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Necrotizing Enterocolitis in PC⁴ and PAC³

April 14-16, 2025/Jennifer Schramm, MD Johns Hopkins School of Medicine
Jeffrey Weiner, MD Vanderbilt Children's Medical Center

Necrotizing Enterocolitis in Two Major Centers



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Acute Care Cardiology



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What the NEC? High NEC Rate Center Experience

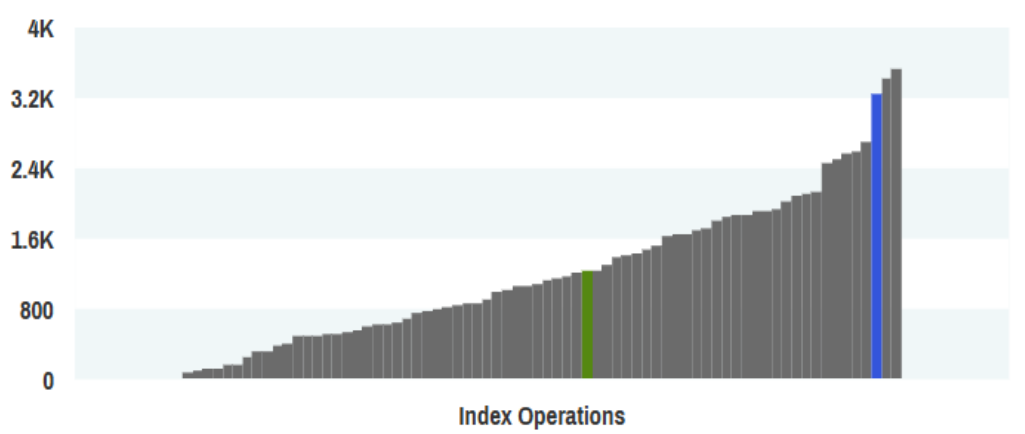
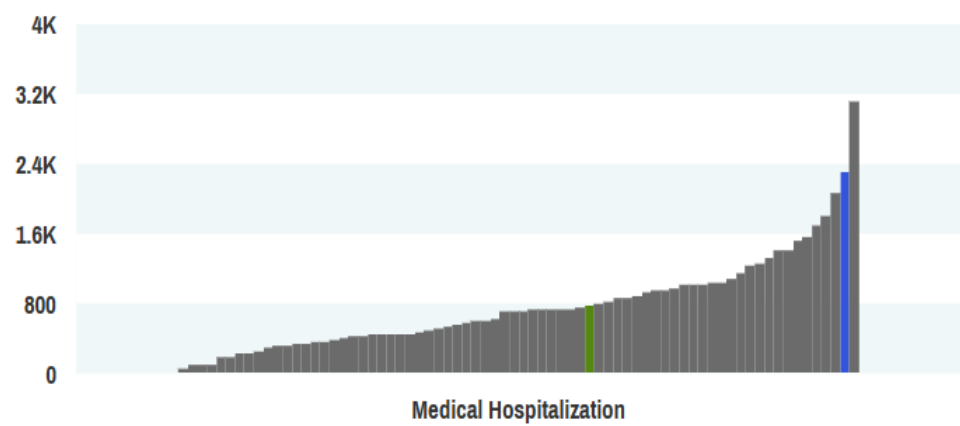
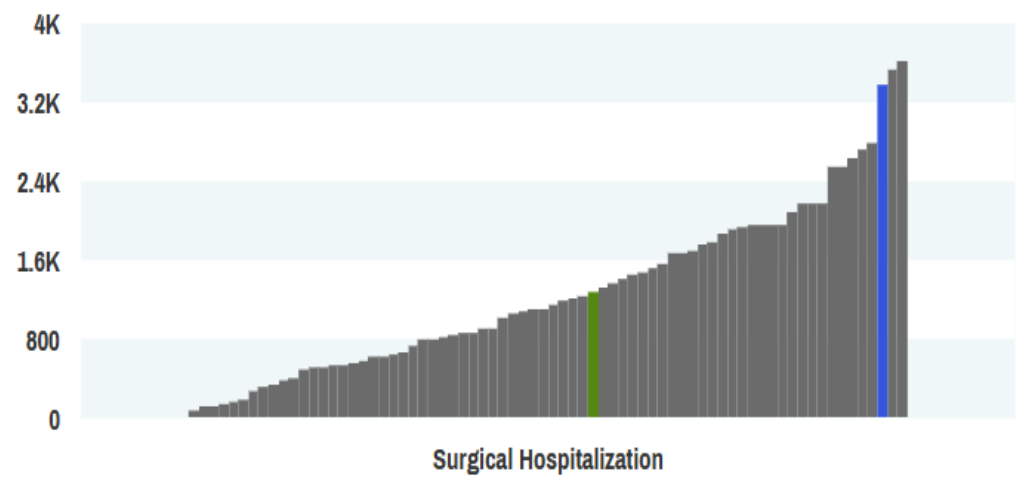
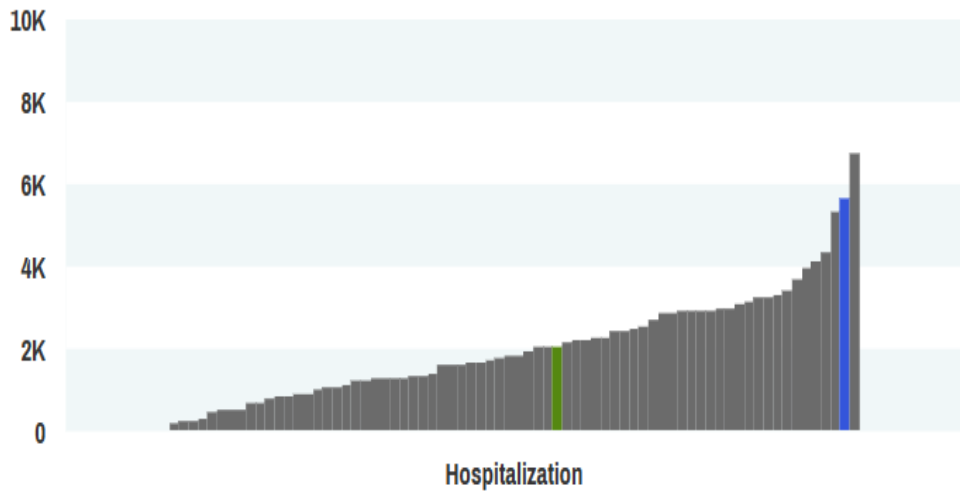
Jarae Payne, MSN, CPNP-AC



Objectives

- Review current necrotizing enterocolitis (NEC) rates
- Examine evaluation of retrospective analyses
- Describe multidisciplinary approach
- Review feeding pathway
- Discuss next steps

Patient Volumes

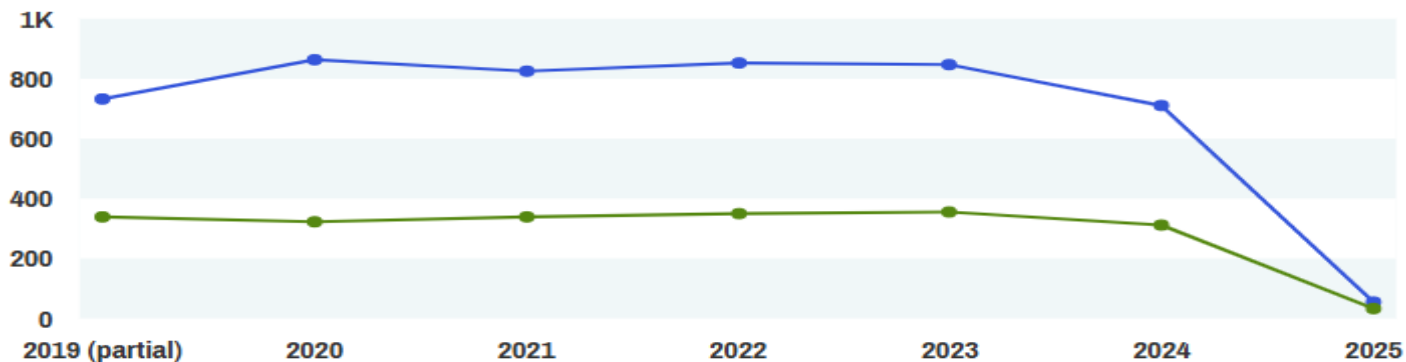


LEGEND ■ Other Sites ■ Aggregate - All ■ CHOP

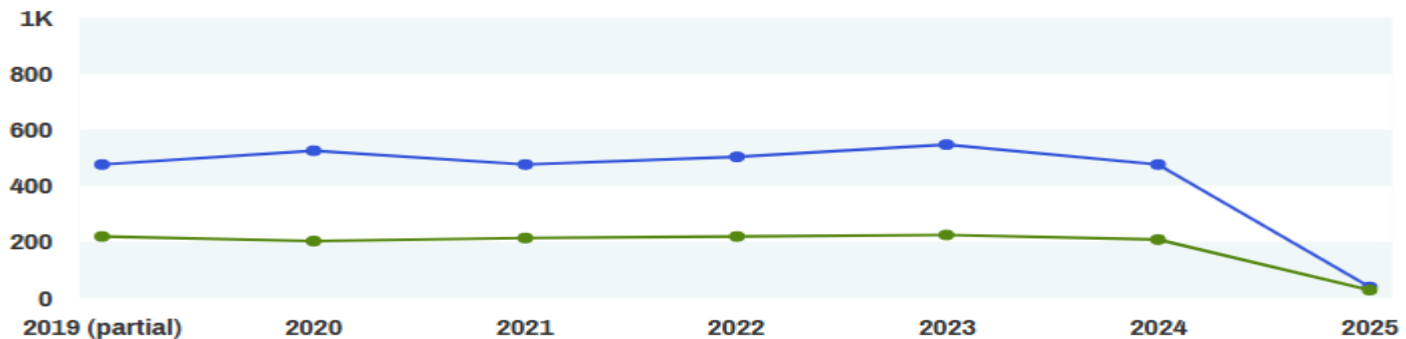


Surgical Case Volumes

CASES



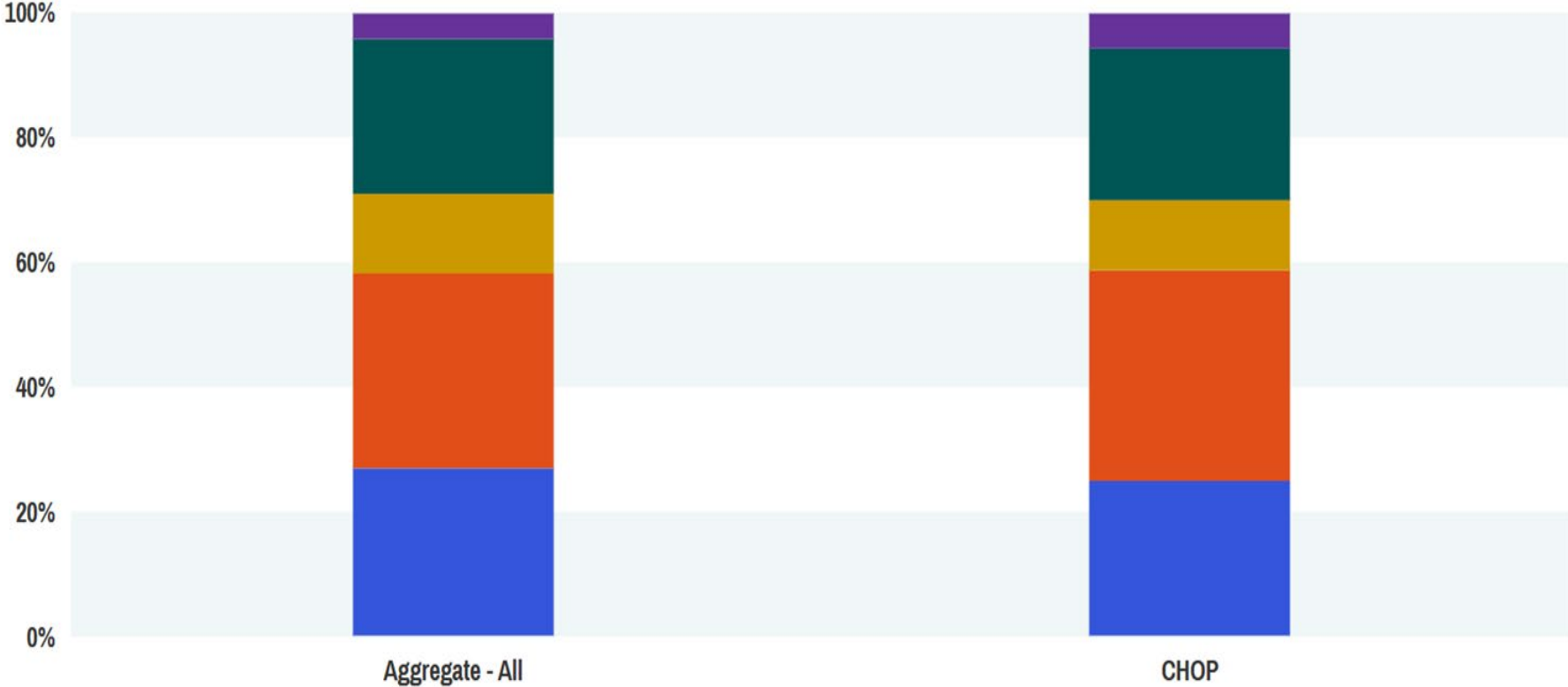
CPB CASES



LEGEND Other Sites Aggregate - All CHOP



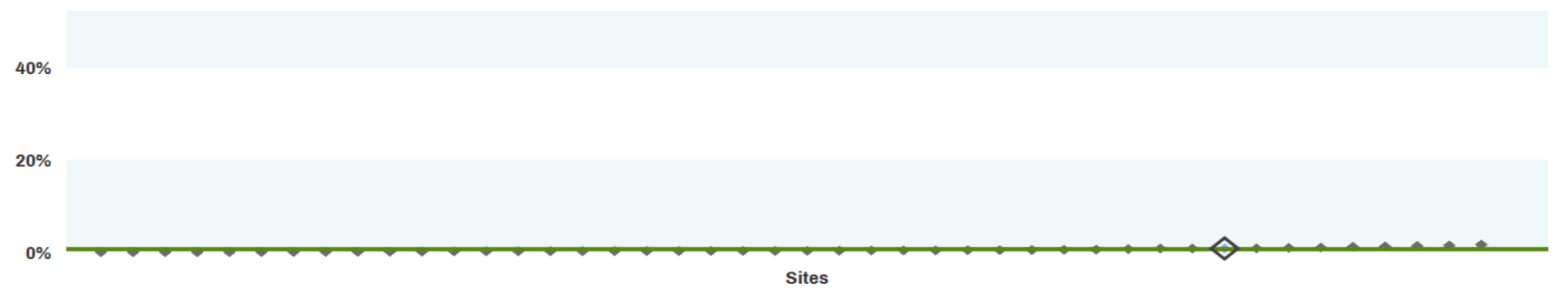
Index Operation STAT Category



■ STAT Category 1 ■ STAT Category 2 ■ STAT Category 3 ■ STAT Category 4 ■ STAT Category 5

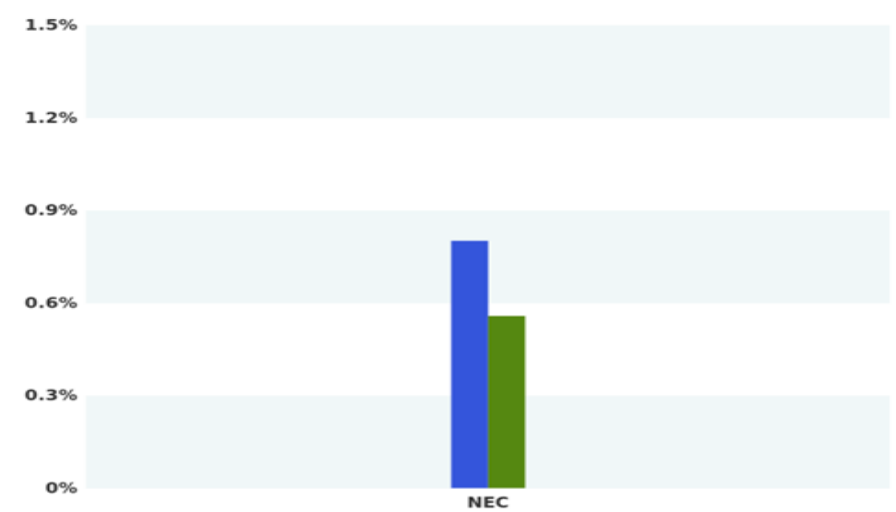


PAC³ NEC Rates



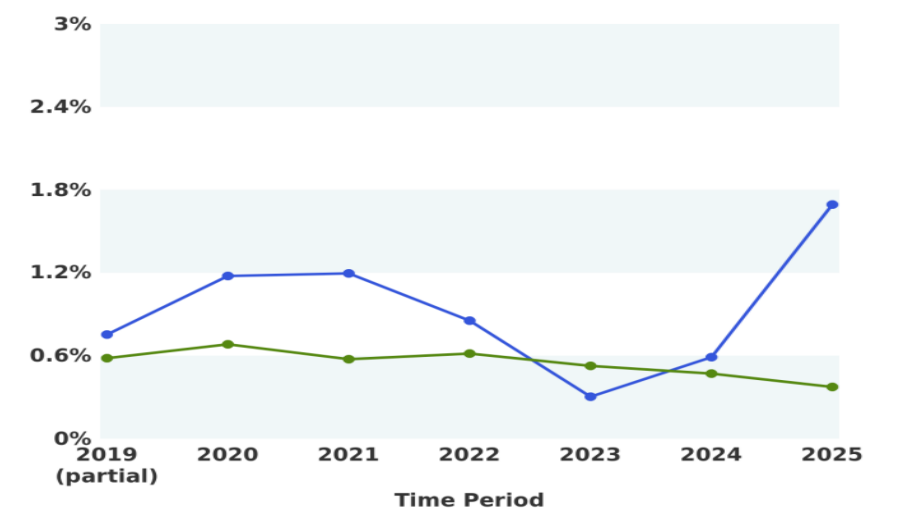
■ Other Sites ■ CHOP — Aggregate - All ■ 95% Confidence Interval

ACCU Complication - NEC



LEGEND ■ CHOP ■ Aggregate - All

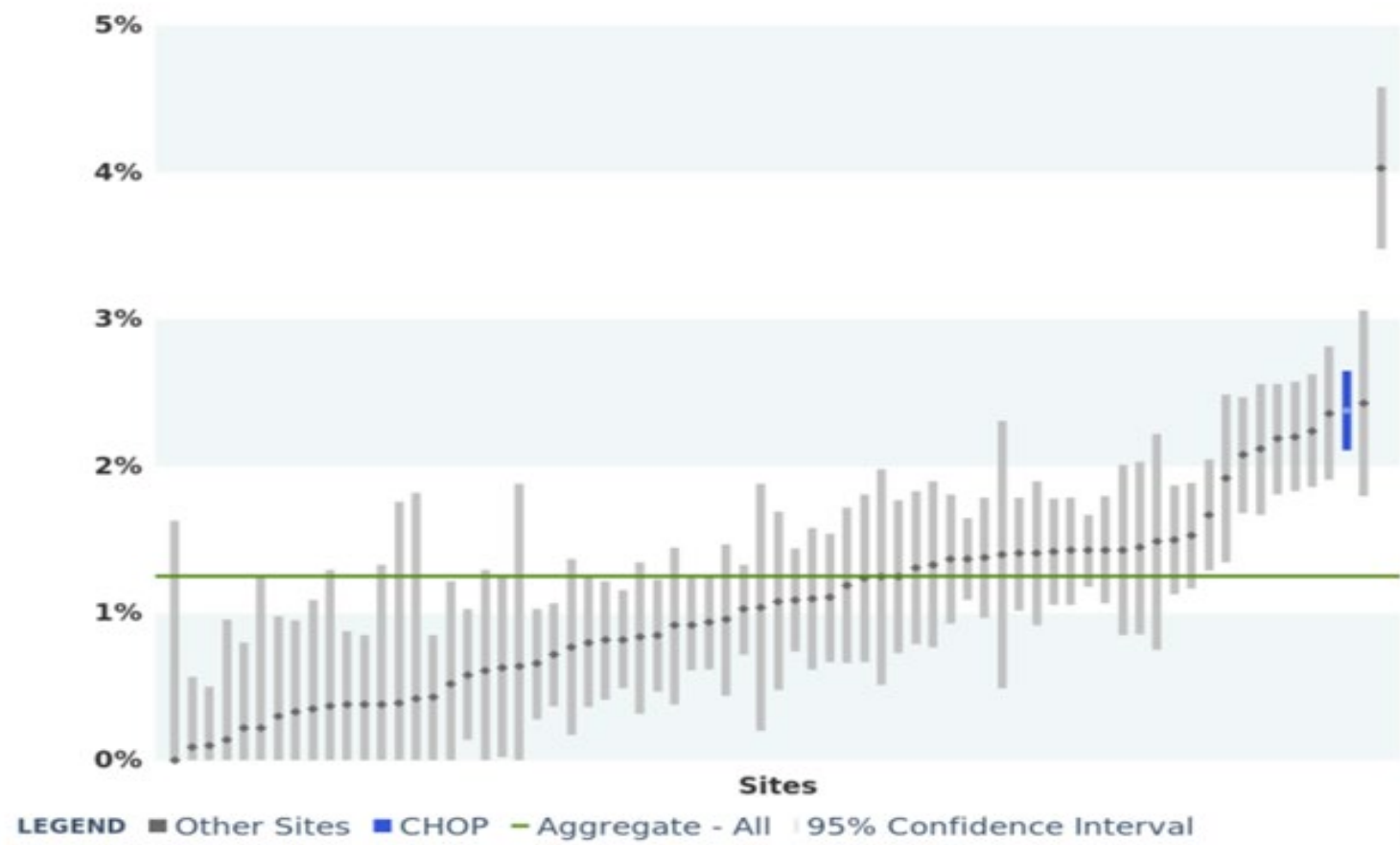
ACCU Complication - NEC



LEGEND ■ CHOP ■ Aggregate - All

PC⁴ NEC Rates

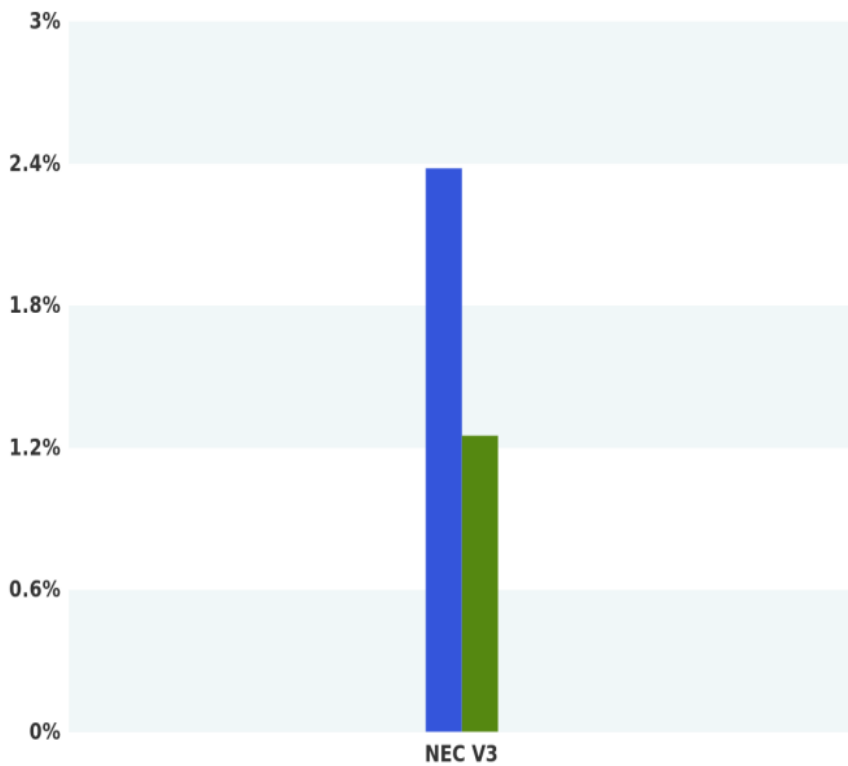
CICU Complication - NEC V3





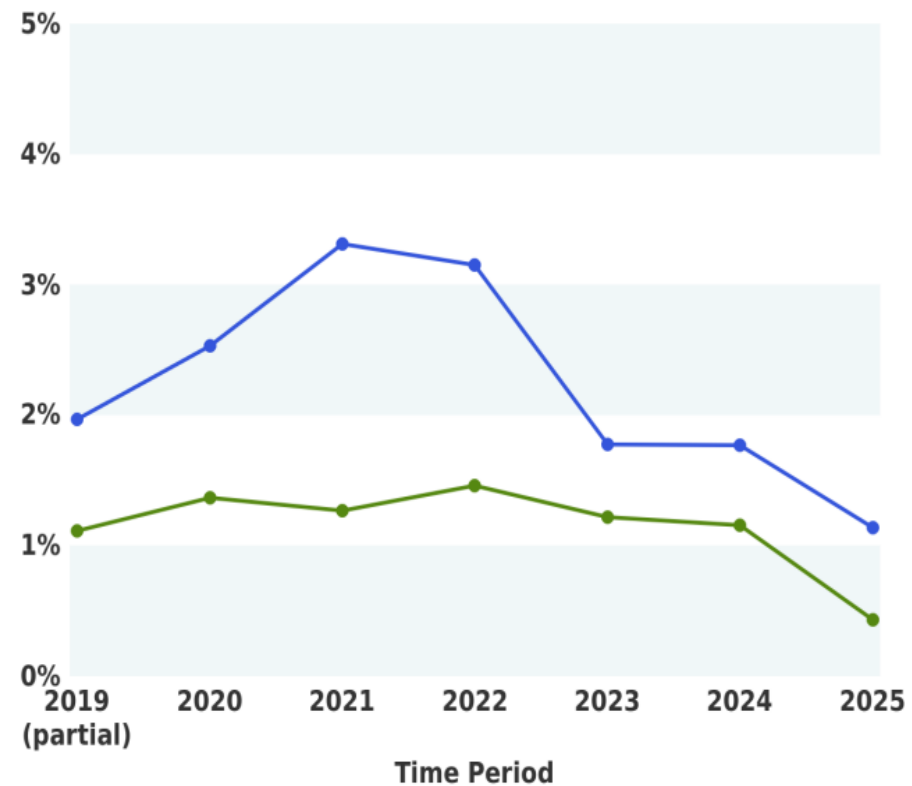
PC⁴ NEC Rates

CICU Complication - NEC V3



LEGEND ■ CHOP ■ Aggregate - All

CICU Complication - NEC V3

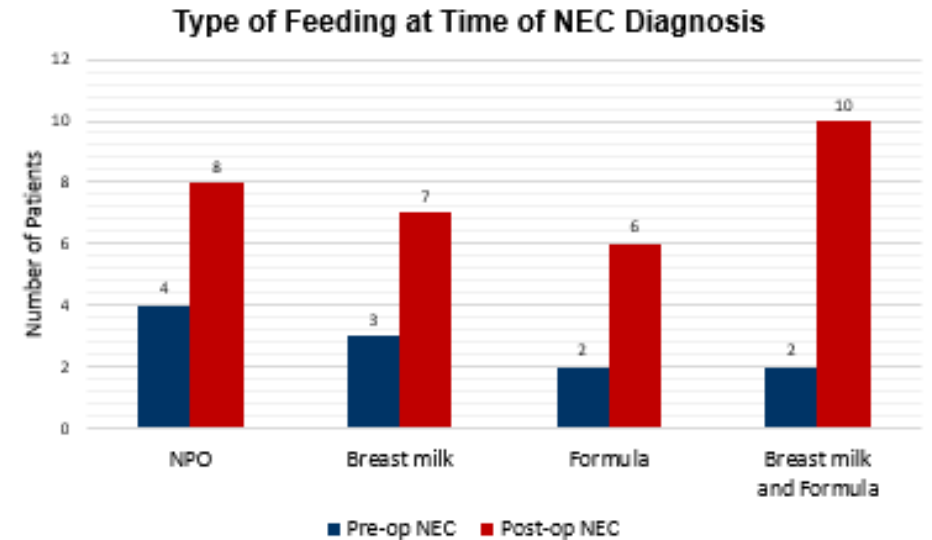
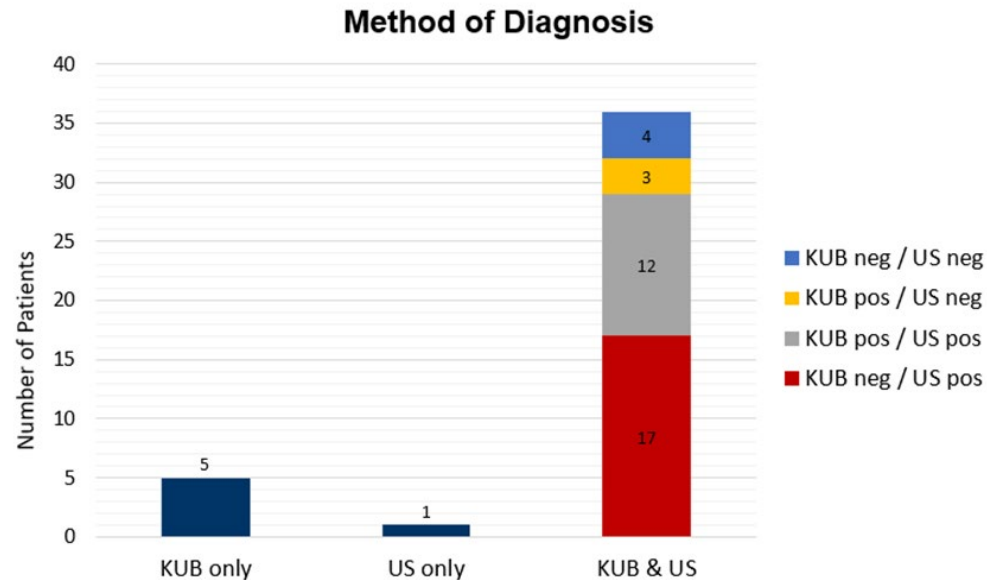


LEGEND ■ CHOP ■ Aggregate - All



Programmatic Reviews

- Evaluation of NEC in CICU surgical patients in FY13 & FY14 (Savoca et al. 2016)
 - Incidence 4.6% (42 of 912 total eligible patients)
 - No feeding regimen associated with increased risk of NEC
 - Longer length of stay and higher overall mortality rate





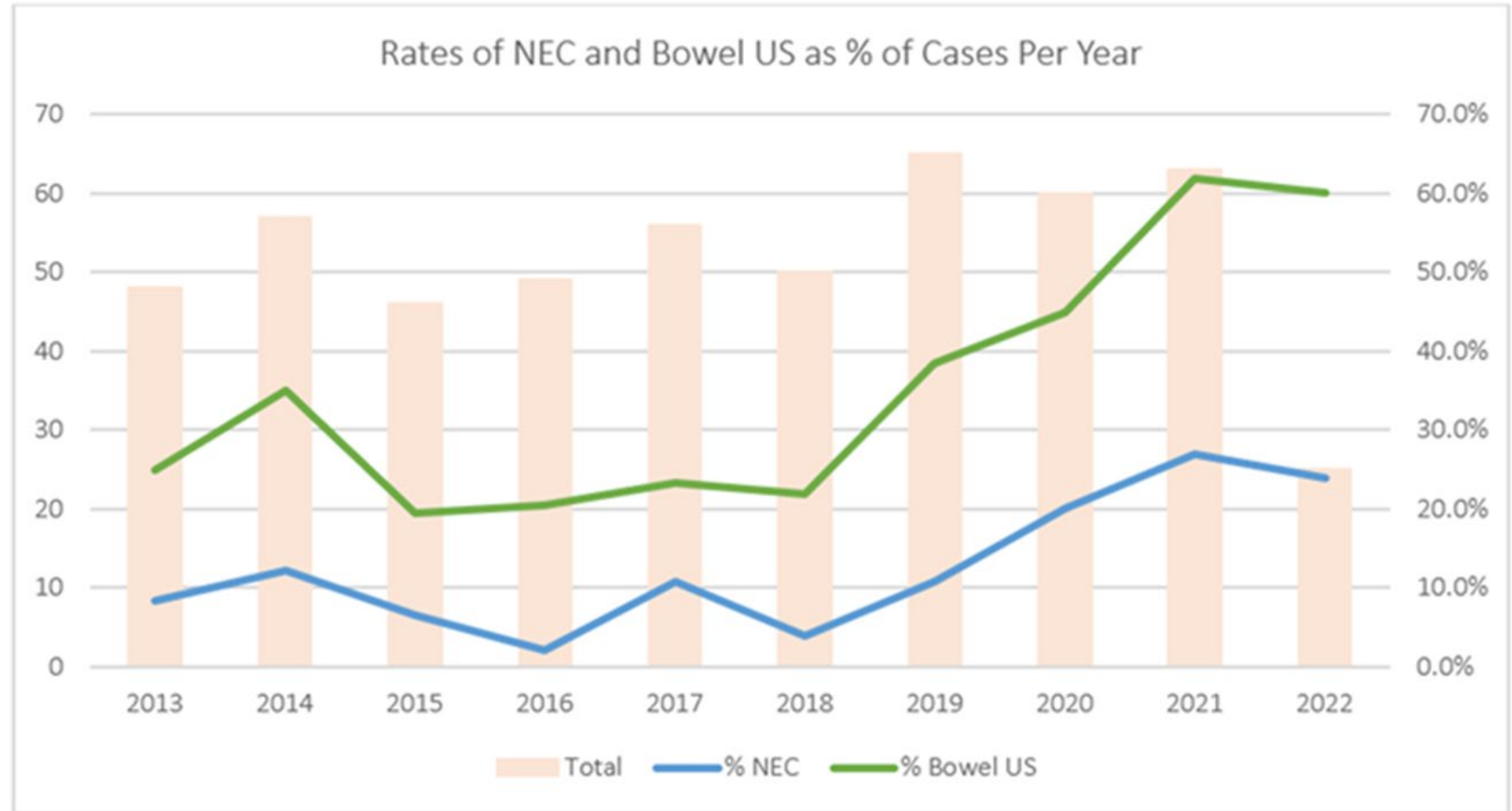
Programmatic Reviews

- 10-year retrospective review in high-risk shunt-dependent patients
 - Initial univariate analysis (FY13 to FY22)
 - 12.5% incidence in high-risk group
 - Increased ultrasound (US) utilization in diagnostics

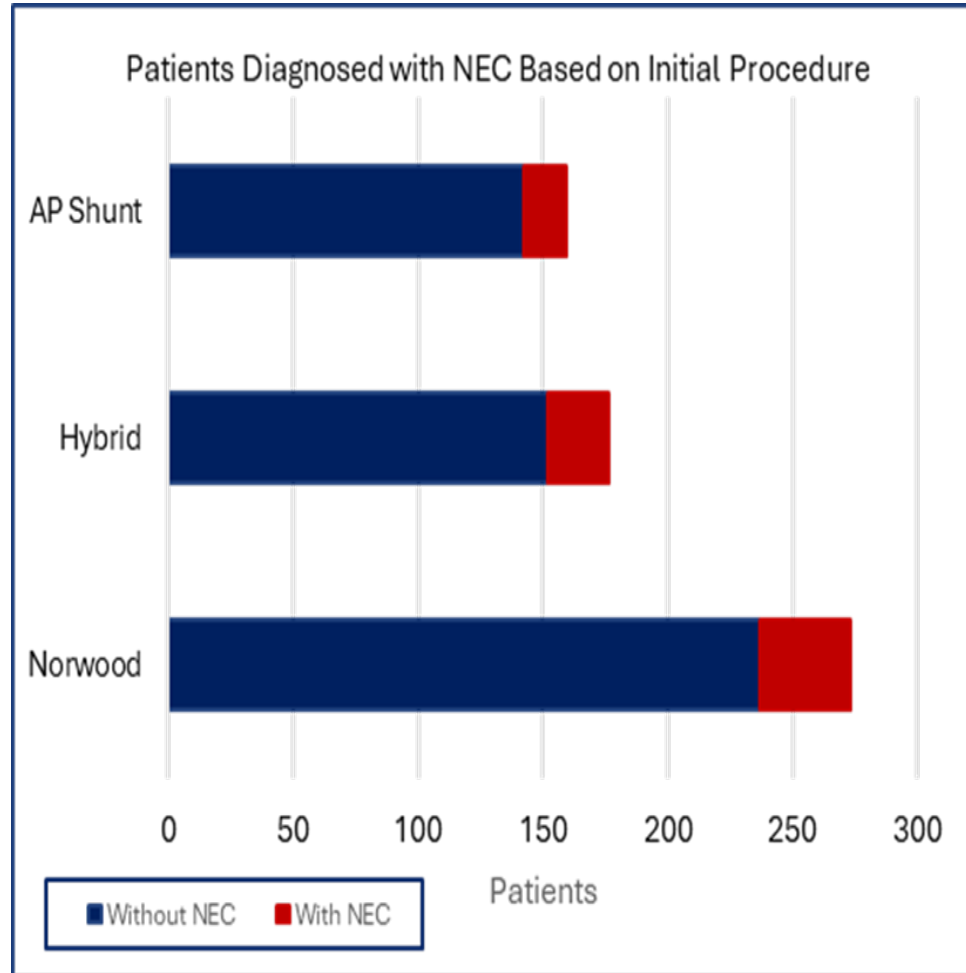
	Total Cohort (n=519)	NEC (n=65)	No NEC (n=453)	p
Index Procedure Details				
Year of Index Procedure (n, %)				0.001
2013	48 (9.2%)	4 (8.3%)	44 (91.7%)	
2014	57 (9.8%)	7 (12.3%)	50 (87.7%)	
2015	46 (8.8%)	3 (6.5%)	43 (93.5%)	
2016	59 (11.3%)	1 (1.7%)	58 (98.3%)	
2017	56 (10.8%)	6 (10.7%)	50 (89.3%)	
2018	50 (9.6%)	2 (4.0%)	48 (96.0%)	
2019	65 (12.5%)	7 (10.8%)	58 (89.2%)	
2020	60 (11.6%)	12 (20.0%)	48 (80.0%)	
2021	63 (12.1%)	17 (27.0%)	46 (73.0%)	
2022	25 (4.8%)	6 (24.0%)	19 (76.0%)	
Age at index procedure (days; median, IQR)	4.5 (2.9, 8.6)	4.5 (2.8, 8.4)	4.5 (3.0, 8.6)	0.899
Procedure type (n, %)				0.170
Norwood + shunt (n, %)	103 (19.8%)	11 (16.9%)	92 (20.3%)	
Norwood + conduit (n, %)	143 (27.6%)	21 (32.3%)	129 (28.5%)	
Shunt only (n, %)	144 (27.7%)	18 (27.7%)	126 (27.8%)	
Hybrid (n, %)	27 (5.2%)	7 (10.8%)	20 (4.4%)	
PDA stent (n, %)	94 (18.1%)	8 (12.3%)	86 (19.0%)	
Cardiopulmonary bypass (min; median, IQR)	87 (74, 109)	103 (84, 152)	86 (73, 104)	<0.001
Interstage bowel US (n, %)	181 (34.9%)	64 (98.5%)	117 (25.8%)	<0.001
Index procedure hospital LOS (median, IQR)	24.0 (15.0, 44.4)	61.1 (37.0, 152.0)	22.0 (14.4, 36.0)	<0.001
Mortality after index operation (n, %)	85 (16.4%)	16 (24.6%)	69 (15.2%)	0.055



Diagnostics: Increased US Utilization



Initial Procedure Patient Distribution





Clinical Factors

	NO NEC N = 531	NEC N = 77	p-value ²
Post-Procedure Details & Outcomes			
Post-procedure ECMO*	37 (7.0%)	13 (17%)	0.003
Post-procedure cardiac arrest*	37 (7.0%)	11 (14%)	0.026
Post-procedure seizure*	40 (7.5%)	12 (16%)	0.018
Post-procedure ventricular dysfunction*	85 (16%)	23 (30%)	0.003
Maximum post-procedure VIS*	8 (3, 12)	11 (7, 15)	<0.001
Minimum post-procedure hemoglobin*	11.3 (10.3, 12.4)	10.5 (9.8, 11.5)	<0.001
Post-procedure abdominal ultrasound*	90 (17%)	66 (86%)	<0.001
Hospital length of stay	23 (15, 37)	70 (40, 164)	<0.001
Deceased during interstage	51 (9.6%)	13 (17%)	0.052

¹n (%); Median (IQR). ²Pearson's Chi-squared test; Fisher's exact test; Wilcoxon rank sum test. *All post-procedural variables measured until NEC diagnosis or up to 21 days after intervention.



Multivariate Analysis

	OR ¹	95% CI ¹	p-value
Gestational age in weeks	0.73	0.60, 0.89	0.002
Indicator of prematurity (<37 weeks GA)	0.33	0.10, 0.98	0.054
Procedure type			
AP shunt	—	—	
Hybrid	0.75	0.36, 1.58	0.4
Norwood	1.12	0.59, 2.21	0.7
Presence of any genetic syndrome	0.93	0.49, 1.68	0.8
Presence of any chromosomal abnormality	1.14	0.66, 1.93	0.6
Era of surgery			
2013-2016	—	—	
2017-2019	1.42	0.70, 2.92	0.3
2020-2022	4.5	2.38, 8.83	<0.001

¹OR = Odds Ratio, CI = Confidence Interval



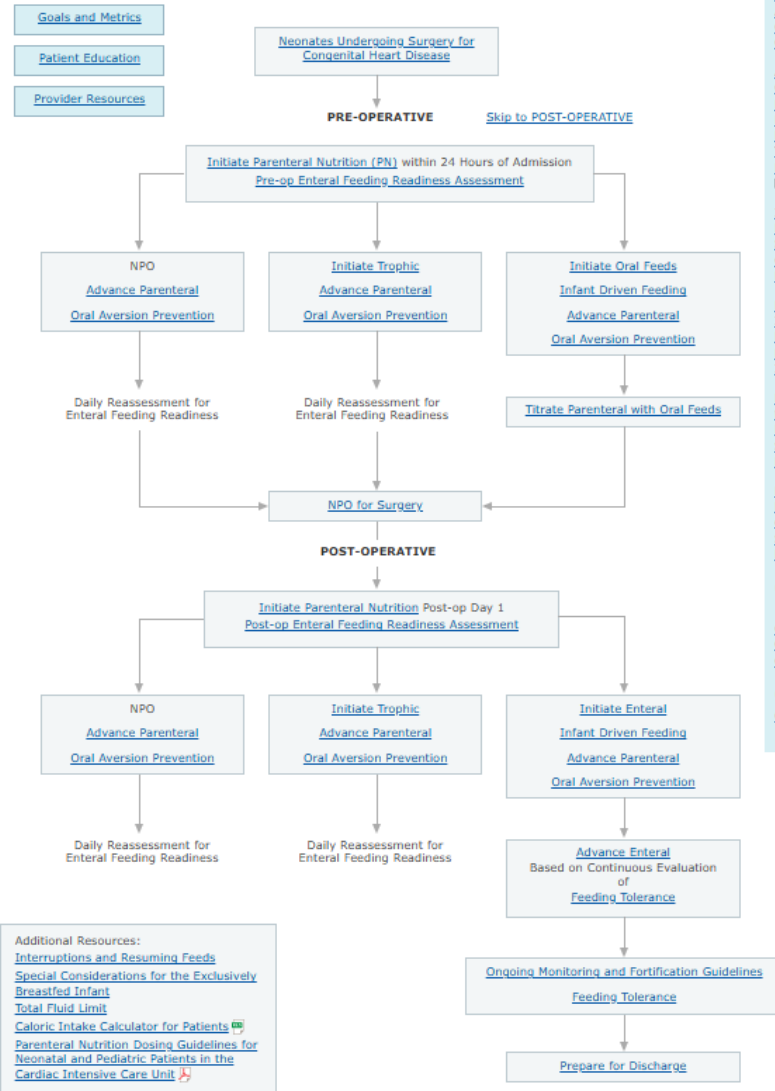
Current State: Diagnostics & Treatment

- Multidisciplinary team
 - CICU medical team
 - General surgery
 - Radiology
- Radiographs vs Ultrasounds
- Near-infrared spectroscopy (NIRS)
- General surgery
 - Treatment timelines: 2, 5, & 7 days NPO and antibiotics
- Post-diagnosis feeding approach



Feeding Pathway

CICU Clinical Pathway for Nutrition of Neonates Undergoing Surgery for Congenital Heart Disease



Evidence

["Low Energy Intakes are Associated with Adverse Outcomes in Infants After Open Heart Surgery."](#)

[ABM Clinical Protocol #2: Guidelines for Hospital Discharge of the Breastfeeding Term Newborn and Mother: "The Going Home Protocol," Revised 2014](#)

[Improved Nutrition Delivery and Nutrition Status in Critically Ill Children with Heart Disease.](#)

[Nutrition Algorithms for Infants with Hypoplastic Left Heart Syndrome: Birth Through the First Interstage Period](#)

[Enteral Feeding Algorithm for Infants with Hypoplastic Left Heart Syndrome Post Stage 1 Palliation](#)

[Resting Energy Expenditure at 3 Months of Age Following Neonatal Surgery for Congenital Heart Disease.](#)

Community Resources

[Growing Stronger with CHD: How an NG Tube Can Help](#)

CHOP Program
CHOP Cardiac Center



Feeding Pathway

Nutrition for Neonates with Congenital Heart Disease Clinical Pathway — CICU

Initiate Enteral Feeds

After assessing feeding readiness, use this information to guide initiation of enteral feeds. Determine type, route and rate and volume and advance while monitoring tolerance to goal of 150 mL/kg/day.

Readiness Assessment includes:

- Adequate cardiac output
- Stable hemodynamics, weaning inotropic support
- Stable rhythm or stable arrhythmia
- No clinical seizure activity for > 12 hours
- No signs/symptoms of NEC or gut ischemia

Step 1

Determine Type of Feed	Human milk or donor milk preferred, based on mother's feeding plan If human milk is not available or parent preference is to use formula: ≥ 37 weeks – Enfamil Infant 20 cal/oz, Good Start Gentle 20 cal/oz, Similac Advance 20 cal/oz ≥ 35 to < 37 weeks – Enfamil Enfacare 22 cal/oz, Similac Expert Care NeoSure 22 cal/oz
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Step 2

Determine Route	BOLUS PO + NG	Demonstrating oral feeding readiness based on these guidelines: On ≤ 2 L NC Resp rate < 70 breaths per minute Demonstrating feeding cues: Awake/alert Rooting Sucking on pacifier Hands to mouth Document feeding cues in EPIC Intake Flowsheet.
	CONTINUOUS NG or ND If ND cannot be placed at the bedside, may attempt continuous NG feeds and consider IR placement of post-pyloric ND tube.	Does not demonstrate oral feeding readiness as listed above. Conditions that require post-pyloric feeds: Congenital GI anomalies Known gastroparesis Severe GERD High-aspiration risk Ileus



Feeding Pathway

Step 3

Determine Appropriate Rate and Advance			
	Continuous (NG or ND)	Bolus (PO + NG)	Goal
Normal Advance ≥ 3 days of age	< 3 kg Initiate at 1 mL/hr Advance by 1 mL/hr q 6 hr to goal ≥ 3 kg Initiate at 2 mL/hr Advance by 2 mL/hr q 6 hr to goal	Initiate at 15 mL q 3 hr Advance by 5 mL q 6 hr to goal Add in the diet order comments the dot phrase .cardiacpoadlib	Advance to goal of 150 mL/kg/day
Slow Advance < 37 weeks gestation < 3 days of age Ready to advance from NPO or trophic feeds	< 3 kg Initiate at 1 mL/hr Advance by 1 mL/hr q 12 hr to goal ≥ 3 kg Initiate at 1 mL/hr Advance by 1 mL/hr q 6 hr to goal	Initiate at 5 mL q 3 hr Advance by 5 mL q 6 hr to goal Add in the diet order comments the dot phrase .cardiacpoadlib	

Advancing (or Titrating) PN While Advancing Enteral Nutrition:

- When enteral feeds are initiated, any enteral volume administered may exceed the intravenous TFL of 100 mL/kg/day up to 130 mL/kg/day prior to weaning PN.
- Continue IV lipids until enteral caloric intake \geq 100 kcal/kg/day.
- Once goal enteral nutrition achieved, discontinue TFL order.
- Discuss/evaluate TFL order daily.

Advancing to Goal Calories

- Goal volume of 150 mL/kg/day will provide minimum requirement of 100 kcal/kg/day.
- Once goal volume is reached, assess growth and determine further caloric goals with dietitian. Infants may require a further increase in volume, hindmilk and/or fortification (See [Fortification Guidelines](#)).

Nursing Documentation of Enteral Calories (kcal/kg/day):

- In EPIC Intake Flowsheet, choose "add rows" and search "kcal". Then choose "Caloric intake past 24 hours."
- For every feed amount that is documented in EPIC, also document the calorie per ounce so that EPIC can accurately calculate the enteral intake (kcal/kg) received.
- The total enteral kcal/kg/day will automatically appear in the CICU and CCU rounding tools. Read the 6 a.m. value when presenting daily intake on rounds.

[See Epic Documentation of Enteral Calories](#)



Takeaways

- Multidisciplinary collaboration to unify diagnosis and treatment
- Ultrasound use leading to conservative treatment plans
- Risk stratification in high-risk populations

Where do we go from here?

- Multicenter coalition to evaluate and research cardiac NEC
- Dedicated evaluation of ultrasound use in NEC diagnoses

Thank You!
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NEC Prevention at Dell Children's Medical Center

Michael Y Liu, MD

April 15, 2025

PAC³/PC⁴ Spring Conference



Objectives

- Overview of patient distribution and care at DCMC
- CCU management strategies
- Surgical considerations
- Diagnosis of NEC and confounding variables

Dell Children's Medical Center Heart Center Overview

CHD patients can be admitted into the following units

- Cardiac Intensive Care Unit: 24 beds
- Acute Care Cardiology: 24 beds
- Neonatal Intensive Care Unit: 48 beds

Most neonates with complex CHD will be admitted to our CCU

- Single ventricle physiology
- Ductal dependent physiology
- Cyanotic heart disease

Dell Children's Medical Center Heart Center Overview

CHD neonates to be admitted to NICU

- Neonates < 34 weeks or < 1800 grams with CHD (case-by-case)

Patients admitted to Acute Care Cardiology

- Postsurgical neonates after CCU deintensification
- *Except for patients with BTT shunt-dependent circulations

Daily Heart Center multidisciplinary rounds in morning

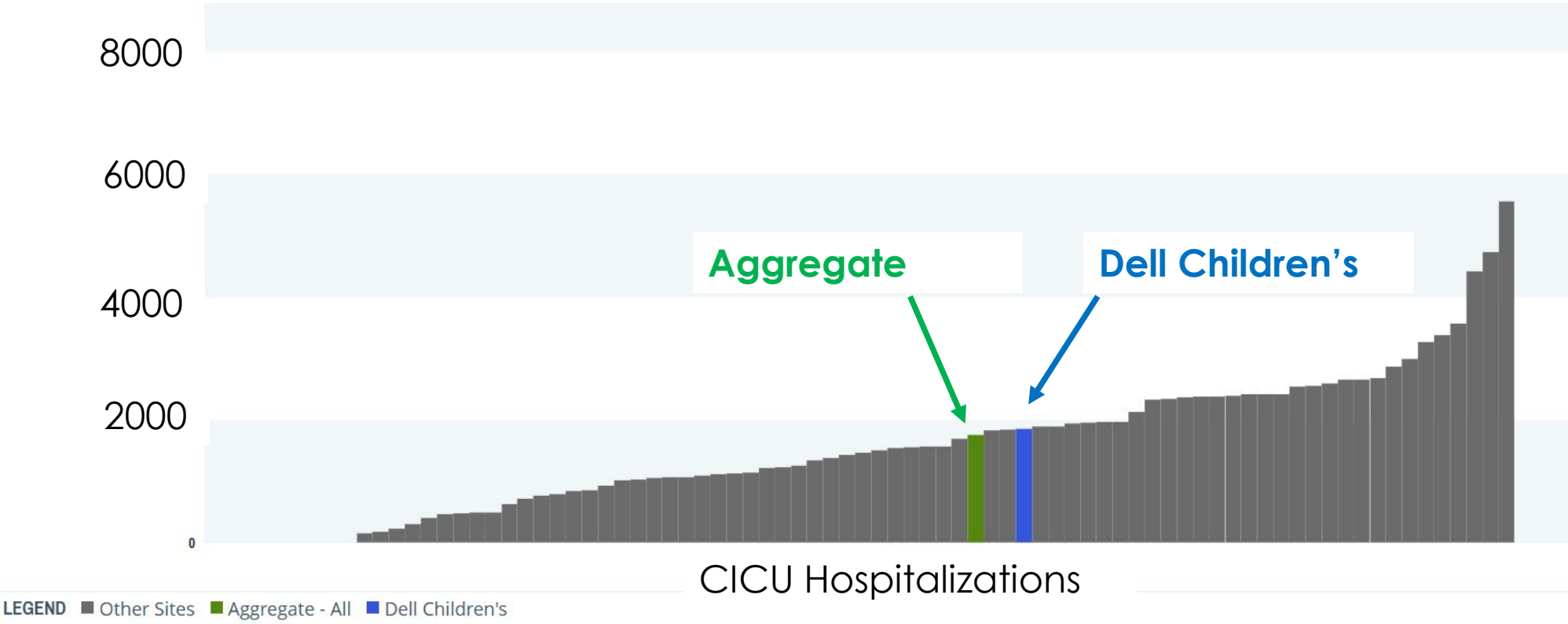


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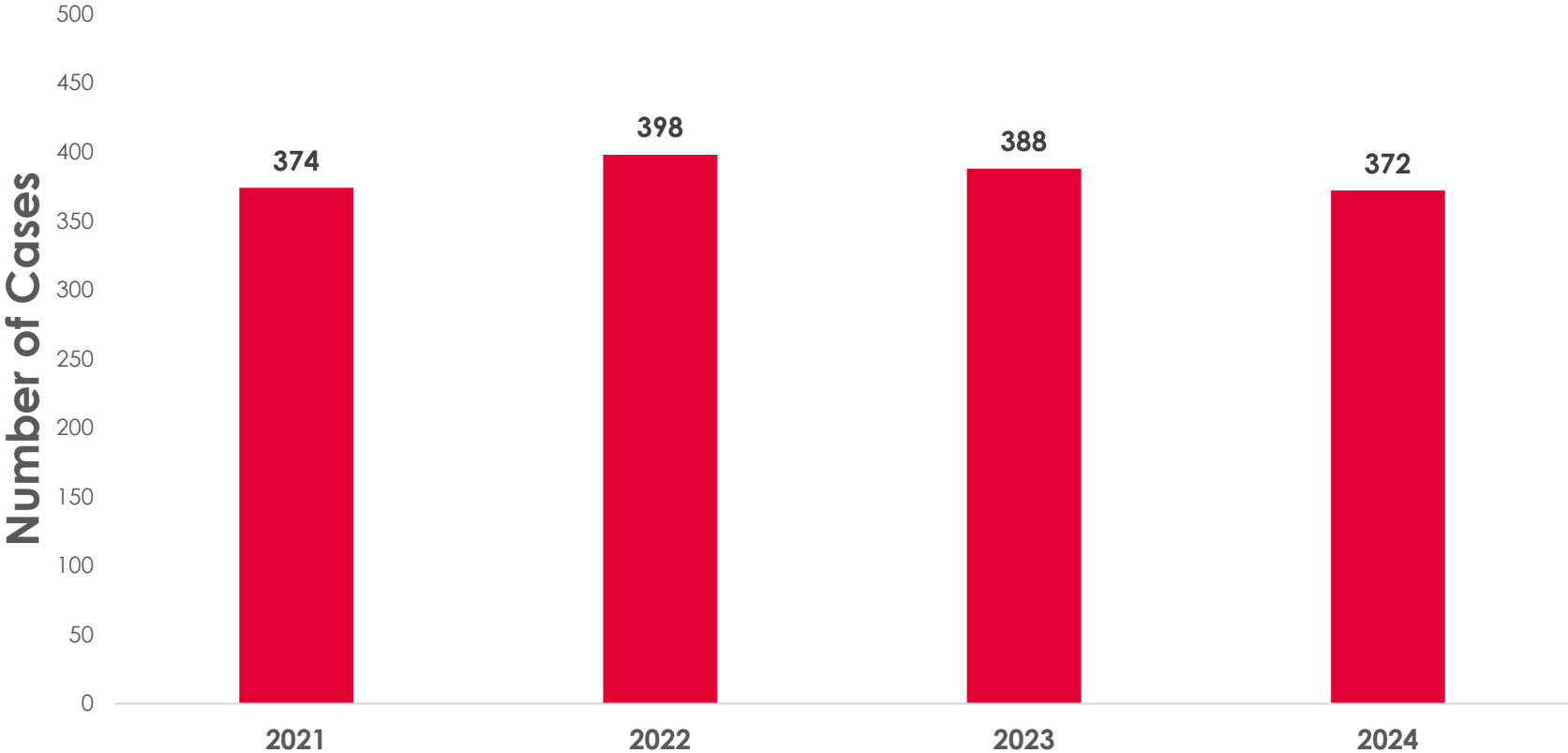
NEC Rate Comparison

Dell Children's Medical Center (PC ⁴)	PC ⁴ Aggregate	Dell Children's Medical Center (PAC ³)	PAC ³ Aggregate
0.38%	1.25%	0.044%	0.56%

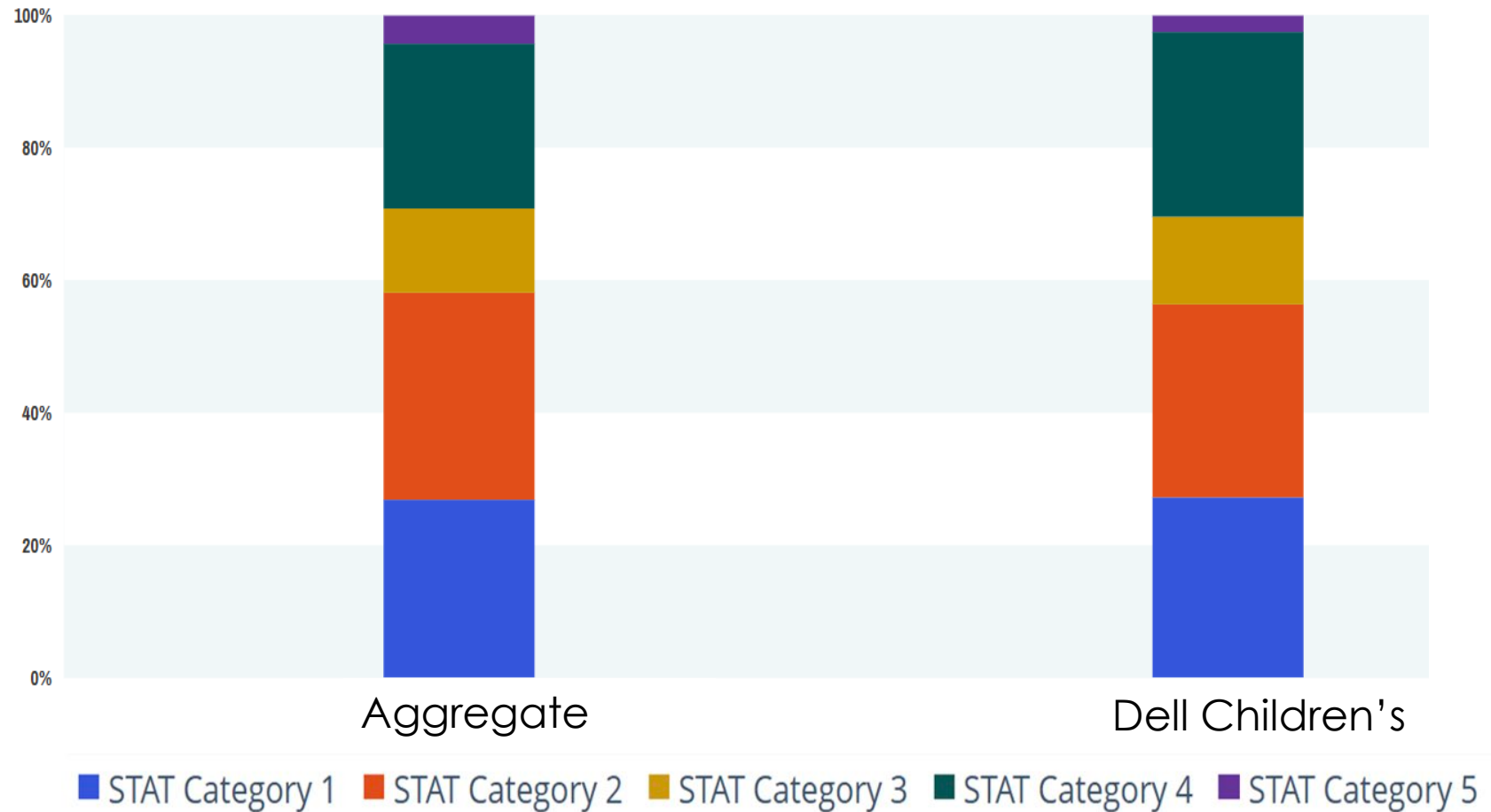
Total Admissions 2020-2024



Surgical Volume by Year



Index Operation STAT Category



Outcomes by Age Category (2021-2024)

Age Category	Surgery Date	Surgery Date	Eligible Index Cases	Perioperative Mortality (N)	Perioperative Mortality (%)	STS Mortality %
Neonate	1/4/2021	12/31/2024	238	10	4.2%	7.4%
Infant	1/4/2021	12/31/2024	405	9	2.2%	2.6%
Child	1/4/2021	12/31/2024	448	4	0.9%	1.1%
Adult	1/4/2021	12/31/2024	93	0	0.0%	1.7%
Grand Total			1,184	23	1.9%	12.8%

CCU management strategies

High-risk patients are generally classified into:

- Patients with systemic outflow obstruction
- Single Ventricle Physiology
- Patients with other significant diastolic runoff lesions (which can encompass the above)

CCU management strategies

Neonates with high-risk lesions:

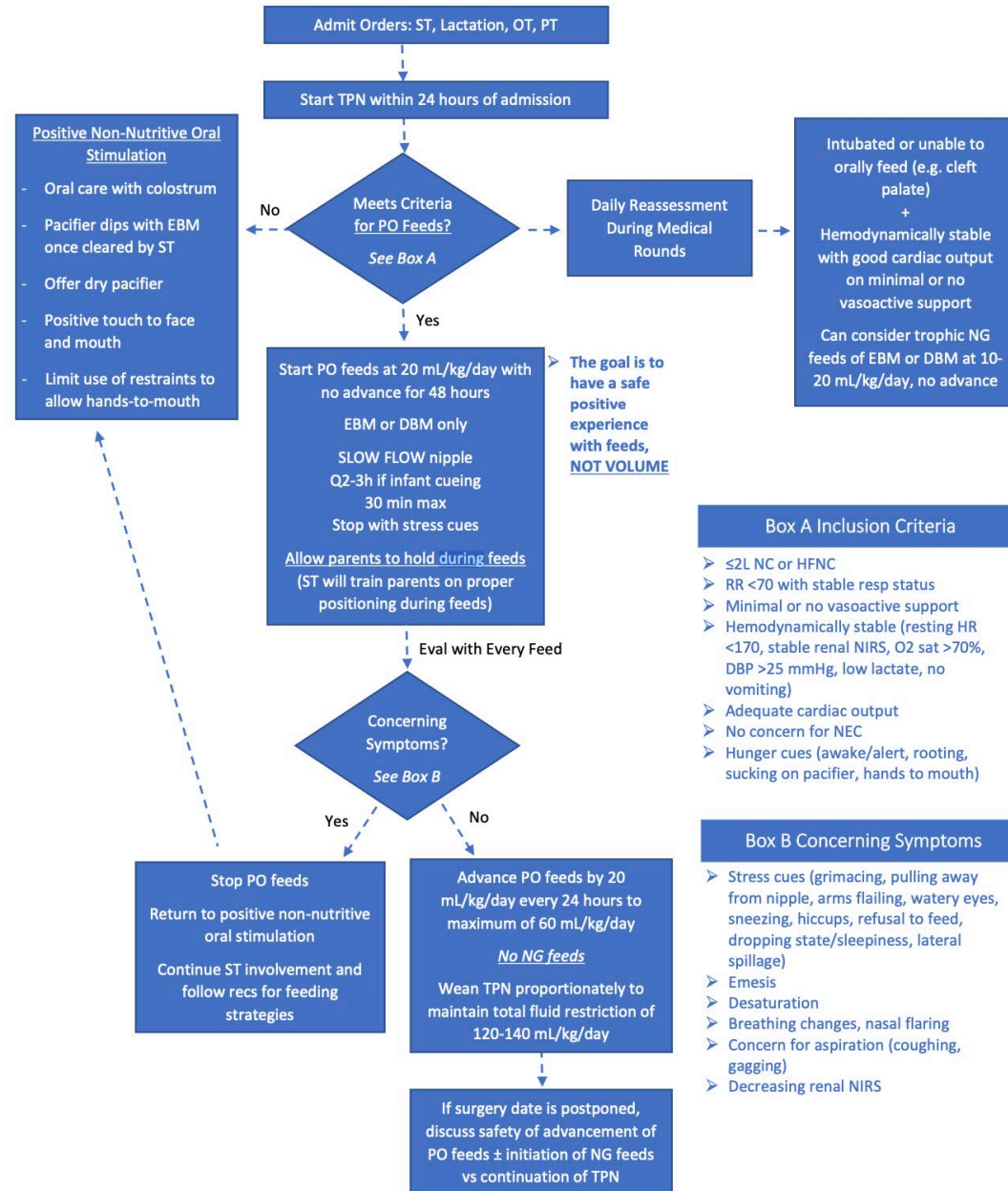
- NPO with IVF for 24 hours and then start trophic feeds on DOL 1 with TPN initiation
- If prostaglandins needed, maintain at low-dose (~0.02 mcg/kg/min)
- High-risk feeding protocol is instated

- Monitoring includes:
 - Umbilical arterial pressure monitoring
 - NIRS-cerebral and flank; increased concerns if <40% or if downtrending
 - Use of abdominal circumference assessment and gastric residual assessment is attending-dependent

TCPCHD Preoperative Feeding Pathway

For neonates with high risk congenital heart disease who are >35 weeks gestation, >2 kg and expected to undergo heart surgery in the first 14 days of life

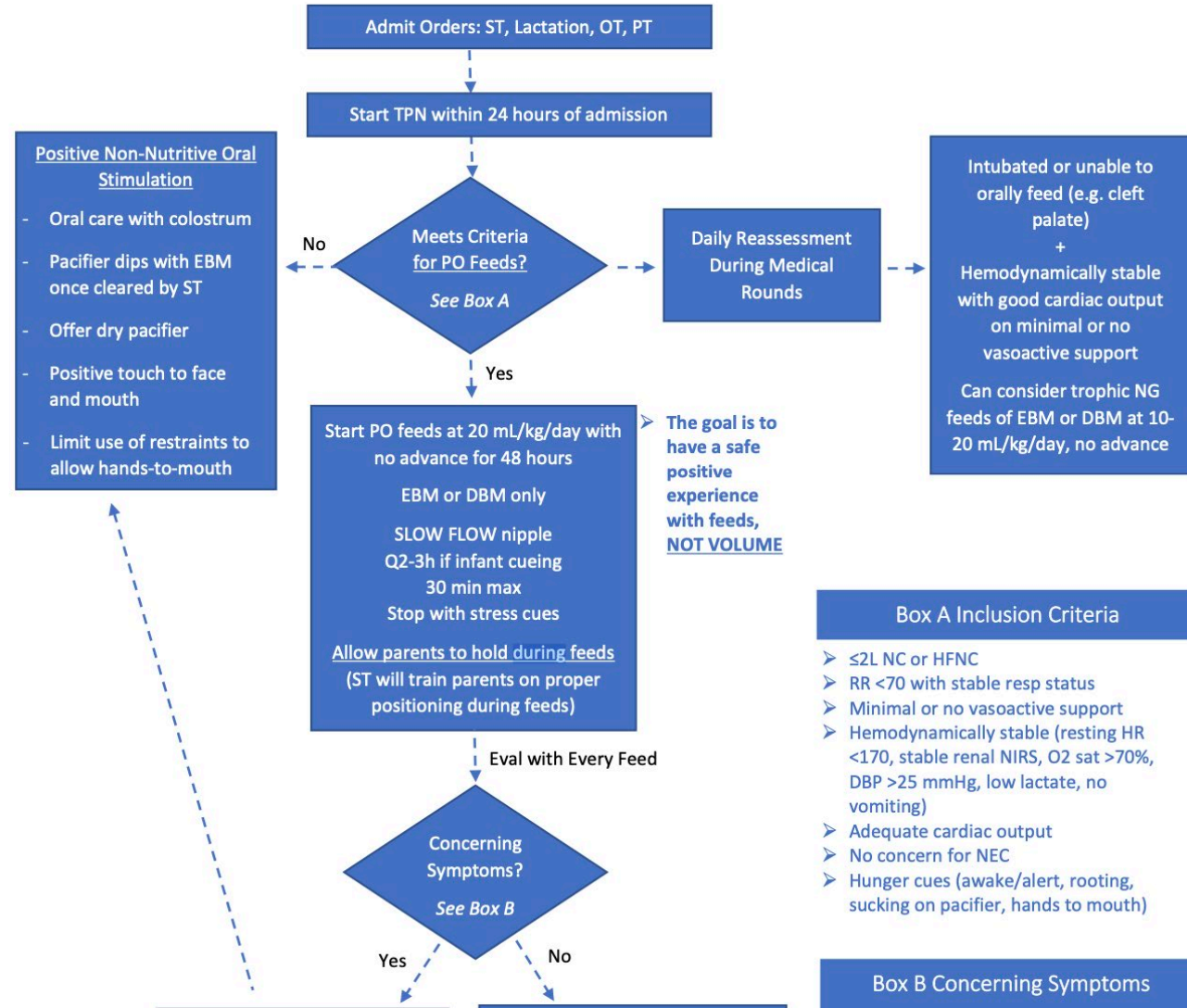
Includes ductal dependent circulation, single ventricle, mixing lesions (D-TGA, truncus arteriosus)

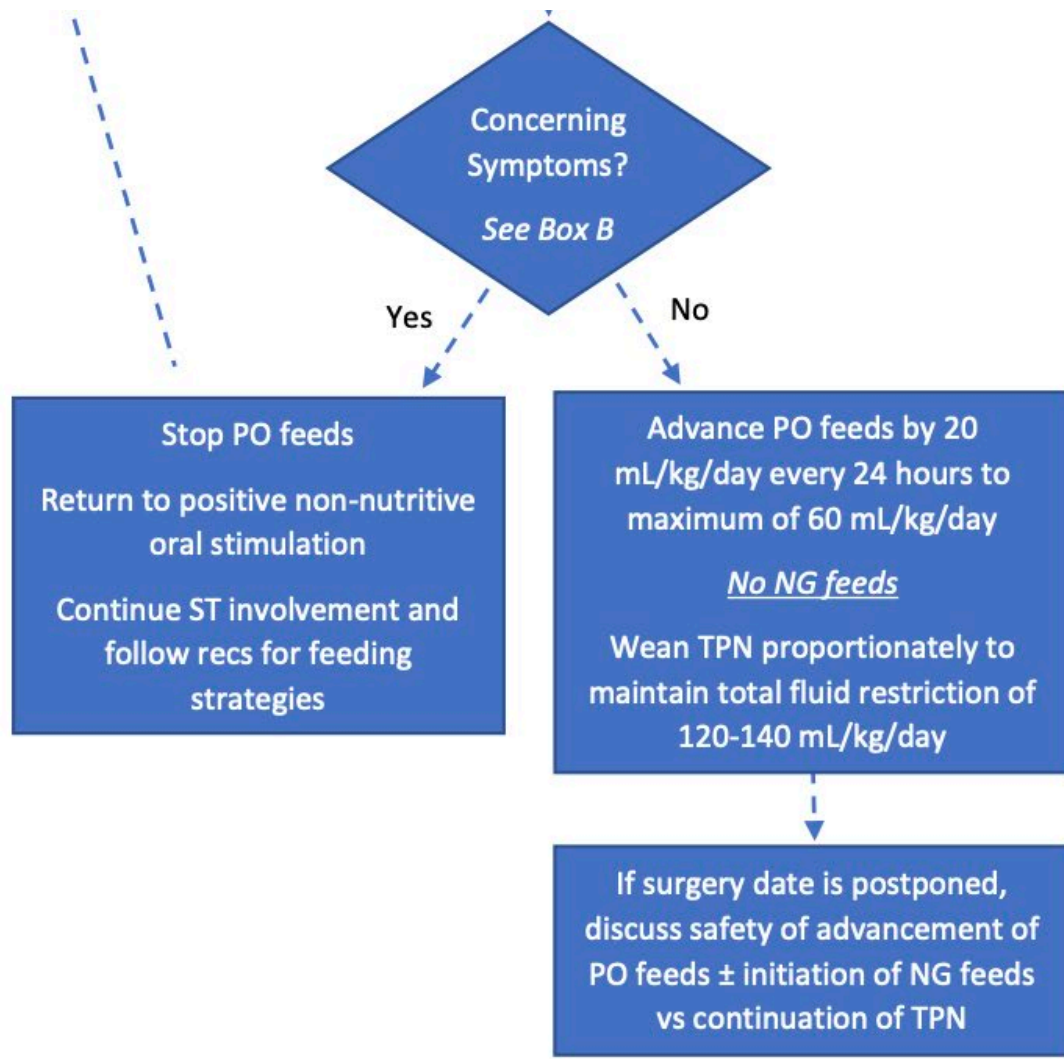


TCPCHD Preoperative Feeding Pathway

For neonates with high risk congenital heart disease who are >35 weeks gestation, >2 kg and expected to undergo heart surgery in the first 14 days of life

Includes ductal dependent circulation, single ventricle, mixing lesions (D-TGA, truncus arteriosus)





DBP >25 mmHg, low lactate, no vomiting)

- Adequate cardiac output
- No concern for NEC
- Hunger cues (awake/alert, rooting, sucking on pacifier, hands to mouth)

Box B Concerning Symptoms

- Stress cues (grimacing, pulling away from nipple, arms flailing, watery eyes, sneezing, hiccups, refusal to feed, dropping state/sleepiness, lateral spillage)
- Emesis
- Desaturation
- Breathing changes, nasal flaring
- Concern for aspiration (coughing, gagging)
- Decreasing renal NIRS

Intraoperative considerations

- **Cerebral and somatic NIRS monitored carefully. Monitor both trends and absolute values. Aggressive with perfusion and hematocrit.**
- **Two arterial lines (one upper and one lower extremity) with titration of MAPs typically based on lower extremity with target mean 30-35 mm Hg in neonates.**
- **For bypass cases:**
 - Hypothermia to 18-22 °C achieved.
 - While on full flow bypass, goal flow rates of 150 cc/kg/min
 - Replete hematocrit aggressively
- **Liberal with peritoneal drain placement. Only criteria to preclude PD placement is if g-tube or if preexisting abdominal pathology.**

High Risk of NEC Post-Op Feeding Pathway

Inclusion Group:
 HLHS-Norwood
 Shunt-dependent physiology
 Single Ventricle with restrictive PBF

Exclusion Group:
 Biventricular Circulation and/or Without
 Total Mixing Lesions



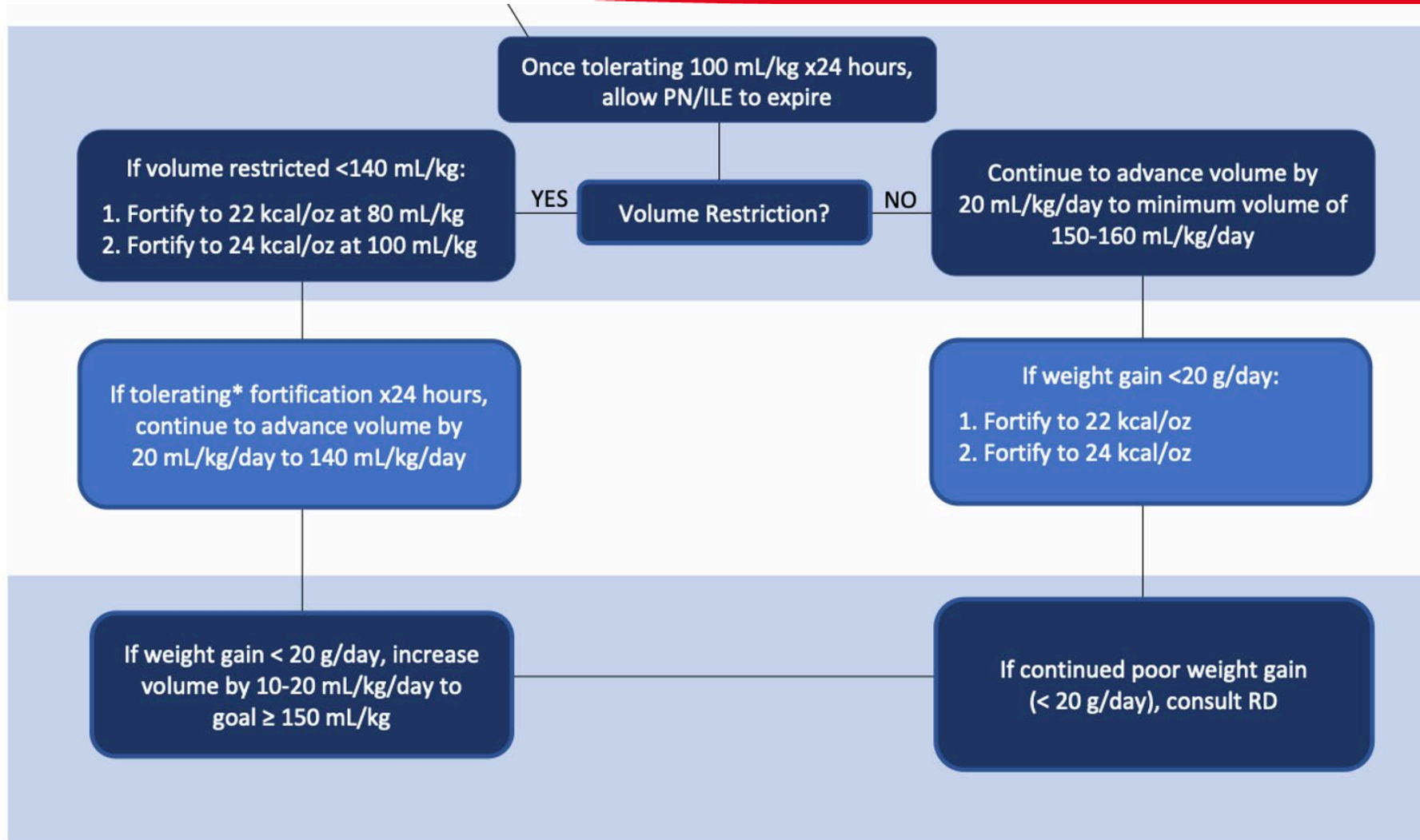
Every effort should be made to promote oral feeding using the Feeding Readiness Assessment Tool.



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Diagnosis

High risk patients with any GI signs or nonspecific signs generally trigger workup:

- Abdominal XR
- Abdominal ultrasound not commonly used, but role is likely increasing
- CBC/lactates considered

Treatment

Patients with possible or suspected NEC (i.e. Modified Bell Stage 1) are treated aggressively*

- Very low threshold to make NPO, gastric decompression via NG
- 5 days of antibiotics, typically amg/gent +/- flagyl
- General surgery consultation

Patients with definitive NEC

- All of the above plus more aggressive monitoring
- Antibiotics are typically 7-10 days; antibiotic regimen may vary

*These patients do not meet definition for NEC in PC⁴

Brief Audit

Of 8 patients coded as having definitive NEC:

- 7 patients had noncardiac/complex issues (e.g. chromosomal abnormality, heterotaxy, prematurity, low birthweight)
- 7 patients had “high-risk” cardiac lesions
 - Exception was a full-term baby with double aortic arch, LPA sling, hypoplastic left lung, complete tracheal rings, tracheal stenosis, multiple extracardiac anomalies, who was the only patient in cohort that had bowel resection
- Most common antibiotic regimen for definitive NEC was vancomycin/cefepime/flagyl for 7 days

Conclusion

- Most of our critically ill neonates are kept in CICU and not NICU
- Multidisciplinary approach is taken on daily basis between intensive care, surgery, and cardiology
- Pre-, intra-, and postoperative protocols are in place with consideration for NEC
- Aggressive management of “suspected NEC” may also contribute to our relatively low rates by PAC³ and PC⁴

Special Thanks

- **Dristi Khanal, MSN, RN**
- **Sarah Schukei, MSN, CPN, CNRN**
- **Sandeep Arya, MD**
- **Erin Gottlieb, MD**
- **Charles Fraser, MD**

	Systemic Signs	Abdominal Signs	Radiographic Signs	Evaluation / Treatment
NEC suspected	<ul style="list-style-type: none"> ➤ Fussiness ➤ Tachycardia ➤ Decreased renal NIRS 	<ul style="list-style-type: none"> ➤ Abdominal distension ➤ Emesis ➤ Small amount of blood in stool 	<ul style="list-style-type: none"> ➤ Normal or intestinal dilation ➤ Indeterminate interpretation by radiology (i.e. cannot exclude pneumatosis) 	<ul style="list-style-type: none"> ➤ NPO ➤ AXR q12h ➤ CBC, CRP, ABG/VBG ➤ Ampicillin, gentamicin and flagyl for 36 hours ➤ If no evidence of NEC (AXRs without pneumatosis, inflammatory markers reassuring, hemodynamically stable with clinical improvement, no more bloody stool), can resume feeds after 24 hours

Pediatric surgery consult for all patients with definite NEC

NEC definite, Medical NEC Mildly ill	<ul style="list-style-type: none"> ➤ Fussiness ➤ Tachycardia ➤ Decreased renal NIRS ➤ Lethargy ➤ Metabolic acidosis ➤ Thrombocytopenia 	<ul style="list-style-type: none"> ➤ Abdominal distension ➤ Emesis ➤ Grossly bloody stool ➤ Decreased bowel sounds 	<ul style="list-style-type: none"> ➤ Intestinal dilation ➤ Pneumatosis 	<ul style="list-style-type: none"> ➤ NPO ➤ AXR q6h ➤ CBC, CRP, ABG/VBG q12h ➤ Blood culture ➤ Ampicillin, gentamicin and flagyl for 7 day course from resolution of pneumatosis
Moderately to severely ill	<p>In addition to the above:</p> <ul style="list-style-type: none"> ➤ Temperature instability ➤ Apnea ➤ Respiratory distress progressing to failure ➤ Hypotension ➤ Poor perfusion ➤ Lactic acidosis ➤ Neutropenia 	<p>In addition to the above:</p> <ul style="list-style-type: none"> ➤ Marked distension ➤ Absent bowel sounds ➤ Abdominal tenderness +/- abdominal redness ➤ Peritonitis 	<ul style="list-style-type: none"> ➤ Intestinal dilation ➤ Pneumatosis ➤ Portal vein gas ➤ Ascites 	<ul style="list-style-type: none"> ➤ NPO ➤ AXR q6h ➤ CBC and CRP q12h ➤ Blood culture ➤ Cefepime and flagyl for 7-10 day course from resolution of pneumatosis *Add vancomycin is there is concern for bacteremia ➤ Fluid resuscitation, ventilator support, inotropic support as needed
NEC definite, Surgical NEC	Same as moderately to severely ill medical NEC	Same as moderately to severely ill medical NEC	<p>In addition to medical NEC:</p> <ul style="list-style-type: none"> ➤ Pneumoperitoneum 	<ul style="list-style-type: none"> ➤ NPO ➤ AXR q6h ➤ CBC and CRP q12h ➤ Blood culture ➤ Cefepime and flagyl for 7-10 days post-op OR until ileus resolved *Add vancomycin is there is concern for bacteremia ➤ Fluid resuscitation, ventilator support, inotropic support as needed

TCPCHD Feeding Intolerance Pathway

Feeding Intolerance (any of the below which are a CHANGE from baseline)		Necrotizing Enterocolitis
<ul style="list-style-type: none"> ➤ Emesis (large volume, above baseline or repeat emesis within 4 hours) ➤ Hemodynamic changes with feeds (desaturation, decreased renal NIRS, tachycardia, worsened perfusion, metabolic acidosis, increased lactate) ➤ Blood in stool ➤ Change in abdominal exam (increased distension, absent bowel sounds, new tenderness, discoloration) ➤ Pain with feeds (agitation, irritability, or inconsolability during feeds) ➤ Diarrhea (>3 watery stools in 24 hours or a change from baseline) 		<ul style="list-style-type: none"> ➤ Breach of the gut mucosal barrier by pathogenic enteric bacteria resulting in intestinal inflammation, hypoxia, ischemia and necrosis ➤ Pathophysiology in CHD likely due to combination of low bowel perfusion pressure and systemic hypoxia placing infants at risk of intestinal hypoperfusion and ischemia ➤ Variable clinical, laboratory and radiologic signs are used to diagnose NEC, assign disease severity and determine treatment ➤ Many infants present with feeding intolerance (but not all feeding intolerance is NEC)
Abdominal Distension	If no other markers of feeding intolerance and abdominal exam otherwise benign ↓ Okay to continue feeds and monitor closely	<u>Consider:</u> <ul style="list-style-type: none"> ➤ AXR and/or abdominal US to evaluate for ileus, pneumatosis, ascites, etc. ➤ Constipation ➤ Recent change in formula, fortification or feeding regimen ➤ Venting NG/GT
Significant Emesis	If no other markers of feeding intolerance, abdominal exam benign and no blood in stool ↓ Hold feeds for 2 hours if continuous or until next bolus feed and re-trial feeding ↓ If continued emesis with need to hold feeds up to 3 times in 24 hours, hold feeds pending discussion with clinical team	<u>Consider:</u> <ul style="list-style-type: none"> ➤ Trial of anti-reflux or pro-kinetic agent ➤ Constipation ➤ Need for change in feeding regimen (bolus feeds over shorter/longer time, transition to continuous feeds, post-pyloric feeds) ➤ Intolerance of recent formula change or fortification ➤ Checking enteral tube position ➤ Withdraw from weaning drug habituation meds ➤ GI consult
Small blood in stool (single episode)	Single episode of a small amount of blood in stool with benign abdominal exam and no other markers of feeding intolerance ↓ Obtain AXR, CBC and CRP, if normal, okay to continue feeds	<u>Consider:</u> <ul style="list-style-type: none"> ➤ Perianal fissure ➤ Milk protein sensitivity/allergy ➤ Intolerance of recent formula change or fortification

Thank You!
PC⁴ ♥ PAC³
 **Children's National.**