Nutrition and growth in congenital heart disease: a challenge in children

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Purpose of review
Growth failure secondary to feeding problems after complex neonatal cardiac surgery is well documented, but not well understood. The purpose of this review is to describe feeding and growth pattern in children with congenital heart defects.

Recent findings
Nearly half of the infants with univentricular heart defects require supplementation with nasogastric or gastrostomy tube at discharge from neonatal surgery. Feeding challenges contribute to parental stress, and persist beyond infancy. These infants are 'stunted' with both weight and height being below normal. Nearly a quarter of these infants meet the definition of 'failure to thrive' in the first year of life. Short stature is a significant problem for many of these children, and has an impact on neurodevelopmental outcomes. A structured nutritional program can have a positive impact on growth in the interstage period prior to the superior cavopulmonary connection.

Summary
Optimizing nutritional intake has been targeted as a key component of the National Pediatric Cardiology Quality Improvement Collaborative. This initiative has enabled the development of best practices that have the potential to mitigate poor growth in children with congenital heart defects.

Keywords
growth failure, NPC-QIC, nutritional surveillance, stunted growth

INTRODUCTION

Malnutrition and failure to thrive have long been recognized as common systemic consequences of congenital heart defects (CHDs). Infants with cyanotic CHD and complex univentricular lesions are particularly susceptible to acute and chronic malnutrition [1–3]. Adequate nutrition is essential for growth, wound healing, and immune function. The cause of growth failure is multifactorial and likely includes a hypermetabolic state, inadequate caloric intake, swallowing dysfunction, malabsorption, gastroesophageal reflux, immaturity of the gastrointestinal tract, and genetic factors. Inadequate caloric intake is probably a major contributor to growth failure in children requiring cardiac surgery in the neonatal period. Although caloric intake standards exist for healthy neonates, such standards are lacking for those with CHD. Due to the enormity of the problem, growth has been targeted as a key component in improving interstage outcome in infants with hypoplastic left heart syndrome (HLHS) by the National Pediatric Cardiology Quality Improvement Collaborative (NPC-QIC) initiated by the Joint Council on Congenital Heart Disease Quality Improvement Task Force [4]. In this study, we report findings from several published reports on nutrition and growth in children with CHD, with particular emphasis on univentricular CHD.

FACTORS CONTRIBUTING TO GROWTH FAILURE IN CHILDREN WITH UNIVENTRICULAR CONGENITAL HEART DEFECT

The cause of growth failure is multifactorial, but basically related to imbalance between caloric

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KEY POINTS

- Feeding difficulties and growth failure are significant issues in children with congenital heart defects (CHDs), particularly prior to the superior cavopulmonary connection (SCPC).
- Nutritional surveillance should continue after hospital discharge.
- Establishing best nutritional practices may mitigate growth failure.

intake and energy expenditure. Children with univentricular CHD undergo a two or three-staged reconstruction to achieve completion of the Fontan operation or total cavopulmonary connection (TCPC). A majority require a systemic-pulmonary shunt or a right ventricle–pulmonary artery connection/Sano shunt as part of the Norwood operation as neonates, and have an inherently inefficient circulation. The single ventricle which supplies both systemic and pulmonary blood flow has a significant volume load. Thus, energy expenditure may be increased secondary to congestive heart failure. In addition, the inflammatory cascade activated by cardiopulmonary bypass may further increase energy expenditure in the postoperative period. In critically ill children, energy requirements can increase by approximately 30% for mild to moderate stress, 50% in severe stress, and 100% in major burns [3]. In the setting of increased metabolic demands, these infants often have decreased caloric intake. In a retrospective review of daily enteral caloric intake in 100 consecutive infants, including 52 with univentricular physiology, the median intake was less than 100 kcal/kg/day, the minimum amount required for normal infants [5]. In a study measuring oxygen consumption using respiratory mass spectrometry, a hypermetabolic response was demonstrated in the first 72 h after the Norwood operation, while caloric and protein intake was inadequate to meet energy requirements [6].

Other factors contributing to feeding difficulty include vocal cord injury, uncoordinated sucking and swallowing, uncharacterized genetic influences, and alteration in serum growth factors and growth hormone [7,8]. The recurrent laryngeal nerve is vulnerable during arch reconstruction, which is an essential part of the Norwood operation. The reported incidence of vocal cord abnormalities, including paralysis, after the Norwood operation is approximately 30% [9,10▪▪]. Feeding evaluation by modified barium study reveals swallowing dysfunction in nearly 50% of infants after the Norwood operation [9]. Unfortunately, feeding dysfunction persists beyond infancy. In a study of 2-year-old children who had experienced neonatal surgery for CHD, 22% had feeding disorders [11▪]. There was a strong relationship between feeding disorders and the duration of perioperative tube feeding, length of stay during first hospitalization, and duration of mechanical ventilation.

In addition to swallowing dysfunction, relative immaturity and edema of the gastrointestinal tract may impair digestion and absorption [12]. Patients with a systemic–pulmonary shunt may have relative splanchnic ischemia due to diastolic run-off from the shunt, and are at increased risk for necrotizing enterocolitis [13,14]. A theoretical advantage of the 'Sano' modification or the right ventricle-to-pulmonary artery shunt is limitation of diastolic flow reversal. Studies have demonstrated flow reversal in the mesenteric or celiac artery in a higher proportion of patients with a systemic-pulmonary shunt compared with those with the right ventricle-to-pulmonary artery shunt. In a multicenter study that included 44 patients undergoing the Norwood operation, the celiac artery resistive index was higher in the systemic-pulmonary shunt group ($P = 0.02$), but this did not translate to gastrointestinal outcomes, including risk of necrotizing enterocolitis or feeding intolerance [15,16▪].

DOES TYPE OF FORMULA HAVE AN IMPACT ON GROWTH?

Human milk is better absorbed and may have 'healing properties' for the intestinal mucosa; however, it may not have adequate caloric strength to support growth in infants with CHD. Several studies support the judicious use of higher-concentration formula in alleviating growth failure in children with CHD [17]. Interestingly, a recent study does not support this concept [18▪]. In an observational study of 122 infants undergoing surgery for both univentricular and biventricular CHD, postoperative growth rate or length of stay was not influenced by type of milk (human milk, standard or hypercaloric premature infant formulas). Although human milk may have other properties which are beneficial for long-term outcomes, there are no current studies on this topic.

METHOD OF FEEDING

Nearly 50% of infants with univentricular CHD require supplementation with nasogastric tube or gastrostomy tube prior to discharge from initial hospitalization [19,20▪▪,21▪]. Feeding practice varies

across centers. A majority of centers discharge these infants home on supplemental nasogastric tube feedings, and limit gastrostomy tube placement to those with vocal cord injury and documented aspiration (clinical or by milk scan) or those with the inability to tolerate any oral feeds. On the contrary, some centers are much more aggressive with gastrostomy tube placement due to the potential risks associated with both replacement and inadvertent displacement of the nasogastric tube. A retrospective study was performed to evaluate the association between method of feeding at discharge and interstage mortality in infants undergoing surgery for univentricular CHD [22▪▪]. One hundred and ninety of 334 (57%) were discharged home with supplemental nasogastric feedings, 17% underwent placement of a gastrostomy tube, and 26% were discharged feeding entirely by mouth. Indications for gastrostomy tube placement included the presence of significant gastroesophageal reflux along with failure to thrive or aspiration. The relative risk of interstage mortality in infants with a gastrostomy tube versus those without a gastrostomy tube was 2.38 ($P = 0.04$). For infants who did not undergo gastrostomy tube, use of nasogastric tube feeding did not increase the risk of interstage mortality. Infants with gastrostomy tube were more likely to have undergone the Norwood operation, and had a more complicated postoperative course. Thus, gastrostomy tube was a marker for greater severity of illness rather than the cause of mortality.

GROWTH PATTERN IN CHILDREN WITH UNIVENTRICULAR CONGENITAL HEART DEFECT AND RISK FACTORS FOR POOR GROWTH

In an analysis of 1245 infants with univentricular CHD screened across 10 centers in North America as part of the prospective Infant Single Ventricle (ISV) trial, low birth weight, defined as birth weight less than 2.5 kg, occurred in 18 versus 8% in normal children ($P < 0.001$), and small for gestational age, defined as weight below 10th percentile for gestational age, occurred in 22 versus 10% ($P < 0.001$) [23]. The percentage of low birth weight and small for gestational age was similar in patients with and without HLHS. Thus, growth failure may begin *in utero* due to alterations in fetal blood flow, and other uncharacterized factors. The disruption of normal fetal growth is further supported by the higher prevalence of microcephaly in infants with HLHS [24]. Following the expected initial physiologic weight loss, a healthy neonate is expected to gain 20–30 g/day during the first 6 months of life. Infants with univentricular CHD frequently require surgery during this period of rapid growth. Several studies have demonstrated that poor growth is a significant problem in infants with univentricular CHD, particularly prior to performance of the superior cavopulmonary connection (SCPC) [19,20▪▪, 25,26]. In 50 infants with HLHS who underwent the Norwood operation, median weight at discharge was unchanged from admission weight [25]. In a prospective study of 61 infants with univentricular CHD undergoing neonatal surgery, the mean change in weight-for-age z-score (WAZ) between surgery and discharge was -1.5 ± 0.8 [19]. Similar findings were noted in the ISV trial, where growth was the primary outcome [26]. In this prospective randomized trial of enalapril in infants with univentricular CHD, weight, height, and head circumference were measured longitudinally from enrolment, and clinical course was characterized throughout the first 14 months of life. Infants between 1 week and 45 days of age with stable systemic and pulmonary blood flow in whom a SCPC was planned were eligible for participation in the trial. Exclusion criteria included prematurity (gestational age <35 weeks), small for gestational age, and presence of chromosomal or phenotypic syndromes known to be associated with growth failure. One hundred and forty-five of 230 (63%) had a diagnosis of HLHS. In a secondary analysis of these data, WAZ and height-for-age z-scores decreased significantly from baseline to pre-SCPC or period one, and then increased significantly from pre-SCPC to 14 months of age or period two ($P < 0.01$ for each paired comparison) [20▪▪]. This growth pattern is illustrated in Fig. 1. The mean change in WAZ for period one was -0.37 ± 1.15 ($n = 197$), and period two 1.12 ± 0.89 ($n = 173$) (Fig. 2). Greater gestational age, younger age at study enrollment, tube feeding at discharge from neonatal hospitalization, and clinical center were associated with worse growth in period one, whereas younger age and greater caloric intake at the time of SCPC were associated with better growth in period two. Thus, supplemental tube feeding did not mitigate growth failure. It was interesting to note that HLHS was not a risk factor for poor growth as compared with other forms of univentricular CHD. Similarly, height z-score decreased by -0.26 ± 1.16 in period one; however, there was a less dramatic improvement by 0.34 ± 0.97 in period two. Infants with WAZ less than -2 were 26% at study enrollment, 36% pre-SCPC, and 11% at 14 months. Thus, infants with univentricular CHD undergoing staged reconstruction are 'stunted' with both weight and height being below normal.

Anthropometric abnormalities persist even after the TCPC. In a retrospective study of 65 children undergoing staged reconstruction from 1990 to

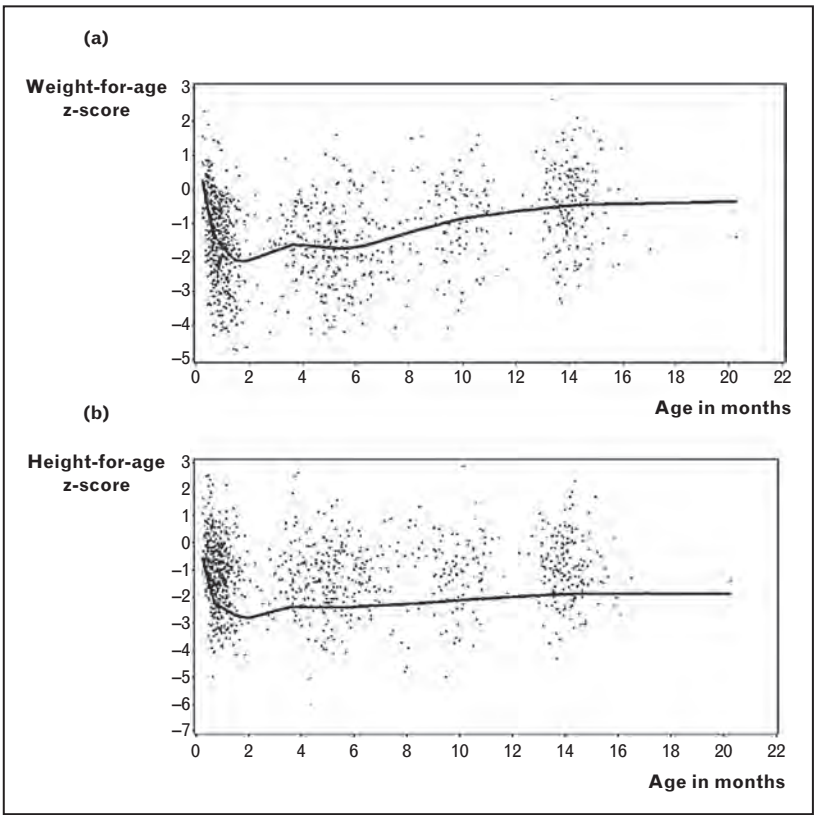

FIGURE 1. Growth pattern of weight and height in the first 14 months of age in children with univentricular heart defects. Modified from [20▪▪].

1995, mean height z-score was -1.15 ± 1.2 at mid-term follow-up of 4.4 ± 1.4 years after the TCPC, and was significantly less compared with parents and siblings [27]. In another study of anthropometry in 544 children, 8.4 ± 3.4 years after the TCPC, mean height z-score was -0.8 ± 1.3 and the mean BMI z-score was -0.6 ± 1.5 [28]. Nearly a quarter had height z-score less than -1.5, compared with the expected 13.4% in the normal population. Factors independently associated with lower height z-score were the presence of at least moderate atrioventricular valve regurgitation prior to TCPC, and behavioral and orthopedic problems. One-tenth had BMI-z less than -1.5, 8% had BMI-z at

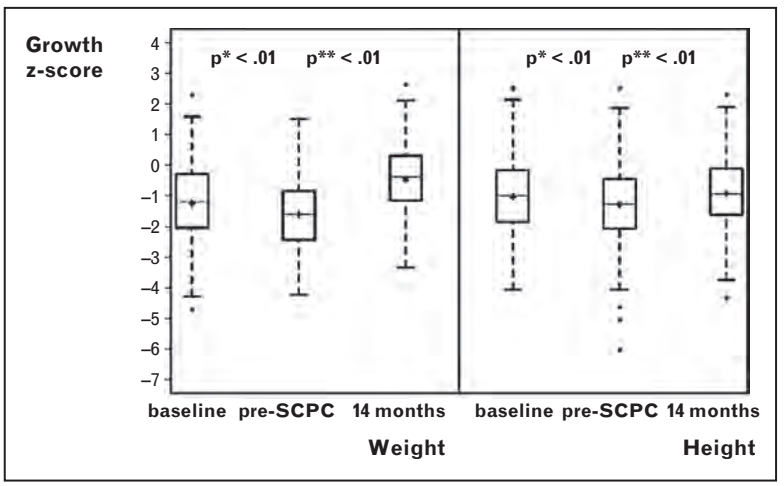

FIGURE 2. Boxplots of weight and height z-scores at baseline, pre-Superior Cavopulmonary Connection (SCPC) and 14 months. Modified from [20▪▪].

least 1.5, whereas a majority, 82%, had a midrange BMI-z (between −1.5 and 1.5). The cause of shorter stature in the long term is unclear, and may be secondary to chronic hypoxemia and low cardiac output, which is quite typical after TCPC.

GROWTH IN CHILDREN WITH BIVENTRICULAR CONGENITAL HEART DEFECT

Growth failure is well described in infants with heart failure secondary to left-to-right shunt lesions such as ventricular septal defect, atrioventricular canal defect and patent ductus arteriosus. In a series of 476 children undergoing 'corrective' surgery or catheter-based interventions in India, WAZ and height z-score less than −2 were present in 59 and 26% of children, respectively, at presentation at a mean age of 15.2 ± 16.2 months [29]. Nearly two-thirds were infants and had left-to-right shunt lesions. Children were followed by a registered dietician for 2 years postintervention. WAZ improved significantly from −2.2 ± 1.2 to −1.4 ± 1 ($P < 0.001$), but there was no change in height z-score. Factors independently associated with worse growth included birth weight less than 2.5 kg, nutritional status at presentation, and parental height. Thus, similarly to children with univentricular CHD, those with biventricular physiology demonstrate catch-up growth with weight but not height.

There are limited data on nutrition and growth in children with complex heart defects undergoing surgery resulting in biventricular physiology. In a secondary analysis of data from a prospective cohort study, factors affecting growth were assessed in 76 infants undergoing biventricular repair [30]. Infants with known risk factors for poor growth such as low birth weight, chromosomal abnormalities, congenital and acquired neurologic insults, and congenital facial and gastrointestinal abnormalities were excluded. The most common diagnosis was transposition of great arteries, followed by tetralogy of Fallot. Median age at surgery was 5 days (1 to 44). The median change in WAZ from surgery to discharge was −1.0 (−2.3 to 0.2). Delayed postoperative nutrition ($P = 0.001$) and reintubation following initial postoperative extubation ($P = 0.001$) were independently associated with decrease in WAZ.

IMPLICATIONS OF POOR GROWTH AND NUTRITION

Malnutrition and poor growth can adversely affect postoperative outcomes and neurodevelopment, as shown by the studies summarized below.

Impact of poor growth on postoperative outcomes

Poor nutrition has been associated with longer hospital length of stay and infections in adults. Even though growth failure is quite prevalent in the CHD population, there are few reports of its impact on postoperative outcomes. In a retrospective case series of 100 infants undergoing SCPC at a single center, length of stay was the primary outcome [31]. Similarly to other reports, WAZ decreased from −0.3 (−2.6–3.2) at neonatal admission to −1.3 (−3.9–0.6) at SCPC. The median length of stay for the cohort was 6 days (3–56). Lower WAZ at the time of SCPC was independently associated with longer length of stay ($P = 0.02$). In another study, WAZ less than −2 at TCPC was associated with a higher risk of infection [32].

Poor growth and neurodevelopment

Growth failure during early infancy has been implicated in impaired executive function and worse school performance in children without CHD [33–35]. In the ISV trial, neurodevelopment was assessed at 14 months using the Bayley Scale of Infant Development [36▪▪]. Mean psychomotor (PDI) and mental developmental indices (MDIs) were 80 ± 18 and 96 ± 14, respectively (normal 100 ± 15; $P < 0.001$ for each). In this multicenter study that excluded known risk factors for growth failure, height had the greatest impact on neurodevelopment. Infants with closer-to-normal height z-scores had predicted PDI scores 15 points higher than those who on average had low height z-scores over the first 14 months of life. Height similarly affected MDI scores as well. This is the first study in the CHD population showing an association between short stature and adverse neurodevelopmental outcomes in infancy.

In the cross-sectional TCPC study, lower height z-score was associated with worse functional health status [28]. Since formal neurodevelopmental testing was not performed, the impact of short stature on neurodevelopment could not be ascertained.

Association of poor growth with mortality

Eskedal *et al.* [37] described the growth pattern of children who died late (>30 days) after surgery for CHD. Of 2247 surgeries performed at one center in Norway from 1990 to 2002, 204 patients died during follow-up, including 80 who died late. Mean follow-up from birth was 8.1 years (0–15.2 years). The study included 74 children with sufficient weight data and their matching surviving controls. The Aristotle score, for complexity of the congenital heart surgical

procedure, which included both univentricular and biventricular CHD, was 8 (3–14.5). Median time of follow-up from last recorded operation was 4.8 months; 70% died before 2 years of age. WAZ at birth, time of surgery, and last recorded weight was 0.07, −1.21, and −2.01, respectively, in 31 children without extra-cardiac abnormalities or trisomy 21, compared with 0.05, −1.10, and −0.99 in matched surviving controls. The odds ratio for death was 13.5 [95% confidence interval (CI) 3.6 to 51.0] if there was a decrease in WAZ of at least 0.67 after the last operation. This is the first study to show that, in children without obvious noncardiac causes of growth failure, a significant decrease in WAZ in the first few weeks to months after cardiac surgery can be an ominous sign, and should alert clinicians to look for hemodynamic causes for poor weight gain.

Parental stress related to feeding and growth

Concerns about infant feeding behaviors contribute to ongoing family stress [38▪]. Once an infant survives the surgical procedure, weight gain emerges as the most salient stressor for parents. Given that 50% of infants with univentricular CHD are discharged to home with tube feeds, the demands around feeding times are significant. During focus group sessions, mothers expressed concern about the time and energy involved in using the tube, cleaning, and replacement of the tube should it become dislodged. They reported increased stress with feedings lasting up to 2 hours, frequent vomiting episodes, confusing infant hunger cues, and night-time tube feedings. Most of all, many of the participants worried about the long-term effects of tube feeding on their infants' ability to feed normally in the future.

STRATEGIES TO PREVENT/TREAT GROWTH FAILURE

On the basis of the available literature and clinical experience, we have summarized interventions that may have a significant impact on growth in children with CHD.

Does preoperative feeding make a difference to postoperative nutritional outcomes?

The physiologic and nutritional benefits of early enteral feedings in neonates are well documented; however, the risks of enteral feedings for infants with prostaglandin-dependent CHD have not been well defined [39▪]. In a survey of 200 caregivers, routine preoperative feeding in prostaglandin-dependent infants ranged from 56% (US) to 93% (outside the US). In two separate studies, it appears that feeding prostaglandin-dependent infants is safe, with no increase in necrotizing enterocolitis [40–42]. While there is a general assumption that preoperative enteral nutrition may lead to improved feeding behaviors postsurgery, there was no difference in the need for nasogastric feedings at discharge between presurgical and postsurgical feeding groups [40].

Nutritional surveillance and intervention

A potential intervention is close monitoring of growth and nutrition both in the inpatient setting and after discharge. Centers have established feeding protocols in an attempt to standardize care for inpatients, with ongoing surveillance as outpatients. The novel idea of a home monitoring program (HMP) for infants with HLHS in the 'high-risk' interstage period between the Norwood operation and SCPC was first introduced in 2000 [43]. Nutritional surveillance and management is an integral part of this program. Patients are required to consume a minimum of 110 kcal/kg/day, and demonstrate adequate weight gain before discharge. Families are discharged home with a pulse oximeter and weighing scale, and trained to record daily weights. The HMP team performs nutritional assessments during regular phone conversations and interstage clinic visits. Parents notify the team for the following 'red flags' or breaches in nutritional criteria: enteral intake less than 100 ml/kg/day, weight loss above 30 g/day, or failure to gain at least 20 g in 3 days. Once the team establishes that failure to gain weight is not related to an anatomic problem (such as coarctation), worsening heart failure, or intercurrent illness, adjustments in the nutritional plan are made. Hehir *et al.* and Ghanayem *et al.* recently evaluated the growth patterns of patients enrolled in the HMP from 2000 to 2009 [10▪▪]. One hundred and forty-five of 148 (98%) patients discharged to home after the Norwood operation survived to SCPC. HLHS was the diagnosis in 84% of infants. Median age at the time of SCPC was 3.8 months (1.6–9.1), and mean weight was 5.68 ± 0.7 kg. WAZ decreased from -0.4 ± 0.9 at birth to -1.3 ± 0.9 at Norwood discharge. However, unlike previous studies, WAZ increased by 0.4 to -0.9 ± 1 at the time of SCPC. The growth velocity of the entire cohort was 26 ± 8 g/day, and parallels normal infant growth. Two-thirds gained at least 20 g/day. The mean caloric density during the interstage period was 26.6 ± 2.1 kcal/ounce. Further sub-group analysis demonstrated greater growth velocity in infants who fed entirely orally, and those followed in the most recent era. This is the first study

of a structured nutritional program resulting in growth in infants with CHD paralleling that of normal infants. The important role of nutritional surveillance is also confirmed by a retrospective review of feeding practices reported by several centers in the United States to the NPC-QIC [21▪]. This study showed significant variation in interstage growth in 132 infants with HLHS among 16 centers. Centers that used a standard feeding evaluation before discharge and closely monitored weight in the interstage period demonstrated better growth than those that did not use these practices.

Recommendations based on lessons learned from the NPC-QIC

The NPC-QIC is the first multicenter quality improvement collaborative in Pediatric Cardiology. The goal of the first project is 'to improve survival and quality of life in infants with HLHS in the interstage period between discharge from Norwood hospitalization and SCPC' [4]. Currently more than 50 centers in the US contribute data to this HLHS registry. A feeding working group was established in an attempt to identify best nutritional practices [44▪▪]. Based on an extensive review of the available literature, the group has made recommendations, which have the potential to improve nutrition and growth in the interstage period (given below).

Recommendations for feeding in the preoperative and postoperative period, and after hospital discharge:

(1) Preoperative period
   (a) Use of enteral nutrition in prostaglandin-dependent infants who are hemodynamically stable, with appropriate monitoring
   (b) Early use of parenteral nutrition
(2) Postoperative period
   (a) Active involvement of a registered dietician
   (b) Use of parenteral nutrition in the early postoperative period and while enteral feeds are being advanced
   (c) Initiation of enteral feeds as soon as hemodynamic stability is established
   (d) Advancing feeds based on a standardized protocol developed at each institute
   (e) Incorporating swallowing evaluation by laryngoscopy and modified barium study (MBS) when vocal cord dysfunction is suspected in the setting of feeding difficulties
   (f) Maximizing treatment for gastroesophageal reflux
(3) After discharge
   (a) Ongoing nutritional surveillance and intervention after discharge
   (b) Use of 'red flags' to guide appropriate evaluation and intervention (see section on nutritional surveillance for details)

CONCLUSION

Feeding difficulties and growth failure are life-long issues in children with CHD, particularly in those with univentricular CHD. Growth failure in infancy can have an impact on postoperative outcomes and long-term neurodevelopment. Short stature is a significant problem in children with CHD. Clinicians should be attentive to poor linear growth in the first year of life as a marker for potential neurodevelopmental abnormalities. Preoperative feeding, standardizing nutritional practice, ongoing nutritional surveillance, and timing of SCPC can have a positive impact on growth. Future research should concentrate on measures to improve growth and nutrition in the early postoperative period.

Acknowledgements

None.

Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
- ▪ of special interest
- ▪▪ of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 261–262).

1. Varan B, Tokel K, Yilmaz G. Malnutrition and growth failure in cyanotic and acyanotic congenital heart disease with and without pulmonary hypertension. Arch Dis Child 1999; 81:49–52.
2. Cameron JW, Rosenthal A, Olson AD. Malnutrition in hospitalized children with congenital heart disease. Arch Pediatr Adolesc Med 1995; 149:1098–1102.
3. Irving SY, Simone SD, Hicks FW, Verger JT. Nutrition for the critically ill child: enteral and parenteral support. AACN Clin Issues 2000; 11:541–558.
4. Kugler JD, Beekman Iii RH, Rosenthal GL, *et al.* Development of a pediatric cardiology quality improvement collaborative: from inception to implementation. From the Joint Council on Congenital Heart Disease Quality Improvement Task Force. Congenit Heart Dis 2009; 4:318–328.
5. Schwalbe-Terilli CR, Hartman DH, Nagle ML, *et al.* Enteral feeding and caloric intake in neonates after cardiac surgery. Am J Crit Care 2009; 18:52–57.
6. Li J, Zhang G, Herridge J, *et al.* Energy expenditure and caloric and protein intake in infants following the Norwood procedure. Pediatr Crit Care Med 2008; 9:55–61.
7. Dinleyici EC, Kilic Z, Buyukkaragoz B, *et al.* Serum IGF-1, IGFBP-3 and growth hormone levels in children with congenital heart disease: relationship with nutritional status, cyanosis and left ventricular functions. Neuro Endocrinol Lett 2007; 28:279–283.
8. Burnham N, Ittenbach RF, Stallings VA, *et al.* Genetic factors are important determinants of impaired growth after infant cardiac surgery. J Thorac Cardiovasc Surg 2010; 140:144–149.
9. Skinner ML, Halstead LA, Rubinstein CS, *et al.* Laryngopharyngeal dysfunction after the Norwood procedure. J Thorac Cardiovasc Surg 2005; 130:1293–1301.
10. ▪▪ Hehir DA, Rudd N, Slicker J, *et al.* Normal interstage growth after the Norwood operation associated with interstage home monitoring. Pediatr Cardiol 2012; 33:1315–1322.

In this study, the authors evaluate the growth patterns of 145 patients enrolled in a home monitoring program from 2000 to 2009. The growth velocity of the entire cohort was 26 ± 8 g/day, and parallels normal infant growth. This is the first report of a structured nutritional program resulting in growth in infants with univentricular heart disease paralleling that of normal infants.

11. Maurer I, Latal B, Geissmann H, *et al.* Prevalence and predictors of later ■ feeding disorders in children who underwent neonatal cardiac surgery for congenital heart disease. Cardiol Young 2011; 21:303–309.
In this study, feeding disorders were present in 22% of 2-year-old children who had undergone neonatal surgery for congenital heart disease. Feeding disorders were defined by the presence of one or more of the following criteria: a child still partially or completely dependent on tube feeding, child only drinks or takes pureed foods or the weight of the child is below the third percentile.
12. Licht DJ, Shera DM, Clancy RR, *et al.* Brain maturation is delayed in infants with complex congenital heart defects. J Thorac Cardiovasc Surg 2009; 137:529–536; discussion 536–537.
13. McElhinney DB, Hedrick HL, Bush DM, *et al.* Necrotizing enterocolitis in neonates with congenital heart disease: risk factors and outcomes. Pediatrics 2000; 106:1080–1087.
14. Jeffries HE, Wells WJ, Starnes VA, *et al.* Gastrointestinal morbidity after Norwood palliation for hypoplastic left heart syndrome. Ann Thorac Surg 2006; 81:982–987.
15. del Castillo SL, Moromisato DY, Dorey F, *et al.* Mesenteric blood flow velocities in the newborn with single-ventricle physiology: modified Blalock–Taussig shunt versus right ventricle-pulmonary artery conduit. Pediatr Crit Care Med 2006; 7:132–137.
16. Johnson JN, Ansong AK, Li JS, *et al.* Celiac artery flow pattern in infants with ■ single right ventricle following the Norwood procedure with a modified Blalock-Taussig or right ventricle to pulmonary artery shunt. Pediatr Cardiol 2011; 32:479–486.
In this multicenter study, celiac artery flow velocity was measured in 44 infants after the Norwood operation. The celiac artery resistive index was higher in the systemic-pulmonary shunt group compared with the right ventricle-pulmonary artery shunt ($P = 0.02$), but this did not translate to gastrointestinal outcomes, including risk of necrotizing enterocolitis or feeding intolerance.
17. Pillo-Blocka F, Adatia I, Shareef W, *et al.* Rapid advancement to more concentrated formula in infants after surgery for congenital heart disease reduces duration of hospital stay: a randomized clinical trial. J Pediatr 2004; 145:761–766.
18. Rosti L, Vivaldo T, Butera G, *et al.* Postoperative nutrition of neonates ■ undergoing heart surgery. Pediatr Med Chir 2011; 33:236–240.
In this observational study, Rosti *et al.* reviewed records from 122 infants undergoing heart surgery (for univentricular and biventricular heart disease) with the aim to determine which type of feeding would allow better weight growth in the few days after surgery. Contrary to previous reports, they found that postoperative growth rate or length of stay was not influenced in either group by type of milk (human milk, standard or hypercaloric premature infant formulas).
19. Medoff-Cooper B, Irving SY, Marino BS, *et al.* Weight change in infants with a functionally univentricular heart: from surgical intervention to hospital discharge. Cardiol Young 2010; 12:1–9.
20. Williams RV, Zak V, Ravishankar C, *et al.* Factors affecting growth in infants ■■ with single ventricle physiology: a report from the Pediatric Heart Network Infant Single Ventricle trial. J Pediatr 2011; 159:1017–1022.
This is a secondary analysis of data from the ISV trial, a prospective multicenter randomized trial evaluating the safety and efficacy of enalapril in infants with univentricular physiology. Detailed anthropometric measurements were made from trial enrollment until the age of 14 months in over 200 infants with univentricular heart defects. This analysis showed that weight-for-age and height-for-age z-scores decreased significantly in infants with univentricular physiology from baseline to pre-SCPC, and then increased significantly from pre-SCPC to 14 months of age. Thus, infants with univentricular heart defects undergoing staged reconstruction are 'stunted' with both mean weight and height being below normal.
21. Anderson JB, Iyer SB, Schidlow DN, *et al.* Variation in growth of infants with a ■ single ventricle. J Pediatr 2012; 161:16–21.
This is a retrospective study that reviews feeding practices in infants with hypoplastic left heart syndrome, reported by several centers in the United States to the National Pediatric Cardiology Quality Improvement Collaborative. There was a significant variation in interstage growth in 132 infants among 16 centers. Centers that used a standard feeding evaluation before discharge, and closely monitored weight in the interstage period, demonstrated better patient growth than those that did not use these practices.
22. Hebson CL, Oster ME, Kirshbom PM, *et al.* Association of feeding modality ■■ with interstage mortality after single-ventricle palliation. J Thorac Cardiovasc Surg 2012; 144:173–177.
This is a retrospective study that evaluates the association between feeding modality at discharge and interstage mortality in infants undergoing univentricular palliation. One hundred and ninety of 334 or 57% of infants were discharged home with supplemental nasogastric tube feedings, and 56 or 17% underwent placement of a G-tube prior to discharge. The relative risk of interstage mortality was significantly higher in infants with a G-tube. For infants who did not undergo gastrostomy tube feeding, use of nasogastric tube feeding did not increase the risk of interstage mortality.
23. Williams RV, Ravishankar C, Zak V, *et al.* for the Pediatric Heart Network Investigators. Birth weight and prematurity in infants with single ventricle physiology: pediatric heart network infant single ventricle trial screened population. Congenit Heart Dis 2010; 5:96–103.
24. Shillingford AJ, Ittenbach RF, Marino BS, *et al.* Aortic morphometry and microcephaly in hypoplastic left heart syndrome. Cardiol Young 2007; 17:189–195.
25. Kelleher DK, Laussen P, Teixeira-Pinto A, Duggan C. Growth and correlates of nutritional status among infants with hypoplastic left heart syndrome (HLHS) after stage I Norwood procedure. Nutrition 2006; 22:237–244.
26. Hsu DT, Zak V, Mahony L, *et al.* Enalapril in infants with single ventricle: results of a multicenter randomized trial. Circulation 2010; 122:333–340.
27. Cohen MI, Bush DM, Ferry RJ, *et al.* Somatic growth failure after the Fontan operation. Cardiol Young 2000; 10:447–457.
28. Cohen MS, Zak V, Atz AM, *et al.* Anthropometric measures after Fontan procedure: implications for suboptimal functional outcome. Am Heart J 2010; 160:1092–1098.
29. Vaidyanathan B, Radhakrishnan R, Sarala DA, *et al.* What determines nutritional recovery in malnourished children after correction of congenital heart defects? Pediatrics 2009; 124:e294–e299.
30. Anderson JB, Marino BS, Irving SY, *et al.* Poor postoperative growth in infants with two-ventricle physiology. Cardiol Young 2011; 21:421–429.
31. Anderson JB, Beekman RH, Border WL, *et al.* Lower weight-for-age z score adversely affects hospital length of stay after the bidirectional Glenn procedure in 100 infants with a single ventricle. J Thorac Cardiovasc Surg 2009; 138:397–404.
32. Anderson JB, Kalkwarf HJ, Kehl JE, *et al.* Low weight-for-age z-score and infection risk after the Fontan procedure. Ann Thorac Surg 2011; 91:1460–1466.
33. Black MM, Dubowitz H, Krishnakumar A, Starr RH Jr. Early intervention and recovery among children with failure to thrive: follow-up at age 8. Pediatrics 2007; 120:59–69.
34. Dykman RA, Casey PH, Ackerman PT, McPherson WB. Behavioral and cognitive status in school-aged children with a history of failure to thrive during early childhood. Clin Pediatr 2001; 40:63–70.
35. Bhoomika K, Shobini R, Chandramouli B. Cognitive development in children with chronic protein energy malnutrition. Behav Brain Funct Biomed Central 2008; 1–12.
36. Ravishankar C, Zak V, Williams IA, *et al.* Pediatric Heart Network Investigators. ■■ Association of impaired linear growth and worse neurodevelopmental outcome in infants with single ventricle physiology: a report from the pediatric heart network infant single ventricle trial. J Pediatr 2013; 162:250–256.
This study describes the neurodevelopmental outcome at 14 months of age in 170/185 infants enrolled in the Infant Single Ventricle trial. Mean PDI and MDI were 80 ± 18 and 96 ± 14, respectively (normal 100 ± 15; $P < 0.001$ for each). Height had the greatest impact on neurodevelopmental outcomes. This is the first study in the CHD population showing an association between short stature and adverse neurodevelopmental outcomes in infancy.
37. Eskedal LT, Hagemo PS, Seem E, *et al.* Impaired weight gain predicts risk of late death after surgery for congenital heart defects. Arch Dis Child 2008; 93:495–501.
38. Hartman D, Medoff-Cooper B. Transition to home after neonatal surgery for ■ congenital heart disease. MCN Am J Matern Child Nurs 2012; 3:95–100.
This study used parent focus groups to assess parental stress related to feeding behavior. During focus group sessions, mothers expressed concern about tube feedings, worrying about the time and energy involved in using the tube, feeding, cleaning and replacement of the tube should it become dislodged.
39. Howley LW, Kaufman J, Wymore E, *et al.* Enteral feeding in neonates with ■ prostaglandin-dependent congenital cardiac disease: international survey on current trends and variations in practice. Cardiol Young 2012; 22: 121–127.
In a survey of 200 caregivers, routine preoperative feedings in prostaglandin-dependent infants ranged from 56% (United States) to 93% (outside the US), showing variability in feeding practices across the world.
40. Natarajan G, Reddy Anne S, Aggarwal S. Enteral feeding of neonates with congenital heart disease. Neonatology 2010; 98:330–336.
41. Willis L, Thureen P, Kaufman J, *et al.* Enteral feeding in prostaglandin-dependent neonates: is it a safe practice? J Pediatr 2008; 153:867–869.
42. del Castillo SL, McCulley ME, Khemani RG, *et al.* Reducing the incidence of necrotizing enterocolitis in neonates with hypoplastic left heart syndrome with the introduction of an enteral feed protocol. Pediatr Crit Care Med 2010; 11:373–377.
43. Ghanayem NS, Hoffman GM, Mussatto KA, *et al.* Home surveillance program prevents interstage mortality after the Norwood procedure. J Thorac Cardiovasc Surg 2003; 126:1367–1377.
44. Slicker J, Hehir DA, Horsley M, *et al.* Nutrition algorithms for infants with ■■ hypoplastic left heart syndrome; birth through the first interstage period. Congenit Heart Dis 2012 (in press).
The National Pediatric Cardiology Quality Improvement Collaborative established a feeding working group in an attempt to identify best nutritional practices in infants with hypoplastic left heart syndrome in the interstage period. Based on an extensive review of the available literature, the group has made recommendations, which have the potential to improve nutrition and growth in infants with congenital heart defects.