.72). In addition, the odds of EN interruption were 20 times higher among patients with mechanical ventilation than those without, independent of the length of exposure to EN (95% CI, 1.35–310.45). No other variables were associated with EN interruption after adjusting for these 2 covariates. Although patients with EN interruptions were associated with longer duration of EN and PICU length of stay, the severity of illness at admission was not significantly higher in this group compared to those without EN interruptions. The ROC curve generated by the multivariate regression model showed a threshold for EN duration as 4 days, with maximized true positivity (83%) and minimized false positivity (13%). This threshold indicates that

83% of the time, patients with 4 or more days of EN were correctly classified as experiencing interruptions to EN, whereas those with 3 or fewer days of EN were correctly classified as not experiencing EN interruptions.

In patients with only avoidable EN interruptions, multivariable logistic regression analysis of data showed that each additional day of EN was associated with increased odds of an avoidable EN interruption of 1.39 (95% CI, 1.20–1.60). No other variables were associated with EN interruption after adjusting for days of EN.

Discussion

Although EN is the preferred mode of nutrient delivery in critically ill patients, barriers to optimal delivery of enteral nutrients at the bedside persist.¹⁰ The care of a critically ill patient involves multiple interventions, which often compete with the delivery of EN in the intensive care setting. Elective procedures, unplanned interventions, or diagnostic tests often require a fasting state, requiring interruption of EN. In addition, feed intolerance or contraindications to enteral feeding related to the disease processes may require feeding to be postponed or discontinued in the PICU. However, a significant number of eligible patients are deprived of EN during critical illness because of avoidable factors, such as suboptimal prescription, failure to initiate EN early, or frequent and prolonged interruptions to enteral feeding.^{6,7,11} Delayed initiation and subsequent interruptions contribute to suboptimal EN administration in the PICU.

Most patients who received EN in our study were started on enteral nutrients early in their PICU course. Patients who did not receive EN included those who had a short stay in the PICU or in whom EN was contraindicated (following major thoracoabdominal surgery with ileus or in cases with hemodynamic instability). This was in accordance with our existing nutrition support guidelines. Despite the successful institution of early EN in most patients in this study, we recorded a high rate of subsequent EN interruptions. It is indeed remarkable that more than half of all episodes of EN interruption in our study were deemed avoidable (Figure 1), either because of unacceptably long duration of fasting or unclear reason for feed interruption. These observations provide opportunities for anticipatory education of healthcare workers and vigilance to prevent episodes of unnecessary fasting.

Frequent or prolonged interruptions to EN during critical illness may result in either suboptimal delivery of macronutrients and failure to achieve caloric goal or reliance on PN. Patients with avoidable EN interruptions in our study required significantly longer periods to reach the prescribed caloric goal and were more than 3 times more likely to be started on PN. Increased reliance on PN during critical illness may expose the patient to the higher cost, infectious risks, and other morbidities associated with PN.¹² The use of PN to supplement suboptimal EN in select patients with unavoidable EN interruptions may be reasonable. Of the 6 patients without EN interruptions who received PN, 4 had delayed EN initiation, and 2 were unable to advance EN to meet caloric goals and were supplemented with PN. Achievement of caloric goal is another relevant outcome in critically ill children. Failure to meet caloric goals because of suboptimal nutrient delivery has been previously reported in critically ill children.^{6,13-15} The most common reasons for suboptimal enteral nutrient intake in these studies were fluid restriction, procedural feed interruptions, and feed intolerance. Consistently underachieved nutrition goals due to hindered enteral nutrient intake may affect patient outcomes.¹⁵⁻¹⁷ Failure to meet energy goals was associated with significant weight loss during the PICU course in critically ill infants following cardiac surgery.⁶ Identifying patients at high risk of EN deprivation will allow targeted interventions aimed at optimizing EN delivery during critical illness.

The characteristics of patients with unavoidable and avoidable EN interruptions in our study have highlighted important risk factors for EN deprivation in the PICU. Patients with EN interruptions were younger, were more likely to require mechanical ventilatory support, had a delayed initiation of EN, and were more likely to be fed via the postpyloric route. In addition, they had significantly longer duration of stay in the PICU as well as higher number of days of EN intake. Longer PICU stay may increase the exposure to EN, which may then increase the likelihood of interruptions to EN. After adjusting for the length of PICU stay, we identified EN duration and

the need for mechanical ventilation as the most significant risk factors associated with EN interruptions. Exposure to EN for 4 days or longer was particularly associated with the risk of EN interruptions in our analysis. The reason for this threshold is unclear, but it may be clinically relevant for targeting patients for educational efforts and anticipatory interventions aimed at reducing the likelihood of feed interruptions. Critically ill children requiring mechanical ventilation and with an anticipated need for EN longer than 4 days would be the population of interest for future studies on EN delivery. Patients with avoidable interruptions had similar characteristics, with a significantly higher PN use and failure as well as delay in reaching caloric goal. Despite longer PICU stay, patients with avoidable EN interruptions did not have significantly higher illness severity scores on admission. Furthermore, the proportion of their PICU stay that they received EN was actually less than the rest of the patients. Thus the longer PICU stay in patients with EN interruption was neither related to illness severity on admission nor associated with increased EN exposure. PICU length of stay is an important outcome of critical illness, and its relationship with suboptimal EN delivery needs to be examined further in future studies.

Many of the problems with EN in critically ill children reported in our study were described in the adult critical care population nearly a decade ago.¹¹ Persistence of some of these avoidable deficiencies in EN provision during critical illness is regrettable, especially as the enthusiasm for EN has grown over the years. The episodes of avoidable EN interruption in our study need careful examination to identify the barriers and plan interventions to prevent or minimize EN deprivation around these events. These episodes included longer periods of fasting for procedures that were scheduled in the morning (after overnight fasting), procedures for which the time was not specified, or procedures/diagnostic tests that were rescheduled or canceled. Careful consideration of procedure times, communication between team members, and strict adherence to hospital policies for fasting times before procedures would prevent several hours of unnecessary fasting in PICU patients.

Intolerance to enteral feeding was the most frequently reported reason for stopping EN delivery in our cohort. We observed a high degree of variability among the healthcare team in dealing with this problem. Increased abdominal girth, high gastric residual volume (GRV), abdominal discomfort, and diarrhea were some of the criteria used by healthcare workers to diagnose enteral feeding intolerance. GRV is frequently used as a surrogate for delayed gastric emptying. However, its correlation with the risk of aspiration in critically ill children is debatable, and the lower limit of GRV that protects from risk of aspiration is not known.^{18,19} In the absence of severely delayed gastric emptying, computer modeling has shown that

GRV plateaus at under 900 mL in critically ill adults.²⁰ Furthermore, studies have shown a poor correlation of GRV with clinical and radiographic examination and questioned the precision of measured GRV in predicting gastric emptying.²¹ Thus the value of GRV monitoring in enterally fed critically ill children is doubtful and may pose a barrier to EN provision. The routine use of GRV measurement as a guide to enteral feeding or as a marker of risk of aspiration is questionable.^{22,23} Future studies that clarify the relevance of GRV in the pediatric population will instruct practical guidelines and allow uniform management at the bedside. Other tests to detect delayed gastric emptying, dysmotility, or aspiration have had limited success. There is an urgent need to develop safe, reliable, and efficacious diagnostic tests to detect aspiration and gastric emptying in children. PN may have a role in children with true EN intolerance or in children with unavoidable EN interruptions. In these cases, PN may substitute or supplement EN to achieve nutrient intake goals.

Endotracheal tube–related procedures were the second most common reason for EN interruptions in our study. Most episodes of preintubation or preextubation EN interruptions exceeded our recommended institutional guidelines for fasting periods around these procedures. Feeding tubes were often removed at the time of extubation, necessitating replacement in many of these patients. In some cases where planned extubation was rescheduled, feeding was held for more than 24 hours until the actual procedure. Guidelines for prudent duration of fasting for gastric- and postpyloric-fed patients around these episodes would help prevent unnecessarily prolonged feed interruption. In patients fed via the postpyloric route who were awaiting extubation, there might be a case for smaller periods of fasting or even continuing postpyloric EN, with no increase in the rate of aspiration, vomiting, diarrhea, or abdominal distension.²⁴

Postpyloric route was used in 20% of patients on EN and in a majority of patients with EN interruptions in our study. In a randomized trial comparing gastric vs postpyloric feeds in 74 critically ill children, there were no differences in microaspiration, tube displacement, and feed intolerance between the 2 groups, but a higher percentage of patients in the postpyloric group achieved their daily caloric goals compared to the gastric-fed group. Improved feed tolerance and decreased incidence of abdominal distension has been reported in critically ill children receiving early (less than 24 hours after PICU admission) vs late postpyloric feeds.²⁵ Despite the lack of strong evidence to support the use of one route of feeding over the other, the postpyloric route has been successfully used for nutrition support of the critically ill child.^{5,26,27} The postpyloric route may be a reasonable option for patients not able to tolerate gastric feeding and may reduce the rate of complications and costs associated with the use of PN in this subgroup of patients.²⁸

However, the postpyloric administration of nutrients may be limited by availability of local expertise in the placement of transpyloric feeding tubes. A dedicated team of trained nurses provides bedside support for the placement and troubleshooting of transpyloric tubes on our unit. Despite the on-site interventional radiology support and experience with the bedside placement of postpyloric feeding tubes, tube malposition, obstruction, and placement failure were some of the mechanical issues responsible for EN interruptions in 43% of patients who received postpyloric feeding. Failure to address mechanical tube issues within 2 hours was recorded in 9 of the 12 episodes of EN interruption in these patients. The incidence of EN interruptions because of such mechanical issues may offset the perceived benefits of postpyloric feeding.²⁹

Our study has a number of limitations. We have reported a single-center experience with EN and identified risk factors that were associated with a high risk of EN failure in critically ill children in our PICU. It is likely that individual centers may have problems with EN delivery that are unique to their institution. Enteral nutrient delivery is widely variable between units, with a significant disparity between prescribed and delivered enteral volumes in critically ill adults.⁷ However, the main results of our study are generalizable to any medium- or larger-sized PICU. The study did not involve any interventions, and bedside nurses recorded the data. The investigators did not participate in providing care to the patients enrolled in this study, and hence the observations are unlikely to be biased. We do not routinely measure resting energy expenditure in all PICU patients, and hence estimated caloric and volume goals were used to prescribe caloric or volume intake. We did not measure the protein intake and excretion in our patients and hence cannot comment on the effect of EN deprivation on protein balance. With the use of standard age-based formulas, the caloric and protein content of diet is likely to correlate with the volume administered. Future studies could examine the effect of suboptimal EN on caloric and protein balance, gastrointestinal mucosal function, change in anthropometric parameters after their discharge, and other relevant outcomes. Our study was not powered to detect outcomes such as infectious complications, long-term morbidity, or mortality. However, our observations related to the inability or delays in achieving caloric goal and increased PN use in patients with interrupted EN are interesting. These observations will need to be repeated in a multicenter study to examine the true impact of suboptimal EN on clinical outcomes in the PICU population. A targeted intervention aimed at patients who are at a high risk of EN interruptions is the next step toward achieving the perceived benefits of optimal EN during critical illness and its impact on long-term outcomes.

In conclusion, despite early initiation of EN, feeding was interrupted in many critically ill children admitted to

our busy medical and surgical PICU. Avoidable EN interruptions were associated with more than a 3-fold increase in the use of PN and significant delay in reaching caloric goals. This collaborative study, examining bedside nutrition practice, illustrates some of the challenges to the provision of nutrition support and highlights opportunities for practice modification. Fasting for procedures and intolerance to EN were the most common reasons for prolonged EN interruptions. Interventions aimed at optimizing EN delivery must be designed after examining existing barriers to EN and directed at high-risk individuals who are most likely to benefit from these interventions. In our study, patients with EN interruptions were younger, were more likely to need mechanical ventilation, were more likely to be fed via the postpyloric route, and had a longer stay in the PICU. Educational intervention and practice changes targeted at these high-risk patients may decrease the incidence of avoidable interruptions to EN in critically ill children. The potential impact of such an intervention on clinical outcomes is exciting.

References

- Heyland DK, Dhaliwal R, Drover JW, Gramlich L, Dodek P. Canadian clinical practice guidelines for nutrition support in mechanically ventilated, critically ill adult patients. *JPEN J Parenter Enteral Nutr.* 2003;27:355-373.
- Moore FA, Moore EE, Haenel JB. Clinical benefits of early post-injury enteral feeding. *Clin Intensive Care.* 1995;6:21-27.
- Hamaoui E, Lefkowitz R, Olender L, et al. Enteral nutrition in the early postoperative period: a new semi-elemental formula versus total parenteral nutrition. *JPEN J Parenter Enteral Nutr.* 1990;14:501-507.
- Moore FA, Feliciano DV, Andrassy RJ, et al. Early enteral feeding, compared with parenteral, reduces postoperative septic complications: the results of a meta-analysis. *Ann Surg.* 1992;216:172-183.
- Chellis MJ, Sanders SV, Webster H, Dean JM, Jackson D. Early enteral feeding in the pediatric intensive care unit. *JPEN J Parenter Enteral Nutr.* 1996;20:71-73.
- Rogers EJ, Gilbertson HR, Heine RG, Henning R. Barriers to adequate nutrition in critically ill children. *Nutrition.* 2003;19:865-868.
- Adam S, Batson S. A study of problems associated with the delivery of enteral feed in critically ill patients in five ICUs in the UK. *Intensive Care Med.* 1997;23:261-266.
- Canete A, Duggan C. Nutritional support of the pediatric intensive care unit patient. *Curr Opin Pediatr.* 1996;8:248-255.
- Hosmer DW, Lemeshow S. *Applied Logistic Regression.* New York: John Wiley; 1989.
- Heyland D, Cook DJ, Winder B, Brylowski L, Van deMark H, Guyatt G. Enteral nutrition in the critically ill patient: a prospective survey. *Crit Care Med.* 1995;23:1055-1060.
- McClave SA, Sexton LK, Spain DA, et al. Enteral tube feeding in the intensive care unit: factors impeding adequate delivery. *Crit Care Med.* 1999;27:1252-1256.
- Simpson F, Doig GS. Parenteral vs. enteral nutrition in the critically ill patient: a meta-analysis of trials using the intention to treat principle. *Intensive Care Med.* 2005;31:12-23.
- Taylor RM, Preedy VR, Baker AJ, Grimble G. Nutritional support in critically ill children. *Clin Nutr.* 2003;22:365-369.
- Meert KL, Daphtary KM, Metheny NA. Gastric vs small-bowel feeding in critically ill children receiving mechanical ventilation: a randomized controlled trial. *Chest.* 2004;126:872-878.
- de Groof F, Joosten KF, Janssen JA, et al. Acute stress response in children with meningococcal sepsis: important differences in the growth hormone/insulin-like growth factor I axis between nonsurvivors and survivors. *J Clin Endocrinol Metab.* 2002;87:3118-3124.
- Mehta NM, Bechard LJ, Leavitt K, Duggan C. Severe weight loss and hypermetabolic paroxysmal dysautonomia following hypoxic ischemic brain injury: the role of indirect calorimetry in the intensive care unit. *JPEN J Parenter Enteral Nutr.* 2008;32:281-284.
- Raff T, Hartmann B, Germann G. Early intragastric feeding of seriously burned and long-term ventilated patients: a review of 55 patients. *Burns.* 1997;23:19-25.
- McClave SA, Dryden GW. Critical care nutrition: reducing the risk of aspiration. *Semin Gastrointest Dis.* 2003;14:2-10.
- McClave SA, Snider HL. Clinical use of gastric residual volumes as a monitor for patients on enteral tube feeding. *JPEN J Parenter Enteral Nutr.* 2002;26(suppl):S43-48; discussion S49-S50.
- Lin HC, Van Citters GW. Stopping enteral feeding for arbitrary gastric residual volume may not be physiologically sound: results of a computer simulation model. *JPEN J Parenter Enteral Nutr.* 1997;21:286-289.
- Tamion F, Hamelin K, Dufflo A, Girault C, Richard JC, Bonmarchand G. Gastric emptying in mechanically ventilated critically ill patients: effect of neuromuscular blocking agent. *Intensive Care Med.* 2003;29:1717-1722.
- McClave SA, Lukan JK, Stefater JA, et al. Poor validity of residual volumes as a marker for risk of aspiration in critically ill patients. *Crit Care Med.* 2005;33:324-330.
- Petrillo-Albarano T, Pettignano R, Asfaw M, Easley K. Use of a feeding protocol to improve nutritional support through early, aggressive, enteral nutrition in the pediatric intensive care unit. *Pediatr Crit Care Med.* 2006;7:340-344.
- Lyons KA, Brilli RJ, Wieman RA, Jacobs BR. Continuation of transpyloric feeding during weaning of mechanical ventilation and tracheal extubation in children: a randomized controlled trial. *JPEN J Parenter Enteral Nutr.* 2002;26:209-213.
- Sanchez C, Lopez-Herce J, Carrillo A, Mencia S, Vigil D. Early transpyloric enteral nutrition in critically ill children. *Nutrition.* 2007;23:16-22.
- Briassoulis G, Zavras N, Hatzis T. Malnutrition, nutritional indices, and early enteral feeding in critically ill children. *Nutrition.* 2001;17:548-557.
- Briassoulis GC, Zavras NJ, Hatzis MT. Effectiveness and safety of a protocol for promotion of early intragastric feeding in critically ill children. *Pediatr Crit Care Med.* 2001;2:113-121.
- De Lucas C, Moreno M, Lopez-Herce J, Ruiz F, Perez-Palencia M, Carrillo A. Transpyloric enteral nutrition reduces the complication rate and cost in the critically ill child. *J Pediatr Gastroenterol Nutr.* 2000;30:175-180.
- Creel AM, Winkler MK. Oral and nasal enteral tube placement errors and complications in a pediatric intensive care unit. *Pediatr Crit Care Med.* 2007;8:161-164.