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ORIGINAL ARTICLE

WILEY Congenital Heart Disease

Toward standardization of care: The feeding readiness assessment after congenital cardiac surgery

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Abstract

Background: Feeding practices after neonatal and congenital heart surgery are complicated and variable, which may be associated with prolonged hospitalization length of stay (LOS). Systematic assessment of feeding skills after cardiac surgery may earlier identify those likely to have protracted feeding difficulties, which may promote standardization of care.

Methods: Neonates and infants ≤3 months old admitted for their first cardiac surgery were retrospectively identified during a 1-year period at a single center. A systematic feeding readiness assessment (FRA) was utilized to score infant feeding skills. FRA scores were assigned immediately prior to surgery and 1, 2, and 3 weeks after surgery. FRA scores were analyzed individually and in combination as predictors of gastrostomy tube (GT) placement prior to hospital discharge by logistic regression.

Results: Eighty-six patients met inclusion criteria and 69 patients had complete data to be included in the final model. The mean age of admit was five days and 51% were male. Forty-six percent had single ventricle physiology. Twenty-nine (42%) underwent GT placement. The model containing both immediate presurgical and 1-week postoperative FRA scores was of highest utility in predicting discharge with GT (intercept odds = 10.9, $P = .0002$; sensitivity 69%, specificity 93%, AUC 0.913). The false positive rate was 7.5%.

Conclusions: In this analysis, systematic and standardized measurements of feeding readiness employed immediately before and one week after congenital cardiac surgery predicted need for GT placement prior to hospital discharge. The FRA score may be used to risk stratify patients based on likelihood of prolonged feeding difficulties, which may further improve standardization of care.

KEYWORDS
congenital heart disease, feeding readiness, gastrostomy tube, quality improvement

Abbreviations: AUC, area under the curve; CICU, cardiac intensive care unit; FRA, feeding readiness assessment; GT, gastrostomy tube; LOS, length of stay; NG, nasogastric; ROC, receiver operating characteristic; STAT, Society of Thoracic Surgeons—European Association for Cardio-Thoracic Surgery.

1 | INTRODUCTION

Neonates and infants often have feeding difficulties after congenital cardiac surgery.[1,2] The reasons for this are multifactorial and include neurodevelopmental, gastrointestinal and genetic causes.[3–6] A significant percentage of patients will require supplemental tube feeding at discharge.[7–10] However, the decisions surrounding feeding near discharge are complicated, variable and often center specific.[8,11] This variability may be associated with prolonged length of stay (LOS), provider and parental frustration, and other outcomes associated with survival, such as interstage weight gain.[12–14]

One of the key drivers for practice variability may be the difficulty in predicting which patients are likely to have protracted postoperative feeding difficulties. Current national guidelines outline benchmarks for feeding advancement and removal of supplemental feeding tubes, but these rely on largely on expert consensus.[15] Additionally, there are a lack of user-friendly risk-stratification tools to identify those who will be unable to optimally progress in feeding skills. Our center has employed a postoperative feeding algorithm since 2012 that similarly relies on group consensus. We recently found our adherence to be suboptimal,[16] which was driven by clinician attempts to subjectively predict improvement in feeding abilities. This was associated with a trend toward resulting in increased LOS. We suspect that this subjective calculus is not limited to our heart institute.[7,11]

To promote standardization of care, we sought to determine whether more evidence-based, systematic measurements of feeding skills, assigned in the form of feeding readiness assessment (FRA) scores, may help to predict protracted feeding difficulties early during the hospitalization. We hypothesized that FRA scores assigned in the cardiac intensive care unit (CICU) would predict the need for supplemental gastrostomy tube (GT) feeding at the time of hospital discharge.

2 | METHODS

2.1 | Design and patient selection

This investigation was approved by the Children's Hospital Colorado Organizational Research Risk & Quality Improvement Review Panel as part of a larger quality improvement project focused on improving the quality and consistency of our postoperative feeding practices.[16] A retrospective review of electronic health records of patients ≤3 months old admitted to the CICU for their first cardiac surgery between January 1, 2015, and December 1, 2015, was performed. Since the FRA score was analyzed before surgery and 1, 2, and 3 weeks after surgery, patients were excluded from analyses for which they did not have documented FRA scores (eg, the patient was discharged before the FRA at a predetermined time point could be assigned). Variables collected in addition to the primary predictor (FRA score) and outcome (GT placed before discharge), included demographics (gender, early and late prematurity, diagnosis, single ventricle physiology, confirmed genetic anomaly, admission age, admission weight) and peri-/postoperative data (Society for Thoracic Surgeons—European Association for Cardio-Thoracic Surgery [STAT] congenital heart surgery mortality categories for surgical complexity,[17] CICU LOS, and hospitalization LOS). During the study period, it was the practice of our heart institute to not send patients home with nasogastric (NG) tubes.

2.2 | The feeding readiness assessment score

All neonates and infants admitted to the CICU at our heart institute are followed by our multidisciplinary feeding team. Evaluations are performed by a speech and/or occupational therapist from admission through discharge. Many patients are allowed to feed orally before cardiac surgery. Oral feeding skills are assessed by the feeding team using a standardized feeding readiness assessment (FRA) adapted from a previously validated guideline (Figure 1).[18] To ensure standardization of FRA scoring, each patient is assigned a primary member of the feeding team who performs nearly all of the feeding assessments throughout the hospitalization. The characteristics of each FRA level have also been standardized within our feeding group to maintain consistency should the primary therapist not be available on a particular day. FRA scores are assigned Monday through Friday at intervals ranging from daily to every three days, depending on individual patient need. For the purposes of data collection, when the 1-, 2-, and 3-week time points fell on a weekend, the FRA score assigned closest to that day, either before or after, was documented. All patients had an FRA score recorded prior to surgery.

2.3 | Analytic approach

Continuous variables are reported as means with standard deviations. Categorical variables are reported as frequencies and proportions. Descriptive comparisons included *t*-tests for continuous variables and chi-square tests for categorical variables. The primary analyses were conducted using logistic regression. A priori threshold of 90% specificity was utilized for model selection to minimize false positives. Receiver operating characteristic (ROC) curves and their associated summary measures including area under the curve (AUC), sensitivity, and specificity were performed for each individual and combination of FRA scores. Optimal leave-one-out cross-validation was used to assess internal validity. FRA scores were analyzed as continuous variables by making the assumption that the intervals between each score level were equivalent. One patient with a CICU LOS of greater than 200 days led to computational issues, and thus the variable was set to a maximum of 60 days. The analysis was conducted in R version 3.3.1 (The R Foundation for Statistical Computing, Vienna, Austria). ROC curves and related statistics were calculated using a previously published open-source package.[19] The a priori significance level was set to 0.05.

3 | RESULTS

Eighty-six patients met inclusion criteria, and 69 patients had complete data to be included in the final model. Among those included in the final model, the mean age of admit was 5 days and 51% were male (Table 1). Forty-six percent had single ventricle physiology. The mean

Feeding Readiness Assessment

Stage	Characteristics	Oral intake
Pre-feeding	- Emerging physiologic stability with handling - Short periods of quiet alert state - Weak oral reflexes - All nutrition by feeding tube or IV	0%
Non-nutritive sucking	- Physiologic stability with handing - Increasing duration of quiet alert state - Rooting or licking to show interest in sucking - Working on physiologic stability while sucking - All nutrition by feeding tube or IV	0%
Therapeutic tastes	- Stable breathing rate - Alert state for short periods with handling or sucking - Interest and enjoyment with small tastes - Monitored closely for physiologic stability - Most nutrition by a feeding tube or IV	Negligible amount, 5mL or less
Nutritive sucking 1	- Stable breathing rate - Maintains alert state for short periods while practicing feeding - Manages saliva by swallowing - Sucks on the pacifier, breast, or finger - May fall asleep quickly after starting oral feeding	<10%
Nutritive sucking 2a	- Stable breathing rate - Starts showing hunger cues at feeding times - Sucks, swallows, and breathes without stress during most feeding attempts - May not have energy to complete a full feeding	10-25%
Nutritive sucking 2b	See nutritive sucking 2a	25-50%
Nutritive sucking 2c	See nutritive sucking 2a	50-80%
Nutritive sucking 3	- Shows hunger cues at every feeding - Sucks, swallows, and breathes without stress for the whole feeding - Looks calm and satisfied at the end of feedings - Grows and gains weight with feeding by mouth	80-100%

FIGURE 1 The feeding readiness assessment (FRA)

CICU and hospitalization LOS were 18 and 37 days, respectively. Twenty-nine (42%) patients underwent GT placement. Patients who were discharged with supplementary GT feeds were more likely to be younger (1 vs 8 days at admit, $P \leq .01$), have single ventricle physiology (72% vs 28%, $P < .001$), and undergo a STAT 4 or 5 surgery (86% vs 60%, $P < .0001$) compared to those discharged on oral-only feeds. The average length of stay was significantly longer in the GT group, both in the CICU (30 vs 10 days, $P = .02$) and for the total hospitalization (62 vs 19 days, $P < .001$).

Results for univariate regressions of GT placement on FRA score are found in Table 2. Each FRA tested individually was significantly associated with GT placement before discharge. The model containing both the FRA immediately prior to surgery and 1 week after surgery was also statistically significant with an intercept odds, corresponding to the odds of GT when "prefeeding" prior to and 1 week after surgery, of 10.9. The model containing the presurgery and 1 week postoperative FRA contained the highest specificity (0.93) and AUC 0.91 of any of the models tested (Table 3 and Figure 2). The leave-one-out cross-validation delta, equal to the mean squared prediction error, was lowest in the presurgery/1 week postoperative FRA model (delta = 0.13) indicating the lowest prediction error of any of the models tested. The false positive rate (false positives/all negatives) was 7.5%. In other words, among all patients who ultimately went home without a GT (40 patients), the model inaccurately predicted the need for GT in 3 patients (3/40 = 7.5%). Among all patients who received GT before discharge, the model was able to predict need for GT one week after surgery in 69%. The addition of other significant co-variates to the model, including STAT category and CICU LOS, did not yield improvement in the ability of the presurgery and 1 week FRA to predict GT; thus, they were excluded.

Using the optimal threshold, a prediction tool was created from the model containing the presurgery and 1 week postoperative FRA (Figure 3). The tool is designed as a coordinate-system, where FRA scores assigned preoperatively and 1 week postoperatively align to yield a prediction about GT placement prior to hospital discharge. For example, a patient who was nutritive sucking 2b prior to surgery and prefeeding 1 week after surgery would be predicted to receive a GT. Conversely, if the same patient obtained a score of nonnutritive sucking 1 week after surgery, they would be predicted to discharge on oral-only feeds.

TABLE 1 Patient characteristics

Characteristics	All (n = 69)	Discharged without GT (n = 40)	Discharged with GT (n = 29)	P value[b]
Male sex	35 (51)	18 (45)	17 (59)	.38
Age at admission, d	5 (13)	8 (16)	1 (1.4)	**<.01**
Gestational age, wk	39 (1.9)	39 (1.6)	38 (2.1)	.36
Late prematurity[a]	7 (10)	3 (7.5)	4 (14)	.44
Admit weight, kg	3.1 (0.6)	3.1 (0.6)	3.1 (0.6)	.94
Preoperative single ventricle physiology	32 (46)	11 (28)	21 (72)	**<.001**
STAT category for cardiac surgery 4 or 5	49 (71)	24 (60)	25 (86)	**<.0001**
Confirmed genetic anomaly	8 (12)	6 (15)	2 (7)	.45
CICU LOS	18 (30)	10 (7)	30 (43)	**.02**
Hospitalization LOS	37 (40)	19 (14)	62 (51)	**<.001**

Bold values indicate statistical significance. Continuous variables are reported as mean with standard deviation. Categorical variables are reported as frequencies and proportions.
Abbreviations: CICU, cardiac intensive care unit; LOS, length of stay; GT, gastrostomy tube, STAT, Society of Thoracic Surgeons—European Association for Cardio-Thoracic Surgery.
[a]Greater than 35 but less than 37 wk gestation.
[b]P value from chi-square test for categorical variables and t-test for continuous variables on comparison of each characteristic between the two groups (discharged without GT vs discharged with GT).

TABLE 2 Results for univariate regressions of GT placement on FRA score

Model	Covariate	Estimate[a]	P value
FRA presurgery	Intercept FRA presurgery	2.2 (1.1–4.6) 0.6 (0.5-0.8)	.04 <.001
FRA 1 wk after surgery	Intercept FRA 1 wk	6.1 (2.4–19) 0.4 (0.2-0.6)	<.001 <.001
FRA 2 wk after surgery	Intercept FRA 2 wk	21 (5.3–140) 0.4 (0.2-0.6)	<.001 <.001
FRA 3 wk after surgery	Intercept FRA 3 wk	38 (6.4–530) 0.5 (0.2-0.8)	<.001 <.001
FRA presurgery + FRA 1 wk after surgery	Intercept FRA presurgery FRA 1 wk	11 (3.5–47) 0.7 (0.5-1.0) 0.4 (0.2-0.6)	<.001 .03 <.001

Abbreviations: GT, gastrostomy tube; FRA, feeding readiness assessment.
[a]Estimates are provided with the 95% confidence interval.

TABLE 3 Threshold, sensitivity, specificity, and AUC for each model[a]

Model	Sensitivity	Specificity	AUC
FRA presurgery	0.72 (0.55-0.90)	0.73 (0.61-0.85)	0.78 (0.67-0.89)
FRA 1 week after surgery	0.79 (0.66-0.93)	0.85 (0.73-0.95)	0.89 (0.82-0.96)
FRA 2 weeks after surgery	0.86 (0.72-0.97)	0.84 (0.68-1)	0.89 (0.79-1)
FRA 3 weeks after surgery	0.57 (0.39-0.75)	1 (1-1)	0.84 (0.69-1)
FRA presurgery + FRA 1 week after surgery	0.69 (0.52-0.68)	0.93 (0.85-1)	0.91 (0.85-0.98)

Abbreviations: AUC, area under the receiver operating characteristic curve; FRA, feeding readiness assessment.
[a]Estimates are provided with the 95% bootstrapped confidence interval.

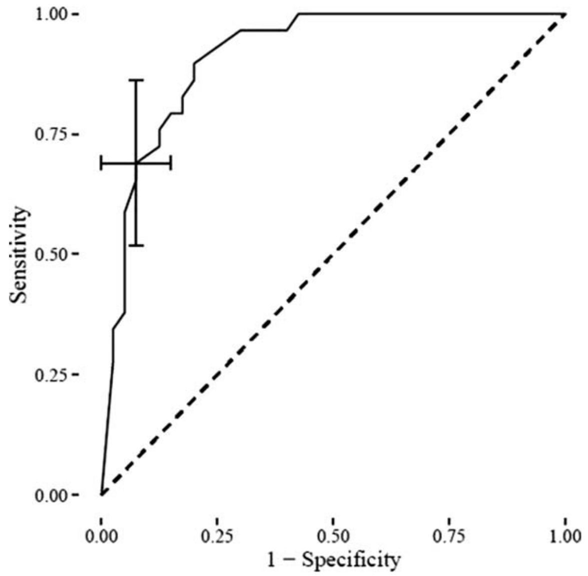

FIGURE 2 Receiver operating characteristic curve for the optimal model containing the FRA score immediately prior to surgery and one week after surgery. FRA, feeding readiness assessment

4 | DISCUSSION

In this single-center analysis, we aimed to determine if systematic measures of feeding readiness could predict need for GT to promote standardization of care. Our analysis found that the model containing the FRA scores assigned immediately preoperatively and 1 week postoperatively predicted GT placement prior to hospital discharge with strong specificity, AUC, and prediction error.

Ours is the first study to use systematic measurements of feeding readiness early in the hospitalization to predict need for GT before hospital discharge. Many postoperative feeding algorithms make decisions about advancement based progression of feeding skills.[15] However, it is often difficult to determine precisely where a patient falls on the continuum of feeding abilities, especially after congenital heart surgery. Our heart institute found this to be a key driver in variability of practice, whereby individual biases and subjective decisions about feeding skills contributed to prolonged hospital length of stay.[16] This challenge is shared by many other centers.[7,11,20,21] We therefore promoted a shared mental model (ie, the FRA score) to maximize consistency and minimize the subjectivity involved in feeding skill assessments. Ad hoc analyses revealed no significant distributional differences in FRA scores assigned by individual members of our feeding team. Thus, we suspect that decisions about feeding progress can be made by any provider in our heart institute based on an assessment that is reliable and universally understood.

The key advantage of using a shared mental model to assess feeding progress is the ability to create a shared understanding of those at high-risk for prolonged feeding difficulties. In our analysis, the combination of presurgical and 1-week postoperative FRA scores successfully identified 69% of all patients that would eventually need a GT by 1 week after surgery. Early risk stratification may influence feeding team resource allocation and prompt earlier discussions about the possibility of home supplemental tube feeding. This may promote standardization of care and communication to families, especially when care transitions occur (eg, different providers, transfer from intensive care to step down care). In our heart center, the FRA forms a crucial part of our postoperative feeding algorithm. These findings highlight the value in using a shared mental model of feeding readiness to guide feeding plans, which may improve our overall algorithm adherence and other key metrics such as parental satisfaction and LOS.

The model containing a combination of presurgical and 1-week postoperative FRA had higher utility than any individual FRA. This suggests that both baseline feeding skills and the rate at which those skills are regained after cardiac surgery are important in predicting prolonged feeding difficulty. We found that patients who took at least 50% of their feeds orally prior to surgery (FRA 2C or 3) were discharged on oral-only feeds, regardless of their FRA score 1 week after surgery. This may support recent associations between any assisted tube feeding preoperatively and need for supplemental tube feeding at hospital discharge.[22] Cardiac surgery with cardiopulmonary bypass, often with long aortic cross-clamp times and the use of deep hypothermic circulatory arrest, likely explains the loss of oral-motor skills found in many patients in the immediate postoperative period.[23,24] Interventions aimed at improving preoperative oral-motor skills have been associated with decreased risk of prolonged feeding difficulties postoperatively,[25] and the degree to which this protects against the anticipated losses in feeding skills after heart surgery should be further explored in multi-

Pre-surgery FRA \ 1 week FRA	Pre-feeding	Non-nutritive sucking	Therapeutic tastes	Nutritive sucking 1	Nutritive sucking 2a	Nutritive sucking 2b	Nutritive sucking 2c	Nutritive sucking 3
Pre-feeding	Predicted GT	Predicted GT	No GT	No GT	No GT	No GT	No GT	No GT
Non-nutritive sucking	Predicted GT	Predicted GT	No GT	No GT	No GT	No GT	No GT	No GT
Therapeutic tastes	Predicted GT	Predicted GT	No GT	No GT	No GT	No GT	No GT	No GT
Nutritive sucking 1	Predicted GT	No GT	No GT	No GT	No GT	No GT	No GT	No GT
Nutritive sucking 2a	Predicted GT	No GT	No GT	No GT	No GT	No GT	No GT	No GT
Nutritive sucking 2b	Predicted GT	No GT	No GT	No GT	No GT	No GT	No GT	No GT
Nutritive sucking 2c	No GT	No GT	No GT	No GT	No GT	No GT	No GT	No GT
Nutritive sucking 3	No GT	No GT	No GT	No GT	No GT	No GT	No GT	No GT

FIGURE 3 Prediction tool created from the model containing the presurgery and one week postoperative FRA. FRA, feeding readiness assessment; GT, gastrostomy tube

center collaborations. Our study provides a framework for studying interventions to promote oral feeding skills, providing a means of measuring feeding skills (eg, the FRA) as an outcome.

Prior studies have used surrogates of disease severity to predict prolonged feeding difficulties after cardiac surgery. Single ventricle physiology, surgical complexity, and postoperative lengths of mechanical ventilation and CICU stay have been associated with protracted oral feeding challenges.[22,24,26,27] Our analysis included a heterogeneous cohort of infants ≤3 months undergoing their first cardiac surgery. We found that the addition of disease severity surrogates, including the STAT surgical complexity category and CICU LOS, did not improve the predictive ability of the FRA. They were thus excluded from the final model. This supports our anecdotal experience that feeding outcomes may be vastly different for two patients that underwent the same, high-risk surgery. Thus, using direct measurements of feeding skills may have more utility in predicting need for GT than indirect measurements of variables known to impact feeding skills. This should be explored in future intermediate and long-term studies of feeding outcomes in this high-risk population.

This study has the following limitations: first, this was a single center retrospective analysis, which by its design limits easy generalizability. Second, though our study illustrated associations between FRA score and GT placement before discharge, other reasons for needing supplemental tube feedings at discharge not related to feeding skills (eg, aspiration) were not explored. The false positive rate of 7.5% translated to three patients during the 1-year study who ultimately discharged on oral-only feeds despite being predicted to need a GT by the model. This highlights the importance of making plans for GT only after multidisciplinary, family-centered discussions and utilizing the model for risk stratification, not prescriptive purposes.

Finally, the model constructed from these data did not account for all methods of discharge supplemental tube feeding (eg, our center did not discharge patients with NG tubes during the study period). As a single-center quality improvement initiative, it was not our intention to generalize our results to other centers that more routinely discharge patients with NG tubes. Rather, we highlight our methods used for standardization of care and the ability of a systematic, shared mental model of feeding progress to earlier identify those at high-risk for feeding difficulties.

5 | CONCLUSIONS

In this analysis, systematic and standardized measurements of feeding readiness employed immediately before and one week after congenital cardiac surgery predicted need for GT placement prior to hospital discharge. The FRA score may be used to risk stratify patients based on likelihood of prolonged feeding difficulties, which may further improve standardization of care.

CONFLICT OF INTEREST

The authors have no conflicts of interest relevant to this article to disclose.

AUTHOR CONTRIBUTIONS

Concept/design, data analysis/interpretation, drafting article, critical revision of article, approval of article, statistics, data collection: Ehrmann

Concept/design, data analysis/interpretation, statistics, critical revision of article, approval of article: Mulvahill

Concept/design, data analysis/interpretation, critical revision of article, approval of article, data collection: Harendt, Church, Stimmler, Batz, Rodgers

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