Improved Nutrition Delivery and Nutrition Status in Critically Ill Children With Heart Disease

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BACKGROUND: This initiative sought to improve nutrition delivery in critically ill children with heart disease admitted to the cardiac ICU (CICU) and neonates undergoing stage 1 palliation (S1P) for single-ventricle physiology through interdisciplinary team interventions. Specific goals were increased caloric and protein delivery for all patients and a more nourished state for infants with single ventricles at the time of discharge.

METHODS: We developed a nutrition flow sheet in the electronic health record to track whether daily nutrition goals were met. Interventions included nurses reporting daily whether caloric and protein goals were met, mandatory involvement of feeding specialists, and introduction of an enteral nutrition guideline. For infants undergoing S1P, weight-for-age z-score (as an indicator for assessing malnutrition) was calculated at admission and discharge.

RESULTS: The percentage of patient days per month when daily caloric goals were met increased from 50.1% to 60.7%, and protein goals met increased from 51.6% to 72.7%. Hospital length of stay, need for ventilation, and mortality did not differ. Patients undergoing S1P demonstrated a statistically significant improvement in weight-for-age z-score compared with the preintervention group (P = .003). Thirteen S1P patients were discharged undernourished in the preintervention group; 5 were severely undernourished. In the intervention group, 4 patients were discharged undernourished, and none were severely undernourished.

CONCLUSIONS: This initiative resulted in improved nutrition delivery for a heterogeneous population of cardiac patients in the CICU as well as significant improvements in weight gain and nourishment status at discharge in infants undergoing S1P.

Outcomes for children with congenital and acquired heart disease who undergo surgical correction or palliation have improved dramatically over the past 2 decades.\(^1\) Mortality rates for even the most complicated lesions have been reduced significantly.\(^1\)–\(^4\) In particular, 30-day and hospital mortality for infants undergoing stage 1 palliation (S1P), or the Norwood procedure, were 11.5% and 16%, respectively, according to the recent Single Ventricle Reconstruction Trial.\(^5\) For this population of infants in particular, significant postoperative complications and morbidity persist, and length of stay and cost of hospitalization are problematic.\(^4\)\(^6\)

Morbidity prolongs hospitalization, taxes institutional and financial resources, stretches family support, and places the child at risk for death. Malnutrition and poor nutrition are

abstract

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Dr Kaufman, Ms Vichayavilas, and Mr Rannie conceptualized and designed the study, performed data analysis, and drafted the initial manuscript; Ms Peyton, Ms Carpenter, Ms Hull and Ms Alpern designed the study and assisted in data collection; Dr Barrett and Dr da Cruz conceptualized and designed the study and revised the manuscript; Dr Roosevelt performed data and statistical analysis and critically reviewed the manuscript; and all authors approved the final manuscript as submitted.


DOI: 10.1542/peds.2014-1835

Accepted for publication Oct 28, 2014

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PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

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FINANCIAL DISCLOSURE: The authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: No external funding.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.
common complications in infants with congenital and acquired heart disease. Poor caloric and protein delivery and inability or loss of ability to orally feed and breastfeed may contribute to neurodevelopmental and neurocognitive delays as well as to parental frustration, anxiety, and disappointment. Lower than growth velocity than that expected for age and gender is prevalent in infants and children with congenital heart disease and may be due to inadequate nutrition delivery. In infants with single-ventricle physiology, providing adequate nutrition can be particularly difficult. For infants undergoing staged palliation, the interstage period (after S1P and before the Glenn procedure) can be particularly challenging and is a time of increased risk of mortality. Poor growth patterns can negatively affect both short- and longer-term outcomes, including infection rates, length of stay, and neurodevelopmental and neurocognitive performance. Improvements in nutrition delivery, consistent weight gain, and adequate growth should be the expectation for patients of all congenital heart centers.

In 2011, the Children’s Hospital Colorado’s Heart Institute identified nutrition and feeding as areas for practice improvement for all patients with congenital and acquired heart disease. A multistep quality improvement project was initiated that examined nutrition on a macrosystem level as well as in infants with single-ventricle physiology. The first objective of this study was to evaluate interventions designed to improve caloric and protein delivery for all patients admitted to the cardiac ICU (CICU). Second, a CICU subset population of infants with single-ventricle physiology was studied to evaluate the impact of interventions on weight gain and nourishment status at discharge. The specific aims of this quality improvement project were to improve daily calorie and protein delivery to all patients in the CICU, as well as to improve the nourishment of infants with single ventricles upon discharge after undergoing S1P.

**METHODS**

**Setting**

Children’s Hospital Colorado is a free-standing, 414-bed, children’s hospital and a referral center for the Rocky Mountain region. The Heart Institute’s CICU admits ~650 children per year, and the Cardiovascular Surgery Program performs ~500 cardiac procedures per year. An interdisciplinary team of nurses, physicians, occupational and speech therapists, and a dietitian was formed in February 2011 to improve nutrition delivery for all patients admitted to the CICU and for infants with single-ventricle physiology. The primary outcome variables for the CICU patients were percentage of patient days in a month when daily caloric and protein goals were met. The primary outcome variable for the single-ventricle infants was their weight-for-age z scores (WAZ) at discharge. WAZ is a World Health Organization standard for assessing malnutrition in children. We chose to include 2 patient populations in our study with different outcome measures to better evaluate how the same interventions would affect different populations of critically ill children with heart disease.

**Interventions**

The team developed a nutrition flow sheet in the electronic health record to identify all patients receiving nutrition support, defined as patients receiving enteral or parenteral nutrition or both, in the CICU during the study period. Baseline data (the preintervention phase) was collected over 8 months from April 2011 to November 2011. The intervention phase was from December 2011 to July 2013 (20 months). Data included demographic and clinical characteristics including the presence of genetic abnormalities defined as trisomy 21, 22q11, and other microdeletions and translocations abnormalities, surgical versus medical admission and the Risk Adjustment for Congenital Heart Surgery (RACHS-1) score when applicable. The RACHS-1 is a procedure-driven complexity categorization used by the Society of Thoracic Surgeons to adjust for baseline case-mix differences when comparing discharge mortality between groups of patients undergoing pediatric congenital heart surgery. Also collected was whether daily protein and calorie goals were met for each patient and, if goals were not met, the percentage of goal calories that was in fact delivered.

The following days were excluded: days of admission and discharge, days of cardiac surgery, days when
neonates received only starter/stock total parenteral nutrition (TPN; composed of 10% dextrose, 3% TrophAmine, and no electrolytes), days when only trophic feeds were delivered, and days when nutrition support was not started. In the preintervention phase, 22.5% of days were excluded; in the intervention phase, 28.3% days were excluded. Examples of why nutrition support was not started were volume limitations, limited access, and medication incompatibility. Starter/stock TPN is typically only administered within the first 24 hours of a neonate’s life. Days with feeding interruptions were included. Reasons for interruptions in feedings are many and varied and include clinical indications such as emesis, abdominal distention and fussiness, as well as interruptions for procedures and studies, and, rarely, staffing and supply issues. As a part of the nutrition assessment, the dietitian entered the caloric and protein goals daily and concluded whether those daily goals were met in the nutrition flow sheet.

Goal calories for full-term intubated infants were estimated to be 80 kcal/kg. This was calculated energy expenditure with an additional 30% to 40% for growth. For nonventilated full-term infants, their caloric goal ranges between 100 and 130 kcal/kg, with frequent adjustments pending weight gain velocity. Estimated energy requirements are set higher for our patients due to catch-up requirements and high energy expenditure. Patients who were feeding on demand were not included. We collected the following variables on the CICU patients: the proportion of patients who required ventilation >24 hours, hospital length of stay, proportion of patients receiving TPN, the number of days of TPN was received, incidence of necrotizing enterocolitis (NEC) requiring surgical exploration or intervention, rates of central-line-associated bloodstream infections, and mortality.

Neonates with diagnoses of single ventricles and who underwent S1P were identified by the Heart Institute’s database of all
cardiothoracic surgical cases (Cardio Access Inc, Fort Lauderdale, FL). All neonates with single ventricle were admitted to the CICU. Exclusion criteria, for this subset, were gestational age <35 weeks and/or genetic abnormalities or syndromes. This cohort included a variety of anatomic diagnoses; the majority had a hypoplastic left ventricle and a morphologically right systemic ventricle. Three subjects of the 52 had hypoplastic right ventricles. The preintervention group included infants who underwent the Norwood procedure from February 2009 to November 2011 (34 months). The intervention group included those
who underwent the Norwood procedure from December 2011 to July 2013 (20 months). The preintervention group time frame was extended to ensure a similar number of patients for comparison with the intervention group.

For infants with single ventricle aged <7 days, admit weight was the mean weight averaged over 6 days or until surgery to account for newborn fluid fluctuations. Infants typically undergo S1P between 3 and 6 days of life. Discharge weight was the weight on day of discharge from hospital or day before discharge when the former was not available. In the preintervention group, 3 infants who died after undergoing S1P before discharge were not included in analysis because there was no discharge weight. Also, 2 subjects in the preintervention group were excluded because of genetic abnormalities. The intervention group did not have any deaths or genetic abnormality exclusions.

**Analytic Approach**

Continuous variables, except for the single-ventricle admit weight, discharge weight, and WAZ scores, and are reported as median and interquartile range given their nonnormal distributions. Categorical variables are reported as proportions with 95% confidence intervals (CIs). Relative risk and 95% CIs were calculated. All statistical analyses were performed with SPSS 22 (IBM SPSS, Armonk, NY). The percentage of patient days in a month when daily caloric and protein goals were met was plotted on statistical process control (SPC) p charts. Three σ limits were used to set the upper and lower control limits. The SPC p charts were created using QI Charts Version 2.0.22 (Scoville Associates, TX).

Because caloric delivery was analyzed as a dichotomous variable (ie, met vs not met), the percentage of calories delivered on days when caloric goals were not met was also calculated.

For the infants undergoing S1P, the World Health Organization 2006 Child Growth Standards were used. Differences in the single-ventricle physiology patients’ weights and WAZ scores between preintervention and intervention periods were analyzed with an independent t test as they were normally distributed. We reported the number of children discharged as malnourished: WAZ scores under −2 were categorized as undernourished and less than −3 to be severely undernourished. This study was approved by the Children’s Hospital Colorado Organizational Research Risk & Quality Improvement Review Panel as a quality improvement project.

**RESULTS**

Demographic, clinical characteristics, and outcomes for patients admitted to the CICU during the preintervention and intervention study periods are presented in Tables 1 and 2. Age, gender, admission weight, genetic abnormalities, ventilation >24 hours, length of hospital stay, TPN use, incidence of NEC, rates of central-line-associated bloodstream infections, and mortality were similar between the 2 groups. Three infants developed NEC requiring surgical exploration and intervention. Two had never been enterally fed and were TPN dependent; the third was on oral feeds ad libitum. No infants on the enteral feeding algorithm developed NEC.

The percentage of patient days in a month when daily caloric goals were met increased from 50.1% to 60.7% from the pre-intervention to intervention period. The percentage of patient days when daily protein goals were met increased from 51.6% to 72.7% from similar periods (Figs 3 and 4). After plotting the pre-intervention monthly percentages, standard SPC charting

### TABLE 1: All CICU Patients: Demographic and Clinical Characteristics

<table>
<thead>
<tr>
<th>Patient Characteristic</th>
<th>Preintervention Period</th>
<th>Intervention Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(8 mo), n = 106</td>
<td>(20 mo), n = 260</td>
</tr>
</tbody>
</table>

- **Admission median age, mo (IQR)**: 1.6 (0.03–6.4) vs 1.4 (0.03–6.9)
- **Male gender, n (%) (95% CI)**: 66 (62) (53–71) vs 158 (61) (55–67)
- **Admission median wt, kg (IQR)**: 3.6 (3.0–6.0) vs 3.9 (3.0–6.4)
- **Genetic abnormalities, n (%) (95% CI)**: 12 (17) (7–20) vs 50 (19) (15–24)
- **Surgical admission, (%) (95% CI)**: 75 (71) (61–79) vs 189 (73) (67–78)
- **RACHS-1b Score 1–2 (95% CI)**: 16 (29) (19–42) vs 54 (34) (27–42)
- **RACHS-1b Score 3 (95% CI)**: 18 (33) (22–46) vs 45 (27) (21–35)
- **RACHS-1b Score 4 (95% CI)**: 8 (14) (7–26) vs 29 (19) (13–25)
- **RACHS-1b Score 5–6 (95% CI)**: 13 (24) (14–36) vs 31 (20) (14–27)

A patient may be included in >1 group (eg, included in both preintervention and intervention periods). IQR, interquartile range.

### TABLE 2: All CICU Patients: Outcome Variables

<table>
<thead>
<tr>
<th>Patient Characteristic</th>
<th>Preintervention Period</th>
<th>Intervention Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(8 mo), n = 106</td>
<td>(20 mo), n = 260</td>
</tr>
</tbody>
</table>

- **Required ventilation >24 h, n (%) (95% CI)**: 91 (86) (78–91) vs 210 (81) (78–85)
- **Median LOS, d (IQR)**: 15.5 (9–30) vs 19 (10–34)
- **Received TPN, n (%) (95% CI)**: 86 (62) (53–71) vs 183 (70) (65–76)
- **Median days of TPN use, n (IQR)**: 4 (2–7) vs 5 (2–10)
- **Incidence of NEC, n (%) (95% CI)**: 1 (1) (0–6) vs 2 (2) (0–3)
- **Rate of CL-associated bloodstream infection/1000 CL days (95% CI)**: 1.29 (0.3–3.1) vs 0.72 (0.1–1.5)
- **Mortality, n (%) (95% CI)**: 7 (7) (3–13) vs 15 (6) (4–9)

A patient may be included in >1 group (eg, included in both preintervention and intervention periods). CI, central line; IQR, interquartile range; LOS, hospital length of stay.

- **Requiring surgical exploration or intervention.**

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rules for determining special cause were used as evidence of improvement. For the caloric goal p chart, 2 of 3 consecutive points were observed close to the upper control limit; this was later followed by a run of >8 consecutive points above the preintervention mean. For the protein goal p chart, there was a run of greater than 8 consecutive points above the preintervention mean. Updated mean and control limits were plotted for the intervention period in the SPC charts after special cause was detected. The percentage of calories delivered on patient days when daily caloric goals in a month were not met increased from 60.6% to 76.4% from the

![Figure 3](image3.png)

**FIGURE 3**
SPC p chart: percentage of patient days in a month when daily caloric goals were met in the CICU.

![Figure 4](image4.png)

**FIGURE 4**
SPC p chart: percentage of patient days in a month when daily protein goals were met in the CICU.
preintervention to intervention period (Fig 5).

Demographic and clinical characteristics for infants with single-ventricle physiology who underwent S1P during the preintervention and intervention study periods are presented in Table 3. Infants in both groups experienced nonstatistically significant absolute weight gain; however, infants in the intervention phase were significantly more nourished at discharge than those in the preintervention phase when their weights were standardized for age (eg, WAZ scores; \( P = .007 \)). Infants in the intervention phase group also had a smaller difference in WAZ from admit to discharge indicating a greater standardized for age weight gain when compared with the preintervention group \( (P = .003; \text{ Table 4}) \). Infants in the intervention period were 1.6 times (95% CI: 1.1–2.3) more likely to be discharged nourished than in the preintervention period. Fewer subjects undergoing S1P in the intervention group were discharged undernourished, and none in the intervention group were discharged severely undernourished (WAZ < −3; Table 5). No infants with single-ventricle physiology developed NEC during the study period.

**DISCUSSION**

This quality improvement initiative successfully improved the daily caloric and protein intake in a heterogeneous population of critically ill children. After initiation, 61% of all CICU inpatients met their daily caloric goals, up from 52%. Those who met daily protein goals improved to 73%, up from 52%. This project also improved nutrition as measured by nourishment status for infants in a specialized cohort: those undergoing stage 1 palliation for single-ventricle physiology. More of these infants were discharged nourished and less undernourished, and they demonstrated an improved weight gain during their hospitalization.

In addition, close attention to these data prompted investigation when results were outside of control limits to discern cases of special cause (eg, in January 2013, a significant decline in caloric goals met was linked to lipid restrictions secondary to a national shortage; Fig 3).

There were multiple interventions initiated over a short time period, and thus the practice change with the greatest effect is difficult to identify. Anecdotally, the authors believe that the adoption of a feeding algorithm and bedside CICU nurses reporting on nutrition status during daily rounds were the 2 most effective interventions.8,10,24 These

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**TABLE 3 Single Ventricle Patients: Demographic and Clinical Characteristics**

<table>
<thead>
<tr>
<th>Patient Characteristic</th>
<th>Preintervention Period (34 mo) ( n = 28 )</th>
<th>Intervention Period (29 mo) ( n = 28 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median age at surgery, d (IQR)</td>
<td>4 (3–5)</td>
<td>5 (3–7)</td>
</tr>
<tr>
<td>Male gender (%) (95% CI)</td>
<td>18 (84) (46–78)</td>
<td>20 (71) (53–85)</td>
</tr>
<tr>
<td>Median LOS, d (IQR)</td>
<td>31 (23–39.75)</td>
<td>30.5 (21.25–44)</td>
</tr>
</tbody>
</table>

IQR, interquartile range; LOS, hospital length of stay.
TABLE 4  Single-Ventricle Infants’ Admission and Discharge Weight and Admission and Discharge WAZ Scores

<table>
<thead>
<tr>
<th></th>
<th>Preintervention Period</th>
<th>Intervention Period</th>
<th>Difference in Means (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean admission wt, kg</td>
<td>3.16</td>
<td>3.27</td>
<td>0.11 (−0.14 to 0.36)</td>
<td>.579</td>
</tr>
<tr>
<td>Mean discharge wt, kg</td>
<td>3.49</td>
<td>3.76</td>
<td>0.27 (−0.05 to 0.57)</td>
<td>.104</td>
</tr>
<tr>
<td>Mean difference from discharge to admit wt</td>
<td>0.341</td>
<td>0.486</td>
<td>0.145 (−0.06 to 0.350)</td>
<td>.162</td>
</tr>
<tr>
<td>Mean admit WAZ</td>
<td>−0.981</td>
<td>−0.132</td>
<td>0.229 (−0.317 to 0.776)</td>
<td>.404</td>
</tr>
<tr>
<td>Mean discharge WAZ</td>
<td>−1.805</td>
<td>−1.031</td>
<td>0.774 (0.219 to 1.329)</td>
<td>.007</td>
</tr>
<tr>
<td>Mean difference from admit to discharge WAZ</td>
<td>−1.444</td>
<td>−0.899</td>
<td>0.545 (0.188 to 0.901)</td>
<td>.003</td>
</tr>
</tbody>
</table>

interventions reduced variability in feeding advancement, increased visibility of the practice improvement effort, and fostered nursing ownership of nutrition practice.

The primary outcome variables of percentage of patient days in a month when daily caloric and protein goals was met, was a dichotomous variable, in contrast to analyzing the percentage of daily caloric and protein goals delivered. Therefore, the SPC charts (Figs 3 and 4) do not distinguish between a patient who met 20% of the goal and a patient who met 80% of the goal. Both values would be reported as a “no,” that is, the patient’s nutrition goal for that day was not met. However, the authors were able to increase the percentage of caloric goal delivered to patients in whom caloric goals were not met by 15% during the intervention period. The most significant and frequently documented barrier to meeting nutritional goals in the CICU was feeding interruptions.

This initiative improved the delivery of protein and calories, but there was no significant difference in clinical outcomes such as need for ventilation, length of stay or mortality in the larger CICU population, or length of stay in the single-ventricle infants. These are complex clinical outcomes of which providing good nutrition is but 1 contributor. For example, Children’s Hospital Colorado’s Heart Institute does not have a standardized process for gastrostomy tube placement for infants unable to meet their oral intake goals. Approximately 40% of infants with single-ventricle physiology undergo gastrostomy tube placement; and the variability in this practice is felt to greatly affect length of stay.

In the single-ventricle population, we observed an absolute decrease in patients malnourished at the time hospital discharge, after undergoing S1P. Improved WAZ has been associated with improved outcomes in children with hypoplastic left heart syndrome as they move through their palliative course. Although infants with single-ventricle physiology represent a small subset of all children with congenital heart disease, they occupy a disproportionate percentage of a heart center’s clinical efforts and financial resources. Their outcomes, throughout their staged palliations and beyond, are considered markers of success for congenital heart programs. Reduction of postoperative morbidity and complications in these patients remains a formidable challenge.

Consistent delivery of nutritional requirements may not be feasible for children with congenital and acquired heart disease. Efforts to sustain goal calories may put these children at risk for adverse events. Among these may be the development of NEC, a greater reliance on central venous catheters to delivery TPN, an increased risk of infection with TPN use, hepatic dysfunction, or prolongation of hospital length of stay to ensure greater weight gain before discharge. Processes should be in place to ensure that attempts to improve nutrition do not compromise other aspects of patient care. During the intervention period, our cohort did not experience an increase in the incidence of NEC, and there was actually a reduction in catheter-associated bloodstream infections.

There are a number of limitations to this study. The results reflect a single center’s experience. Success was aided by a dedicated CICU dietitian and nutrition assistant, as well as clinical informatics support. These positions may not be available at other institutions. We recognize the influence of the Hawthorne effect: providers may have altered their behavior as attention and visibility were given to efforts to improve nutrition. There were other practice improvement initiatives in place during the intervention period, such as efforts to reduce hospital-acquired infections. The positive results of our study may have been influenced by other coexistent quality improvement initiatives. WAZ analysis was limited to the single ventricles; results may not be generalizable to infants with other anatomic lesions. Finally, better weight gain itself may not be associated with improvements in neurodevelopmental and neurocognitive outcomes in infants with single ventricles, as a recent publication has demonstrated.

TABLE 5  Single-Ventricle Infants’ Nourishment Status at Discharge

<table>
<thead>
<tr>
<th>Nourishment State at Discharge</th>
<th>Mean WAZ</th>
<th>Preintervention (n = 28)</th>
<th>Intervention Period (n = 28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nourished</td>
<td>≥ −2</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>Undernourished</td>
<td>−2.01 to −3</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Undernourished</td>
<td>&lt; −3</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

CONCLUSIONS

This collaborative approach resulted in improved caloric and protein delivery to inpatient children with congenital and acquired heart disease as well as improved nourishment status in infants.
undergoing S1P for single-ventricle physiology. Improvements in these areas would seem to offer opportunities for program improvement in congenital heart centers where mortality rates are already low.

ACKNOWLEDGMENTS

We acknowledge Sanja Batz, Emily Bordier, Kaitlyn Goure, Angela Haas, Shaunda Harendt, Debra Paul, Jennifer Rogers, and Sharon Sables-Baus for their contribution to the quality improvement initiative as feeding therapists and specialists. We also acknowledge Samuel Schofield for database support and the nurses of the ICU for their support with the entire initiative.

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Pediatrics 2015;135;e717; originally published online February 16, 2015; DOI: 10.1542/peds.2014-1835

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*Pediatrics* 2015;135;e717; originally published online February 16, 2015;
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