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Achieving caloric goal in postoperative management of CHD surgery

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Abstract

Background: This study investigated the prevalence of malnutrition, time to achieve caloric goals, and nutritional risk factors after surgery for CHD in a cardiac ICU. *Method:* This retrospective study included patients with CHD (1 month-18 years old) undergoing open-heart surgery (2021–2022). We recorded nutritional status, body mass index-for-age z-score, weight-for-length/height z-score, cardiopulmonary bypass and aortic cross-clamp time, Paediatric Risk of Mortality-3 score, Paediatric Logistic Organ Dysfunction-2 score, vasoactive inotropic score, total duration of mechanical ventilation, length of stay in the cardiac ICU, mortality, and time to achieve caloric goals. *Results:* Of the 75 included patients, malnutrition was detected in 17% ($n = 8$) based on the body mass index-for-age z-score and in 35% ($n = 10$) based on the weight-for-length/height z-score. Sex, mortality, cardiopulmonary bypass and aortic cross-clamp time, Paediatric Risk of Mortality-3, Paediatric Logistic Organ Dysfunction-2, and vasoactive inotropic score, duration of mechanical ventilation, and length of cardiac ICU stay were similar between patients with and without malnutrition. Patients who achieved caloric goals on the fourth day and those who achieved them beyond the fourth day showed statistical differences in mortality, maximum vasoactive inotropic score, duration of mechanical ventilation, cardiopulmonary bypass and aortic cross-clamp time, Paediatric Risk of Mortality-3, Paediatric Logistic Organ Dysfunction-2, and length of cardiac ICU and hospital stay ($p < 0.05$). Logit regression analysis indicated that the duration of mechanical ventilation, Paediatric Logistic Organ Dysfunction-2 and Paediatric Risk of Mortality-3 score was a risk factor for achieving caloric goals ($p < 0.05$). *Conclusions:* Malnutrition is prevalent in patients with CHD, and concomitant organ failure and duration of mechanical ventilation play important roles in achieving postoperative caloric goals.

Introduction

The aetiology of malnutrition in children with CHD depends on several factors, such as insufficient energy intake, impaired nutritional absorption, inadequate nutrient utilisation, and increased energy expenditure.[1] Pulmonary vessel congestion is commonly seen in patients with CHD and contributes to poor appetite and feeding difficulties, which can cause vomiting and breathlessness.[2] In addition, compromised cardiac function can lead to intestinal pooling of blood, resulting in intestinal dysfunction and reduced absorption of nutrients.[3] Complications of heart failure, pneumonia, and pulmonary hypertension can also exacerbate hypoperfusion of peripheral tissues, leading to decreased nutrient utilisation.[4]

In recent years, attention has increasingly turned towards understanding the relationship between CHD and nutritional status and its effects on patient outcomes. Studies have consistently reported the increasing prevalence of preoperative underweight, stunting, and wasting among paediatric patients with CHD, which contributes to their vulnerability to malnutrition.[5] As these rates are higher in patients with CHD than in healthy patients, addressing nutritional challenges in patients with CHD is important for patient outcomes in the cardiac ICU. Caloric goals and nutritional status also play an important role in CHD patients, especially after congenital heart surgery.[6] Inadequate caloric intake can result in increased mortality, length of hospital stay, nosocomial infections, mechanical ventilation, impaired wound healing, and poor neurodevelopmental outcomes.[7–9] Enteral feeding should be the preferred first-line route of nutrition in cardiac ICUs when gastrointestinal tracts are functional and intact since it is physiological and cost-effective, preserves gut integrity, reduces possible infectious complications, and decreases length of hospital stay.[10] A delay in enteral feeding within the first 24–48 h in the ICU results in higher mortality.[11,12]

Certain nutrition protocols for critical paediatric patients have been established in light of emerging literature, but a standardized nutrition approach for patients undergoing cardiac surgery has not been established, and practice differs between centres.[13] Optimising postoperative nutrition significantly improves outcomes, especially in paediatric heart-surgery patients.[14] This study provides insight into postoperative nutrition, its components, time to achieve caloric goals, malnutrition prevalence, effects on prognosis, and nutritional complications among paediatric patients in the cardiac ICU after congenital heart surgery.

Materials and method

The study included patients aged 1 month to 18 years followed postoperatively in the cardiac ICU for at least 4 days after paediatric cardiovascular surgery between 2021 and 2022. The exclusion criteria were a history of major gastrointestinal surgery or severe preoperative feeding intolerance (such as protein-losing enteropathy, inflammatory bowel disease, and necrotising enterocolitis) and length of cardiac ICU stay of less than 4 days. The analyses examined height, weight, body mass index, height-for-age, weight-for-age, nutritional status, malnutrition z-score according to the body mass index-for-age and weight-for-length/height, Risk Adjustment for Congenital Heart Surgery-1 score, cardiopulmonary bypass time, aortic cross-clamp time, Paediatric Risk of Mortality-3 score, Paediatric Logistic Organ Dysfunction-2 score, need for vasopressors, maximum vasoactive inotropic score, urine output, concomitant organ failure, bleeding, reoperation, arrhythmia, sepsis, duration of mechanical ventilation, high-flow oxygen therapy duration, length of cardiac ICU stay, cardiac ICU mortality, length of hospital stay, initiation time of enteral feeding, time to achieving caloric goals, nutritional complications, enteral feeding strategy (continuous versus intermittent bolus), nutrition therapy (medical nutrition or regular hospital diet), intolerance during feeding (such as constipation, diarrhoea, vomiting, and abdominal distention), feeding and surgical complications (such as chylothorax), daily estimated energy requirements and enteric caloric intake, daily protein, carbohydrate, and lipid intake, weekly weight gain, discharge weight, albumin, blood urea nitrogen, creatinine, electrolyte imbalances, and total fluid balance. The Koc University Ethics Committee on Human Research approved the study (approval number: 2022.262.IRB1.103).

Nutrition protocol

Enteral feeding started within 24–48 h in haemodynamically stable patients with nasogastric or orogastric tubes, regardless of their intubation status. Intermittent bolus, continuous, and trophic feeding methods were used.

- Intermittent bolus: Start with 20 mL/kg/day for infants. Give daily caloric goal by feeding every 3 h and increase caloric intake by 25–50% every day to achieve the estimated energy requirements. For children aged 1 to 18 years, start feeding to cover 25% of daily energy needs on the first day, and increase by 25–50% daily to reach at least 75% of the daily energy requirement as quickly as possible.
- Continuous: Start with 1–2 mL/kg/h (maximum of 25 mL), 0.5 mL/kg/h in cases of ischaemia risk; increase 1–5 mL/h every 3 h (age <1 year), increase 5–20 mL/h every 3 h (age >1 year) (~10%). Transition from continuous feeding to bolus feeding involves stopping the continuous feeding for 2 h. The total volume that would typically be administered over 3 h during continuous feeding is instead given in a single 60-min bolus. If the patient tolerates this transition well, feeding resumes every 3 h (8 times a day). On subsequent days, the duration of each bolus feed can gradually be reduced from 60 min to 20–30 min, using gravity drip, depending on the patient's tolerance.
- Trophic: 1–2 mL/kg (maximum 20 mL/h) every 3 h, with the option to deliver as either bolus or continuous feeding depending on the patient's tolerance.

Before transitioning from nasogastric to oral feeding, nurse opinion, oral feeding capacity, sucking and swallowing functions, vocal cord function, and risk of aspiration are considered. If oral feeding is chosen, each patient receives trace-amount oral feeding trials before each feeding. Enteral feeding tube discontinues, and full oral feeding starts if the patient can tolerate 50–75% of the caloric goal orally in 48 h. If patients have oral feeding problems, speech-and-swallow therapist consultation or videofluoroscopic swallowing studies may be requested (Figure 1). When the feeding is well tolerated and the patient is haemodynamically stable, breastfeeding can start slowly for infants, but patients should be monitored during breastfeeding.

At 4–6 h before extubation, nutrition stops, and 1–2 meals are skipped. If extubation is well tolerated with no sign of respiratory distress 3 h after extubation and blood gas results are reassuring, feeding starts again with 50% of the previous feeding order and increases 25% every 3 h to reach daily caloric goals.

Tools and definitions

Malnutrition was calculated according to World Health Organization's weight-for-length/height z-score (age 0–23 months) and Centres for Disease Control's body-mass-index-for-age z-score (2–18 years of age).[15,16] Z score ≤ -2 indicate malnutrition. Z-scores for weight-for-length/height and body mass index-for-age were calculated using an online calculator (www.ceddcozum.com), which was developed by the Turkish Paediatric Endocrinology and Diabetes Society.[17] Admission weight is the preoperative weight. The discharge weight refers to the weight that is measured at the time of discharge from the cardiac ICU. Weight change (Δweight; discharge weight–admission weight) was categorised as "balance" (no difference), "negative" (weight loss), and "positive" (weight gain).

As inaccuracies in measurement can affect z-scores of body mass index and weight-for-length, anthropometric measurements of each patient undergoing elective surgery were conducted using optimal instruments within paediatric cardiology outpatient clinics just before the operation. In paediatric cardiology outpatient clinics, height was measured on a flat and still surface in patients under 2 years old, and standing height was measured in patients over 2 years old.[18] Weight measurements for infants were conducted using an infant scale after they were completely undressed. For patients unable to stand independently and who could not fit on the infant scale, their weight was determined by having the mother hold the patient, followed by subtracting the mother's weight from the combined measurement. Patients over 2 years of age who could stand independently were instructed to stand on a scale for measurement.[18] In the cardiac ICU, patients were preferably weighed on beds equipped with scales, with measurements taken twice a week. In instances where a bed with scale was unavailable, the patient's weight was determined by

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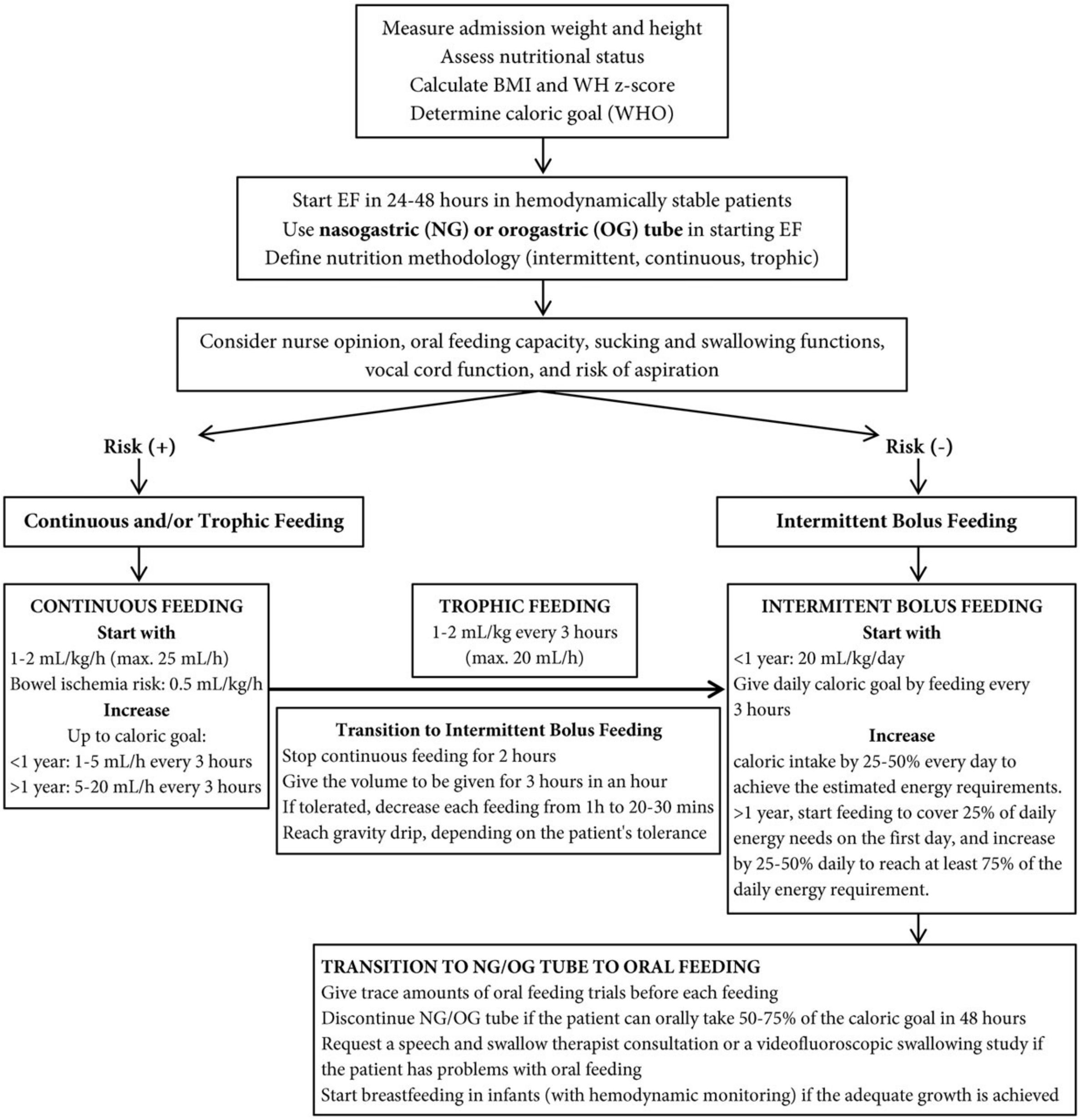

Figure 1. Nutrition protocol.

having a nurse hold the patient and subtracting the nurse's weight from the total measurement.

According to the guidelines of The European Society of Clinical Nutrition and Metabolism, nutritional care was divided into medical nutrition therapy and regular hospital diet.[19] Medical nutrition therapy was classified as oral nutritional supplements, enteral tube feeding/enteral nutrition, and parenteral nutrition. Medical nutrition therapy was based on age:

- 0–6 months: Primarily breast milk, human milk + fortifier (Fantomalt®, Protifar®), human milk + formula (Aptamil®, Pepti Junior®), human milk + enteral feeding solutions (Infasource®, Infatrini®)
- 6–12 months: Human milk + fortifier (Fantomalt®, Protifar®), human milk + formula (Aptamil®, Pepti Junior®), enteral feeding solutions (Infasource®, Infatrini®, Similac® High Energy), regular hospital diet
- >12 months: Enteral feeding solutions (Resource Junior®, Resource Junior Fibre®, Peptamen® Junior, PediaSure® Plus Fibre, PediaSure® Peptide, Fortini® Multi Fibre), regular hospital diet
- If mothers had insufficient breastmilk, human-donor milk was used upon family consent.

The estimated energy requirements were calculated using the World Health Organization's resting energy expenditure equation.[20] Caloric goal achievement was defined as reaching the target enteric caloric intake (at least 75% of estimated energy requirement) within 4 days of cardiac ICU admission (Supplementary Table S1).

The Paediatric Risk of Mortality-3 and Paediatric Logistic Organ Dysfunction-2 scores are used to predict mortality risk based on organ dysfunction severity. Calculations were performed using the worst parameters within 24 h of admission.[21,22] Single or multiple organ failure (neurologic, respiratory, gastrointestinal, hepatic, hematologic, and coagulopathy) was defined using the Paediatric Organ Dysfunction Information Update Mandate criteria.[23] Acute kidney injury was assessed according to the criteria of "Kidney Disease Improving Global Outcomes" and staged as 1–3 based on serum creatinine and/or urine output changes.[24]

Patients with mean arterial pressures below two standard deviations from the normal range for their age were considered hypotensive and given inotropic agents. Maximum vasoactive inotropic scores were calculated and analysed.[25] Sepsis and systemic inflammatory response syndrome were diagnosed with the "International Paediatric Sepsis Consensus Conference in 2005" criteria.[26]

Statistics

Data were analysed using the Statistical Package for Social Sciences for Windows 22.0 and EViews 9. Numbers, percentages, means, and standard deviations were used as descriptive statistics for evaluation. Before hypothesis testing, numerical data distributions were obtained by Kolmogorov–Smirnov tests, and homogeneity of variance was assessed by Levene's test. Mann–Whitney U tests were used for comparing continuous variables between independent groups. Categorical variables were analysed with chi-squared tests.

Factors affecting caloric goal achievement time were analysed as categorical variables between groups using logit regressions in EViews 9. Statistical significance was indicated with $p < 0.05$ (two-way).

Results

The study retrospectively included 75 of the 83 patients with CHD who had open-heart surgery between 2021 and 2022 (We excluded two patients with protein-losing enteropathy, four newborns, and two patients with a history of severe gastrointestinal bleeding and necrotising enterocolitis on extracorporeal membrane oxygenation.). Malnutrition was detected in 17% ($n = 8$, in 47 patients aged 2–18 years) of patients according to body-mass-index-for-age z-scores and 35% ($n = 10$, in 28 patients aged 0–23 months) according to weight-for-length/height z-scores.

Table 1 compares preoperative, perioperative, and postoperative variables in patients with and without malnutrition. No statistical differences occurred between patients with and without malnutrition in terms of sex, daily caloric intake, protein, lipid, and carbohydrate intake, Risk Adjustment for Congenital Heart Surgery-1 score, aortic cross-clamp time and cardiopulmonary bypass time, Paediatric Risk of Mortality-3 score, Paediatric Logistic Organ Dysfunction-2 score, maximum vasoactive inotropic score, total fluid overload, duration of mechanical ventilation, duration of high-flow oxygen therapy, length of cardiac ICU stay, and mortality. Patients with malnutrition had longer length of hospital stay (25 days versus 15 days, $p = 0.012$).

All patients received 15.39 ± 14.76 g of protein daily (no malnutrition: 17.14 ± 16.08 g, malnutrition: 9.84 ± 7.36 g, $p = 0.118$). All patients received 60.15 ± 39.72 g of carbohydrate daily (no malnutrition: 62.45 ± 38.99 g, malnutrition: 52.81 ± 42.31 g, $p = 0.296$). All patients received 24.80 ± 15.77 g of lipid daily (no malnutrition: 26.16 ± 16.55 g, malnutrition: 20.50 ± 12.41 g, $p = 0.243$). Daily protein, carbohydrate, and lipid intakes showed no differences in patients with and without malnutrition.

wPatients were grouped according to caloric goal achievement on the fourth day versus beyond the fourth day (Table 2). The groups had similar ages, sex, Risk Adjustment for Congenital Heart Surgery-1 scores, admission and discharge weights, body mass indexes, and total fluid balance. Cardiopulmonary bypass time and aortic cross-clamp time were longer for those achieving caloric goals beyond 4 days than those achieving them within 4 days (cardiopulmonary bypass time: 175.09 ± 80.37 min versus 115.74 ± 58.93 min, $p = 0.001$; aortic cross-clamp time: 90.04 ± 60.69 min versus 55.03 ± 52.84 min, respectively, $p = 0.020$).

Paediatric Risk of Mortality-3 and Paediatric Logistic Organ Dysfunction-2 scores were higher in those achieving caloric goals beyond 4 days than those achieving them within 4 days (Paediatric Risk of Mortality-3 score: 18.14 ± 7.00 versus 9.55 ± 4.71, $p < 0.001$; Paediatric Logistic Organ Dysfunction-2 score: 20.13 ± 12.66 versus 3.13 ± 7.42, respectively, $p < 0.001$). Maximum vasoactive inotropic scores were greater in those achieving caloric goals beyond 4 days than those achieving them within 4 days (maximum vasoactive inotropic score >2: 100% ($n = 21$) of those achieving caloric goals beyond 4 days, 85.2% ($n = 46$) of those achieving them within 4 days, $p = 0.047$).

Regarding intubation status of the patients upon arrival to the cardiac ICU, 60% ($n = 45$) of patients were ultra-fast-track extubated and 40% ($n = 30$) of patients were intubated. Comparison of ultra-fast-track extubated and intubated patients in achieving caloric goals within 4 days showed that ultra-fast-track extubation patients was higher than intubated patients ($p = 0.025$). Most of the patients on mechanical ventilation for less than 5 days were shown to achieve their caloric goals within 4 days ($p = 0.001$) (Table 2).

Lengths of stay in the cardiac ICU and hospital were also longer in those achieving caloric goals beyond 4 days than those achieving them within 4 days (length of cardiac ICU stay: 18.85 ± 13.24 versus 5.64 ± 2.95 days, $p < 0.001$; length of hospital stay: 28.04 ± 18.04 versus 13.68 ± 10.58 days, respectively, $p < 0.001$). No statistical difference was found in weight change between those achieving caloric goals within 4 days and those achieving them beyond 4 days ($p = 0.176$). Those who achieved caloric goals within 4 days started enteral feeding earlier than those achieving them beyond 4 days (mean starting day of enteral feeding overall: 1.3 ± 1.58 days; goals achieved within 4 days: 1.05 ± 0.40 days; goals achieved beyond 4 days: 2.05 ± 3.03 days; $p = 0.015$) (Table 3). Those achieving caloric goals within 4 days had less organ dysfunction than those achieving them beyond 4 days (according to Paediatric Organ Dysfunction Information Update Mandate criteria: respiratory: $p = 0.014$, neurological: $p = 0.002$, haematological: $p = 0.008$, renal: $p = 0.004$, dialysis: $p = 0.004$, hepatic: $p = 0.023$, sepsis: $p = 0.001$, systemic inflammatory response syndrome: $p = 0.014$, and arrhythmia: $p = 0.004$) (Table 4).

Mortality was higher in those achieving caloric goals beyond 4 days than those achieving them within 4 days (19% versus 0%, respectively, $p = 0.001$). Duration of mechanical ventilation, Paediatric Logistic Organ Dysfunction-2 scores, Paediatric Risk of Mortality-3 scores, cardiopulmonary bypass and aortic cross-clamp time, length of cardiac ICU stay, and length of hospital stay were included in a logit regression, which showed that duration of mechanical ventilation (>5 days), Paediatric Logistic Organ

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Table 1. Demographic and clinical features of patients who had malnutrition (MAL+) and not (MAL-) according to body mass index (BMI)-for-age z-score, and weight-for-length/height (WH) z-score

Categorical variables	All		MAL - (BMI-for-age)		MAL + (BMI-for-age)		MAL - (WH)		MAL + (WH)		χ2 / Z^1	P^1	χ2 / Z^2	P^2
Sex	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	χ2	*p*	χ2	*p*
Boy	41	54.7%	23	59.0%	4	50.0%	8	44.4%	6	60.0%	0.219	0.64	0.62	0.43
Girl	34	45.3%	16	41.0%	4	50.0%	10	55.6%	4	40%				
RACHS-1	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	**χ2**	***p***	**χ2**	***p***
1	1	1.3%	1	2.6%	0	0.0%	0	0%	0	0	6.647	0.08	5.80	**0.06**
2	21	28.0%	5	12.8%	4	50.0%	10	55.6%	2	20.0%				
3	47	62.7%	30	76.9%	3	37.5%	6	33.3%	8	80.0%				
4	6	8.0%	3	7.7%	1	12.5%	2	11.1%	0	0%				
Mortality	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	**χ2**	***p***	**χ2**	***p***
No	71	94.7%	36	92.3%	7	87.5%	18	100%	10	100%	0.197	0.65	0.001	0.98
Yes	4	5.3%	3	7.7%	1	12.5%	0	0%	0	0				
28-Day mortality	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	**χ2**	***p***	**χ2**	***p***
No	71	100.0%	39	100.0%	8	100.0%	18	100.0%	19	100.0%	–	–	–	–
Yes	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%				
Numerical variables	Mean ± SD (Median)		Mean ± SD (Median)		Mean ± SD (Median)		Mean ± SD (Median)		Mean ± SD (Median)		Z^1	P^1	Z^2	P^2
Age (months)	83.7240 ± 363.3 (35.4)		67.24 ± 39.65 (59)		435.11 ± 1101 (45)		7.15 ± 5.57 (6.5)		4.70 ± 3.74 (3.3)		−0.73	0.46	−1.00	0.31
Weight (kg)	13.9759 ± 10.81 (12)		20.25 ± 11.50 (16)		11.44 ± 4.17 (11.9)		6.77 ± 1.98 (6.95)		4.47 ± 1.09 (4)		−2.85	0.00	−2.99	**0.00**
Height (cm)	90.5933 ± 28.90		110.30 ± 21.93		95.12 ± 21.37		64.86 ± 8.64		56.40 ± 4.19		−1.14	0.25	−2.47	**0.01**
Discharge weight (kg)	13.9245 ± 10.74 (12.2)		20.11 ± 11.47 (16.2)		11.3 ± 4.02 (11.55)		6.82 ± 2.45 (6.4)		4.64 ± 1.02 (4.4)		−2.97	0.00	−2.32	**0.02**
Intraoperative variables														
CPB time (min)	132.36 ± 70.37		139.27 ± 72.25		108.76 ± 59.52		136.53 ± 75.53		120.05 ± 52.08		−1.48	0.13	−0.68	0.49
ACC time (min)	64.84 ± 56.97		66.06 ± 59.08		60.64 ± 50.52		66.26 ± 58.91		60.63 ± 52.07		−0.24	0.80	−0.27	0.78
Postoperative variables														
PRISM-3	11.9600 ± 6.65		11.46 ± 6.41		13.64 ± 7.35		11.62 ± 6.85		12.94 ± 6.09		−1.03	0.30	−0.96	0.36
PELOD-2	7.8973 ± 11.91		7.13 ± 11.30		10.51 ± 13.83		7.28 ± 11.48		9.71 ± 13.24		−0.51	0.60	−1.61	0.10
VIS_{max}	2.6000 ± 1.15		2.53 ± 1.17		2.82 ± 1.07		2.60 ± 1.21		2.57 ± 0.96		−0.84	0.39	−0.56	0.57
Total fluid balance (mL)	−538.0 ± 1178.99		−556.72 ± 1196.40		−474 ± 1150.6		−554.7 ± 1188.1		−489.21 ± 118.02		−0.69	0.49	−0.54	0.58
MV duration (days)	2.9933 ± 8.77		2.80 ± 9.24		3.64 ± 7.11		2.89 ± 9.40		3.28 ± 6.77		−0.79	0.42	−1.04	0.29
HFOT duration (days)	4.7800 ± 4.24		4.28 ± 3.48		6.47 ± 6.02		4.08 ± 3.19		6.81 ± 6.09		−1.56	0.11	−1.96	0.05

Table 1. (*Continued*)

LOS CICU (days)	9.3467 ± 9.45	8.63 ± 8.98	11.76 ± 10.83	8.51 ± 9.00	11.78 ± 10.53	−0.99	0.32	−1.18	0.23
LOS hospital (days)	17.7067 ± 14.50	15.77 ± 11.36	24.29 ± 21.28	15.00 ± 11.20	25.68 ± 19.77	−1.38	0.16	−2.51	**0.01**

ACC = Aortic cross-clamp time; CPB = Cardiopulmonary bypass time; CICU = Cardiac intensive care unit; HFOT = High-flow oxygen therapy; MV = Mechanical ventilation; LOS = Length of stay; PELOD-2 = Paediatric logistic organ dysfunction-2; RACHS-1 = Risk Adjustment of Congenital Heart Surgery-1; PRISM-3 = Paediatric risk of mortality-3; SD = Standard deviation; VIS_{max} = Maximum vasoactive inotropic score; χ2 = Chi Square test score, Z = Mann Whitney U test score, *n* = number of observations, $p^1 = p$ value for MAL −and MAL + according to BMI-for-age z-score, $p^2 = p$ value for MAL − and MAL + according to WH z-score, *n*: number of observation, $p < 0.05$ was shown as statistically significant.

Dysfunction-2 scores, and Paediatric Risk of Mortality-3 scores were significant risk factors affecting caloric goal achievement (Table 5).

The rates of nutritional care types were the following: human milk (breast milk) 6.66% ($n = 5$), human milk + fortifier 5.33% ($n = 4$), human milk + formula 8% ($n = 6$), human milk + enteral feeding solutions 10.66% ($n = 8$), enteral feeding solutions 20% ($n = 15$), enteral feeding solutions + age-based regular hospital diet 26.66% ($n = 20$), regular hospital diet 22.6% ($n = 17$). Donor milk was given to 39.1% ($n = 9$) of patients who needed human milk.

Caloric goal achievement times showed no statistical differences between those receiving regular hospital diet and those receiving medical nutrition therapy ($p = 0.162$). However, patients on medical nutrition therapy had higher discharge weight ($p < 0.001$) (Table 6). There were no differences among the two groups regarding nutritional and surgical complications. Vomiting occurred in two patients, two patients developed abdominal distension after feeding, and two had chylothorax.

Discussion

In our study, malnutrition was found in 17% ($n = 8$) of patients according to body-mass-index-for-age z-scores and 35% ($n = 10$) according to weight-for-length/height z-scores. Malnutrition is prevalent in patients with CHD due to underlying heart disease (with concomitant heart failure in some), low caloric intake due to feeding difficulties (reflux and gastric emptying difficulties due to hepatomegaly), gastrointestinal functional impairment (intestinal oedema), and genetic syndromes. Its prevalence is 24.8% according to a recent meta-analysis.[27,28] Correia et al. found a 2.63-fold increase in mortality, 300% increase in hospital cost, and increase in length of hospital stay in malnutrition cases.[29] Malnutrition is an important indicator of morbidity and mortality and is associated with worse postoperative outcomes such as increased duration of mechanical ventilation and length of hospital stay.[30] Ferhatoglu et al. found similar results, and malnutrition was associated with increased infection rate, length of hospital stay, and mortality in patients undergoing congenital heart surgery.[31]

Although several studies show that malnutrition affects postoperative outcomes, we found no differences in patients with and without malnutrition regarding mortality, duration of mechanical ventilation, need for inotropic support, Paediatric Risk of Mortality scores, Paediatric Logistic Organ Dysfunction scores, and length of cardiac ICU stay. However, length of hospital stay showed differences. This could be achieved by our hospital's standardized nutrition protocols. A potential negative outcome could be prevented by a standardized, well-established nutrition protocol that is acknowledged by the whole hospital care team.[32] This means that standardized nutrition protocols are more crucial than malnutrition.

Our hospital's nutrition protocol for patients with CHD has three main components: enteral feeding, primarily use of breastmilk and human-donor milk in infants; early enteral feeding (starting in 24–48 h); and achieving 75% of caloric goals in 4 days. Even though the first two components are achieved in our cardiac ICU, achievement of 75% of caloric goals in the first 4 days was different among patients. In our study, we showed that higher Paediatric Risk of Mortality and Paediatric Logistic Organ Dysfunction scores and longer duration of mechanical ventilation (>5 days) were independent factors affecting this in logit regression analysis. These variables are mostly related to organ

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Table 2. Comparison of demographic and clinical features of patients who achieved caloric goal within the first 4 days (Total Cal ≤ 4) or beyond the 4th day (Total Cal > 4)

Categorical variables	All		Total Cal ≤ 4		Total Cal > 4		χ2 / Z	P[1]
Sex	*n*	%	*n*	%	*n*	%	χ2	*p*
Boy	41	54.7%	29	53.7%	12	57.1%	0.072	0.788
Girl	34	45.3%	25	46.3%	9	42.9%		
RACHS-1	***n***	**%**	***n***	**%**	***n***	**%**	***χ2***	***p***
1	1	1.3%	1	1.9%	0		6.872	0.072
2	21	28.0%	18	33.3%	3	14.3%		
3	47	62.7%	33	61.1%	14	66.7%		
4	6	8.0%	2	3.7%	4	19.0%		
Mortality	***n***	**%**	***n***	**%**	***n***	**%**	***χ2***	***p***
No	71	94.7%	54	100.0%	17	81.0%	***10.865***	**0.001**
Yes	4	5.3%	0	0.0%	4	19.0%		
VIS_{max}	***n***	**%**	***n***	**%**	***n***	**%**	***χ2***	***p***
>2	67	89.3%	44	84.6%	23	100.0%	**3.961**	**0.047**
≤2	8	10.7%	8	15.4%	0	0.0%		
Ultrafast extubation	***n***	**%**	***n***	**%**	***n***	**%**	***χ2***	***p***
Yes	45	60%	37	82%	8	38%	**5.014**	**0.025**
No	30	40%	17	18%	13	62%		
Total MV duration (days)	***n***	**%**	***n***	**%**	***n***	**%**	***χ2***	***p***
> 5	11	14.7%	1	1.9%	10	47.6%	***25.305***	**0.001**
≤ 5	64	85.3%	53	98.1%	11	52.4%		
HFOT duration (days)	***n***	**%**	***n***	**%**	***n***	**%**	***χ2***	***p***
> 5	32	42.7%	20	37.0%	12	57.1%	2.499	0.114
≤ 5	43	57.3%	34	63.0%	9	42.9%		
Numerical variables	**Mean ± SD (Median)**		**Mean ± SD (Median)**		**Mean ± SD (Median)**		***Z***	***p***
Age (months)	83.7240 ± 363.33		47.73 ± 44.73		176.26 ± 684		−1.404	0.160
Weight (kg)	13.9759 ± 10.81		15.36 ± 11.91		10.40 ± 6.17		−1.741	0.082
Height (cm)	90.5933 ± 28.90		95.02 ± 29.94		79.19 ± 22.93		***−2.101***	**0.036**
Discharge weight (kg)	13.9245 ± 10.74		15.34 ± 11.89		10.29 ± 5.70		−1.753	0.080
BMI	15.97 ± 9.41		16.44 ± 10.52		14.48 ± 3.85		−0.342	0.732
CPB time (min)	132.36 ± 70.37 (129)		115.74 ± 58.93 (113)		175.09 ± 80.37 (170)		***−3.428***	**0.001**
ACC time (min)	64.84 ± 56.97 (57)		55.03 ± 52.84 (50.5)		90.04 ± 60.69 (96)		***−2.325***	**0.020**
PRISM-3	11.9600 ± 6.65		9.55 ± 4.71		18.14 ± 7.00		***−4.702***	**0.001**
PELOD-2	7.8973 ± 11.91		3.13 ± 7.42		20.13 ± 12.66		***−4.763***	**0.001**
Total Fluid Balance	−538.09 ± 1178.99 (−483)		−686.33 ± 1028.46 (−576.5)		−156.90 ± 1458.82 (362)		−1.581	0.114
LOS CICU (days)	9.3467 ± 9.45 (7)		5.64 ± 2.95 (5.5)		18.85 ± 13.24(14)		***−5.440***	**0.001**
LOS hospital (days)	17.7067 ± 14.50 (13)		13.68 ± 10.58 (10)		28.04 ± 18.04 (25)		***−4.373***	**0.001**

ACC = Aortic cross-clamp time; CPB = Cardiopulmonary bypass time; CICU = Cardiac intensive care unit; BMI = Body mass index; HFOT = High-flow oxygen therapy; MV = Mechanical ventilation; LOS = Length of stay; PELOD-2 = Paediatric logistic organ dysfunction-2; RACHS-1 = Risk Adjustment of Congenital Heart Surgery-1; PRISM-3 = Paediatric risk of mortality-3; SD = Standard deviation; VIS_{max} = Maximum vasoactive inotropic score; χ2 = Chi Square test score; Z = Mann Whitney U test score; *n* = number of observations; p^1 = *p* value for MAL − and MAL + according to BMI-for-age z-score, p^2 = *p* value for MAL − and MAL + according to WH z-score; *n* = number of observation; $p < 0.05$ was shown as statistically significant.

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Table 3. Comparison of nutritional features of patients that achieve caloric goal with in the first 4 days (Total Cal ≤ 4) versus beyond the 4th day (Total Cal > 4)

Numerical variables	All Mean ± SD	Total Cal ≤ 4 Mean ± SD	Total Cal > 4 Mean ± SD	Z Z	p p
Caloric intake in the first 4 days (calories)	564.78 ± 308.85 (628.75)	603.32 ± 292.43 (650)	459.43 ± 337.9 (360)	−1.97	**0.049**
Protein (grams)	15.39 ± 14.76	17.14 ± 16.08	9.84 ± 7.36	−1.564	0.118
Carbohydrate (grams)	60.15 ± 39.72	62.45 ± 38.99	52.81 ± 42.31	−1.045	0.296
Lipid (grams)	24.80 ± 15.77	26.16 ± 16.55	20.50 ± 12.41	−1.166	0.243
First feeding day in CICU	1.3 ± 1.58	1.05 ± 0.40	2.05 ± 3.03	−2.42	**0.015**

Δ Weight	***n***	**%**	***n***	**%**	***n***	**%**	**χ2**	***p***
Balance	23	30.7	19	36.5	4	17.4	3.47	0.176
Negative	23	30.7	16	30.8	7	30.4		
Positive	29	38.7	17	32.7	12	52.2		

CICU = Cardiac intensive care unit; SD= Standard deviation; Δ weight (Discharge weight–Admission weight) was categorized into balance, negative, and positive. Balance means there is no difference in admission and discharge weight. Negative means weight loss, positive means weight gain. χ2 = Chi Square test score; Z = Mann Whitney U test score; n = number of observations.

dysfunctions and the intraoperative condition, which extends to the postoperative period, rather than the preoperative status of the patient. Prolonged cardiopulmonary bypass time causes complete neuroendocrine response, resulting in a hypercatabolic state and increasing resting energy expenditure in the postoperative period for patients with CHD.[33] Additionally, prolonged cross-clamping and cardiopulmonary bypass time cause myocardial disfunction, ischaemia-reperfusion injury, systemic inflammatory reaction with poor respiratory compliance, and acute lung injury, resulting in prolonged mechanical ventilation.[34] Multicentre studies show that prolonged mechanical ventilation can cause interruption of feeding and is associated with inadequate nutrition.[8,35] In our study, duration of mechanical ventilation over 5 days increased the risk of not achieving caloric goals. We believe that early fast extubation postoperatively is beneficial, decreases perioperative morbidity, decreases mechanical ventilation-related complications, and results in earlier caloric goal achievement. Thus, the most important factor for postoperative nutrition is perioperative conditions.

Those who achieved caloric goals within the first 4 days had lower mortality, duration of mechanical ventilation, cardiopulmonary bypass time, aortic cross-clamp time, Paediatric Risk of Mortality, Paediatric Logistic Organ Dysfunction, cardiac ICU length of stay, and hospital length of stay than those achieving goals beyond 4 days. Organ dysfunction rates, Paediatric Risk of Mortality and Paediatric Logistic Organ Dysfunction scores, and rates of complications such as sepsis, systemic inflammatory response syndrome, and arrhythmia were lower in those achieving caloric goals within 4 days. One of the fundamental factors affecting achieving caloric goals in 4 days is starting enteral feeding in the first 24 h. Several studies show that starting on enteral feeding in the first 24–48 h results in decreased morbidity and mortality.[10,36,37] In our study, patients generally started feeding in the first 24–48 h. However, those achieving caloric goals within 4 days started earlier than those achieving them beyond 4 days (all study groups: 1.3 ± 1.58 days; goals achieved within 4 days: 1.05 ± 0.40 days; goals achieved beyond 4 days: 2.05 ± 3.03 days; $p = 0.015$). This raises the question of whether starting enteral feeding in the first 24–48 h or caloric goal achievement in 4 days is more effective. When goals were achieved beyond 4 days, patients were started on enteral feeding slightly after 48 h (2.05 ± 3.03 days). Although this small difference was significant, we think that not only early enteral feeding but also caloric goal achievement in 4 days has a positive effect on outcomes. Early enteral feeding does not always imply adequate enteral caloric intake.[35]

Regarding the type of nutritional care, no statistical difference was found between medical nutrition therapy and regular hospital diet. Essentially, regular hospital diet may fail to demonstrate caloric intake under some circumstances, especially in infants and toddlers. When meals are not finished completely, it is not easy to calculate the exact caloric intake. Enteral feeding is advantageous in fitting higher calories in smaller volumes. Additionally, caloric intake can be measured and estimated easily. Enteral feeding may result in nutritional intolerance depending on individual practice, but centres with an established nutrition protocol have lower feeding intolerance.[14] In our study, feeding was stopped for only two patients due to vomiting and two patients due to abdominal distension related to feeding. For two patients who experienced chylothorax, lipid modifiable diet reversed the complication.

One of the most significant elements of our protocol could be using breastmilk as a first choice in feeding infants and using human-donor milk when breastmilk is absent or insufficient. This is also probably the reason for fewer nutritional complications occurring. Human-donor milk was provided to 39.1% of patients needing human milk. Breastmilk provides optimal nutritional support to infants and has many health benefits, such as protecting against respiratory and gastrointestinal pathogens and preventing allergic diseases and inflammatory bowel disease.[38] It is safe and beneficial, reduces the incidence of sepsis and necrotising enterocolitis, reduces length of hospital stay, and is cost-effective.[39] The American Paediatric Society advises using pasteurised human-donor milk for preterm and low-birth-weight infants when breastmilk is unavailable.[40]

An essential part of our protocol is assessment of every patient by a registered dietitian, who also attends every visit. This helps in important aspects such as determining weight status, anthropometric changes, caloric, protein, lipid, and carbohydrate intake, regulation of feeding regimens, and assessment of nutritional intolerances.[41]

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Table 4. Comparison of clinical features, organ dysfunctions (respiratory, neurologic, haematologic, hepatic organ dysfunctions according to Paediatric Organ Dysfunction Information Update Mandate criteria), postoperative complications of patients that achieve caloric goal in the first 4 days (Total Cal $\leq$ 4) versus beyond the 4th day (Total Cal > 4)

Categorical variables	All		Total Cal $\leq$ 4		Total Cal > 4		$\chi 2$	P^1
Respiratory	***n***	**%**	***n***	**%**	***n***	**%**	***$\chi 2$***	***p***
No	68	90.7%	50	96.2%	18	78.3%	6.033	**0.014**
Yes	7	9.3%	2	3.8%	5	21.7%		
Neurologic	***n***	**%**	***n***	**%**	***n***	**%**	***$\chi 2$***	***p***
No	71	94.7%	52	100%	19	82.6%	9.553	**0.002**
Yes	4	5.3%	0	0.0%	4	17.4%		
Haematologic	***n***	**%**	***n***	**%**	***n***	**%**	***$\chi 2$***	***p***
No	62	82.7%	47	90.4%	15	65.2%	***7.049***	**0.008**
Yes	13	17.3%	5	9.6%	8	34.8%		
Renal	***n***	**%**	***n***	**%**	***n***	**%**	***$\chi 2$***	***p***
No	69	92%	51	98.1%	18	78.3%	8.508	**0.004**
Yes	6	8%	1	1.9%	5	21.7%		
Dialysis	***n***	**%**	***n***	**%**	***n***	**%**	***$\chi 2$***	***p***
No	69	92%	51	98.1%	18	78.3%	8.508	**0.004**
Yes	6	8%	1	1.9%	5	21.7%		
Hepatic	***n***	**%**	***n***	**%**	***n***	**%**	***$\chi 2$***	***p***
No	63	84%	47	90.4%	16	69.6%	*5*0.143	**0.023**
Yes	12	16%	5	9.6%	7	30.4%		
Sepsis	***n***	**%**	***n***	**%**	***n***	**%**	***$\chi 2$***	***p***
No	70	93.3%	52	100%	18	78.3%	12.112	**0.001**
Yes	5	6.7%	0	0.0%	5	21.7%		
SIRS	***n***	**%**	***n***	**%**	***n***	**%**	***$\chi 2$***	***p***
No	68	90.7%	50	96.2%	18	78.3%	6.033	**0.014**
Yes	7	9.3%	2	3.8%	5	21.7%		
Arrhythmia	***n***	**%**	***n***	**%**	***n***	**%**	***$\chi 2$***	***p***
No	69	92%	51	98.1%	18	78.3%	8.508	**0.004**
Yes	6	8%	1	1.9%	5	21.7%		

SIRS = systemic inflammatory response syndrome; $\chi 2$ = Chi Square test score; $p < 0.05$ was shown as statistically significant.

Table 5. Logit regression analysis of risk factors for achieving caloric goal on the 4th day (based on beyond the 4th day)

Variable	Coefficient	Std. error	*z*-Statistic	*p*
Total MV duration	−0.705051	0.321646	−2.192008	**0.0284**
PELOD-2	−0.102727	0.047011	−2.185173	**0.0289**
PRISM-3	0.235014	0.052102	4.510671	**0.0000**

MV = mechanical ventilation; PELOD-2 = Paediatric logistic organ dysfunction score-2; PRISM-3 = Paediatric risk of mortality score-3; $p < 0.05$ was shown as statistically significant.

According to the studies on malnutrition, the weight-for-height z score is one of the least invasive methods to determine the nutritional status of children under 2 years of age. The WHO suggests using weight-for-length/height for patients lacking previous regular anthropometric measurements in studies screening malnutrition. Malnutrition was hence determined using the weight-for-length/height index.

Even though malnutrition is shown to increase mortality and hinder outcomes, our study showed that optimal postoperative nutrition yielded no statistically significant differences between patients with and without malnutrition. Since the prognosis was shown to be more dependent on achieving the caloric goal, discharge weight was taken into account as weight change is the most accurate predictor of achieving caloric goal in the short term.

Limitations

One of the limitations of this study is that newborns were not included. The most vital operations with the most challenging postoperative nutritional management in newborns are arterial switch operation for transposition of the great arteries and Norwood procedures for single-ventricle heart disease. Newborn

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Table 6. Comparison of regular hospital diet versus medical nutrition therapy

	All		Regular hospital diet		Medical nutrition therapy		χ2	*p*
Admission and discharge weight	*n*	%	*n*	%	*n*	%	χ2	*p*
Balance	25	33.3%	15	48.4%	10	22.7%	***15.218***	**0.00**
Negative	18	24.0%	11	35.5%	7	15.9%		
Positive	32	42.7%	5	16.1%	27	61.4%		
otal Cal (days)	*n*	%	*n*	%	*n*	%	χ2	*p*
≤ 4	54	72.0%	25	80.6%	29	65.9%	1.959	0.162
> 4	21	28.0%	6	19.4%	15	34.1%		

Total Cal = Achieving 75% of the caloric goal; χ2 = Chi Square test score; Z = Mann Whitney U test score; *n* = number of observation; $p < 0.05$ was shown as statistically significant.

patients were followed-up in the neonatal ICU after birth, and their preoperative nutrition was managed by a neonatal nutrition protocol. Postoperatively, they were monitored in the cardiac ICU. Preoperative nutrition and management may affect outcomes in the cardiac ICU, which is why newborns were excluded from the study. However, patients with single-ventricle heart disease who were over one month old had Glenn and Fontan procedures and were monitored in the cardiac ICU were included.

In our study, patients with and without malnutrition were shown to have statistically similar results regarding prognosis. Even though our study findings demonstrated postoperative feeding as a major predictor of prognosis, adequate nutrition in preparation for an elective surgery and taking the time to achieve ideal weight gain are shown to minimise postoperative complications in other studies.[42] Yet due to the retrospective design of our study, patients were not evaluated based on whether they underwent elective or emergency surgery. Nevertheless, there were no emergent cases left after exclusion of newborns from the study. All patients underwent elective operation based on the required elective interval of the underlying cardiovascular disease.

Inaccuracies in measurement can affect z-scores of body mass index and weight-for-length; it is important to acknowledge the limitation of ensuring the accuracy of weight and height measurements. However, anthropometric measurements of each patient undergoing elective surgery were conducted using optimal instruments within paediatric cardiology and paediatric outpatient clinics just before the operation, as explained in the methods section.

Another limitation is that in defining nutrition status, only z-scores ≤ -2 were considered as undernutrition. Patients were not subclassified as having mild, moderate, or severe undernutrition due to the small sample size, which did not allow us to compare malnutrition versus no malnutrition in small subgroups. The nutritional follow-up in the inpatient ward was not included in this study since patients were followed-up by a different team.

Our cohort included critically ill paediatric cardiac patients, where weight fluctuations due to fluid status could confound the assessment of true weight change. To minimise these factors, the definition of Δ weight (discharge weight–admission weight) was used, where discharged weight was accepted as the dry weight after subtracting the fluid balance. The weight gain or loss was estimated as the patient's dry weight calculated after adjusting for the fluid balance documented during the hospital stay. The fluid balance, calculated as the difference between fluid intake and output, was subtracted from the measured discharge weight to estimate the true weight gain or loss changes. We acknowledge that this approach has limitations, particularly in cases of positive fluid balance, where the fluid retained would be subtracted from the discharge weight. However, the aim was to achieve a more accurate reflection of the patient's dry weight changes by accounting for the excess fluid that may have accumulated during the hospital stay. Ideally, patients should be weighed upon cardiac ICU admission to evaluate the effect of cardiopulmonary bypass since the procedure causes volume overload. However, patients with drains and on mechanical ventilation along with the inadequate number of scaled beds in cardiac ICU create a limitation in weighing each patient coming to the cardiac ICU.

Lastly, this study was a retrospective study. While this may be considered a limitation regarding data reliability, the data from the cardiac ICU were recorded instantaneously in a computer system, ensuring that all data were stored in the hospital's database.

Conclusions

Concomitant organ failure and duration of mechanical ventilation play important roles in postoperative caloric goal achievement. Standardised nutrition protocols should be established to prevent interpersonal or inter-centre differences. This can be achieved through multicentre collaborations and studies.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1047951125000484.

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