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Predicting Acute Kidney Injury in Pediatric Cardiac Surgery Patients Using Supervised Machine Learning

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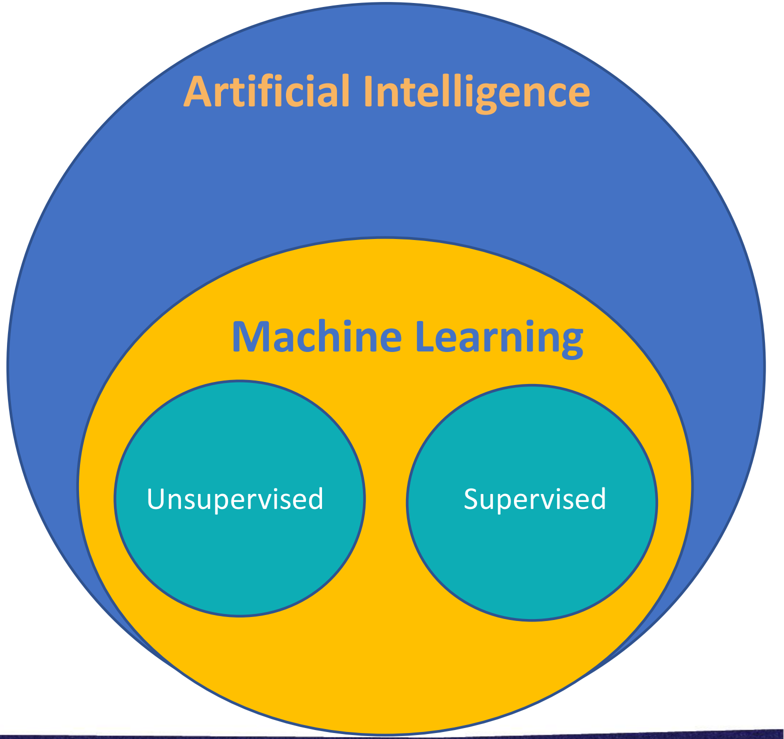
Pediatric Cardiac Surgery Increases AKI Risk

- 10-60% of pediatric cardiac surgery patients develop AKI (CSA-AKI)
  - 3 to 8 times Increased morbidity and mortality
- Markers identified to attempt to identify AKI at early stages
- AKI typically develops 48-72 hours post-op
- **There is a need to better predict children at high risk of developing CSA-AKI in the early post-operative period**

Machine learning (ML) may be a useful predictive tool

- ML is a branch of Artificial Intelligence that "learns" by leveraging data to improve performance on a specific task
- Supervised ML has several advantages
  - Ideal for tabular data
  - Feature extraction
  - Ability to handle linear and non-linear data
- Multiple ML models have been developed for predicting CSA-AKI in adults
- **ML has not been utilized for CSA-AKI prediction in children**



Aims

AIM 1

Predict CSA-AKI in children on POD2 using baseline, intra-op, and immediately post-op parameters using supervised machine learning

AIM 2

Identify the most important contributing factors to CSA-AKI development in children

Data Allocation and Predicted Outcome

- Retrospective chart review
- 402 patients total
  - 321 (80%) used to **train** the model
  - 81 (20%) used to **test** the model
- Outcome
  - No/Mild AKI (KDIGO 0-1) – 86%
  - Moderate/Severe AKI (KDIGO 2-3) – 14%

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KDIGO Stage	Serum Creatinine	Urine Output
1	- 1.5-1.9 times baseline or - ≥0.3 mg/dL increase	- <0.5 mL/kg/h for 6h
2	- 2-2.9 times baseline	- < 0.5 mL/kg/h for 12h
3	- 3 times baseline or - Increase in serum creatine to ≥ 4 mg/dL or - Initiation of renal replacement therapy	- < 0.3 mL/kg/h for 24h or - Anuria for ≥ 12h

Predictor Variables

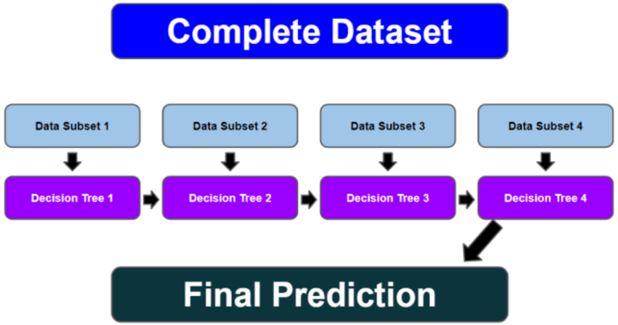
Baseline	Intra-operative	Immediately Post-Operative
Age (months)	Diuretic Intervention (Y/N)	Post-Op Serum Creatinine (mg/dL)
Gender (M/F)	RACHS Score	First 8 hour Urine Output (cc/kg/hr)
Weight (kg)	1	Diuretic Intervention POD 0 (Y/N)
Term Delivery (Y/N)	2, 3	Hematocrit (%)
Gestation (weeks)	4, 5, 6	Albumin (g/dL)
Cyanotic Defect (Y/N)	Surgery Time (min)	pH
Pre-Op Serum Creatinine (mg/dL)	Cardiac Bypass Time (min)	Lactate (mmol/L)
	Aorta Clamping Time (min)	Central Venous Pressure (mmHg)
		Vasoactive Inotropic Score
		Epinephrine Requirement (Y/N)

24 Input Features Included

Light GBM and SHAP were used for model development and analysis

Light GBM (ML Model)

- Ensemble based supervised machine learning
    - Trains on subset of data, and refines with subsequent models



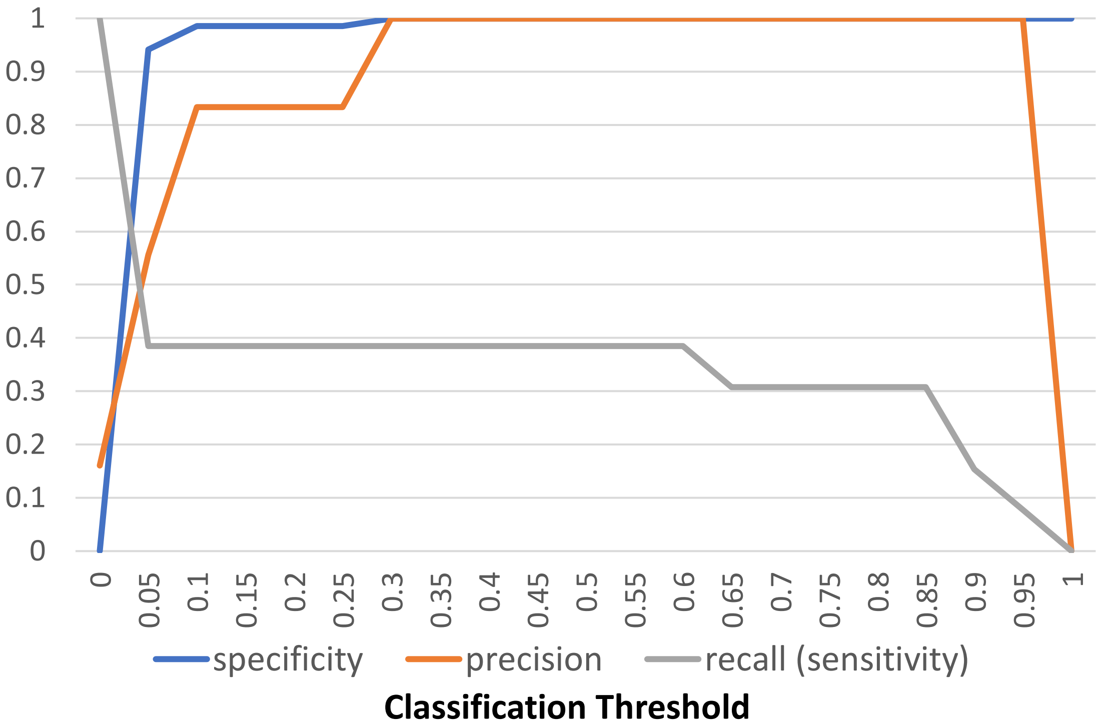
SHAP (Feature Extraction)

- Game theory based algorithm to identify most important features
    - Makes the "black box" of AI explainable

The model showed high specificity but low sensitivity on the test set

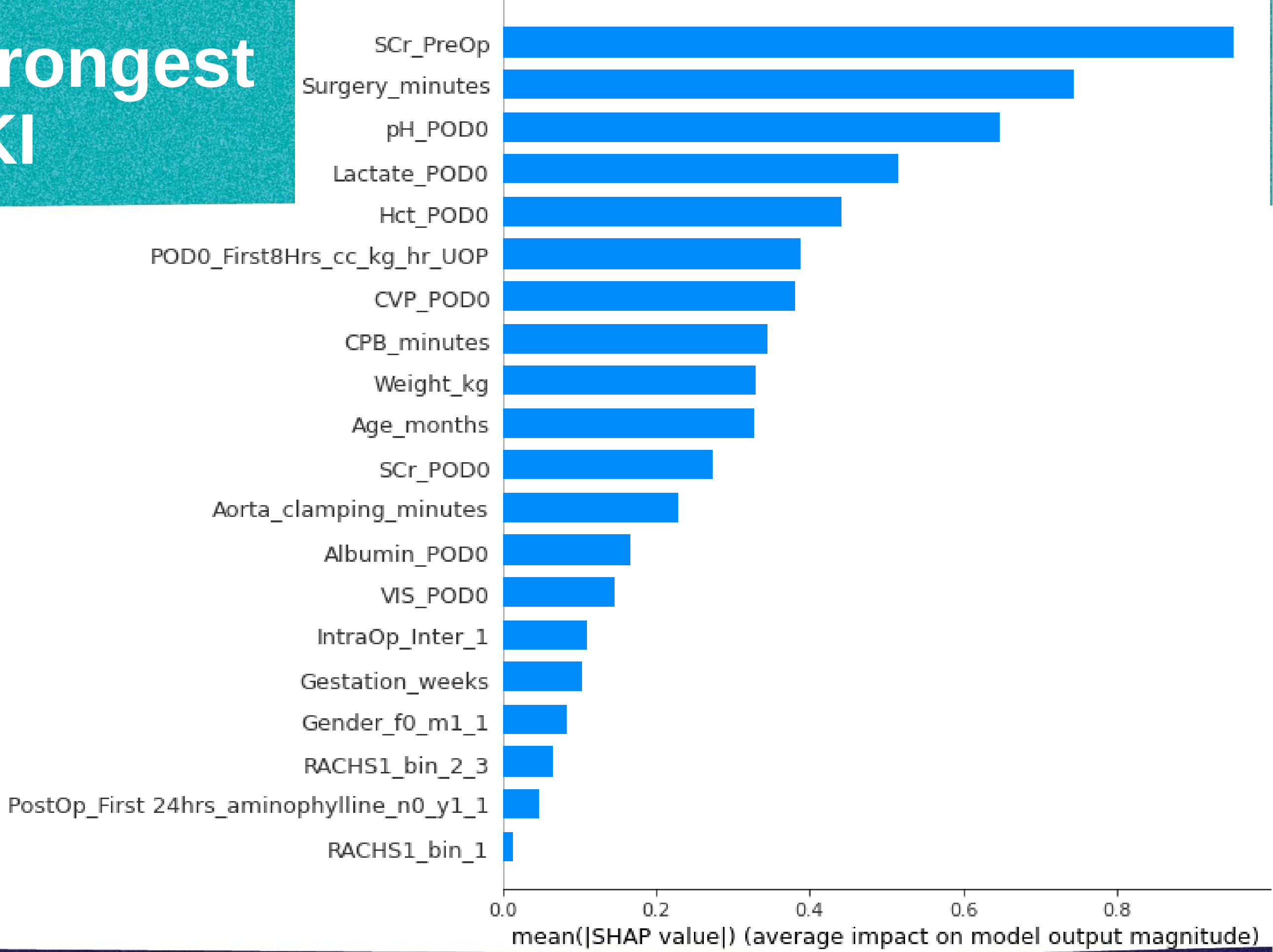
With threshold of 0.5:

- AUC = 0.85
- Accuracy = 0.9 (imbalanced data: 14% with mod/severe AKI)
- Precision = 1.00
- Specificity = 1.00
- Sensitivity = 0.38



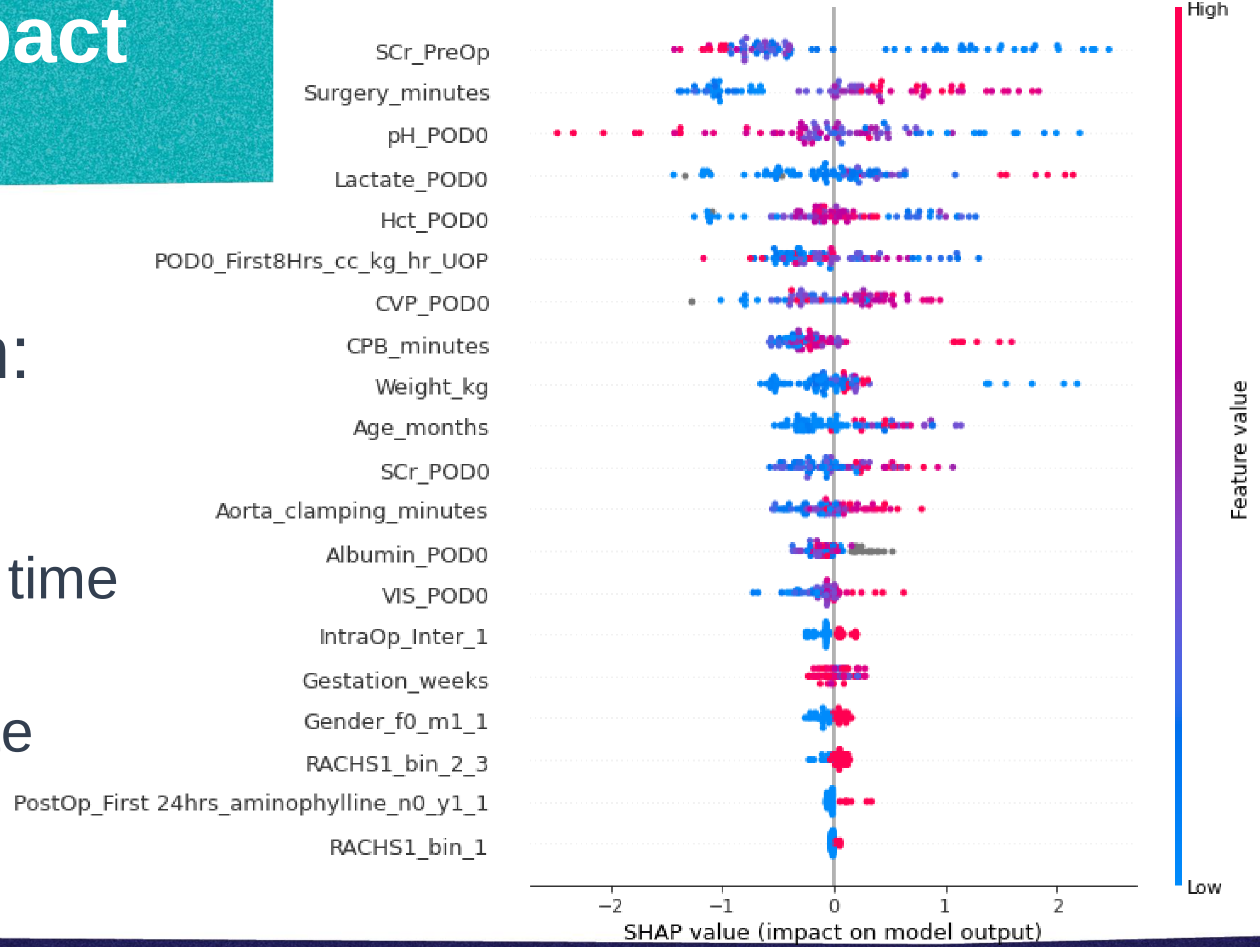
Model shows strongest predictors of AKI

- SHAP values = relative impact on model performance
- The top three predictors were
    1. Pre-op serum creatinine
    2. Length of surgery
    3. Post-op pH

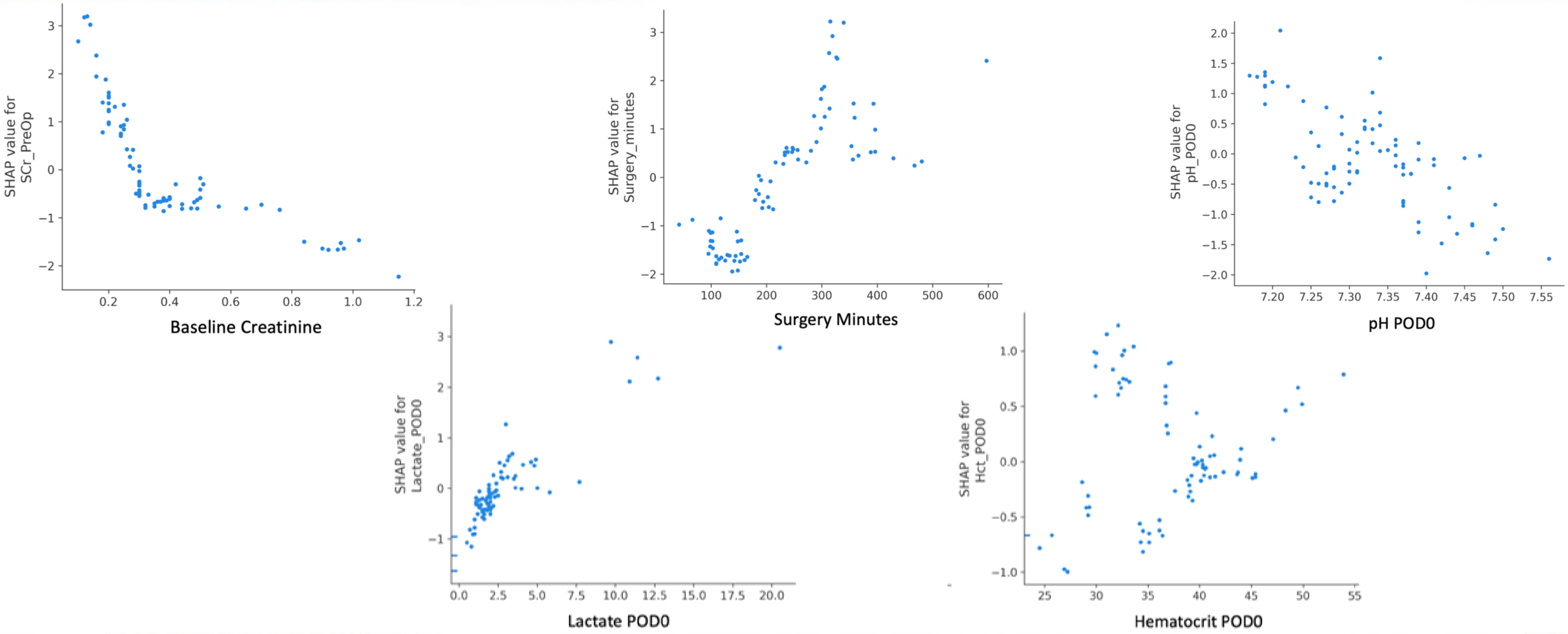


Direction of impact also evaluated

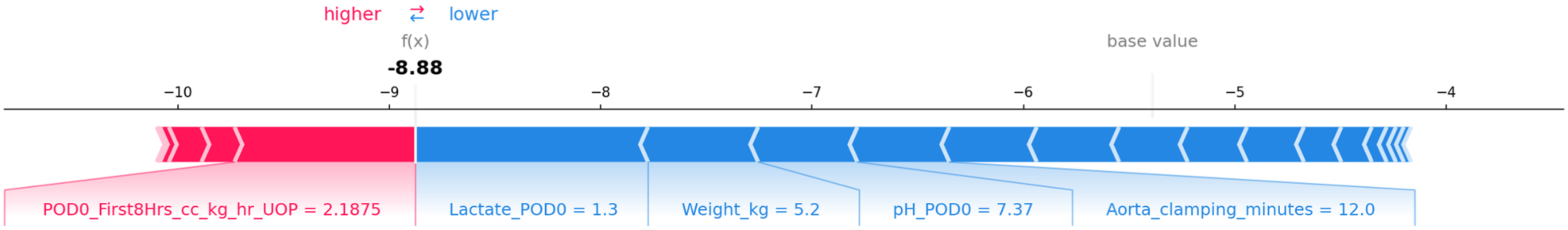
- AKI on POD2 associated with:
  - Lower baseline creatinine
  - Longer surgery time
  - Lower pH
  - Elevated Lactate



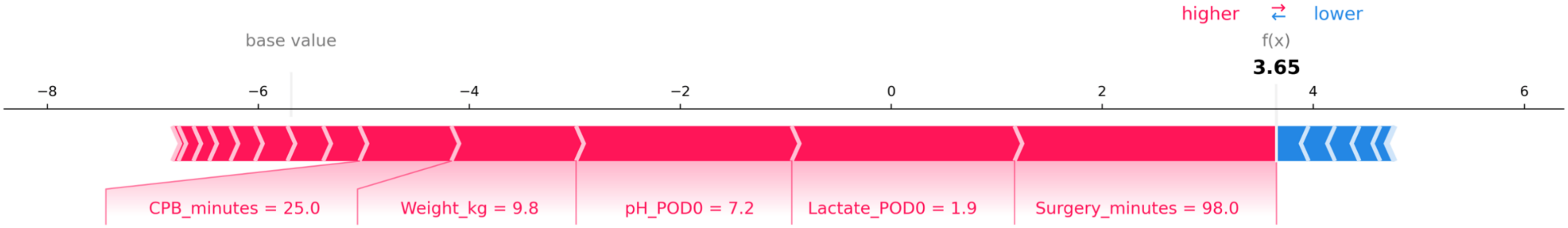
Relationships between top features and SHAP scores



Individual level predictions helps clinicians understand models rationale



Patient without AKI



Patient with AKI

AAP experience

Summary

We developed an explainable supervised machine learning model with high specificity for detecting CSA-AKI in children

Strengths

- Wide array of clinical predictive variables included
- Uniformity in data reporting and collection
- No data were imputed

Limitations

- Small ML sample size
- Lack of external validation
- Lack of "Gold Standard" marker for defining AKI

Next steps

- Include more patients to train model
- Evaluate performance on dataset from different hospital

References and Acknowledgements

For more information on this subject, see the following publications:

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Onder, Ali Mirza, David Rosen, Charles Mullett, Lesley Cottrell, Sherry Kanosky, Oulimata Kane Grossman, Hafiz Imran Iqbal, et al. "Comparison of Intraoperative Aminophylline Versus Furosemide in Treatment of Oliguria During Pediatric Cardiac Surgery." *Pediatric Critical Care Medicine: A Journal of the Society of Critical Care Medicine and the World Federation of Pediatric Intensive and Critical Care Societies* 17, no. 8 (August 2016): 753–63. https://doi.org/10.1097/PCC.0000000000000834.

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Entire study team at WVU

Hidden Slide: Table 1

	Overall		Train (w/cross validation)		Test		P-Value
	Missing		Missing		Missing		
n		402		321		81	
BASELINE DEMOGRAPHICS							
Age, months, median [Q1,Q3]	0	6.0 [2.0,27.0]	0	6.0 [2.0,22.0]	0	9.0 [3.0,42.0]	0.013
Gender, female, n (%)	0	177 (44.0)	0	141 (43.9)	0	36 (44.4)	0.967
Weight, kg, median [Q1,Q3]	0	6.9 [4.4,12.2]	0	6.7 [4.3,10.5]	0	8.9 [5.2,16.0]	0.010
Term Delivery, n (%)	0	281 (69.9)		221 (68.8)		60 (74.1)	0.435
Gestation weeks, median [Q1,Q3]	0	38.0 [37.0,40.0]	0	38.0 [37.0,40.0]	0	39.0 [37.0,40.0]	0.696
Cyanotic Defect, n (%)	0	164 (40.8)		133 (41.4)		31 (38.3)	0.696
Serum Creatinine, median [Q1,Q3]	0	0.3 [0.2,0.5]	0	0.3 [0.3,0.5]	0	0.3 [0.2,0.4]	0.356
INTRA-OPERATIVE							
Diuretic Intervention, n (%)	0	180 (44.8)		148 (46.1)		32 (39.5)	0.346
RACHS Score, n (%)							0.018
1	0	90 (22.4)	0	75 (23.4)	0	15 (18.5)	
2, 3		266 (66.2)		203 (63.2)		63 (77.8)	
4, 5, 6		46 (11.4)		43 (13.4)		3 (3.7)	
Surgery Minutes, median [Q1,Q3]	0	207.5 [140.0,303.0]	0	207.0 [140.0,301.0]	0	212.0 [142.0,305.0]	0.759
Cardiac Bypass Minutes, median [Q1,Q3]	0	68.0 [31.0,113.0]	0	69.0 [32.0,118.0]	0	67.0 [30.0,104.0]	0.408
Aorta Clamping Minutes, median [Q1,Q3]	0	34.0 [12.0,64.8]	0	34.0 [12.0,63.0]	0	35.0 [12.0,65.0]	0.882
POST-OP DAY 0							
Serum Creatinine, median [Q1,Q3]	0	0.4 [0.3,0.6]	0	0.4 [0.3,0.6]	0	0.4 [0.3,0.6]	0.800
First 8 hour Urine Output (cc/kg/hr), median	0	2.2 [1.4,3.7]	0	2.2 [1.4,3.7]	0	2.2 [1.4,3.4]	0.619
Hematocrit, median [Q1,Q3]	3	37.5 [33.9,41.5]	2	37.5 [34.3,42.0]	1	37.1 [32.6,40.4]	0.262
Albumin, median [Q1,Q3]	109	3.0 [2.7,3.3]	91	2.9 [2.7,3.2]	18	3.1 [2.8,3.3]	0.161
pH, median [Q1,Q3]	7	7.3 [7.3,7.4]	7	7.3 [7.3,7.4]	0	7.3 [7.3,7.4]	0.671
Lactate, median [Q1,Q3]	21	2.3 [1.5,3.8]	18	2.4 [1.5,4.0]	3	2.0 [1.5,3.1]	0.156
CVP, median [Q1,Q3]	13	10.0 [8.0,14.0]	12	10.0 [8.0,14.0]	1	10.0 [7.0,13.2]	0.483
Vasoactive Inotropic Score, median [Q1,Q3]	5	14.0 [7.0,22.0]	5	13.8 [6.9,23.0]	0	14.0 [7.5,19.0]	0.402
Epinephrine Requirement, n (%)		104 (25.9)		90 (28.0)		14 (17.3)	0.067
OUTCOMES							
Peritoneal Dialysis, n (%)	0	11 (2.7)	0	8 (2.5)	0	3 (3.7)	0.469
Death, n (%)	0	23 (5.7)	0	16 (5.0)	0	7 (8.6)	0.280
Mod-Severe AKI (KDIGO 2 or 3), n (%)	0	55 (13.7)	0	42 (13.1)	0	13 (16.0)	0.608