Hybrid Today, Norwood Tomorrow: A Contemporary Approach to High-Risk Single Ventricle Physiology

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Hybrid Today, Norwood Tomorrow:
A Contemporary Approach to High-Risk Single Ventricle Physiology

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Why a Session on Hybrid to Rapid Norwood?

- To understand why some heart centers are approaching single ventricle patients with systemic outflow tract obstruction utilizing a quicker hybrid to ultimate Norwood pathway.
- To understand if there are notable changes in resource utilization in approaching single ventricle patients with systemic outflow tract obstruction utilizing a quicker hybrid to Norwood pathway vs a traditional Norwood pathway.
- Share best practices in the management of infants and neonates with single ventricle congenital heart disease with systemic outflow tract obstruction in the current era.

Rationale for Hybrid/Delayed Norwood

1. Avoids neonatal CPB stress

- CPB and circulatory arrest increase risk of **neurologic injury** and **end-organ dysfunction** in premature or unstable neonates.

2. Stabilizes physiology first

- Hybrid can **bridge** fragile newborns to a safer, later Norwood or comprehensive Stage II when weight and organ function improve.

3. Expands treatment eligibility

- Allows palliation when **primary Norwood would be prohibitive** (e.g., low birthweight ≤ 2 kg, chromosomal anomalies).

Practical Center-Driven Motivations

- **Institutional experience/volume:** centers with fewer neonatal CPB cases may favor hybrid to reduce operative risk.
- **Surgeon & cardiologist collaboration:** hybrid often led by interventional programs with strong cath lab teams.
- **Resource utilization:** shorter initial OR time, potential to stabilize extracardiac issues.
- **Family and ethical considerations:** hybrid offers a *reversible* path and time for evaluating viability or transplant candidacy.

Limitations & Trade-Offs

- **Deferred complexity:** later “comprehensive Stage II” is technically harder.
- Higher rate of **pulmonary artery reintervention** (up to 50% in low-volume centers).
- **Retrograde aortic arch obstruction** and **coronary malperfusion risk** due to ductal stent configuration.
- **Total survival advantage unclear**—benefit mainly in select *ultra-high-risk* infants.
- **Optimal timing of Norwood (rather than comprehensive stage II) after Hybrid unclear**

What Centers Utilize This Strategy Most?

Site	Hybrid in neonates (index)	Norwood in neonates (not index)	Norwood in neonates (index)	Norwood in infants (index)	Norwood in infants (not index)
Oklahoma Children's	21	15	7	0	0
B	21	3	1	1	4
C	22	10	16	2	3
Driscoll Children's	20	8	6	9	14

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Hybrid Today, Norwood Tomorrow: A Contemporary Approach to High-Risk Single Ventricle Physiology

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Oklahoma Children's
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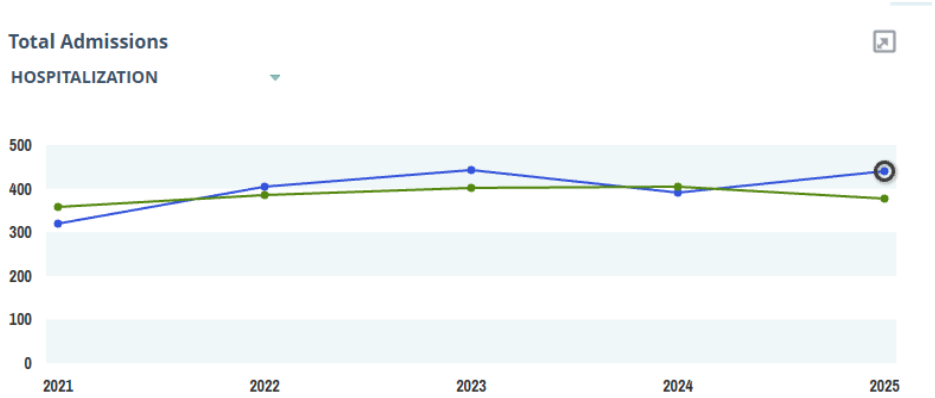
Objectives

- Tell you a little bit about Oklahoma…come visit (or work!)
- Describe data published before PC4 involvement regarding HLHS
- Describe unpublished data from PC4
- Discuss good, bad and the ugly of our strategies

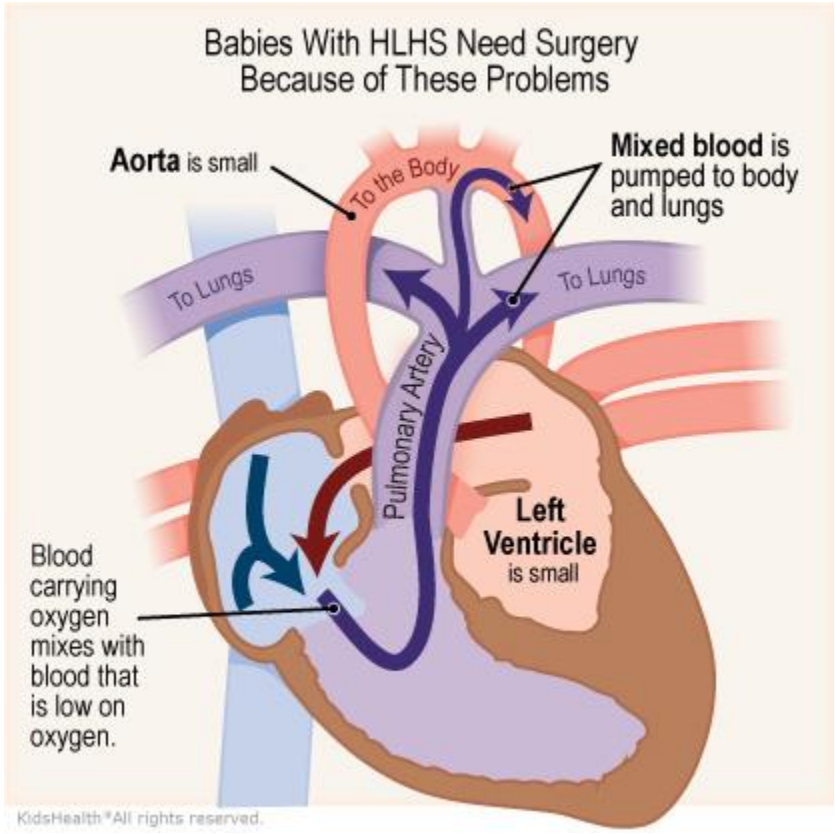
About Oklahoma Children's Hospital

- Serves 4 million in Oklahoma
- 348 beds, 25 CICU beds
- 9 CICU providers, 12 APPs
- 450 admissions in 2025, >300 bypass cases
- Acuity Adaptable Unit
- Expanding to 48 bed CICU and stand alone center 2029



HLHS Physiology

- Before 1980s, diagnosis=death
- Systemic output = ductal dependent
- Pulmonary overcirculation → systemic hypoperfusion
- Balance Qp:Qs critical
- Coronary perfusion vulnerable



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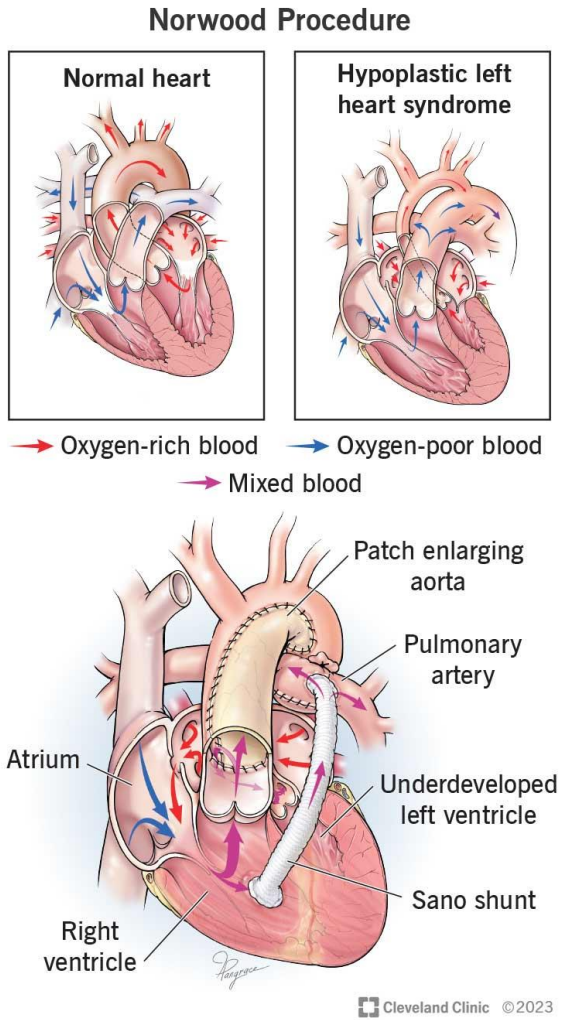
Norwood procedure



High risk

- In-hospital mortality variable - (7-39% Ohye, 2010)
  - Intact/restrictive Atrial Septum
  - AVVR
- Long-term survival 54-89% (Tanem, 2020)
- Multiple interventions to improve outcomes
  - RV to PA conduit vs BTTS
  - Hybrid procedure (bands, ductal stent)
  - Bilateral PA banding (Ota, 2014)
    - Avoid bypass in newborn
    - ID other anomalies
    - Stabilization

Norwood vs Hybrid vs bPAB

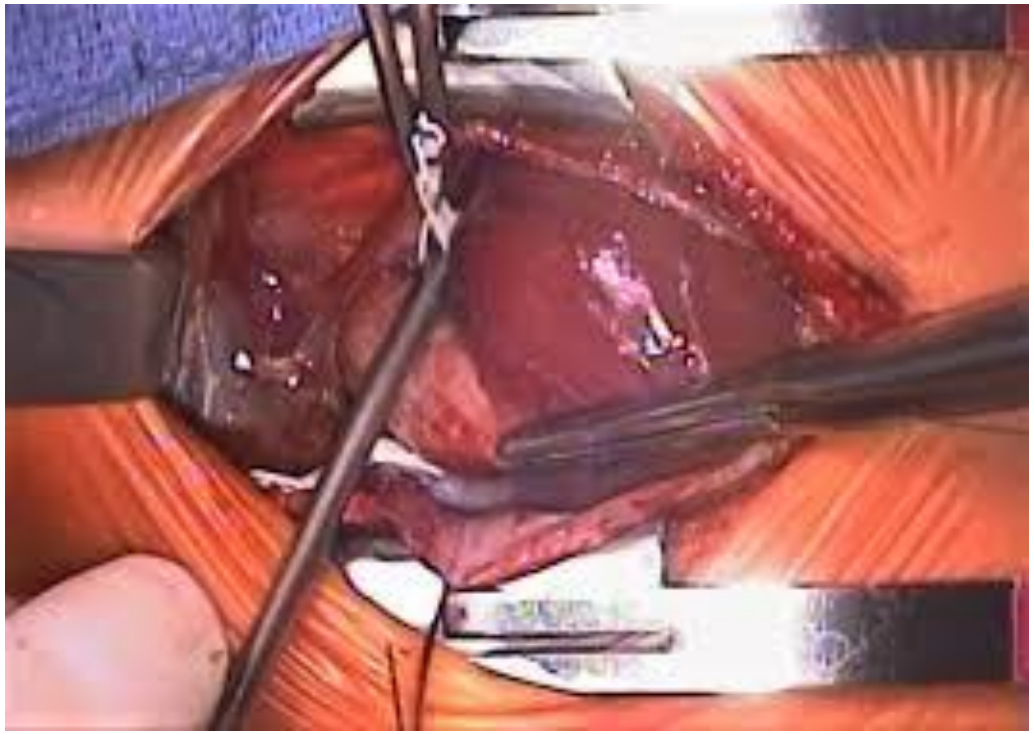
Norwood: full reconstruction, bypass-heavy

Hybrid: PA bands + ductal stent + septostomy

bPAB-alone: staged stabilization approach

bPAB Strategy (Physiology)

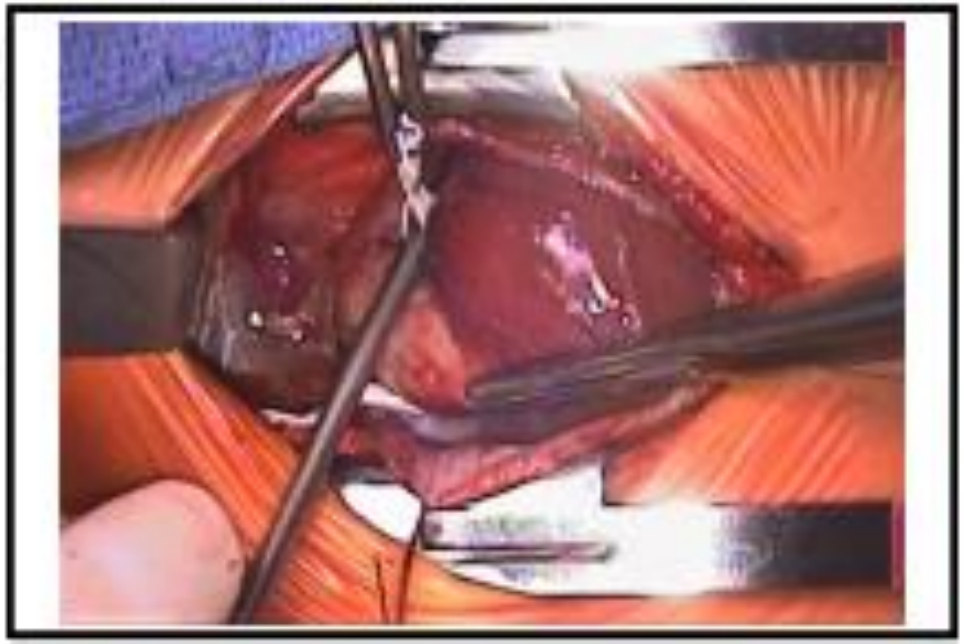
- Restricts pulmonary flow → improves systemic perfusion
- Maintains ductal patency for systemic output
- Avoids CPB inflammatory hit



Bilateral pulmonary artery banding in higher risk neonates with hypoplastic left heart syndrome

Harold M. Burkhart, MD,[a] Yuki Nakamura, MD,[a] Anas Salkini, MD,[b] Randall M. Schwartz, MD,[c] Courtney D. Ranallo, MD,[d] Elizabeth S. Makil, MD,[b] Matthew Campbell, MD,[b] Suanne M. Daves, MD,[c] Emilie D. Henry, MD,[d] and Arshid Mir, MD[b]

- Retrospective review 2015-2021
- N=49 pts with risk factors
- HLHS and variants
- PGE only, no ductal stents
- 11 HLHS →Norwood/excluded
- Primary outcome: survival
- Secondary outcome: progression to stage II repair for HLHS (Glenn)



Intraoperative photo showing left pulmonary artery being banded over a 2.5-mm probe.

Risk factors

TABLE 2. Pre-BPAB patient demographics

Variable	
Sex, n (%)	
Male	34 (69.4)
Female	15 (30.6)
Weight at birth, kg, mean ± SD	2.9 ± 0.5
Age at BPAB, d, median (IQR)	6.0 (4.0)
Weight at BPAB, kg, mean ± SD	3 ± 0.5
Anatomy, n (%)	
MS/AS	16 (32.7)
MS/AA	11 (22.5)
MA/AA	10 (22.4)
MA/AS	4 (8.2)
HLHS variant	8 (16.3)
TR, n (%)	
None/trivial	29 (59.2)
Mild	15 (30.6)
Moderate	5 (10.2)
Severe	0 (0.0)
Ascending aorta size, mm, mean ± SD	2.8 ± 2.5
Pre-BPAB balloon septostomy, n (%)	11 (22.5)

SD, Standard deviation; *BPAB*, bilateral pulmonary artery banding; *IQR*, interquartile range; *MS*, mitral stenosis; *AS*, aortic stenosis; *AA*, aortic atresia; *MA*, mitral atresia; *HLHS*, hypoplastic left heart syndrome; *TR*, tricuspid regurgitation.

TABLE 1. Incidence of the risk factors in the 49 patients

Prematurity, n (%)	9 (18.4)
Low birth weight, n (%)	13 (26.5)
Multiple extracardiac anomalies, n (%)	3 (6.1)
Genetic disorders, n (%)	8 (16.3)
Heterotaxy syndrome, n (%)	1 (2)
Moderate or greater TR, n (%)	5 (10.2)
Moderately or severely depressed cardiac function	0 (0.0)
Tiny ascending aorta (≤2 mm), n (%)	17 (34.7)
Coronary artery fistulas, n (%)	8 (16.3)
IAS, n (%)	6 (12.2)
Restrictive atrial septum, n (%)	17 (34.7)
Atresia of the coronary artery ostium, n (%)	1 (2)
Pre-BPAB mechanical intubation, n (%)	36 (73.5)
Pre-BPAB shock, n (%)	4 (8.2)
Pre-BPAB shock with MOF, n (%)	1 (2)

TR, Tricuspid regurgitation; *IAS*, intact atrial septum or severely restrictive atrial septum; *BPAB*, bilateral pulmonary artery banding; *MOF*, multiple organ failure.

Risk factors

TABLE 3. Risk factors in the 49 patients and progression to the Norwood procedure

Variable	Norwood (n = 40)	Non-Norwood (n = 9)	*P* value
Prematurity, n (%)	9 (22.5)	0 (0.0)	.179
Low birth weight, n (%)	8 (21.620.0)	5 (55.6)	.043
Multiple extracardiac anomalies, n (%)	0 (0.0)	3 (33.3)	.005
Genetic disorders, n (%)	4 (10.0)	4 (44.4)	.028
Heterotaxy syndrome, n (%)	0 (0.0)	1 (11.1)	.184
Moderate or greater TR, n (%)	5 (12.5)	0 (0.0)	.569
Tiny ascending aorta (≤2 mm), n (%)	15 (37.5)	2 (22.2)	.467
Coronary artery fistulas, n (%)	8 (20.0)	0 (0.0)	.322
IAS, n (%)	4 (10.0)	2 (22.2)	.302
Restrictive atrial septum, n (%)	14 (35.0)	3 (33.3)	>.999
Atresia of the coronary artery ostium, n (%)	1 (2.5)	0 (0.0)	>.999
Pre-BPAB mechanical intubation, n (%)	29 (72.5)	7 (77.8)	>.999
Pre-BPAB shock, n (%)	3 (7.5)	1 (11.1)	.569
Pre-BPAB shock with MOF, n (%)	0 (0.0)	1 (11.1)	.184

TR, Tricuspid regurgitation; *IAS*, intact atrial septum or severely restrictive atrial septum; *BPAB*, bilateral pulmonary artery banding; *MOF*, multiple organ failure.

Bilateral pulmonary artery banding in higher risk neonates with hypoplastic left heart syndrome

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49 patients identified bPAB

- 40 (81%) →Norwood
- 9 failed to advance to Norwood
  - Risk factors of fail to advance
    - LBW (p=0.043)
    - Extracardiac anomalies (p=0.005)
    - Genetic disorders (p=0.028)

9 failed to advance to Norwood

- 1→ heart transplant Severe TR/MR
- 2→died sepsis
- 3→required ECMO, died
  - Poor cardiac output
  - NEC/GI perforations
  - Left atrial rupture during repeat BAS
- 3→parental comfort care-genetic anomalies

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Post bPAB Management

- Goals Post-bPAB
  - Qp:Qs ~1 with tight balance of SVR/PVR
  - PGE stays on
  - Avoid desaturation and over ventilation (lower CO2→lower PVR and higher Qp)
  - Stable lactate <2
  - Judicious inotropes
  - Adequate diastolic pressure for coronaries
  - NIRS and echo surveillance
- To Norwood
  - Near 40 GA, 3 kg
  - “healthy” lungs

The Norwood

TABLE 4. Risk factors and hospital mortality after the Norwood procedure

Variable	Survival (n = 37)	Mortality (n = 3)	*P* value
Prematurity, n (%)	8 (21.6)	1 (33.3)	.545
Low birth weight, n (%)	7 (18.9)	1 (33.3)	.498
Multiple extracardiac anomalies, n (%)	0 (0.0)	0 (0.0)	N/A
Genetic disorders, n (%)	4 (10.8)	0 (0.0)	>.999
Heterotaxy syndrome, n (%)	0 (0.0)	0 (0.0)	N/A
Moderate or greater TR, n (%)	5 (13.5)	0 (0.0)	>.999
Tiny ascending aorta (≤2 mm), n (%)	14 (37.8)	1 (33.3)	>.999
Coronary artery fistulas, n (%)	8 (21.6)	0 (0.0)	>.999
IAS, n (%)	2 (5.4)	2 (66.7)	.022
Restrictive atrial septum, n (%)	12 (32.4)	2 (66.7)	.276
Atresia of the coronary artery ostium, n (%)	1 (2.7)	0 (0.0)	>.999
Pre-BPAB mechanical intubation, n (%)	27 (73.0)	2 (66.7)	>.999
Pre-BPAB shock, n (%)	3 (8.1)	0 (0.0)	>.999
Pre-BPAB shock with MOF, n (%)	0 (0.0)	0 (0.0)	N/A

N/A, Not available; *TR*, tricuspid regurgitation; *IAS*, intact atrial septum or severely restrictive atrial septum; *BPAB*, bilateral pulmonary artery banding; *MOF*, multiple organ failure.

- 40 patients progressed to Norwood
- Of those, 3 Died (7.5%)
  - ECMO after RCA thrombus
  - IAS, PV stenosis, arch obstruction at 3 months
  - IAS, Glenn, takedown due to pulmonary infection

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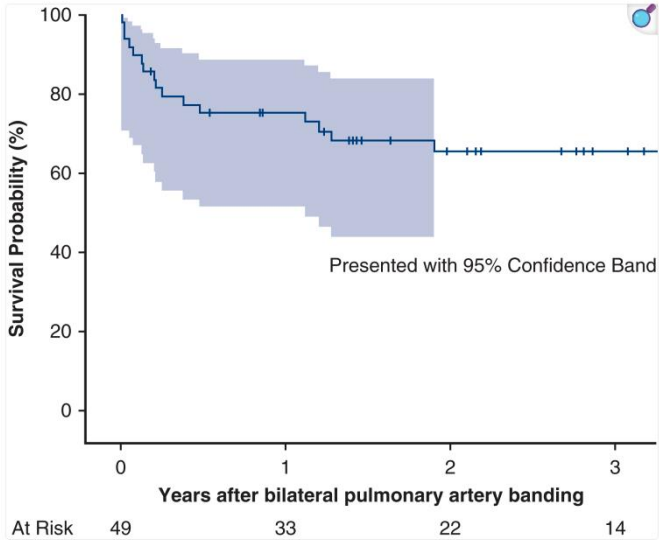
Key Results

- Improved early survival vs expected Norwood risk
- Allows physiologic stabilization
- Variable interstage attrition

Figure 2.

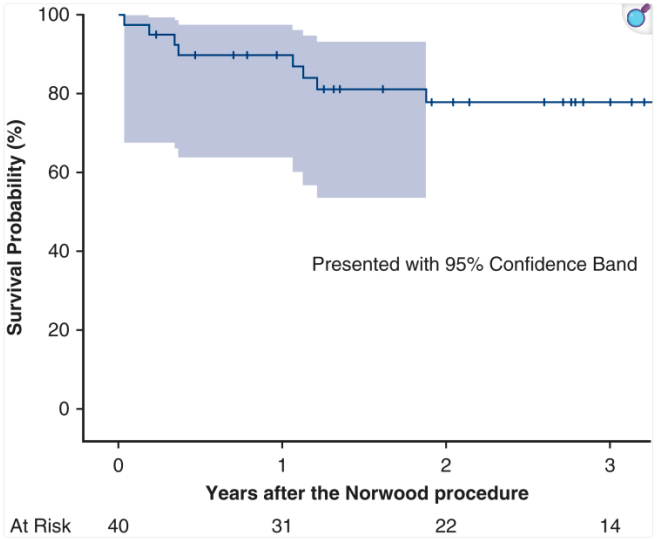


Bilateral pulmonary artery banding in greater-risk neonates with HLHS. Bilateral pulmonary artery banding was performed in 49 neonates with HLHS. In total, 40 patients progressed to Norwood procedure with a 30-day mortality of 2.5%. Risk factors for failure to advance to Norwood include LBW, extracardiac anomaly and genetic anomaly.

Key Results

- Improved transplant free survival

Figure 3.



Overall transplant-free survival. Overall transplant-free survival curve for the 40 patients with the risk factors undergoing Norwood procedure is shown.

Complications

- PA distortion → future surgical complexity
  - 36% interstage catheter intervention on PA
  - 23% intraoperative intervention on PA in BDG
- Band migration or mismatch
- Interstage instability
- Coronary insufficiency risk

Decision Algorithm

Stable, good weight → Norwood

Moderate risk → Hybrid

Severe instability → bPAB bridge

Key Takeaways

- Match strategy to physiology, not protocol
- bPAB = bridge, not destination
- Frequent reassessment is critical

Unpublished data-PC4

2021-2025

	Norwood	bPAB to Norwood
N	24	33
Male	18 (75%)	20 (61%)
Female	6 (25%)	13 (39%)
Median Age (days) *	6	6
Median Weight (kg) *	2.9	2.9
30 day survival	24 (100%)	28 (85%)
CICU LOS mean	69 days	58 days
CICU LOS Median	40 days	48 days
Ventilator days mean	30 days	32 days
Ventilator days median	14 days	21 days

- Notably, in the last 1.5 years→2/3 straight to Norwood, 1/3 bPAB

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So Many Questions…

- Optimal timing to Stage II?
- Long-term PA growth outcomes?
- Neurodevelopment impact?
- Patient selection criteria refinement

Questions?

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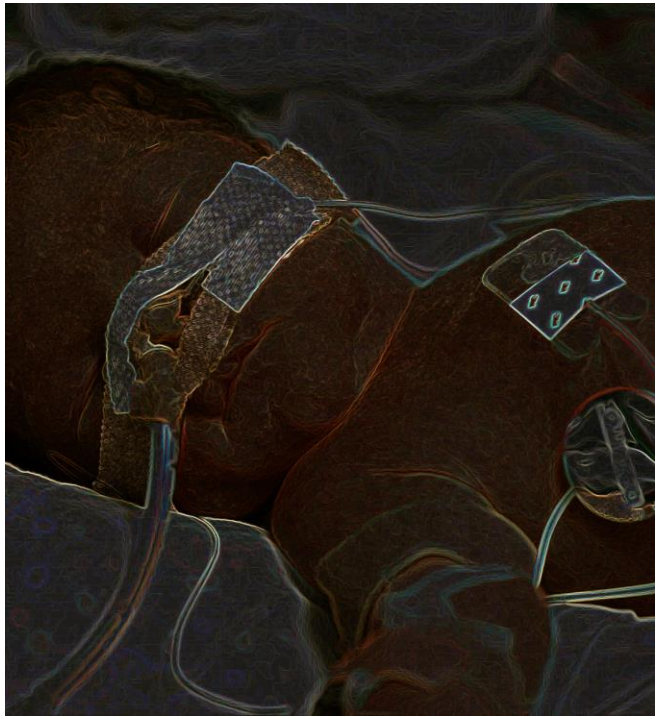
Case 1

- 2.3 kg, on vasopressin, epi, lactate 4 at 2 days old
- Mechanically ventilated, rising creatinine
- Restrictive atrial septum

- Would you choose bPAB for this patient?



Case 1 Discussion

- High operative risk for Norwood
  - Size, shock, lactate, AKI, mechanical ventilation
- bPAB for stabilization when LA <2 and indices improved
- Relieve atrial restriction urgently

Case 2

- 3.2 kg, stable, good function
- No organ dysfunction
- Balanced circulation

Case 2 Discussion

- Good Norwood candidate
- Definitive repair upfront
- Avoid staged inefficiency

Case 3

- 2.8 kg, mild dysfunction
- Intermittent instability
- Concern for pulmonary overcirculation

Case 3 Discussion

- Hybrid reasonable
- Avoid full bypass
- Maintain flexibility

Thank You!

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Discussion Prompts

- Would you choose bPAB for this patient?
- What are your physiologic targets?
- When do you escalate or convert strategy?

bPAB Physiology Diagram (Explain)

- Bands ↓ pulmonary flow
- ↑ systemic perfusion
- Ductal-dependent systemic output

Hybrid Pathway Diagram (Explain)

- PA bands + ductal stent
- Delayed arch reconstruction
- Bridges to Stage II

Is routine rapid-staged bilateral pulmonary artery banding before stage 1 Norwood a viable strategy?

Noritaka Ota, MD, Masaya Murata, MD, Yuko Tosaka, MD, PhD, Yujiro Ide, MD, Maiko Tachi, MD, Hiroki Ito, MD, Ai Sugimoto, MD, and Kisaburo Sakamoto, MD

Survival After Norwood Procedure in High-Risk Patients

Jena Tanem, MS, APNP, Nancy Rudd, MS, APNP, Jennifer Rauscher, MSN, APNP, Ann Scott, MS, APNP, Michele A. Frommelt, MD, and Garick D. Hill, MD

Department of Pediatrics, Medical College of Wisconsin, Milwaukee, Wisconsin; and the Division of Cardiology, Children's Hospital of Wisconsin, Milwaukee, Wisconsin

0003-4975/$36.00
https://doi.org/10.1016/j.athoracsur.2019.07.070

Bilateral pulmonary artery banding for resuscitation in high-risk, single-ventricle neonates and infants: A single-center experience

Kristine J. Guleserian, MD,[a] Gregory M. Barker, MD,[b] Mahesh S. Sharma, MD,[a] Joy Macaluso, RN,[a] Rong Huang, PhD,[b] Alan W. Nugent, MBBS,[b] and Joseph M. Forbess, MD[a]

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Hybrid to Norwood

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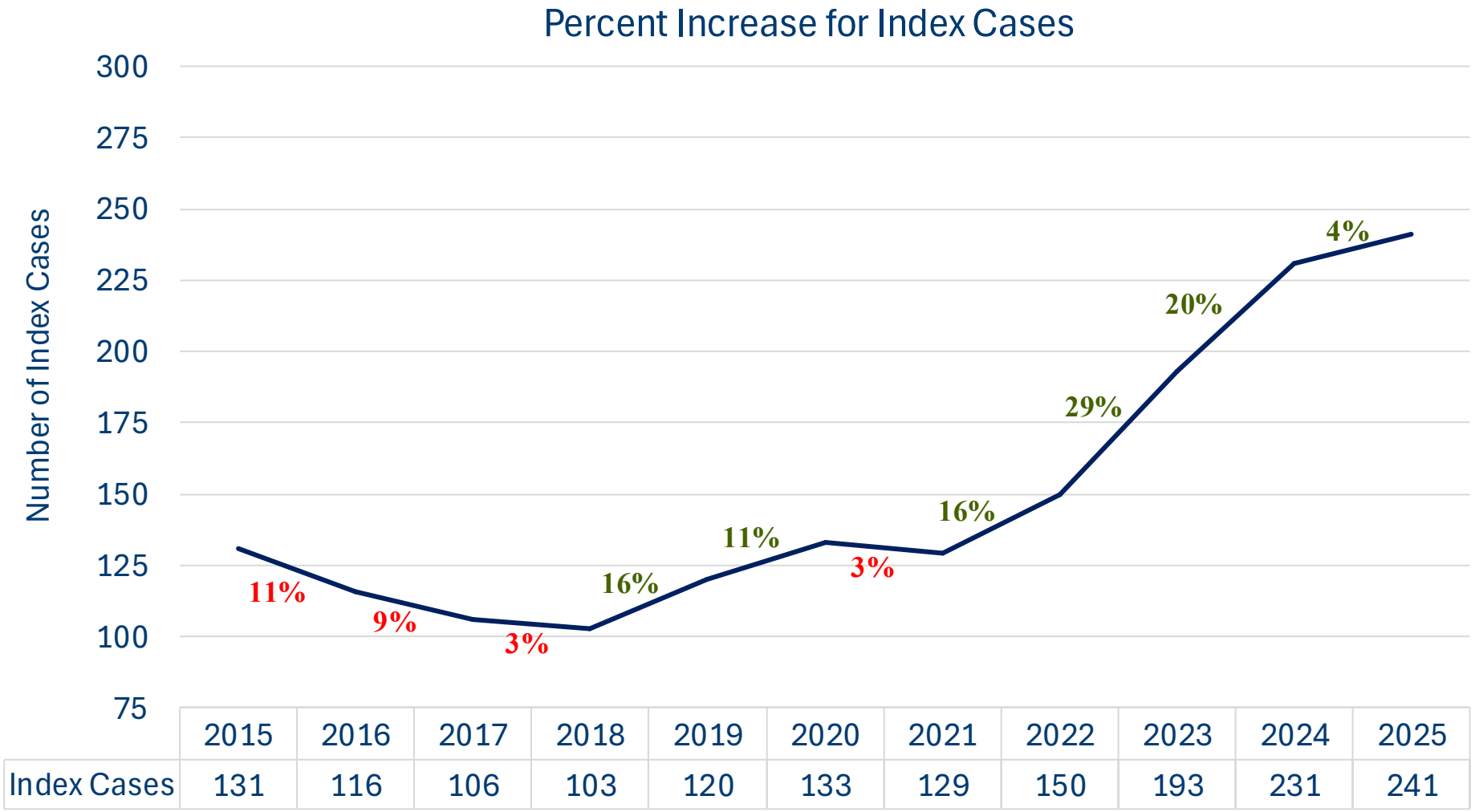
Driscoll Heart Center

CICU Room

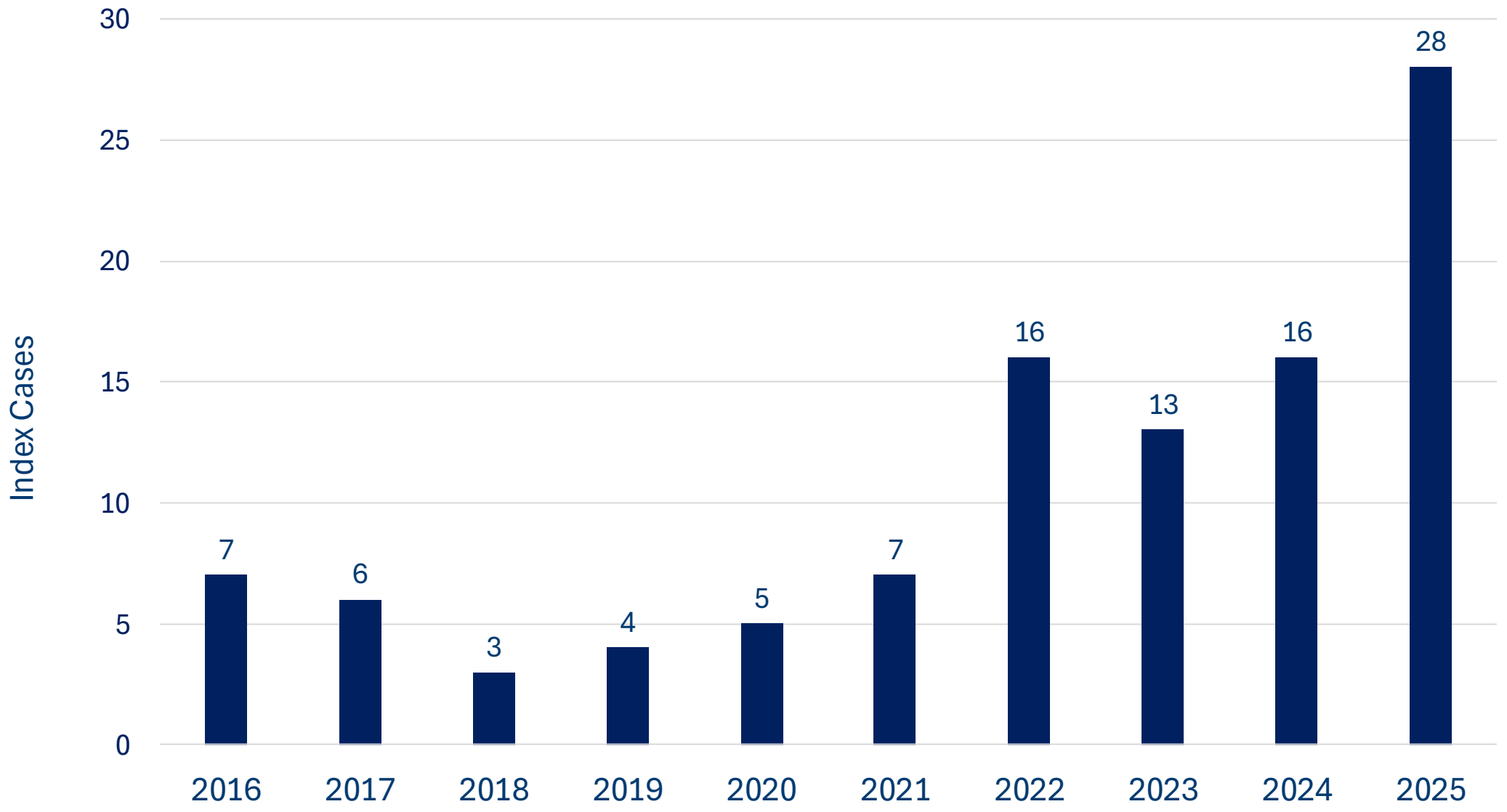
CV OR

Growth in Volume 2015-2025



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Index Cases	131	116	106	103	120	133	129	150	193	231	241

STAT 5 Cases

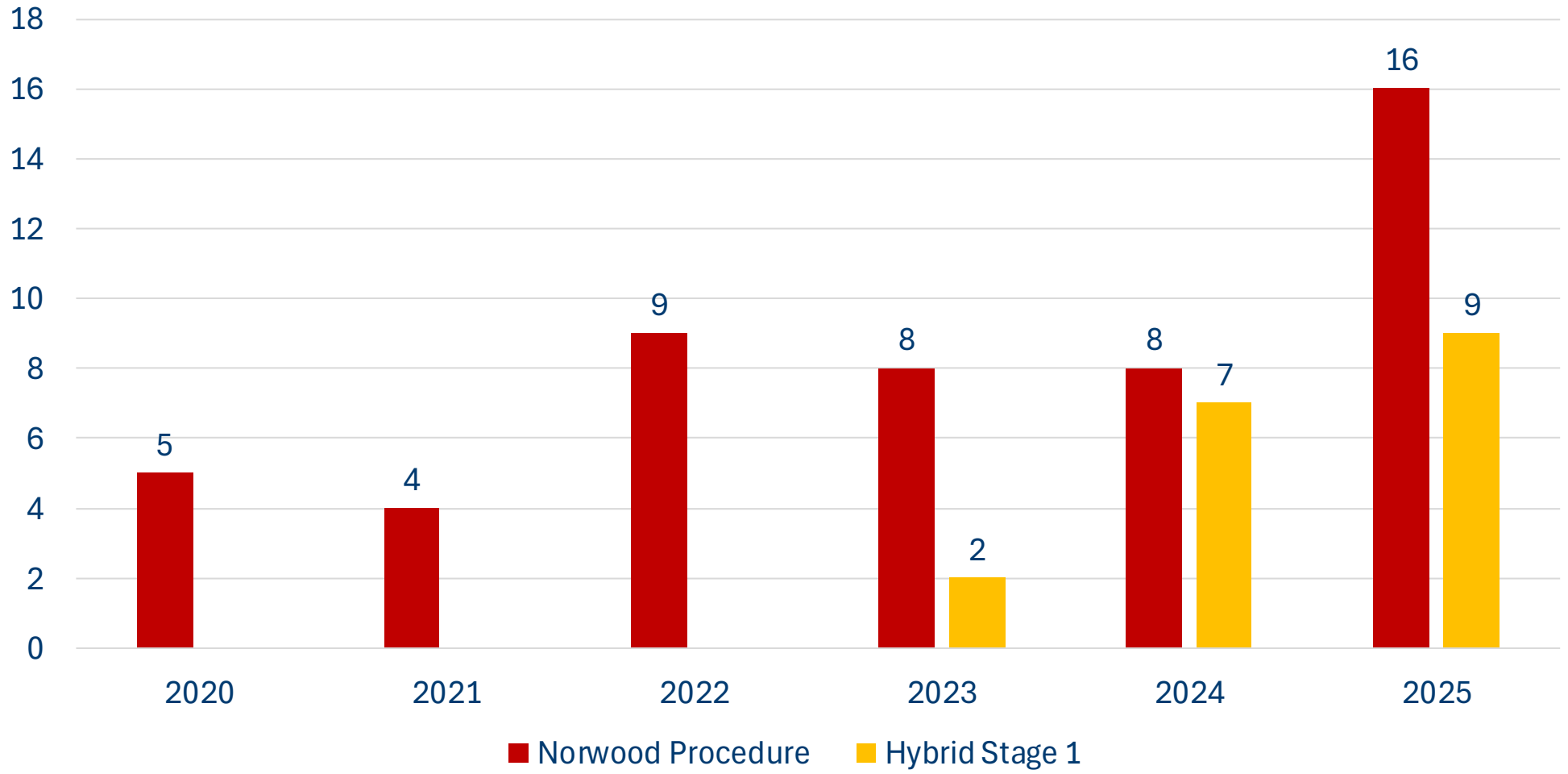

Index Cases
30
25
20
15
10
5
0
7
6
3
4
5
7
16
13
16
28
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025

Observed and Adjusted Mortality Driscoll Children's Hospital

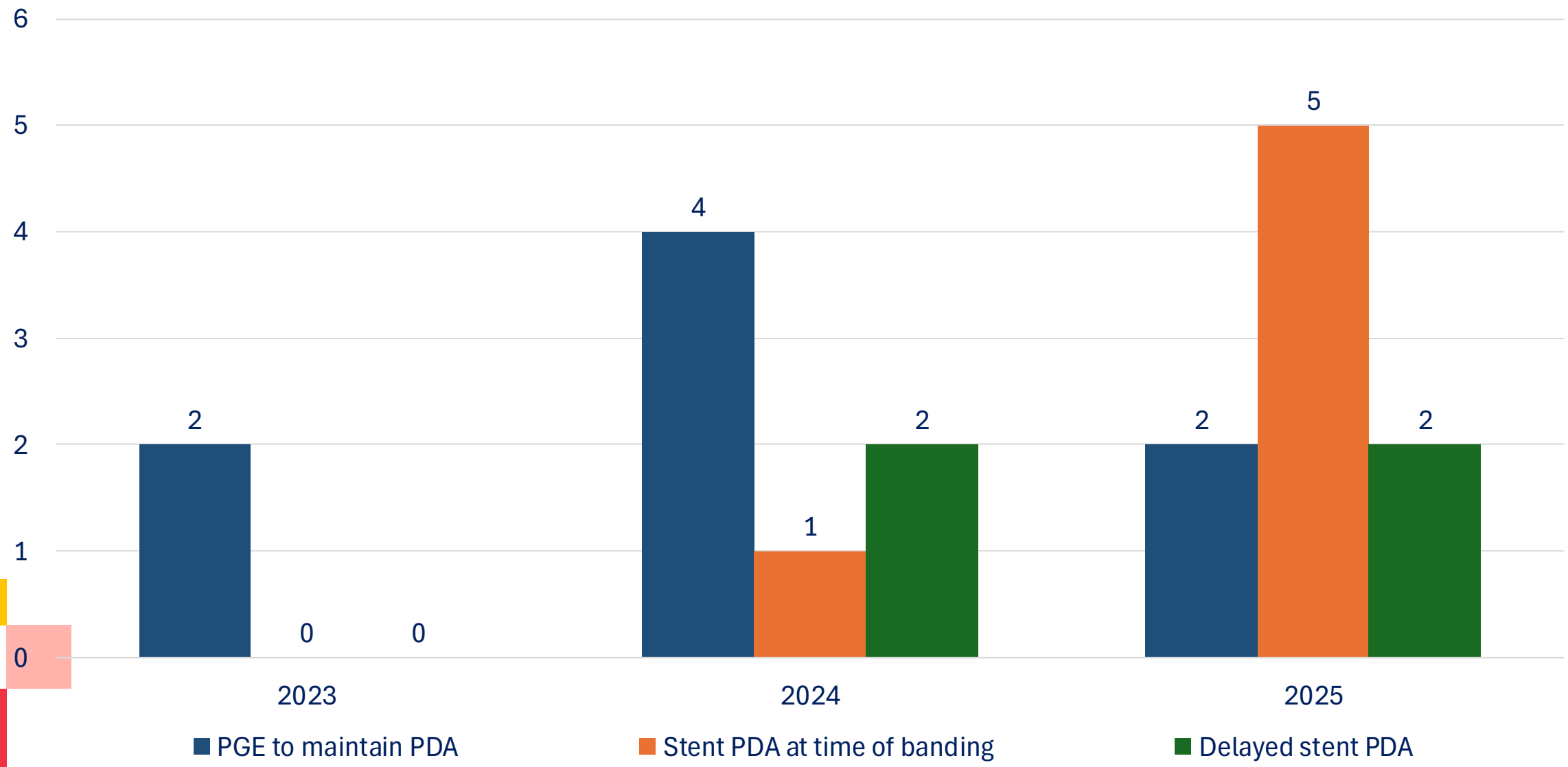
	# / Eligible	Observed Mortality	Expected Mortality by Hospital Case Mix	O/E Ratio	Risk Adjusted Mortality	STS
Overall	**13 / 698**	**1.86%**	**3.47%**	**0.54 (0.25, 0.83)**	**1.43%**	**2.66%**
STAT 1	0 / 297	0%	0.49%	0 (0, 2.5)	**0%**	0.59%
STAT 2	5 / 142	3.52%	2.14%	1.65 (0.54, 3.76)	**3.31%**	2.01%
STAT 3	1 / 83	1.2%	3.15%	0.38 (0.01, 2.07)	**1.27%**	3.32%
STAT 4	5 / 124	4.03%	6.16%	0.65 (0.21, 1.49)	**4.86%**	7.44%
STAT 5	**2 / 52**	**3.85%**	**18.15%**	**0.21 (0.03, 0.73)**	**3.25%**	**15.34%**

Congenital Heart Surgery Public Reporting | STS Public Reporting

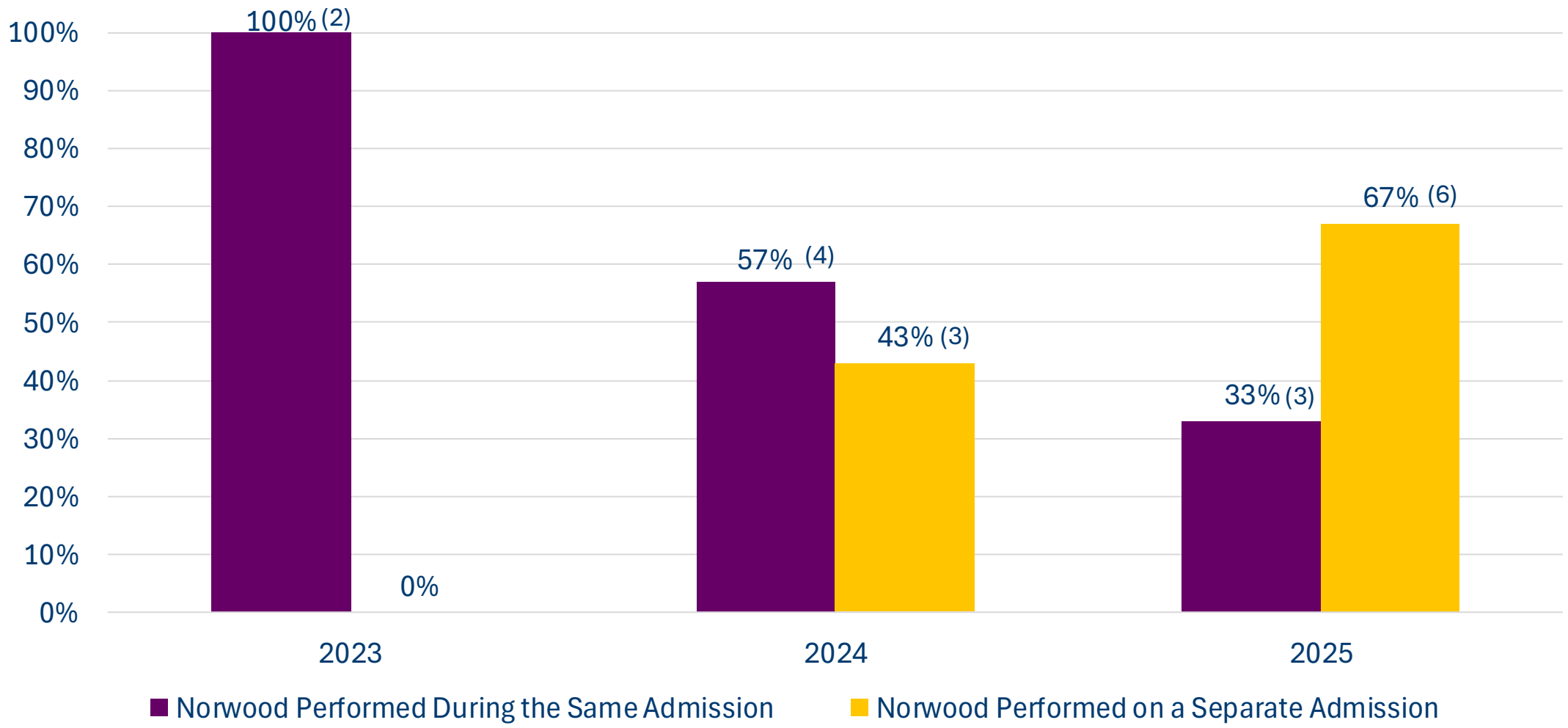
Institutional Volume of Norwood and Hybrid Stage I Procedures Since 2020



Approach to Arterial Duct Patency



Shift in Norwood Timing



Diagnosis for Patients Undergoing Hybrid Stage I Procedure Prior to a Norwood

Hypoplastic left heart syndrome (HLHS), AA+MA	7
Hypoplastic left heart syndrome (HLHS), AA+MS	2
Hypoplastic left heart syndrome (HLHS), AS+ MS	3
DILV, Aortic Stenosis	1
DILV, Aortic Atresia	1
Heterotaxy, Unbalanced Canal, Right Aortic Arch, Aortic Stenosis	1
TGA – VSD, hypoplastic RV, Aortic Stenosis	1
Interrupted Aortic Arch (IAA), Aortic Valve Hypoplasia	2

Genetic Factors Associated with Hybrid Decision

Gender Distribution

Male	67%
Female	33%

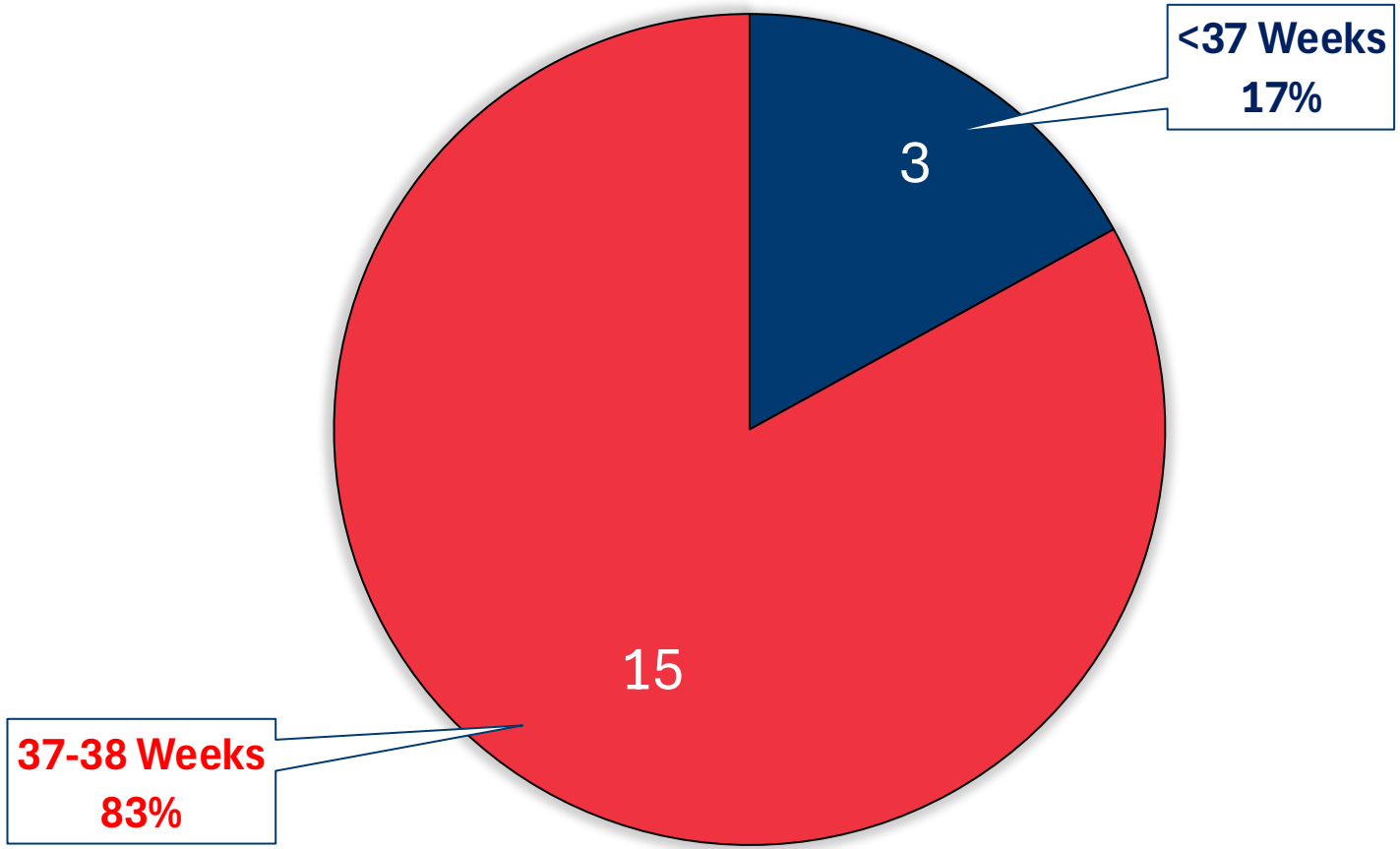
Non-cardiac Anatomic Abnormalities

39% of patients had a known non-cardiac anatomic abnormality

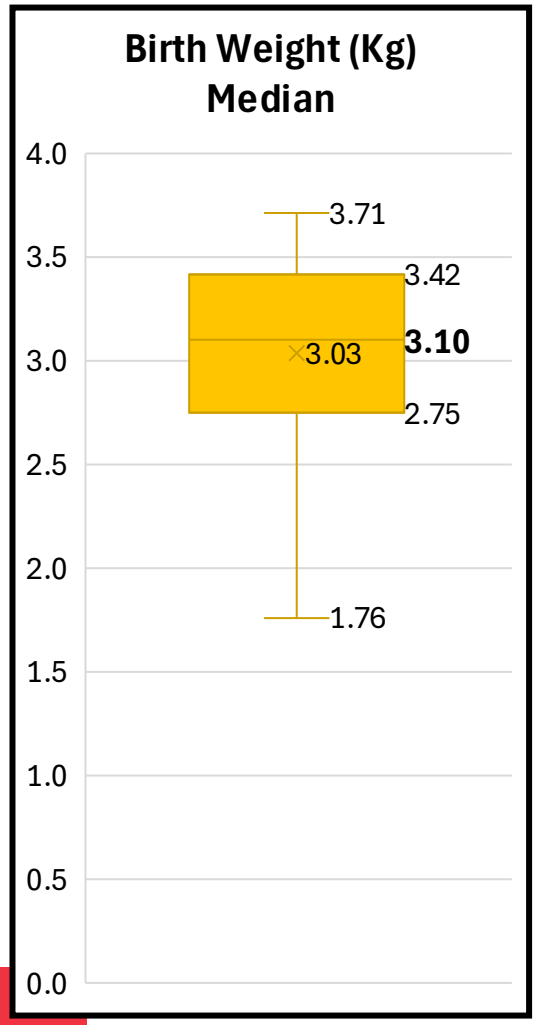
Chromosomal Abnormalities

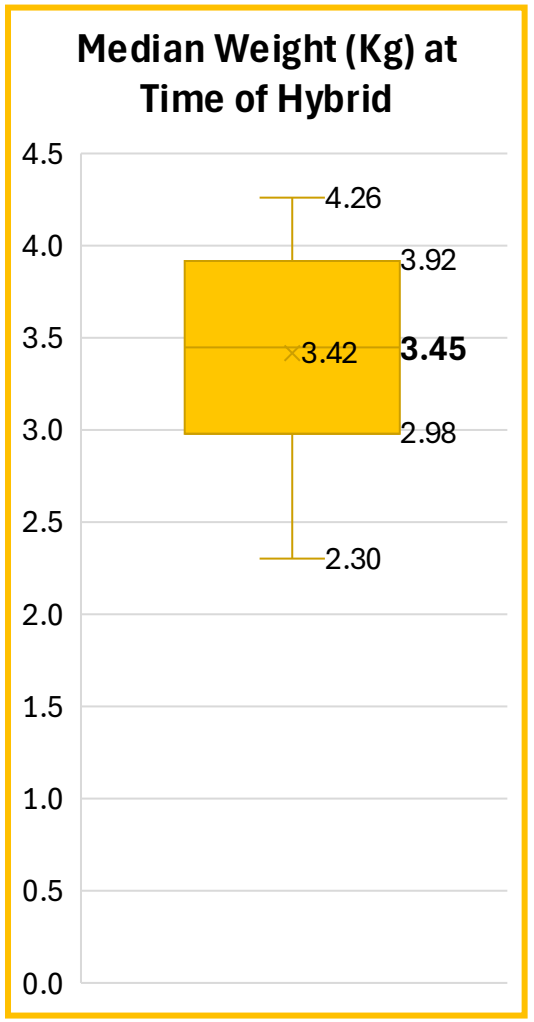
56% of patients had a known chromosomal abnormality

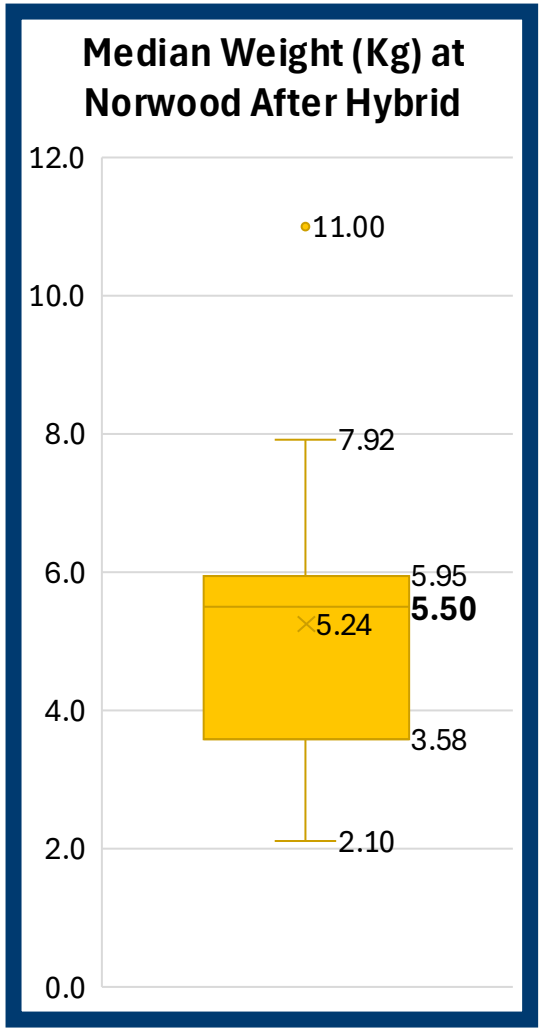
Gestational Age Distribution

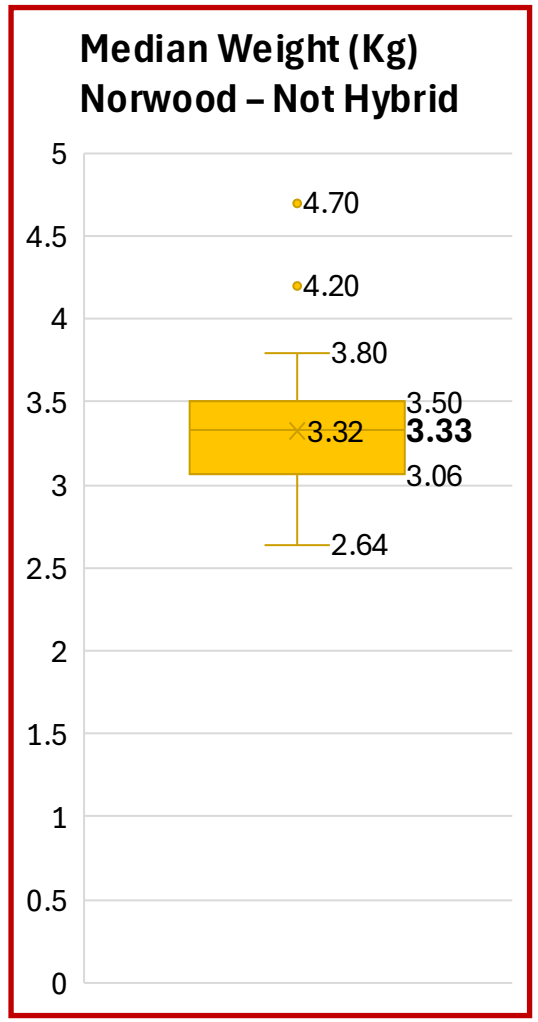


Weight Distribution at All Stages

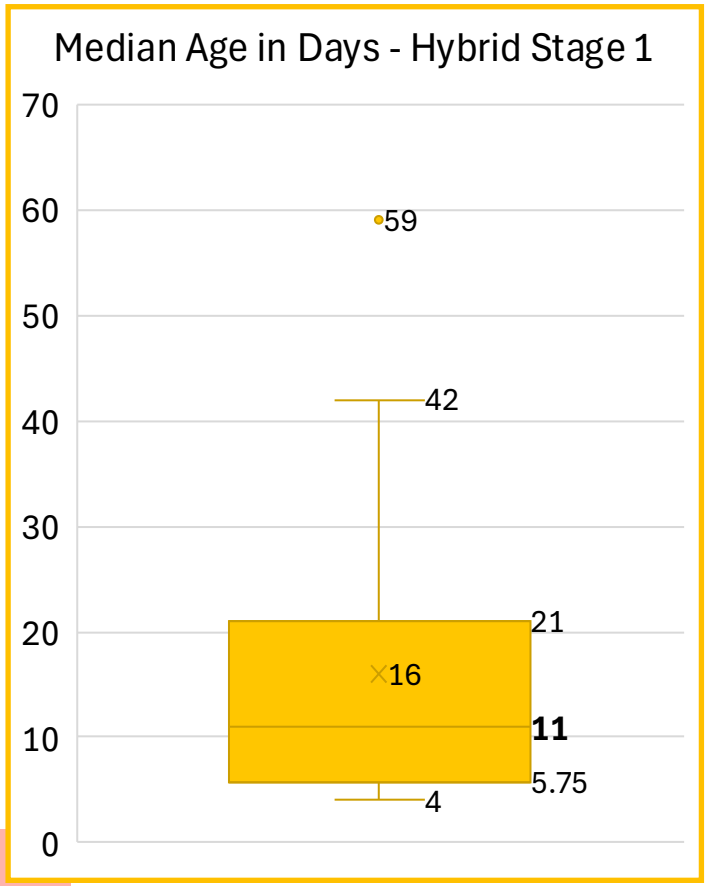


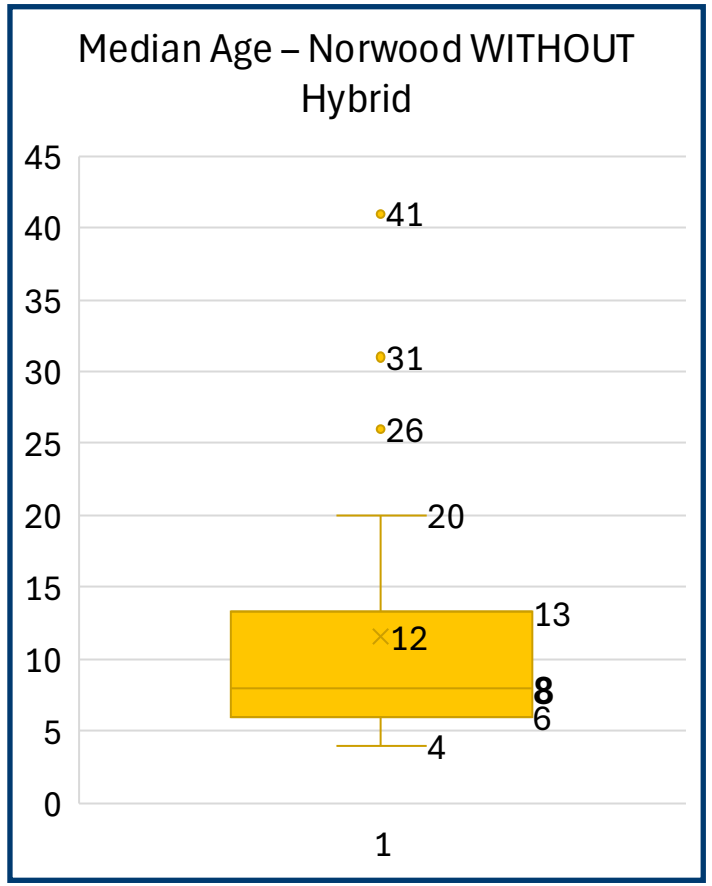


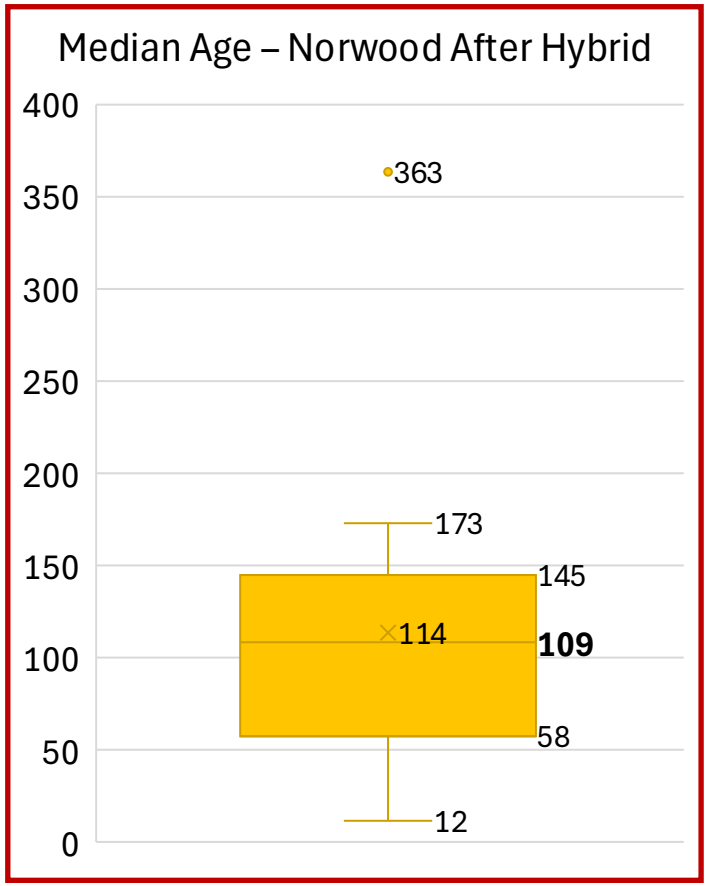




Age (in days) of Patients Undergoing Hybrid Stage I Procedure Prior to a Norwood







Outcomes

Mortality

# / Eligible	Observed Mortality
2/18	11%

Median In-Hospital Post-Operative Length of Stay

Patient Surgical Status at Discharge	Length of Stay in Days
Norwood Procedure WITHOUT Hybrid	21
Norwood Procedure After Hybrid	22
Hybrid “Stage 1” Procedure	37
Hybrid with Norwood during Same Hospital Stay	70

Conclusion & Clinical Implications

- Hybrid “Stage I” utilization is increasing at our institution
- We are increasingly able to discharge patients after their Hybrid procedure
- Primary Norwood vs Hybrid decision is difficult (Hybrid patients have high incidence of chromosomal abnormalities); at our institution we have been guided by genetic and anatomical substrate.

Thank You!

ST. LOUIS Children's HOSPITAL BJC HealthCare

PC4 PAC3

WashU Medicine