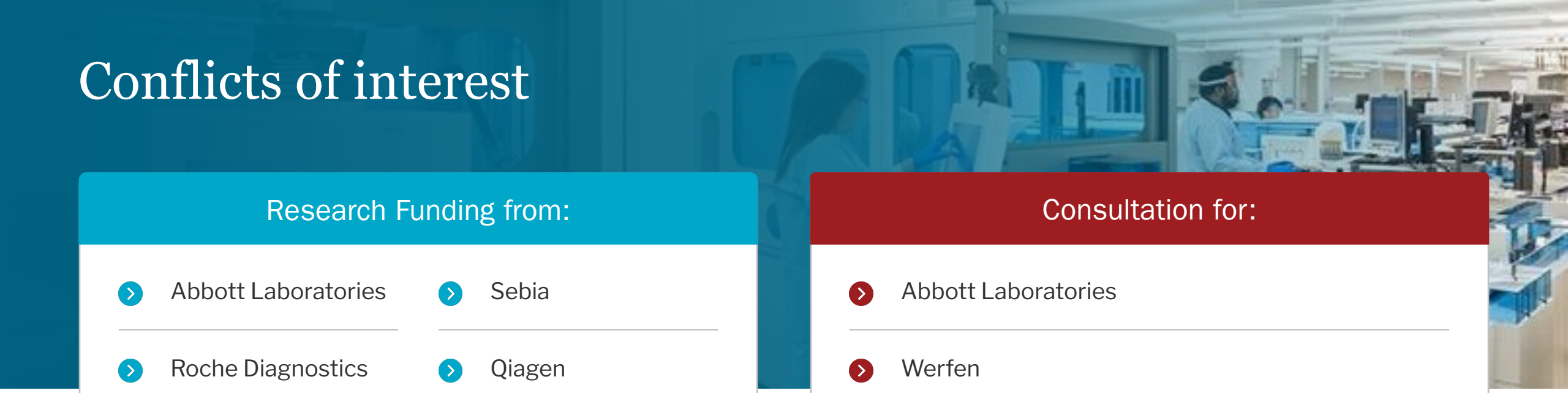
Modern tools to reduce errors in blood collection and trasnport

Christopher W. Farnsworth, PhD, DABCC, FADLM
Associate Professor of Pathology and Immunology
Section Director, Clinical Chemistry
Washington University in St. Louis

Washington University in St. Louis
School of Medicine

Conflicts of interest



Research Funding from:

- Abbott Laboratories
- Roche Diagnostics
- Beckman Coulter
- Siemens Healthineers
- Biomerieux
- Sebia
- Qiagen
- Cepheid
- Werfen

Consultation for:

- Abbott Laboratories
- Werfen
- Cytovale

No conflicts in the area of preanalytics!!!

Learning Objectives

01 Assess the impact of preanalytical error on specimen quality and diagnostic accuracy

02 Implement a multi-disciplinary approach to improve specimen collection and handling through the preanalytical phase to improve patient outcomes

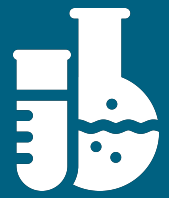
Lab error occurs frequently and are mostly preanalytic

01/2022 – 03/2023

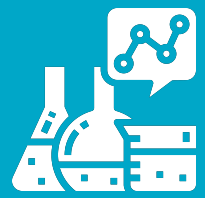
45,812,367
Billable Tests

~11,000,000
Specimens

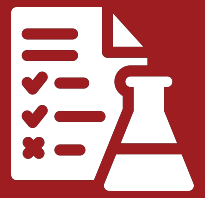
87,317
Errors
(0.79% of billable tests)



98.4%
Preanalytical Errors



1.1%
Analytical Errors



1.1%
Postanalytical Errors

Can we capture and reduce these errors???

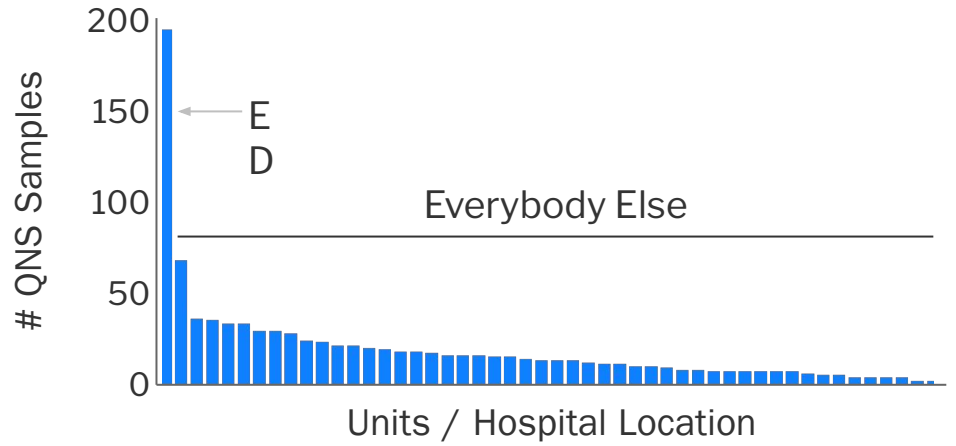
Category	N=	Freq. (%)
Hemolyzed reported	41,047	48.2
Hemolyzed masked	19,701	23.1
Quantity not sufficient	8,068	9.5
Clotted samples	5,840	6.9
Collection errors	5,780	6.8
Transport errors	1,502	1.8
Not on ice	1,369	1.6
IV contamination	1,122	1.3
Too old to test	550	0.6
Sample integrity	92	0.1
Requisition errors	62	0.1
Total	85,133	100

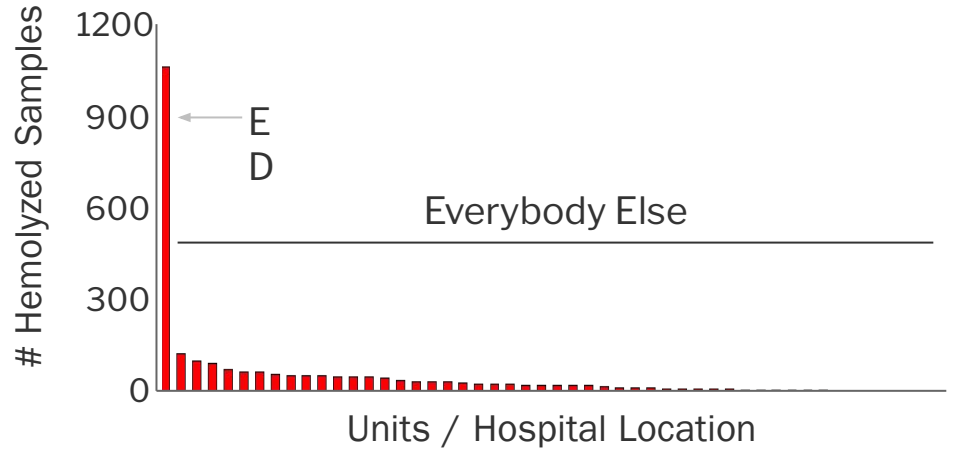
Under Review BJH/ Wash U data

I.

Collection of Specimens from Phlebotomy

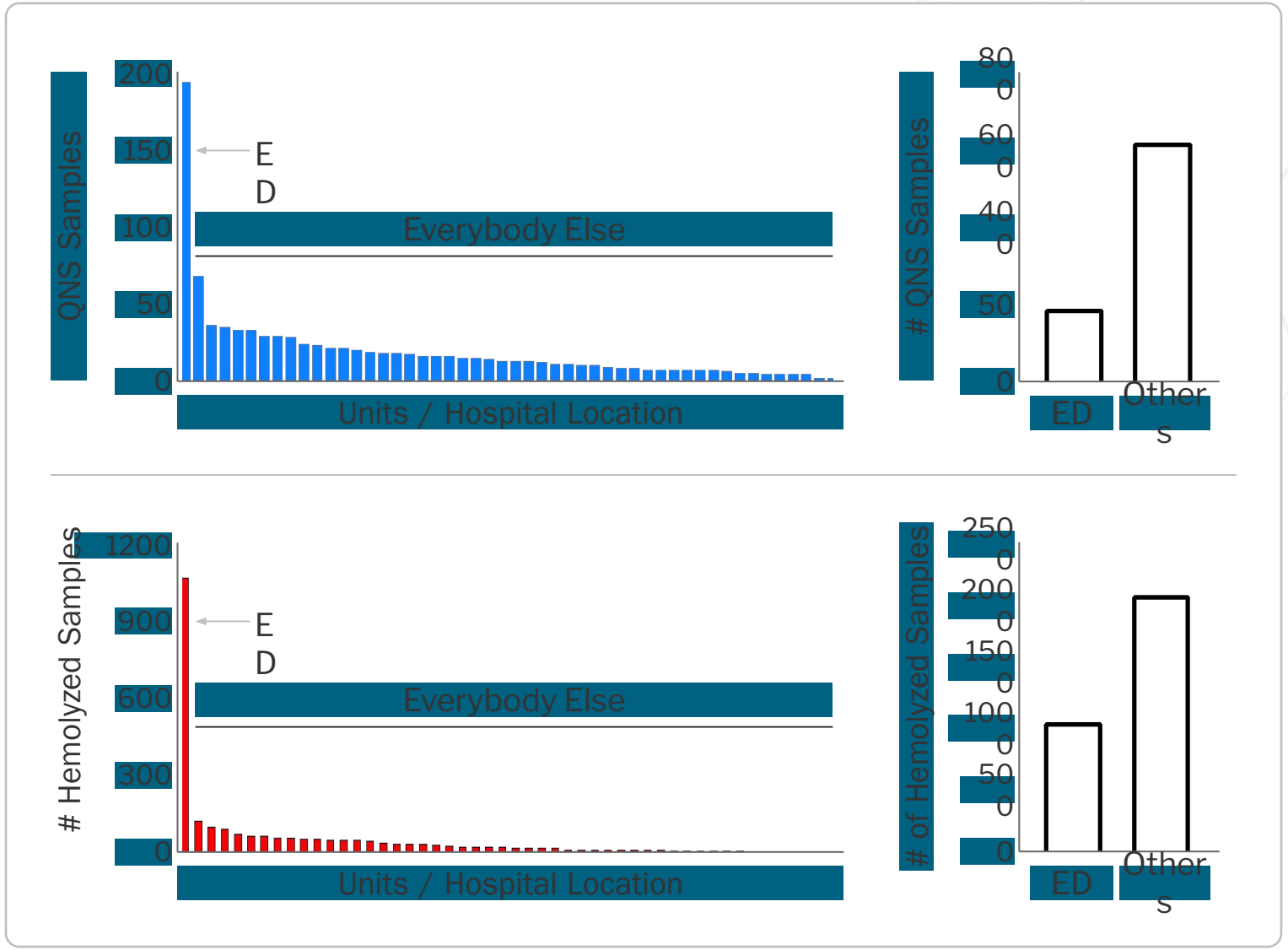
Quantity not sufficient (QNS) and Hemolyzed Samples by Unit





Qavi AJ Clin Biochem 2023;115:137-143.

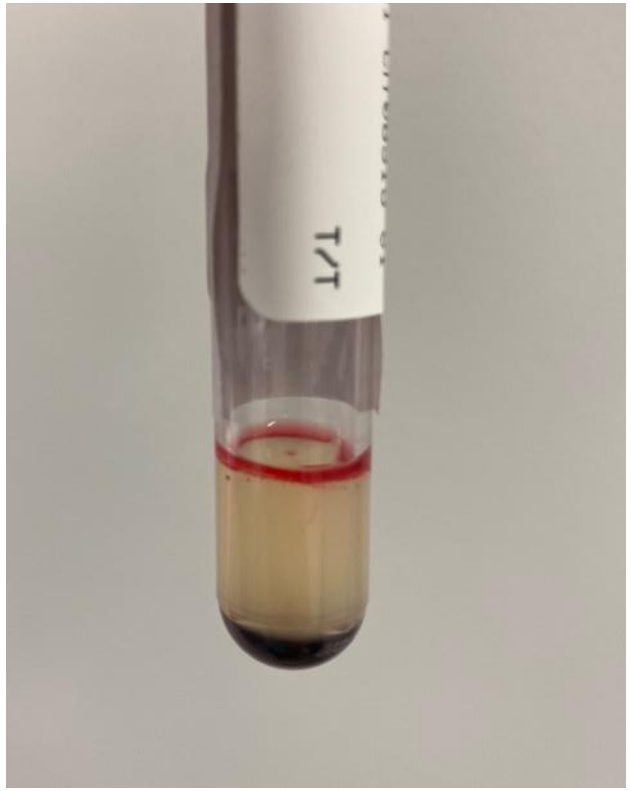
ED only accounts for 25% of QNS and 33% hemolyzed



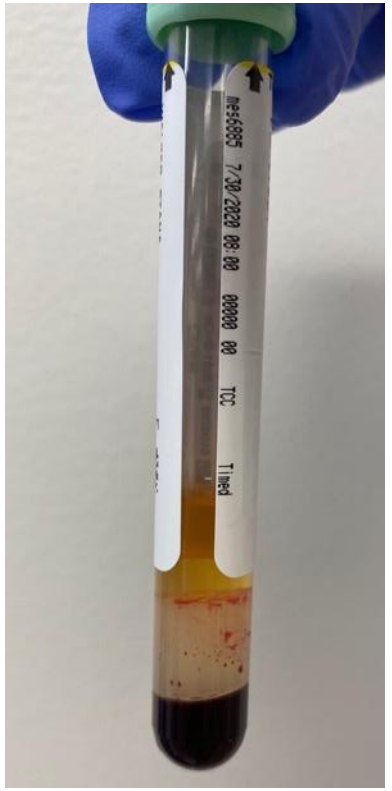
Qavi AJ Clin Biochem 2023;115:137-143.

ED collaboration goal: Reduce QNS samples

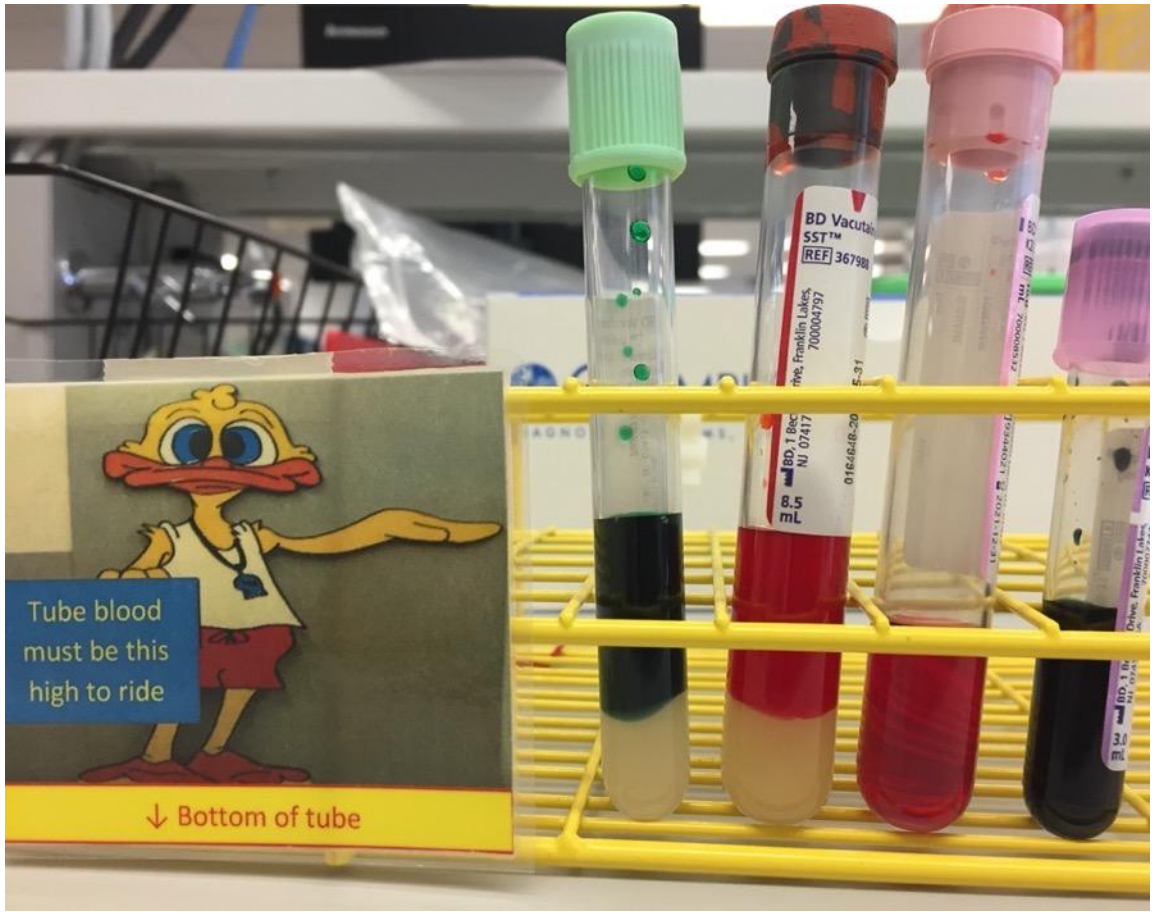
Of these

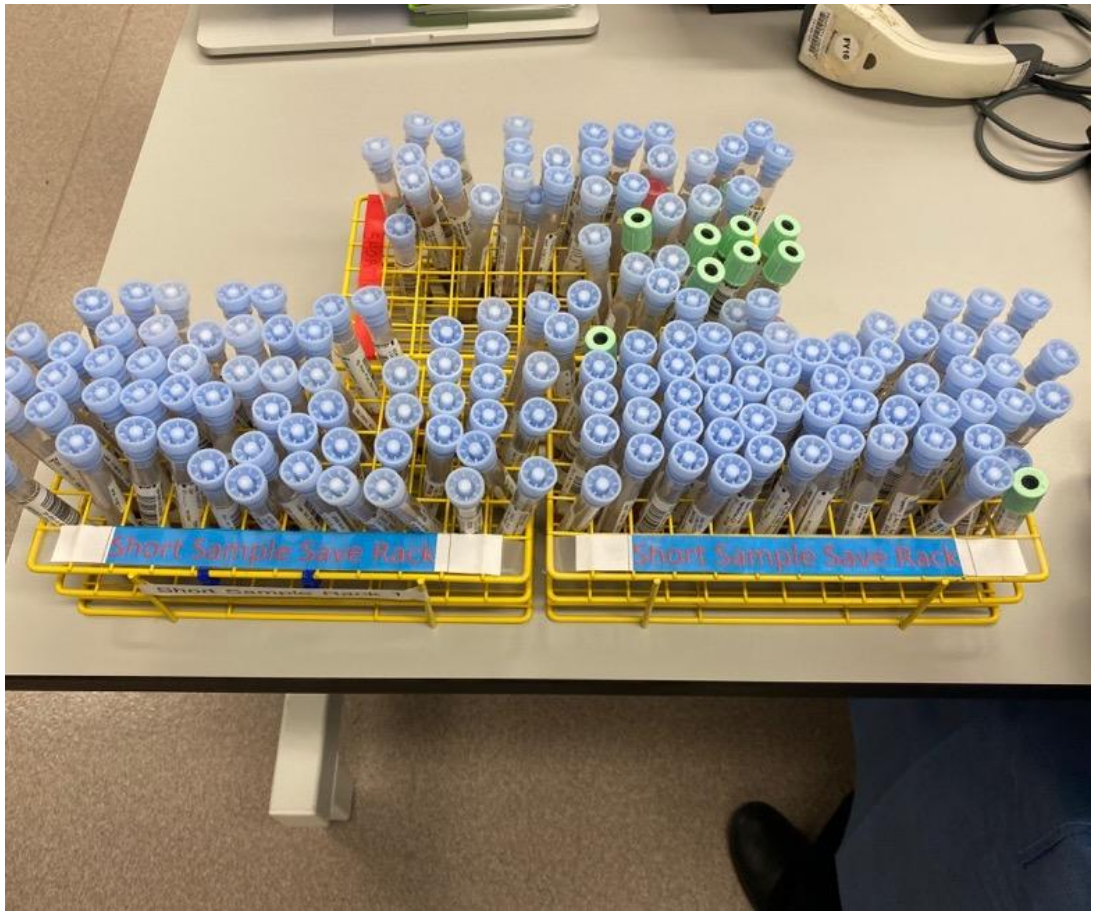


…and these

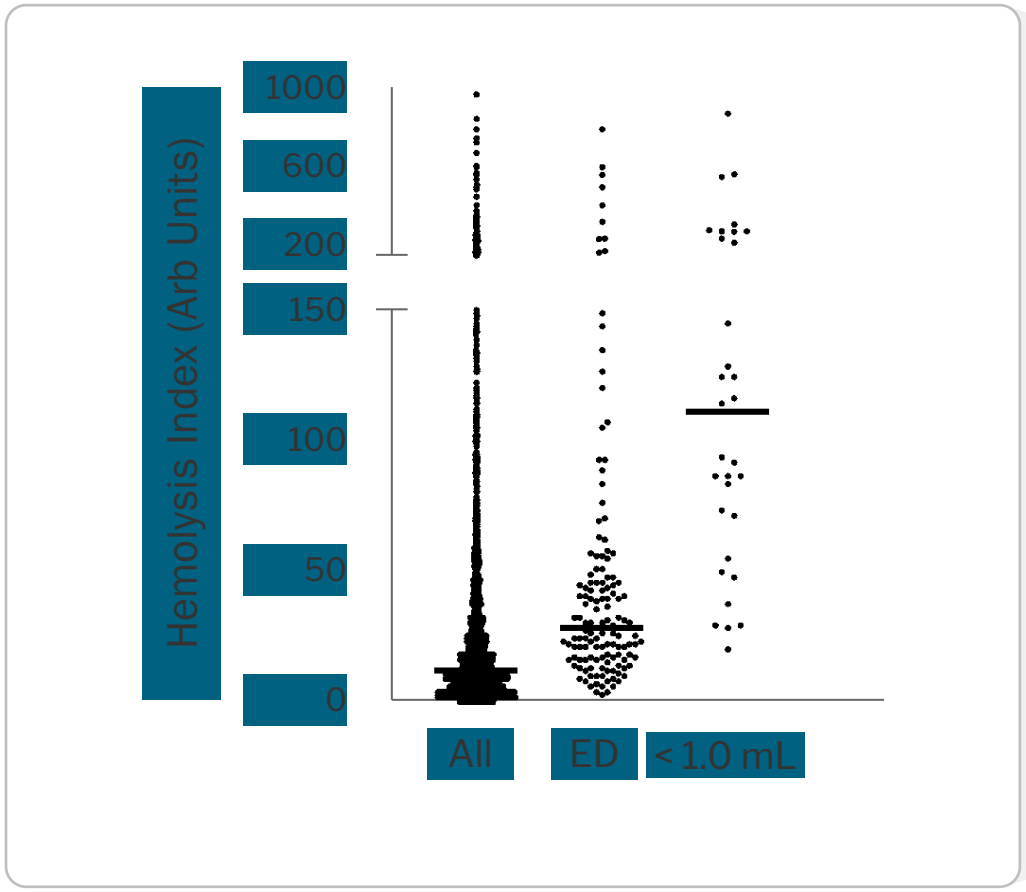


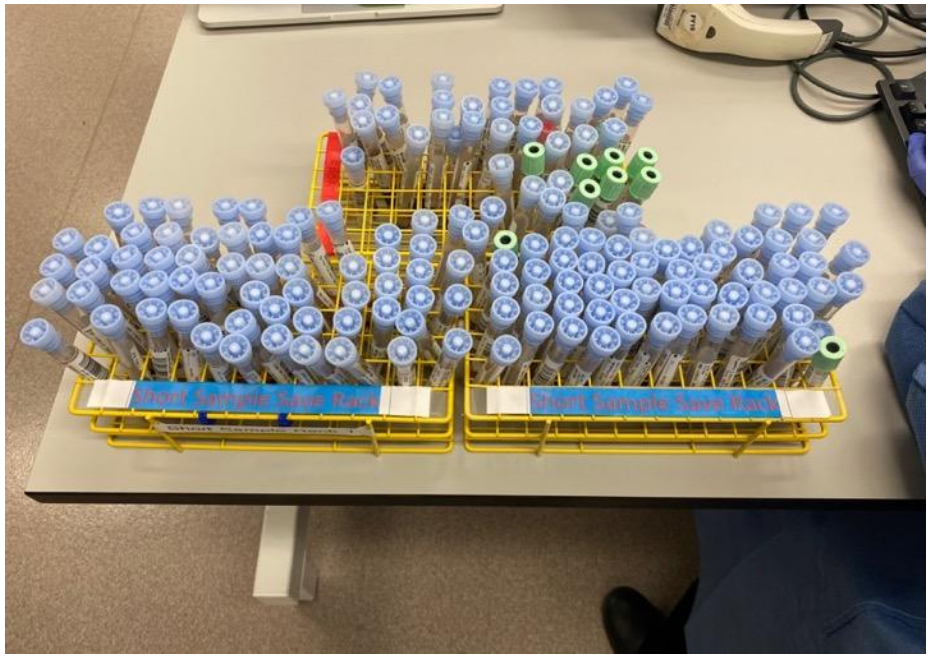
QNS samples are common….





QNS samples are more likely to be hemolyzed

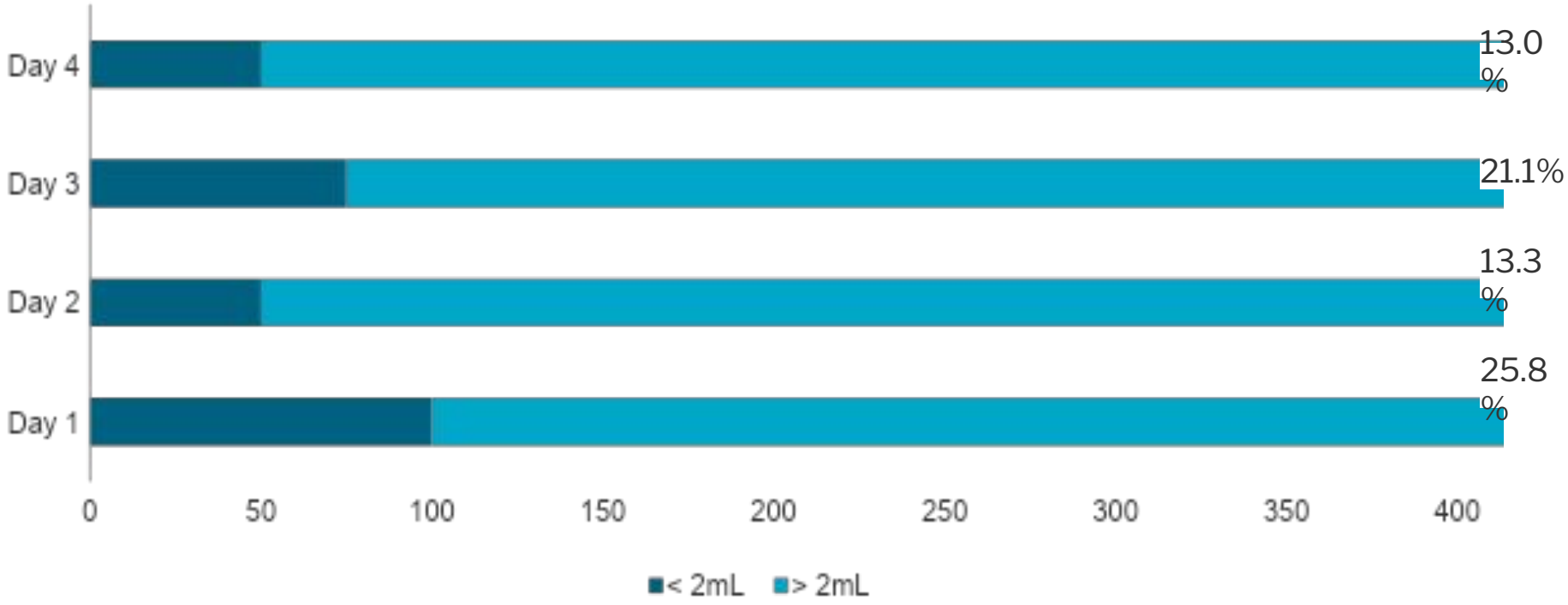


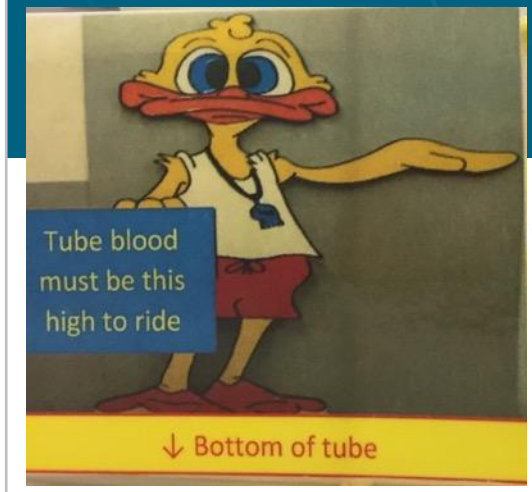


Take Home: QNS samples = more hemolysis, more redraws

Intervention- cancel all specimens < 2mL of blood

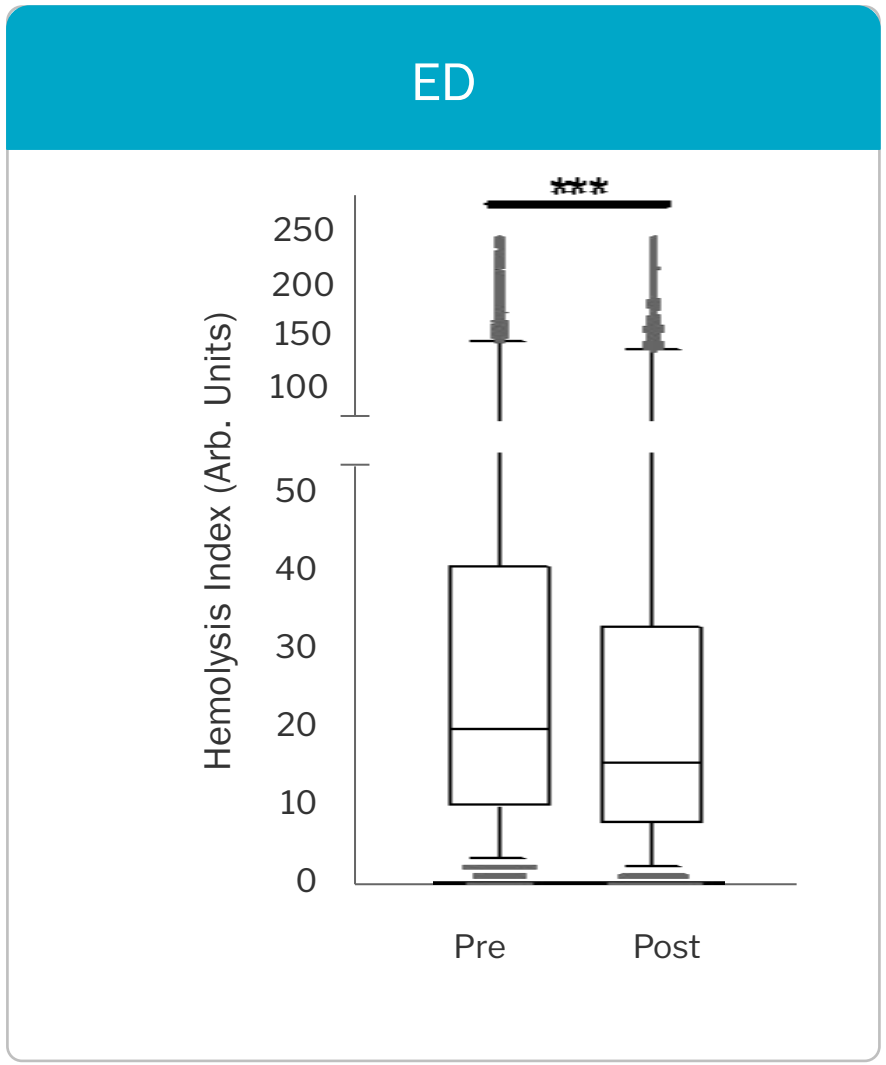
4 day grace period we measured and call back all samples < 2 mL to the ED



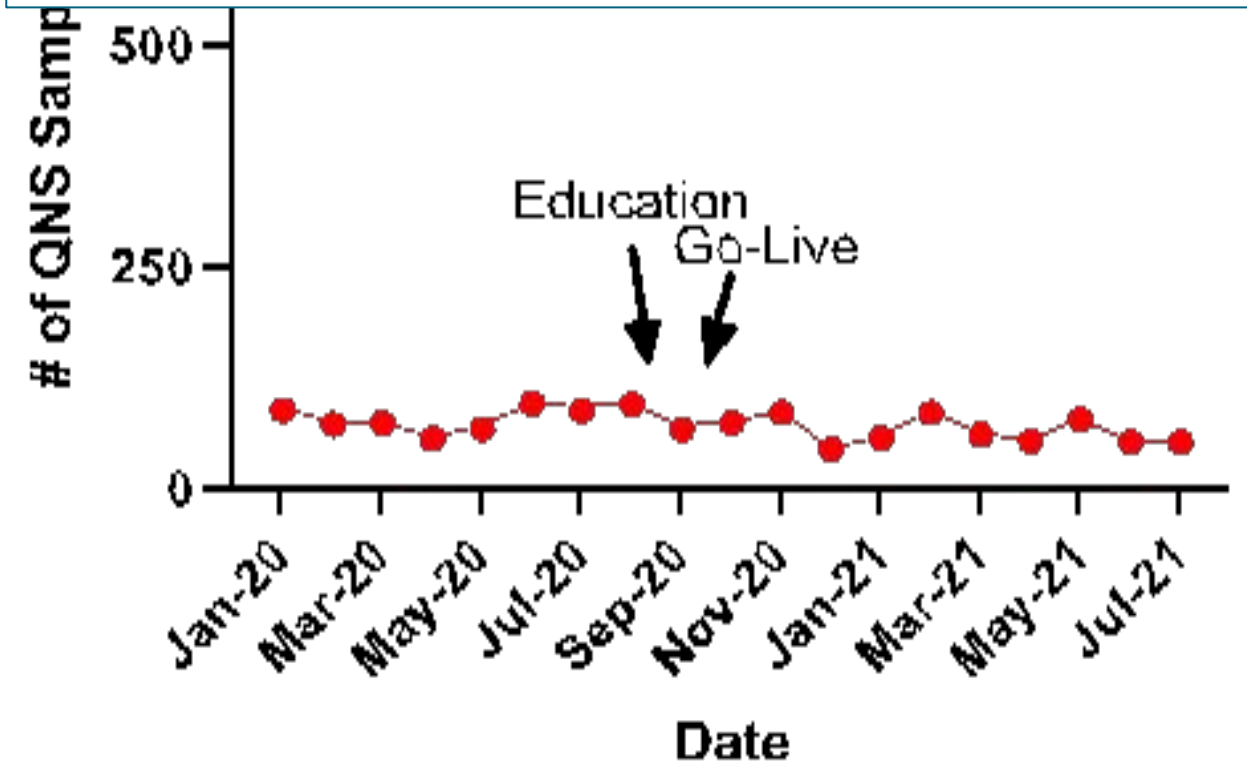


Qavi AJ Clin Biochem 2023;115:137-143.

Intervention reduced hemolysis, no change in QNS



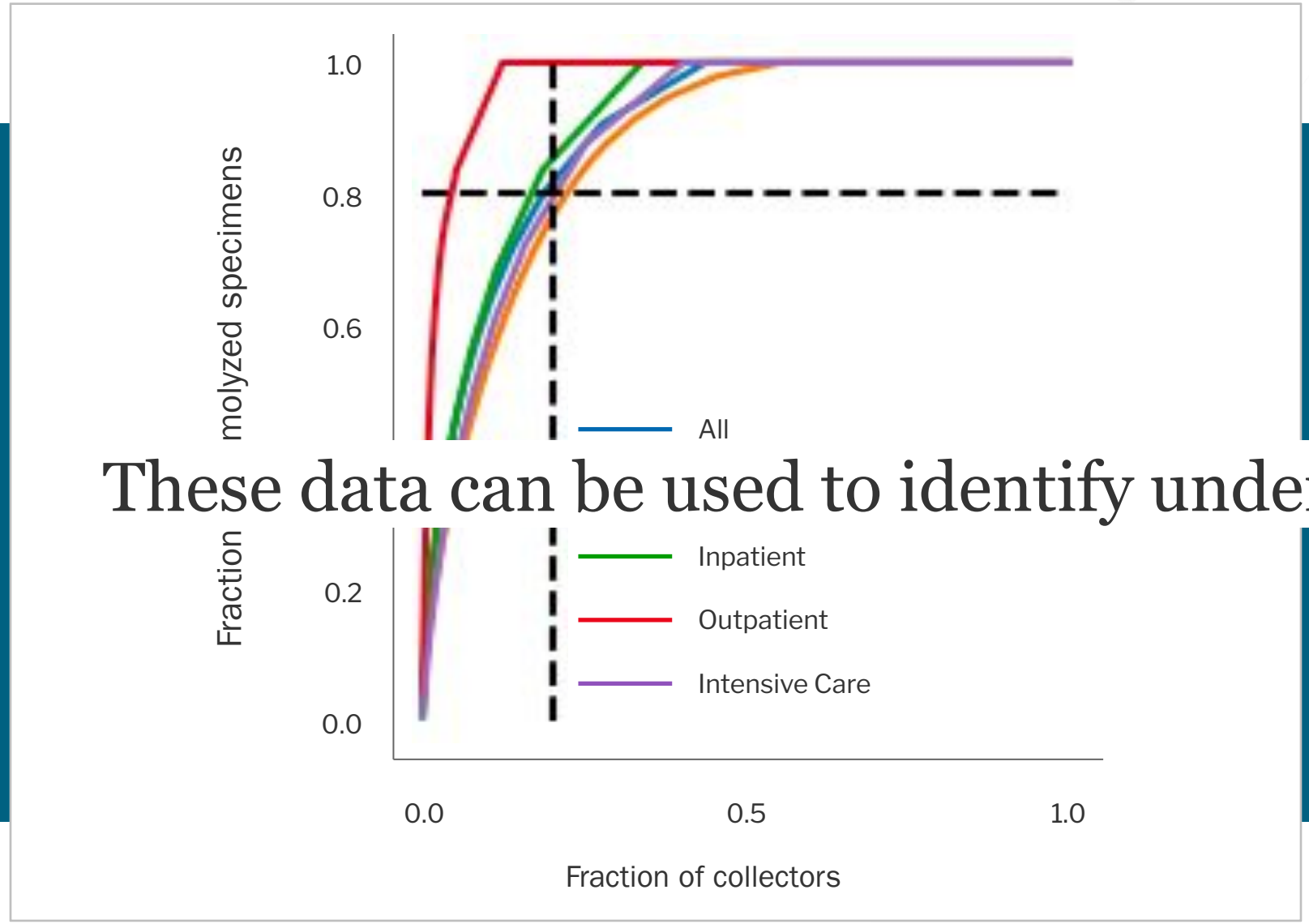
Shouldn't we be encouraging our staff to collect FULL Tubes?



Qavi AJ Clin Biochem 2023;115:137-143.

Use of positive patient identification to identify collectors

20% of collectors cause 80% of rejected samples

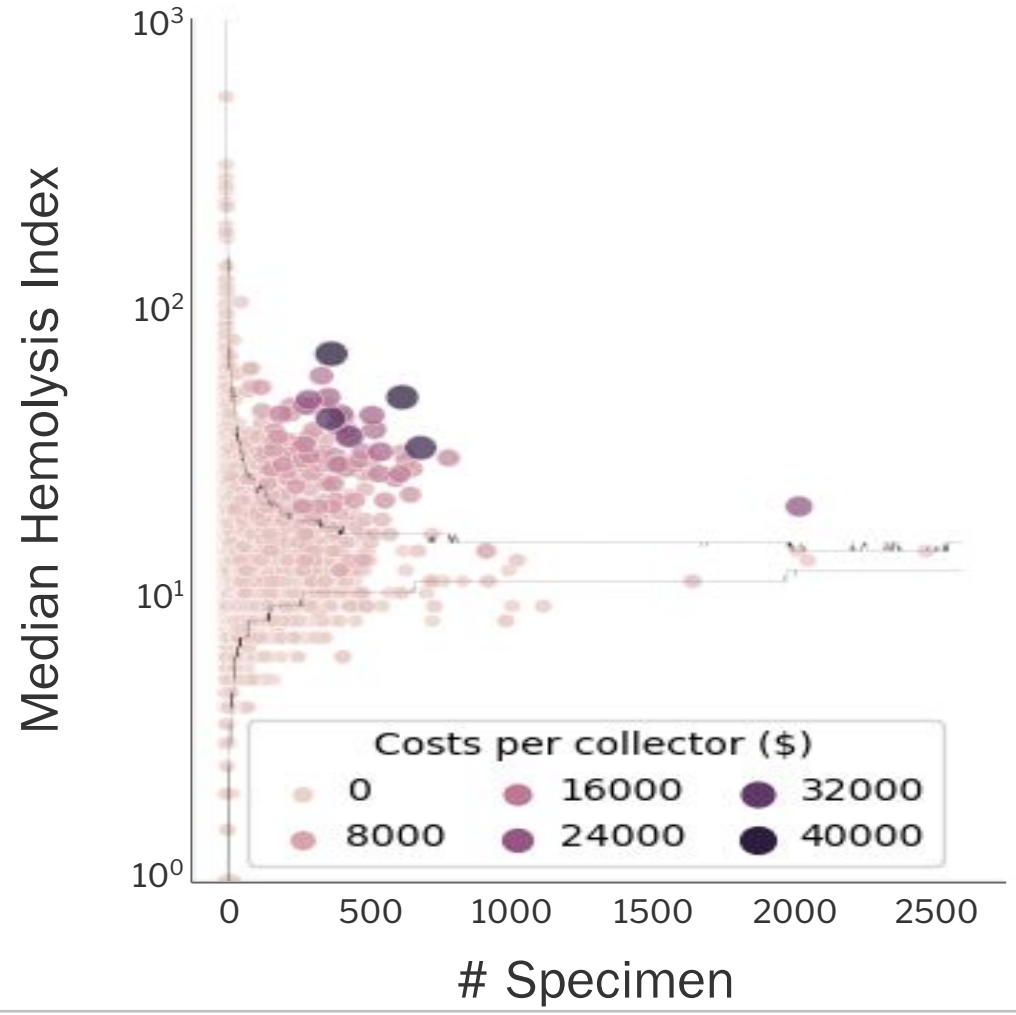


These data can be used to identify under performers!

Mark Zaydman, MD, PhD
Assistant Professor, Wash U

Farnsworth CW Zaydman M, Internal Data

Statistical model predicts underperforming collectors



Prediction accuracy (future 20%):

Sensitivity = 71%

Specificity = 93%

Accuracy = 88%

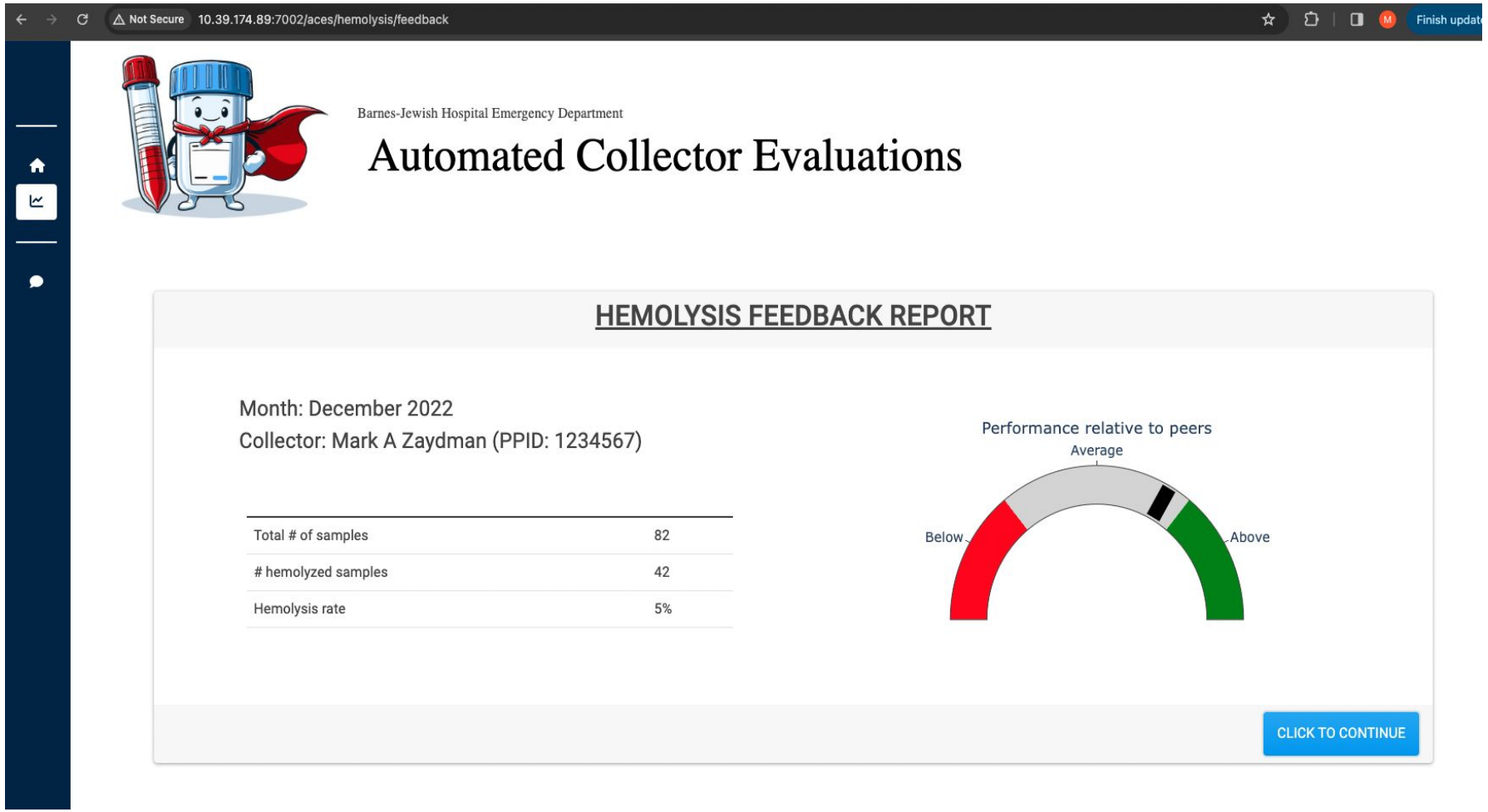
Other approaches:

Most recollections

Average -Highest HI

Farnsworth & Zaydman Unpublished Data.

Next steps: Automated feedback…



Farnsworth & Zaydman Unpublished Data.

Takeaways: Mitigating and detecting hemolysis

01

Hemolysis is a major cause of preanalytical error

- Consider working with nursing and ED to establish methods to detect collection underperformers

02

QNS rates may considerably impact TAT and hemolysis

II.

Specimen Transport

Specimens are transported by pneumatic tube systems (PTS)

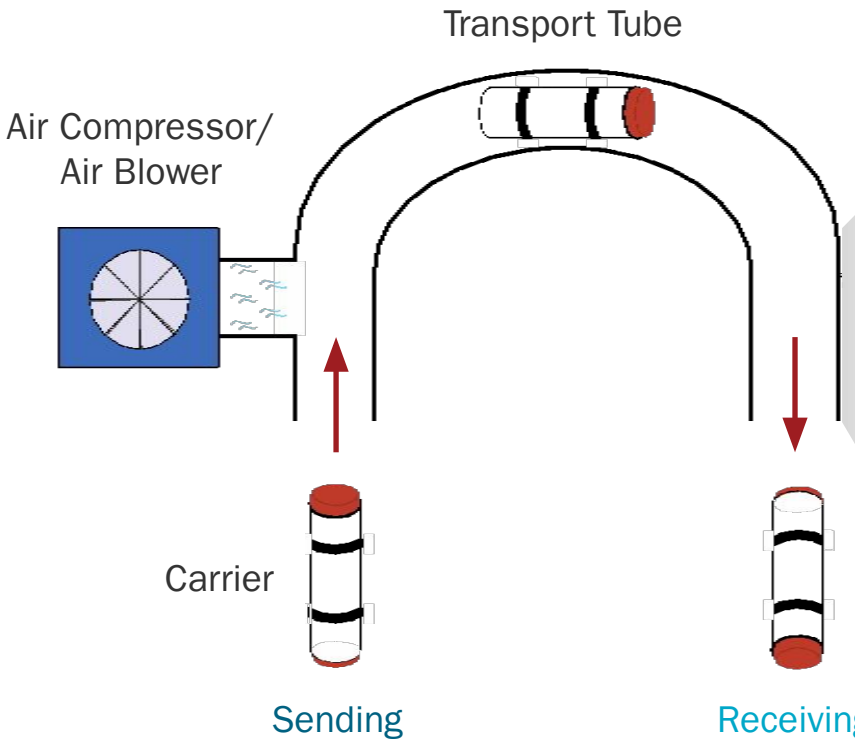
Invented in 1850's to transport telegraphs

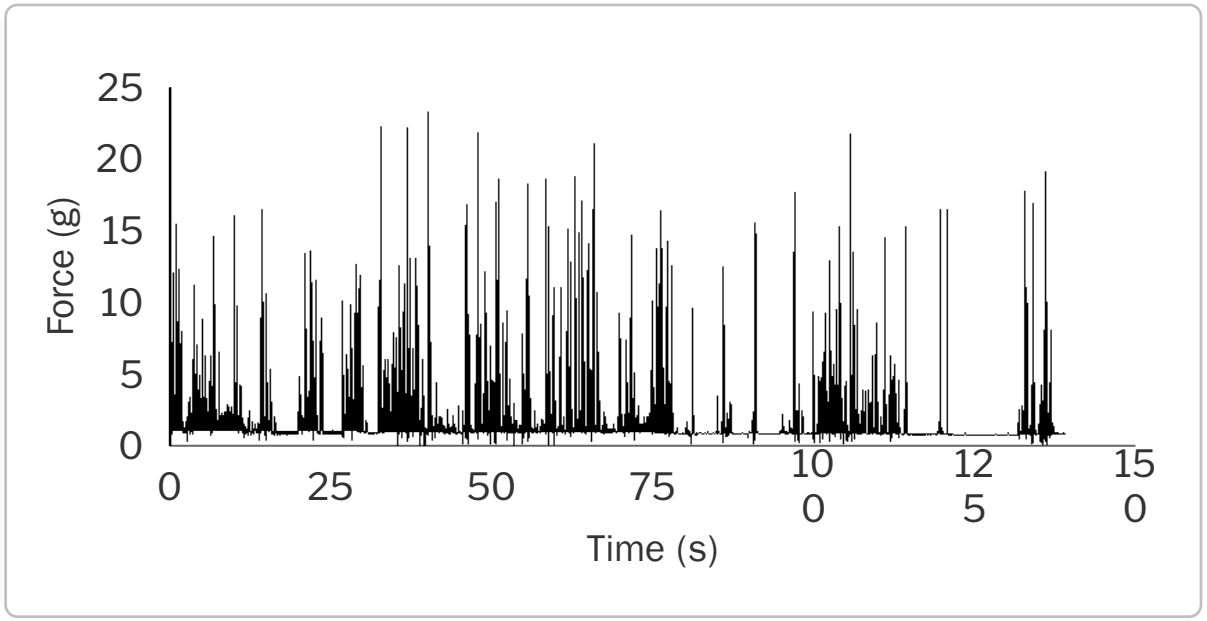
PTS provides rapid transport of patient specimens to laboratories

Reduce turnaround time by ~10 minutes

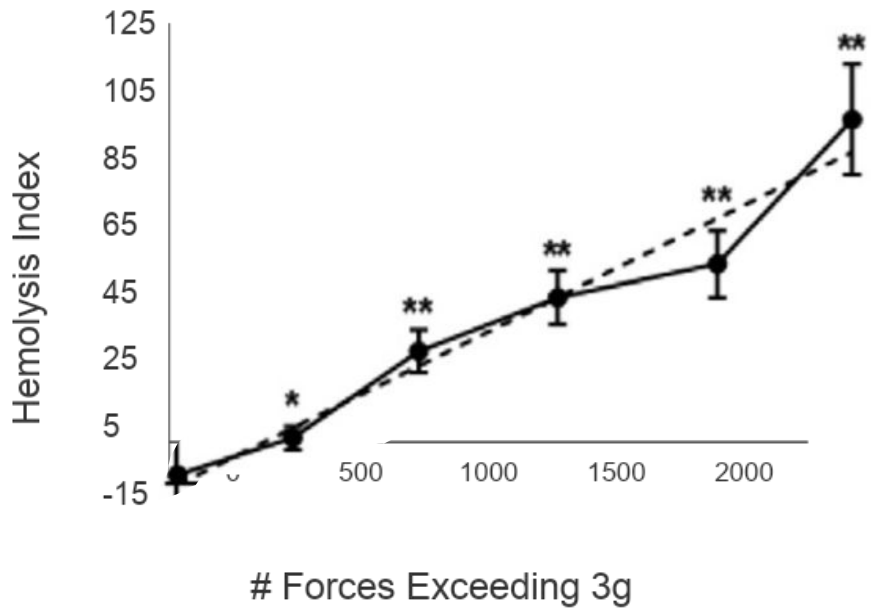
Guss DA et al, Ann Emerg Med 2008; 51:181-5.

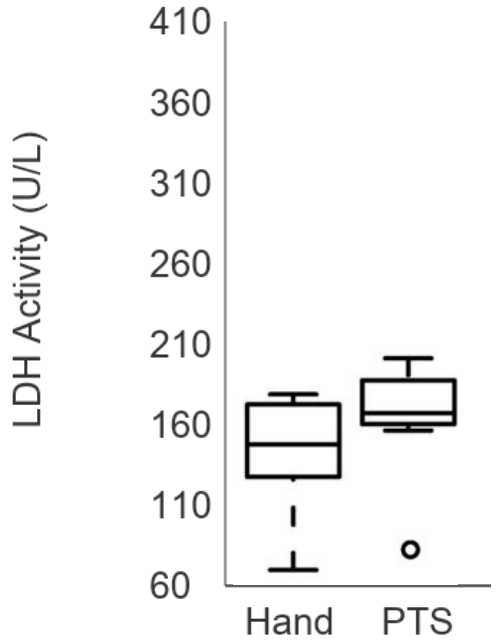
PTS generates extreme accelerations during transport





Specimen transport by PTS increases hemolysis

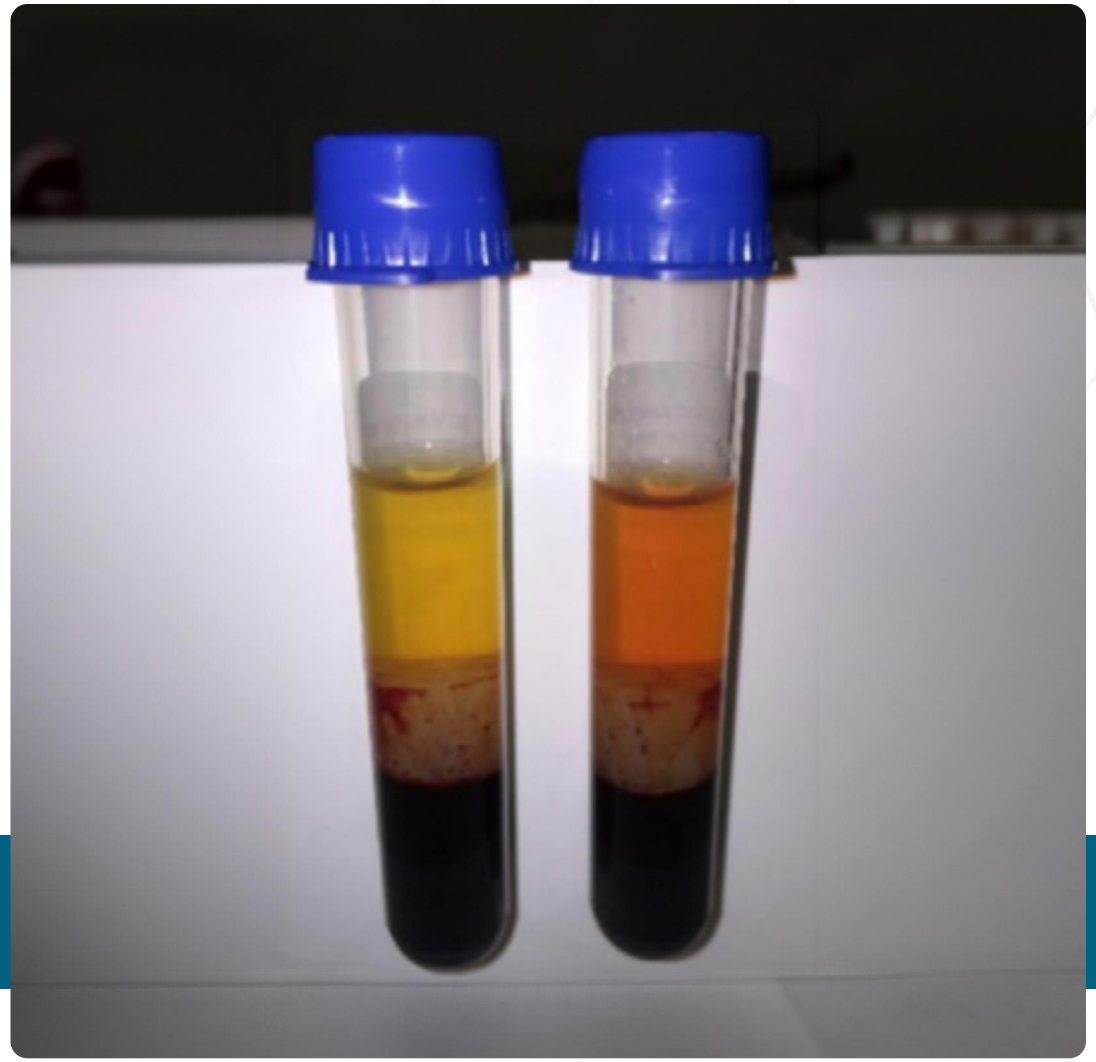




Mullins GR *et al.* Clin Chem Acta 2016; 462:1-5.
Streichert T *et al.* Clin Chem. 2011;57:10.

Analytes impacted by PTS transport- mostly intracellular

	Mean (N = 30)	
	Control	Trans
Na (mmol/liter)	141.1	140.1
Cl (mmol/liter)	103.9	103.8
CO2 (mmol/liter)	24.5	24.4
Ca (mg/dL)	9.59	9.58
P1 (mg/dL)	3.06	3.08
Bilirubin (mg/dL)	0.54	0.54
Uric acid (mg/dL)	6.20	6.19
K (mmol/liter)	4.45	4.56
Hb (mg/100 ml)	4.76	12.64
LDH (U/liter)	98	148



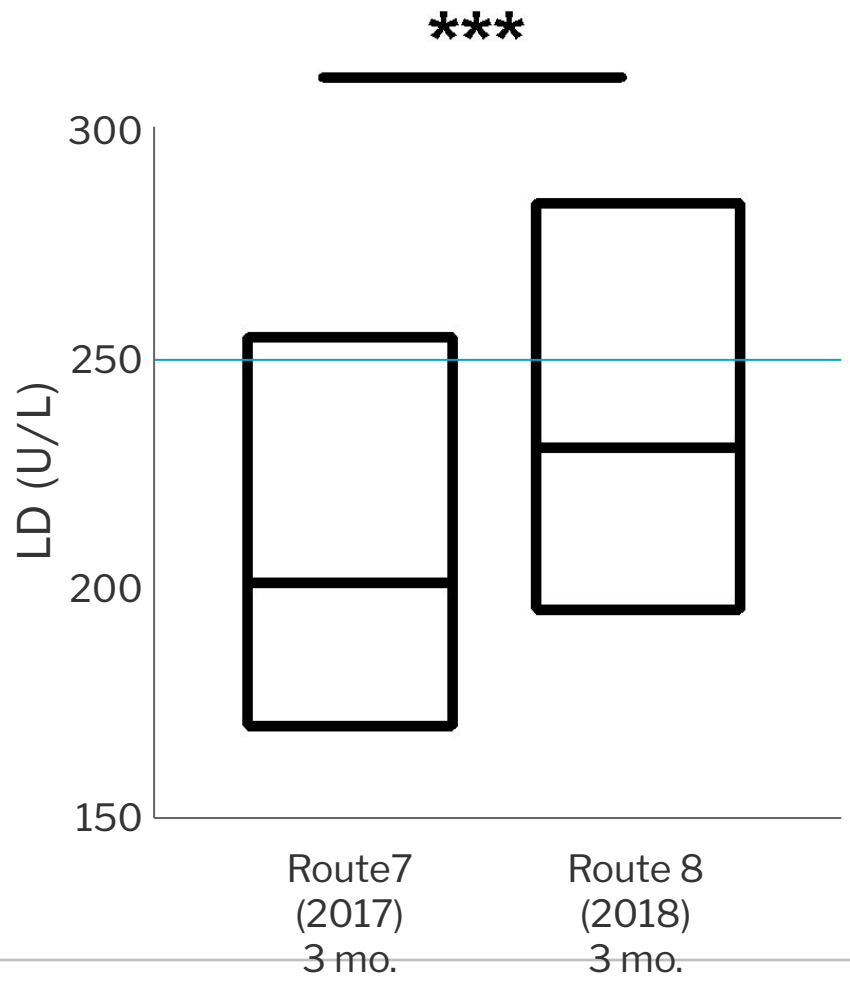
And known to be impacted by pneumatic tube transport!

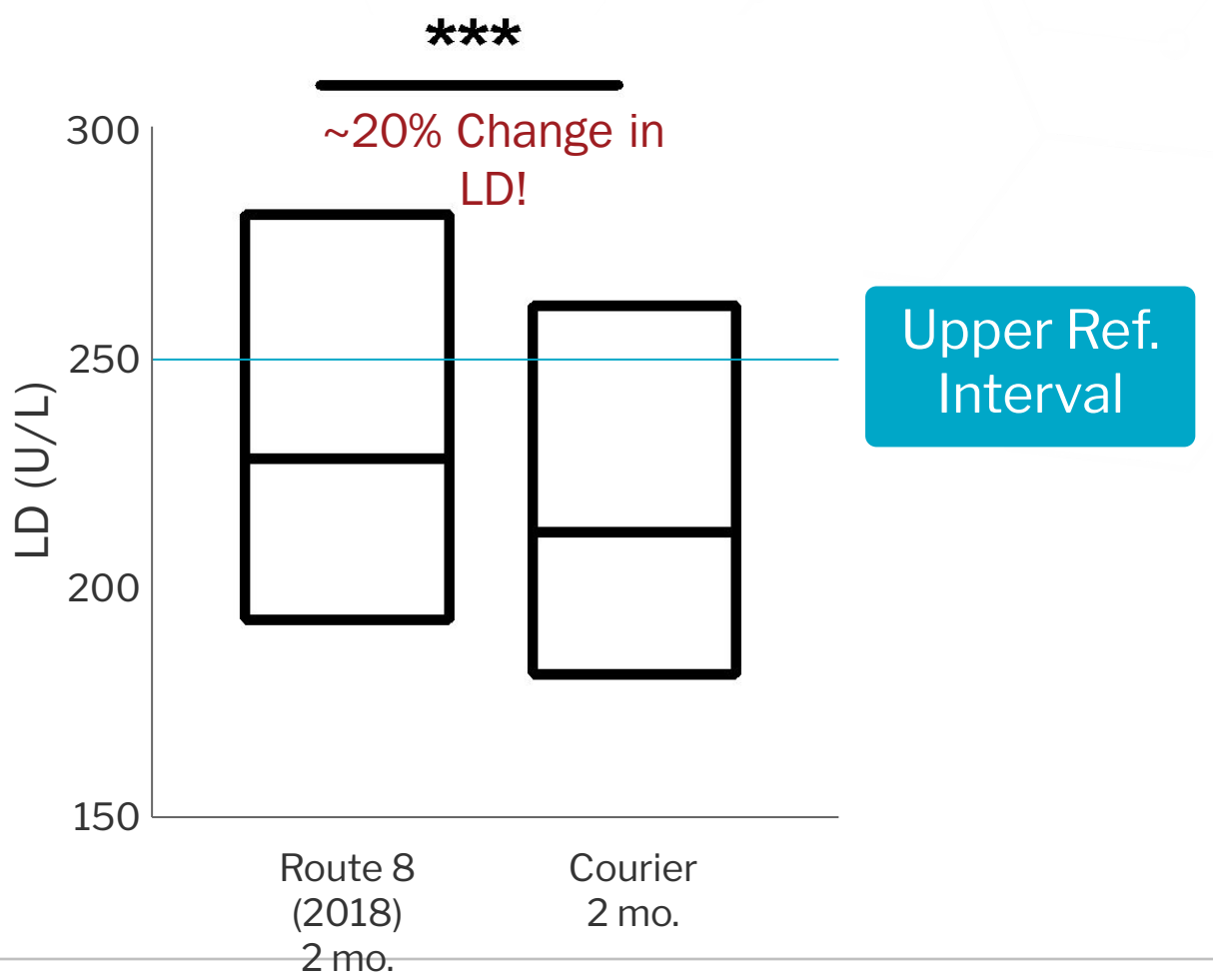
Steige H *et al.* Clin Chem. 1971; 17:12.
Mullins GR *et al.* Clin Chemica Acta. 2016; 462.
Nybo M *et al.* Clin Chem. 2018; 64:5.

Typical PTS study design: Compare paired samples

Farnsworth CW *et al.* Clin Chem. 2019;65:694-702.

Leveraging your data to assess PTS performance





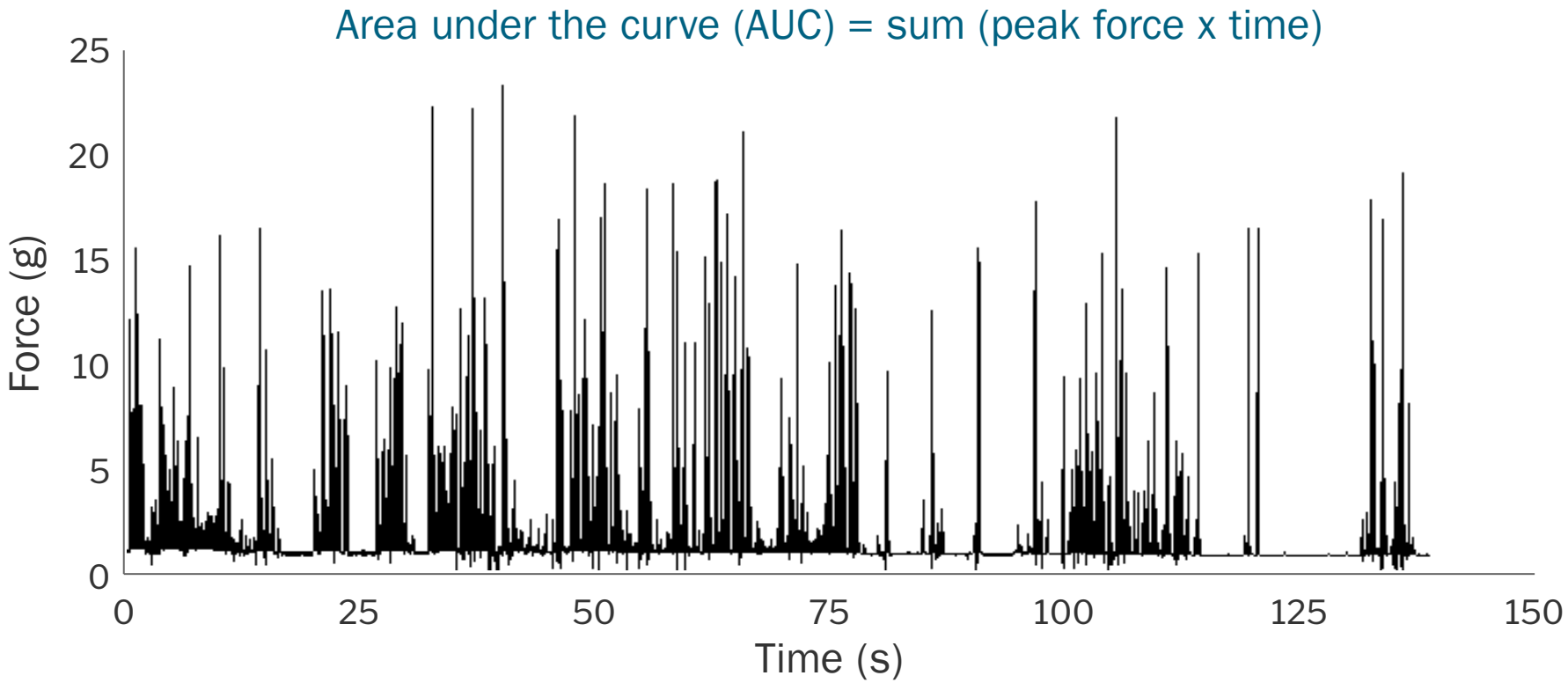
Farnsworth CW *et al.* Clin Chem. 2019;65:694-702.

3-axis accelerometers measure forces from PTS transport

Accelerometer

iPhone 6s running
Google Science Journal

Dataloggers monitor the number of accelerations over time



Start of run → End of run

Validation method

- Collect 5 tubes of blood
- Healthy subjects
- 15 total subjects
- 3 different days
- 2 different routes

1 tube walked to lab (control)

Remaining specimens ship through PTS

Remove one specimen

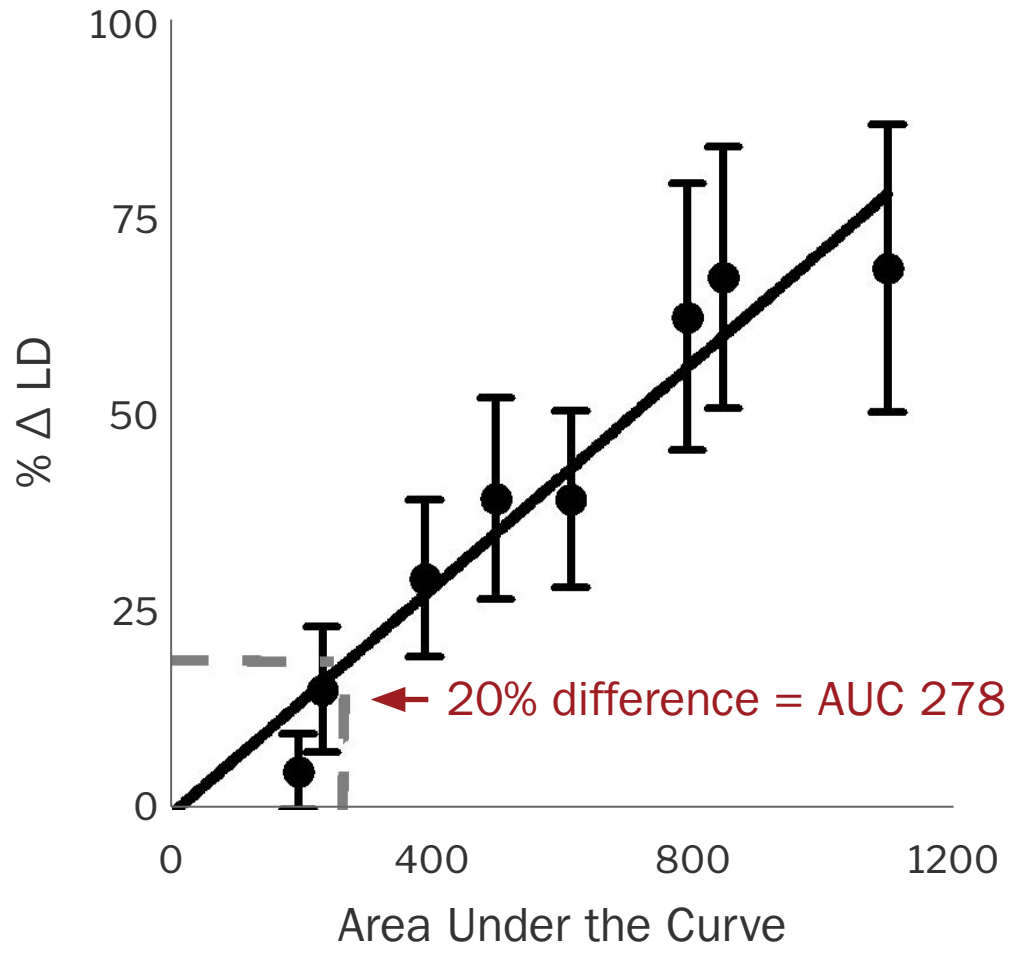
Remaining specimens ship through PTS

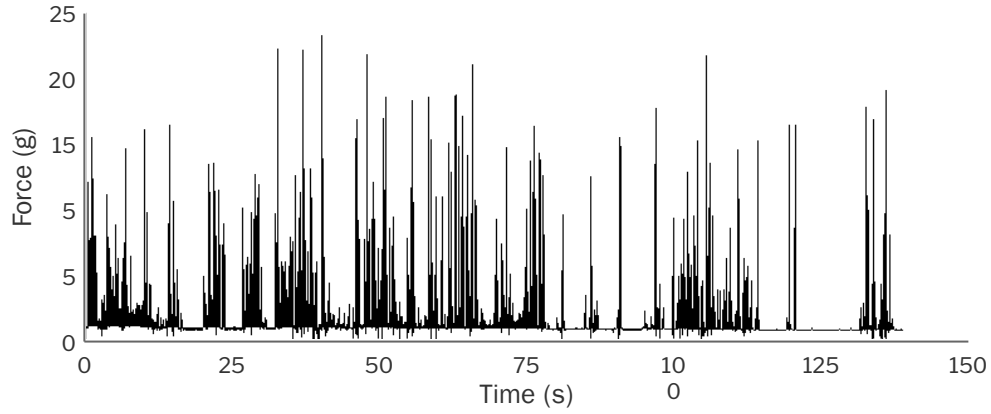
….. Up to 4 times X 2 routes

Analyze K+, LD, and HI

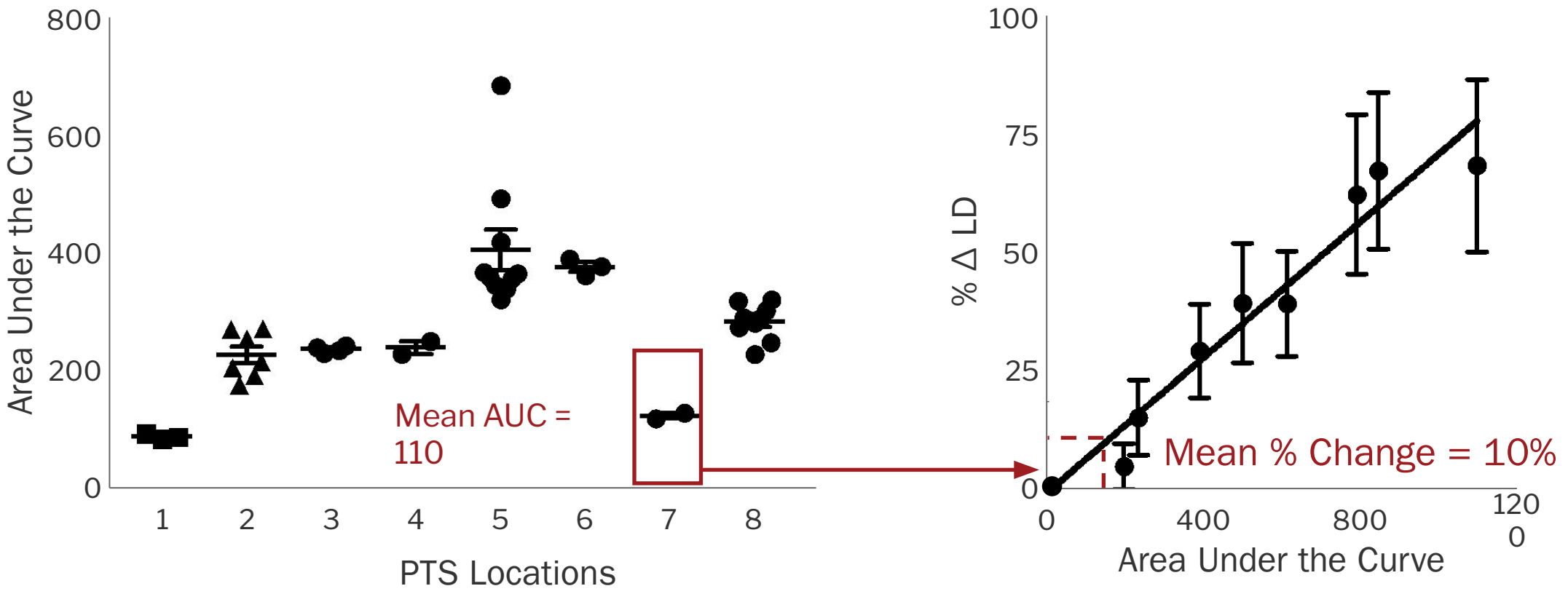
OR ANY ANALYTE OF INTEREST

Correlating PTS parameters with change in LD

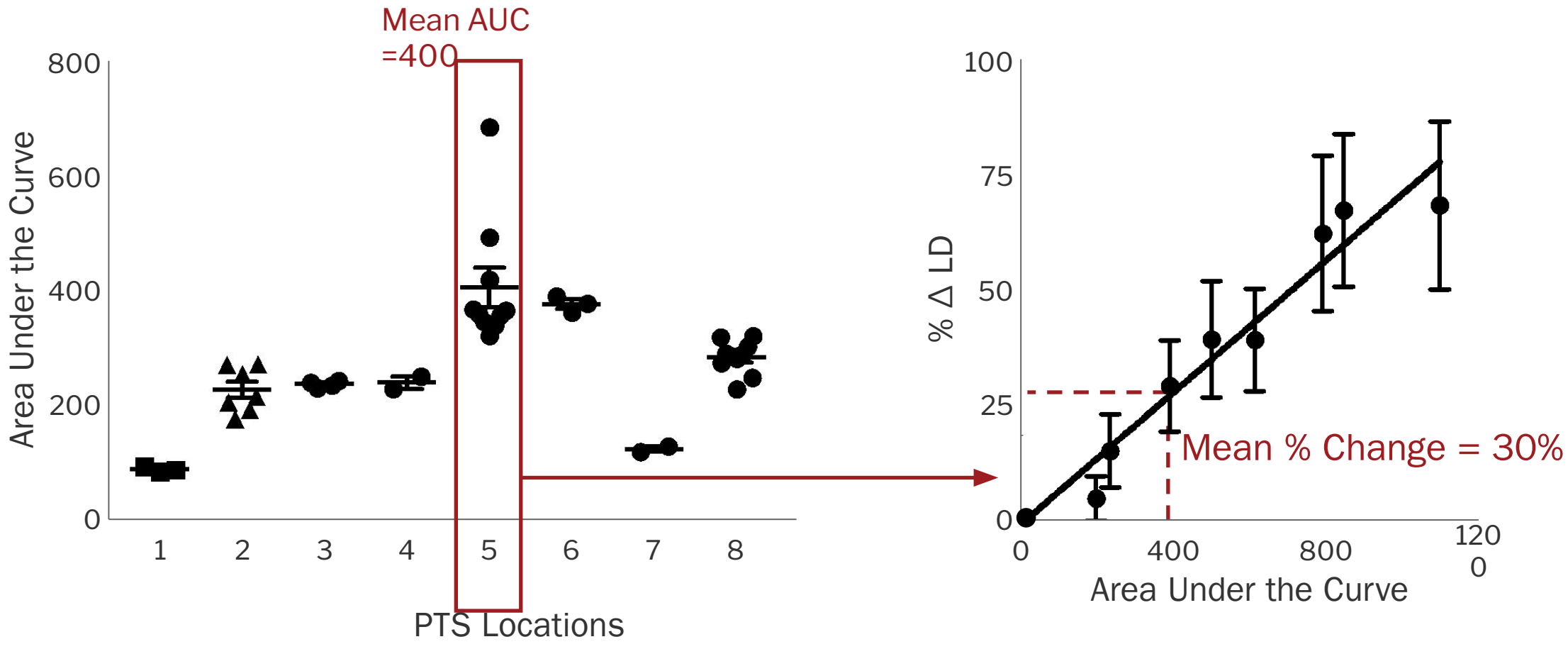




Correlating PTS parameters with change in LD

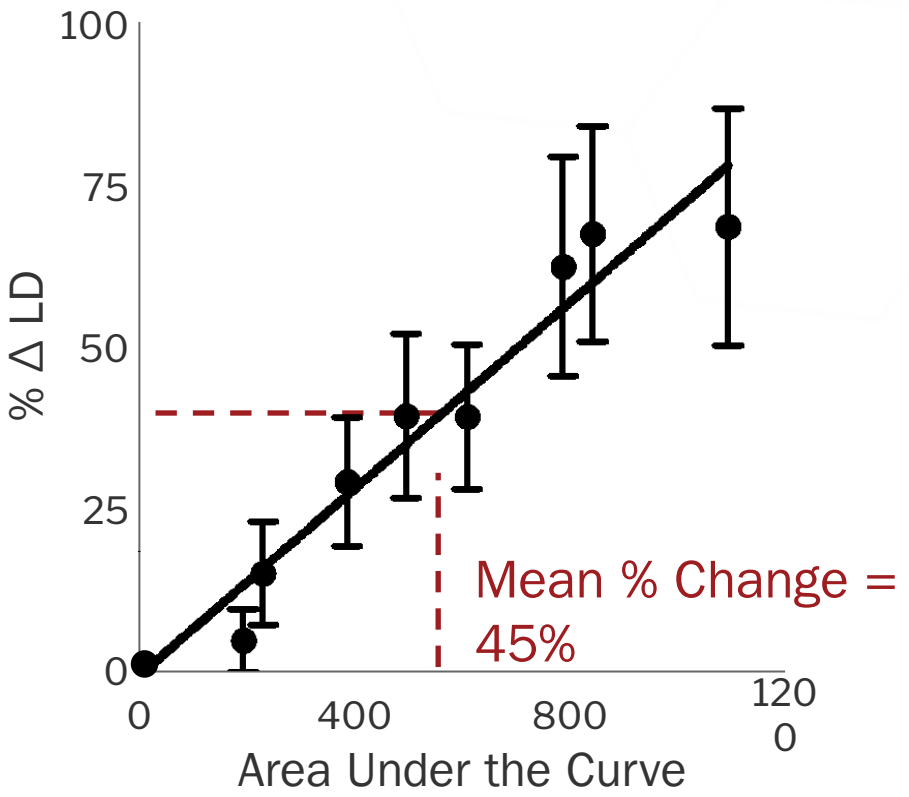


Correlating PTS parameters with change in LD



Farnsworth CW *et al.* Clin Chem. 2019;65:694-702.

Using datalogger to assess new PTS routes

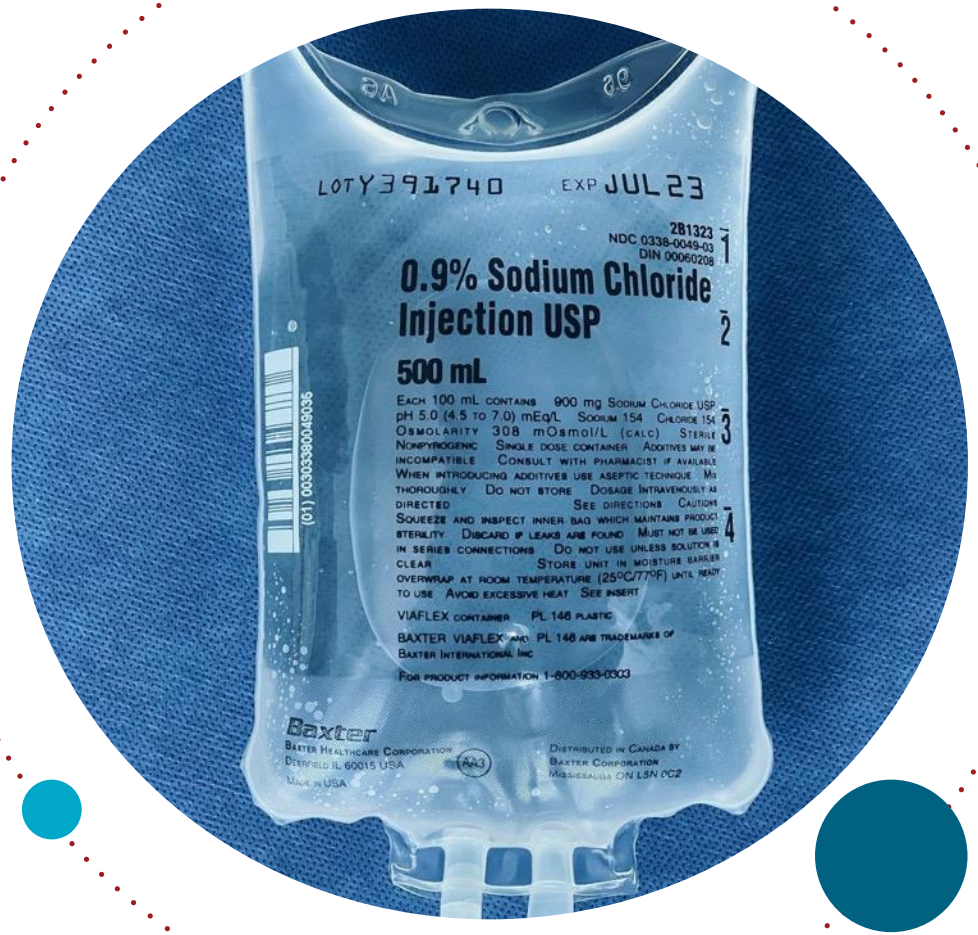


Takeaway: laboratories should consider assessing the PTS

01

Methods to assess for PTS performance

1. Paired specimens (Walked and sent through PTS)
2. Use of retrospective data from your laboratory
3. 3-axis accelerometers



III.

Detecting Contamination from Intravenous Fluids (IVF)

How frequent is IVF contamination?

Category	N=	Freq. (%)
Hemolyzed reported	41,047	48.2
Hemolyzed masked	19,701	23.1
Quantity not sufficient	8,068	9.5
Clotted samples	5,840	6.9
Collection errors	5,780	6.8
Transport errors	1,502	1.8
Not on ice	1,369	1.6
IV contamination	1,122	1.3
Too old to test	550	0.6
Total	85,133	100

).

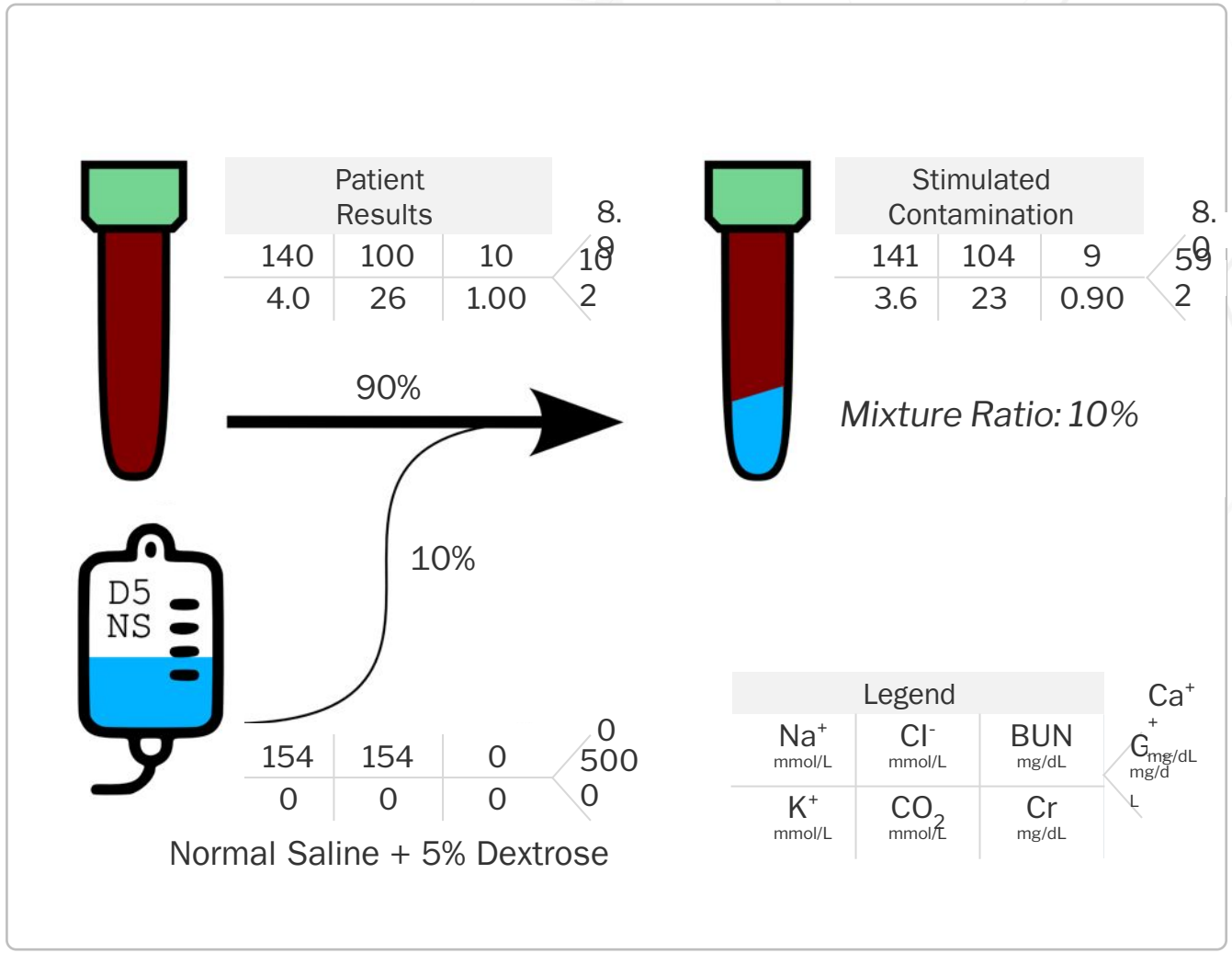
Under Review BJH/ Wash U data

How hard is it to detect IVF contamination?

Study Design

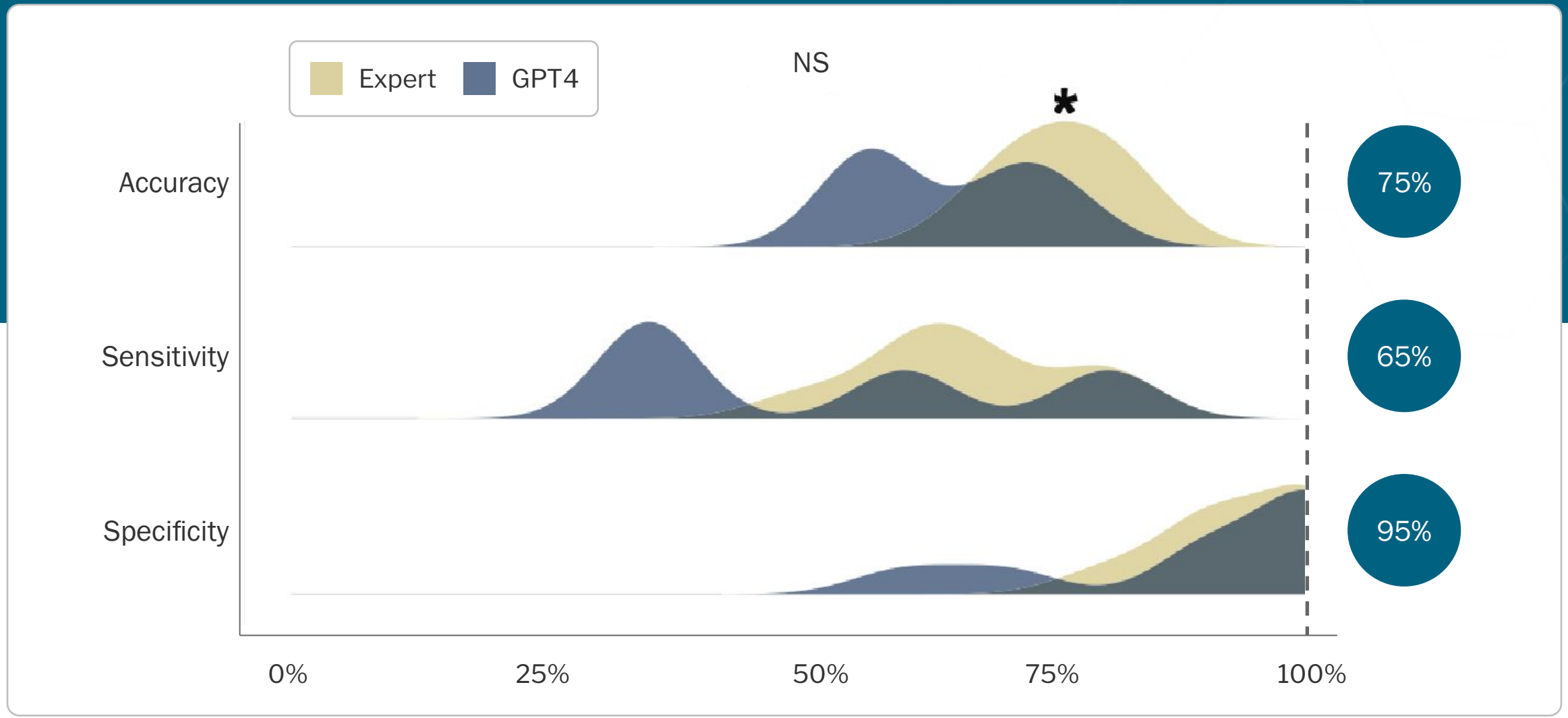
- 2 PhD Directors
- 2 PhD Clinical Fellows
- 1 MD Lab Medicine Residents
- 2 MD Internists
- 1 Laboratory Technologist
- GPT-4 (AI based Large Language Model)

Gave them results from 60 Basic metabolic panels



Are they contaminated??

Humans are bad at detecting IVF contamination



Spies N et al. JALM 2023;8:1092-1100.

Delta checks are commonly used to distinguish potential error

Table 1. Selected Comparison Delta values and Repeat Criteria for Delta Check	
Test	Criteria for repeat (differences between consecutive results on the same patient)
Albumin	~ 15 g/liter
Calcium, total	~0.25 mmol/liter (1.0mg/dl)
Potassium	~2.0 mmol/liter and no hemolysis
Protein, total	10 g/liter
Sodium	~20 mmol/liter

CLIN. CHEM. 21/11, 1648-1653 (1975)

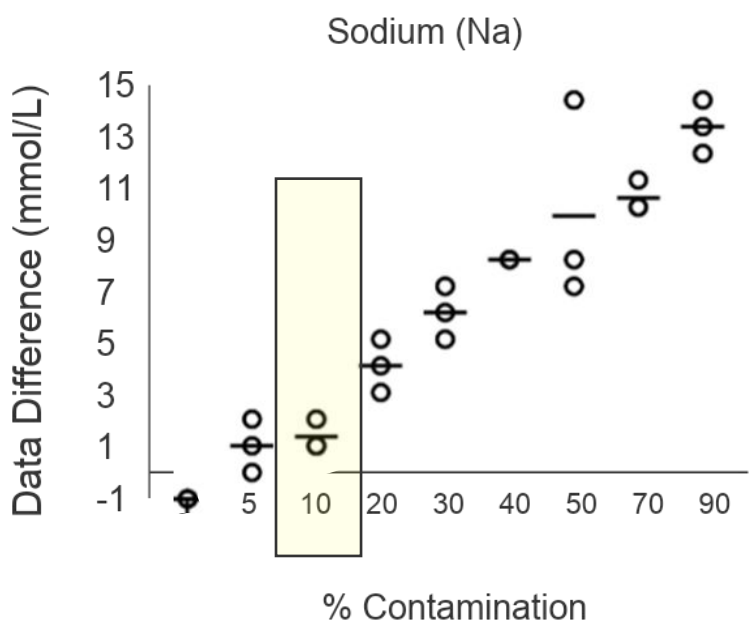
Patients as Their Own Controls: Use of the Computer to Identify "Laboratory Error"

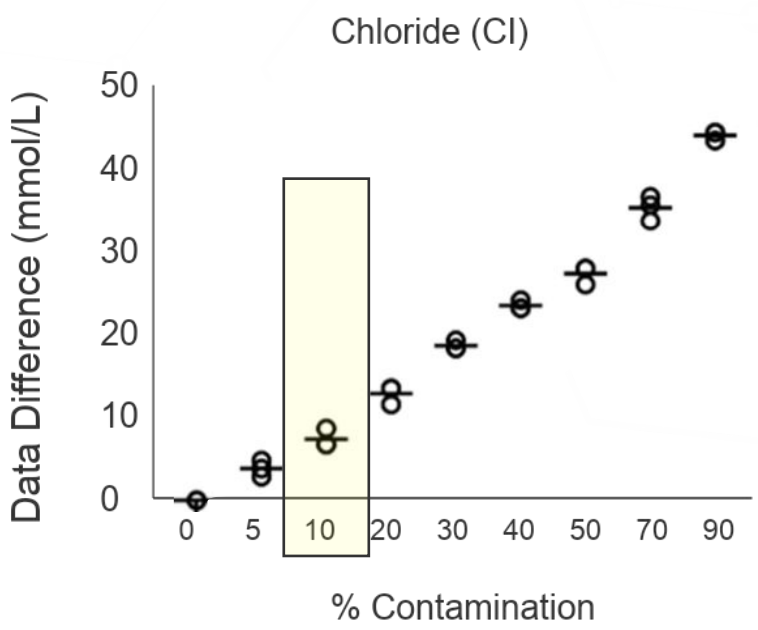
Jack H. Ladenson

Ladenson JH et al. Clinical Chemistry 1975;21:1648-53.

Multianalyte Delta Checks to assess for IVF Contamination

Added normal saline to blood at increasing proportions

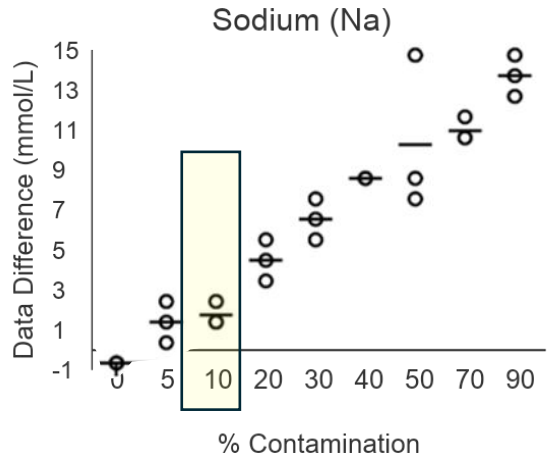


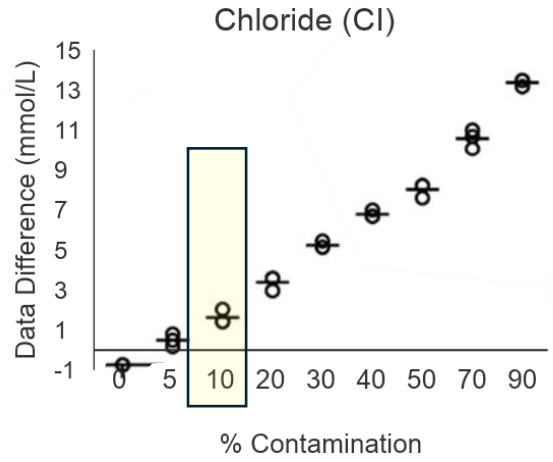


Fluid Compositions of Normal Saline								
	Sodium	Chloride	Potassium	C02	Creatinine	BUN	Calcium	Glucose
	154	154	0	0	0	0	0	0

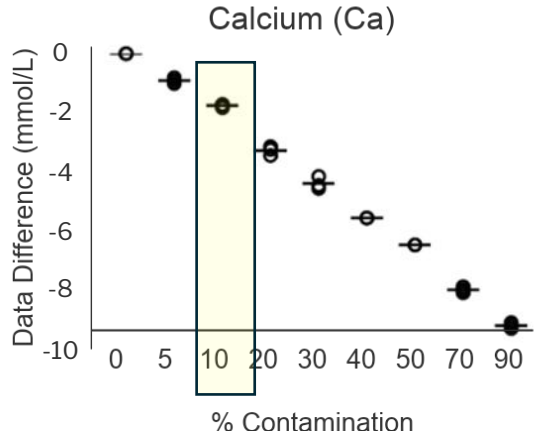
Choucair I et al. Clinical Chimic Acta 2023;539:22-28.

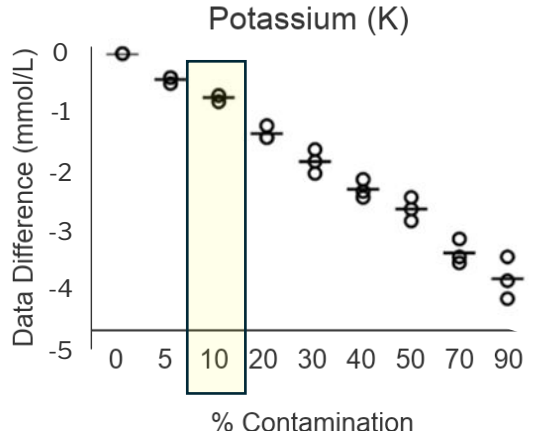
Multianalyte Delta Checks to assess for IVF Contamination





Normal Saline Contamination of 10% = Δ Cl > 7.7, Δ K> -0.7 and Δ Ca > -1.7

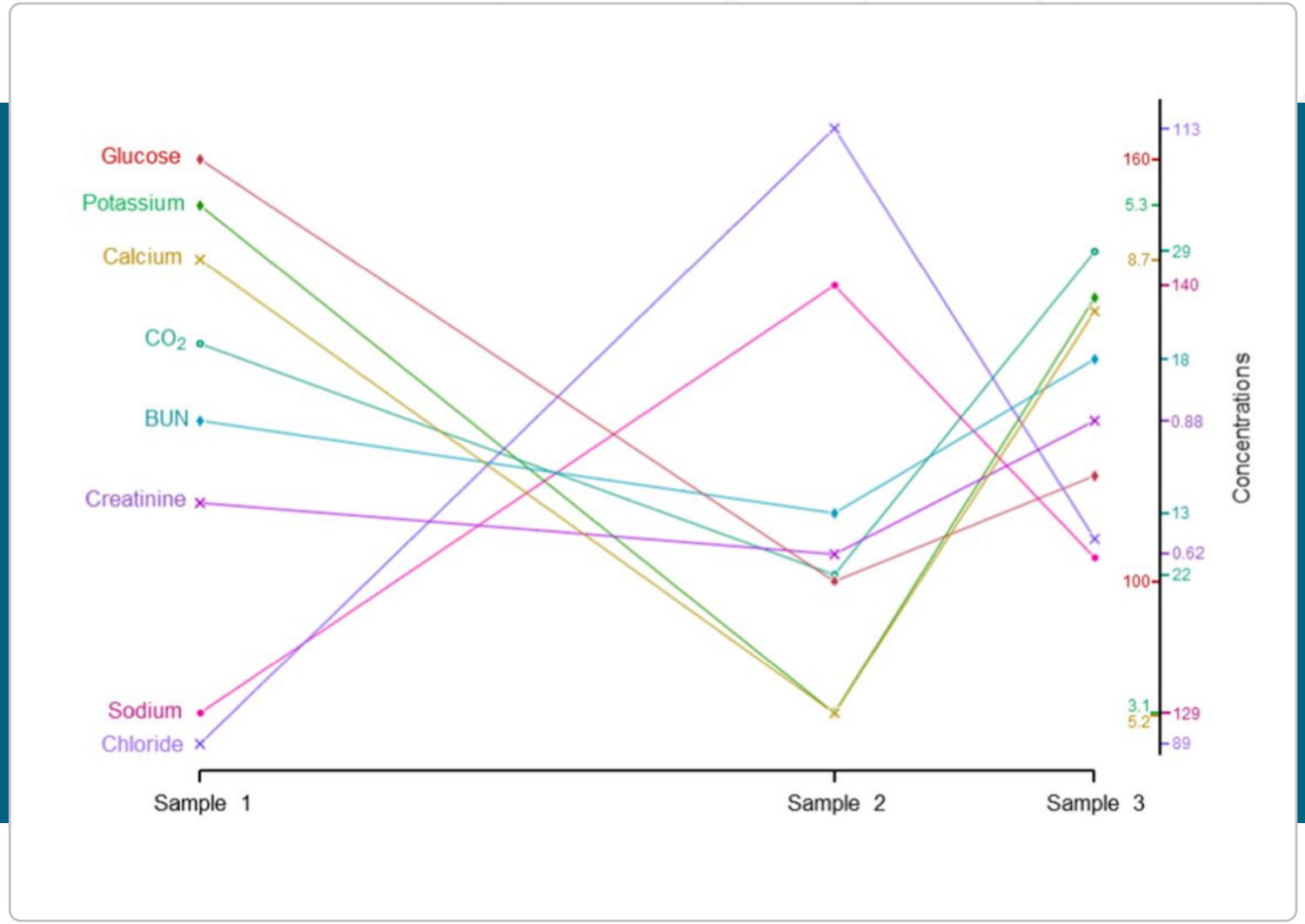




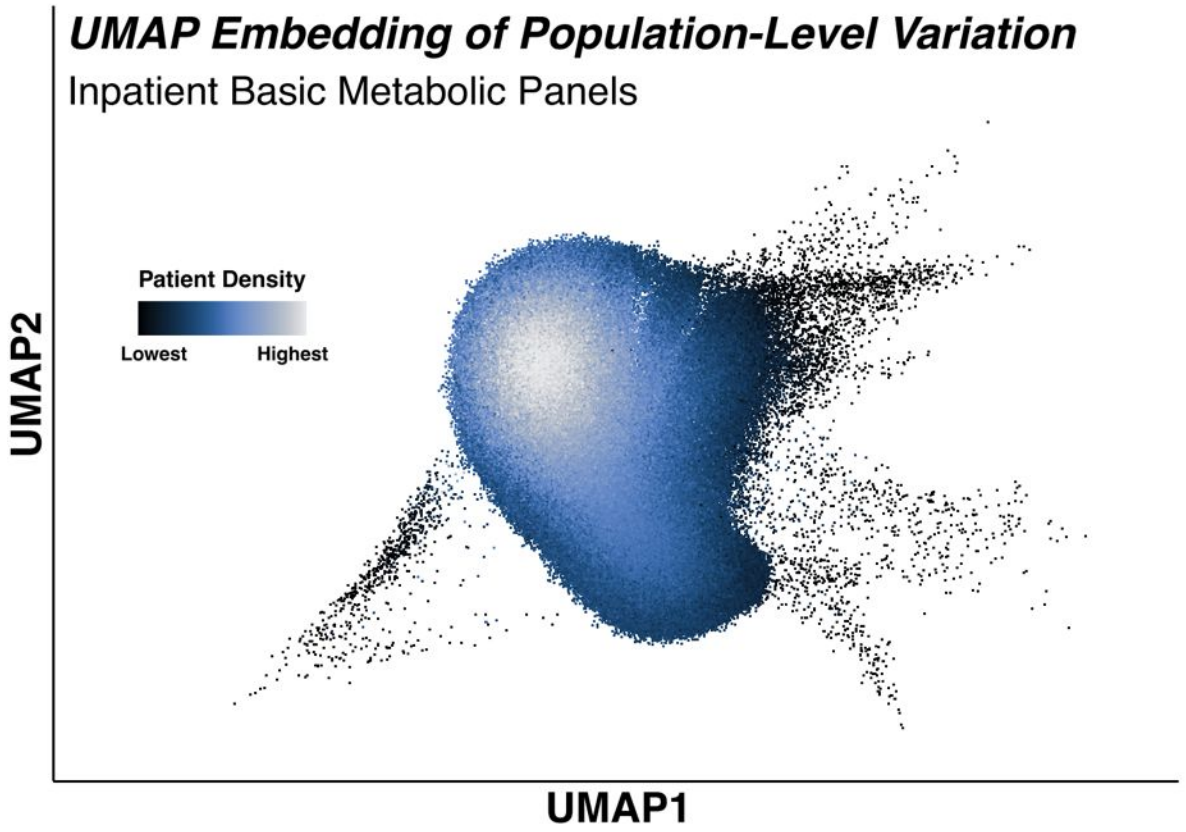
Choucair I et al. Clinical Chimic Acta 2023;539:22-28.

Anomaly with Resolution (AWR) with IVF Contamination

- Reviewed 10 patients in which the rule would have fired
- All exhibited the AWR pattern
- All receiving NS at time of specimen collection



Emerging approaches for detecting IV fluid: Machine learning



		WashU			
		Expert Review		MCC	0.747
				Sens	0.858
Pipeline		-	+	Spec	0.993
	-	8509	18	PPV	0.657
	+	57	109	NPV	0.998
Contamination Rate per 1000			**14.61**	Acc	0.991

Spies NC et al. Clinical Chemistry 2024;70:444-52.

Spies NC et al. Clinical Chemistry 2024: In press

Key Takeaways:

01 IVF contamination is likely common in hospitals but hard to detect

02 Delta check rules can be implemented and their impact maximized by leveraging studies or your own data

03 Ways of interfacing machine learning algorithms into the LIS are needed

Conclusions

01 Preanalytical error is common (~0.8% of all samples in a core lab) and is underrecognized.
- Better tools are needed to identify preanalytical error

02 The LIS can be leveraged to identify common preanalytical error
- However labs needs better access to the LIS to apply these rules

03 Working with other departments including the ED and nursing can help reduce preanalytical error

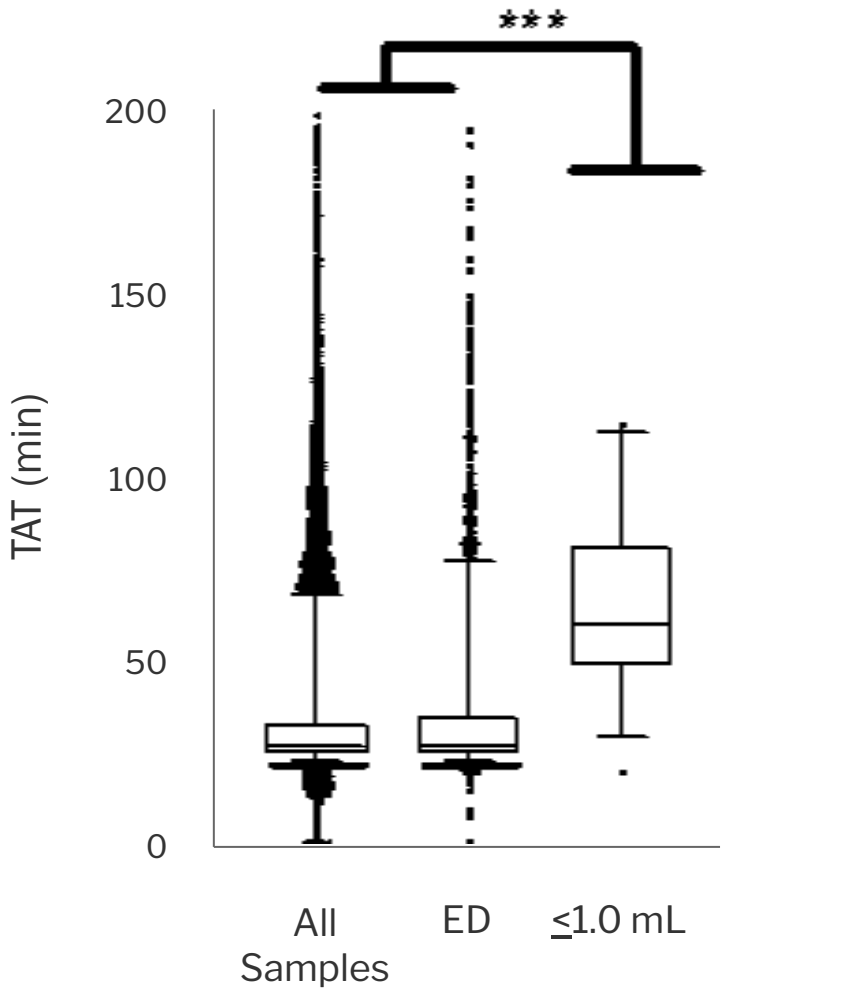
Thank you!

Nick Spies, MD
Yanchun Lin, PhD
Hannah Brown, PhD
Mark Zaydman, MD, PhD
Ann Gronowski, PhD
Abe Qavi, MD, PhD

cwfarnsworth@wustl.edu

Testing methods in modern laboratories have changed

QNS samples = longer turnaround time (TAT)



Normal sample TAT: **30 mins**

Short sample TAT: **62 mins**

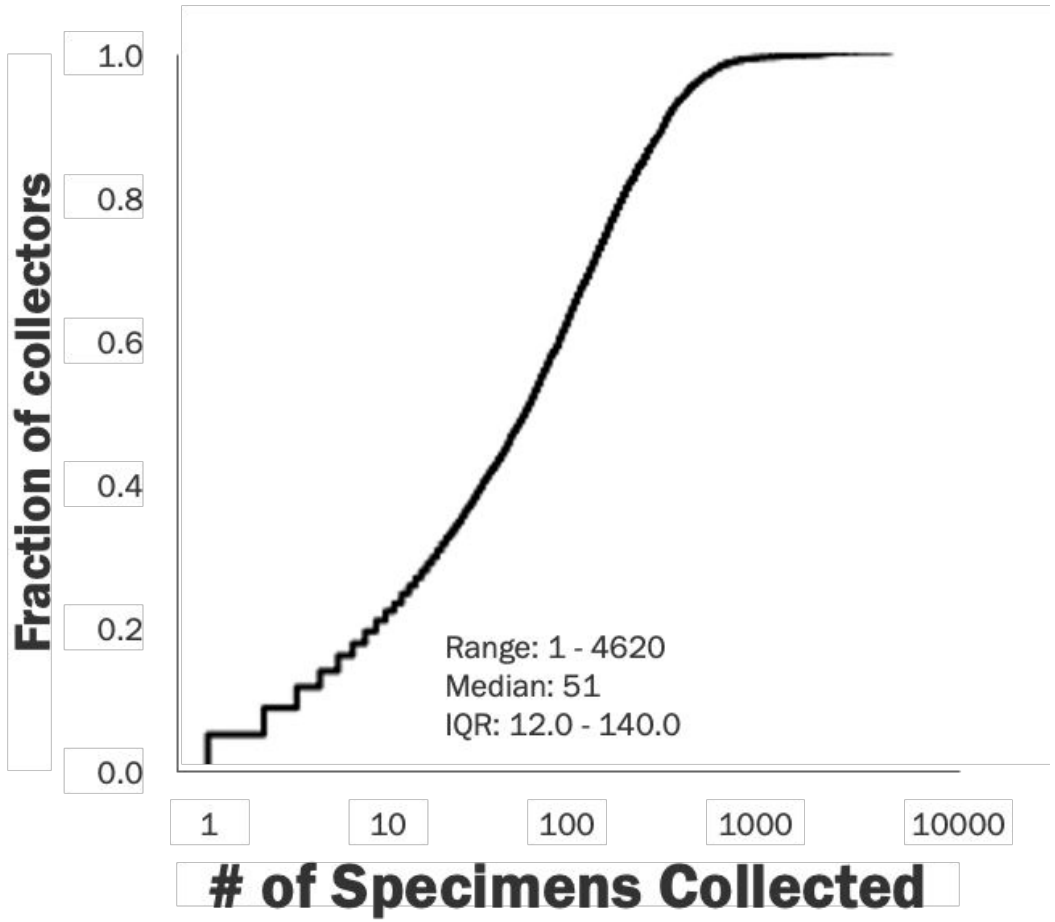
Canceled Sample TAT: **127 mins**

Big problem in ED's

- Prolonged length of stay
- Low throughput
- Long boarding times

Qavi AJ Clin Biochem 2023;115:137-143.

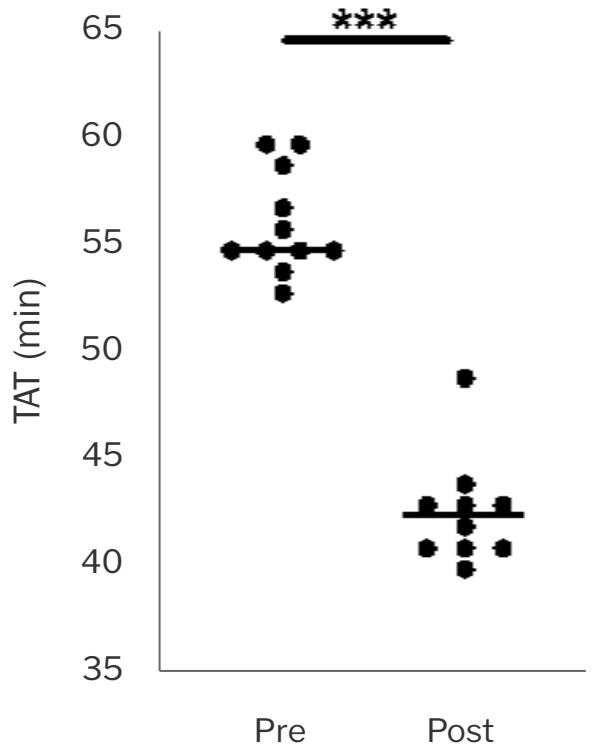
Substantial variability in # of collections and hemolysis frequency



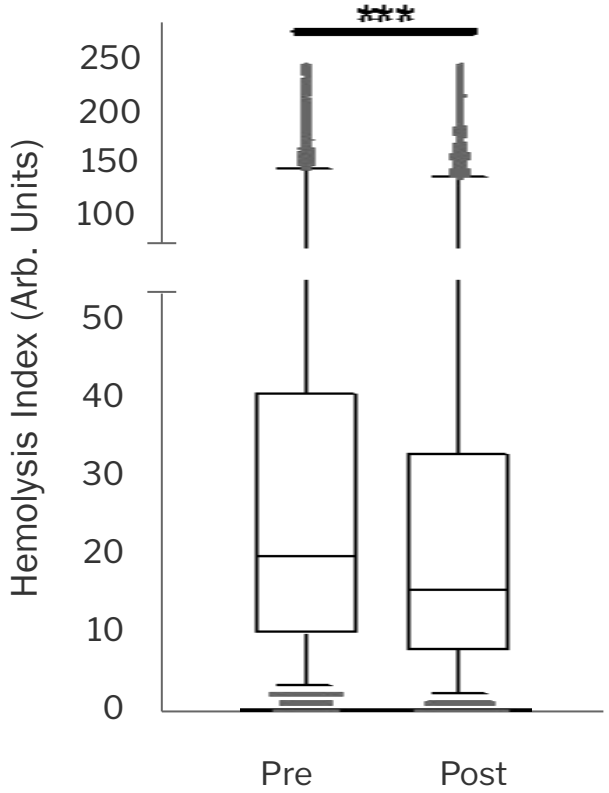
Farnsworth CW Zaydman M, Internal Data.

QNS Policy improves in-lab TAT and reduces hemolysis

TAT 90%

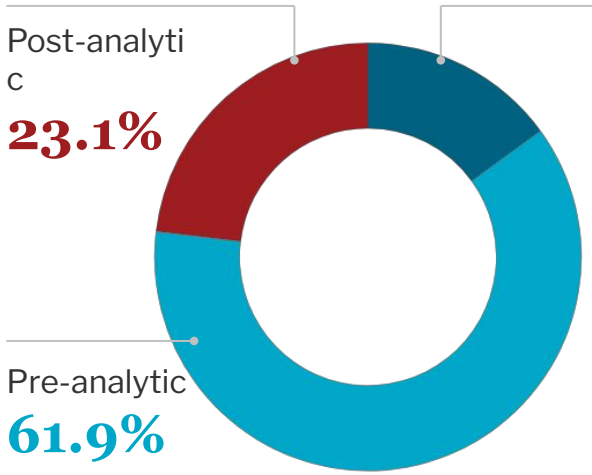


ED



Qavi AJ Clin Biochem 2023;115:137-143.

Errors can occur at any point in the lab testing process



393	160	51,746
questionable findings	confirmed errors	analyses

Carraro P et al. Clinical Chemistry 2007; 53:7 1338 –1342.

- Physicians and nurses told to pay attention to test results
- Suspected laboratory error was recorded
- Daily, lab physician visited and appraised for errors

Assessing causes of error in the BJH/ Wash U Laboratory

Preanalytical Category

- Collection errors
- IV contamination
- Specimens too old
- Improperly Labeled

Analytical

- QC out of Range (assay drift)
- Instrument problems
- Reagent Issues (bad reagent pack)

Post-analytical Category

- Comment errors
- Result entry errors
- Dilution errors

Data Sources

- Errors captured by querying LIS or by LIS flagging.
- Daily report manually curated by a trained medical laboratory scientist.

Lab error occurs frequently and are mostly preanalytic

87,317 Errors

60,748 Were hemolysis errors!

Category	N=	Freq. (%)
Hemolyzed reported	41,047	48.2
Hemolyzed masked	19,701	23.1
Quantity not sufficient	8,068	9.5
Clotted samples	5,840	6.9
Collection errors	5,780	6.8
Transport errors	1,502	1.8
Not on ice	1,369	1.6
IV contamination	1,122	1.3
Too old to test	550	0.6
Sample integrity	92	0.1
Requisition errors	62	0.1
Total	85,133	100

Under Review BJH/ Wash U data

Lab error occurs frequently and are mostly preanalytic

87,317 Errors

60,748 Were hemolysis errors!

= 94% Of all error!
Without hemolysis, preanalytical error

24,385 of 25,808 errors

Category	N=	Freq. (%)
Hemolyzed reported	41,047	48.2
Hemolyzed masked	19,701	23.1
Quantity not sufficient	8,068	9.5
Clotted samples	5,840	6.9
Collection errors	5,780	6.8
Transport errors	1,502	1.8
Not on ice	1,369	1.6
IV contamination	1,122	1.3
Too old to test	550	0.6
Other- specimen integrity	92	0.1
Requisition errors	62	0.1
Total	85,133	100

Under Review BJH/ Wash U data

CAP requires feedback to collectors for quality

GEN. 40499 Specimen Collection Feedback Phase I

There is a mechanism to provide feedback to the collectors of specimens on issues relating to specimen quality and labeling.

Note: The accuracy of an analytic result depends upon the initial quality of the specimen. Proper collection techniques are essential.

Evidence of Compliance:

- Written procedure defining methods for providing feedback to specimen collectors AND
- Records of communication of specimen collections issues, such as QM reports, staff meeting minutes OR records of employee counseling

Problem: Who do you provide feedback to??

College of American Pathologists. Lab General Checklist. Accessed February 2024.

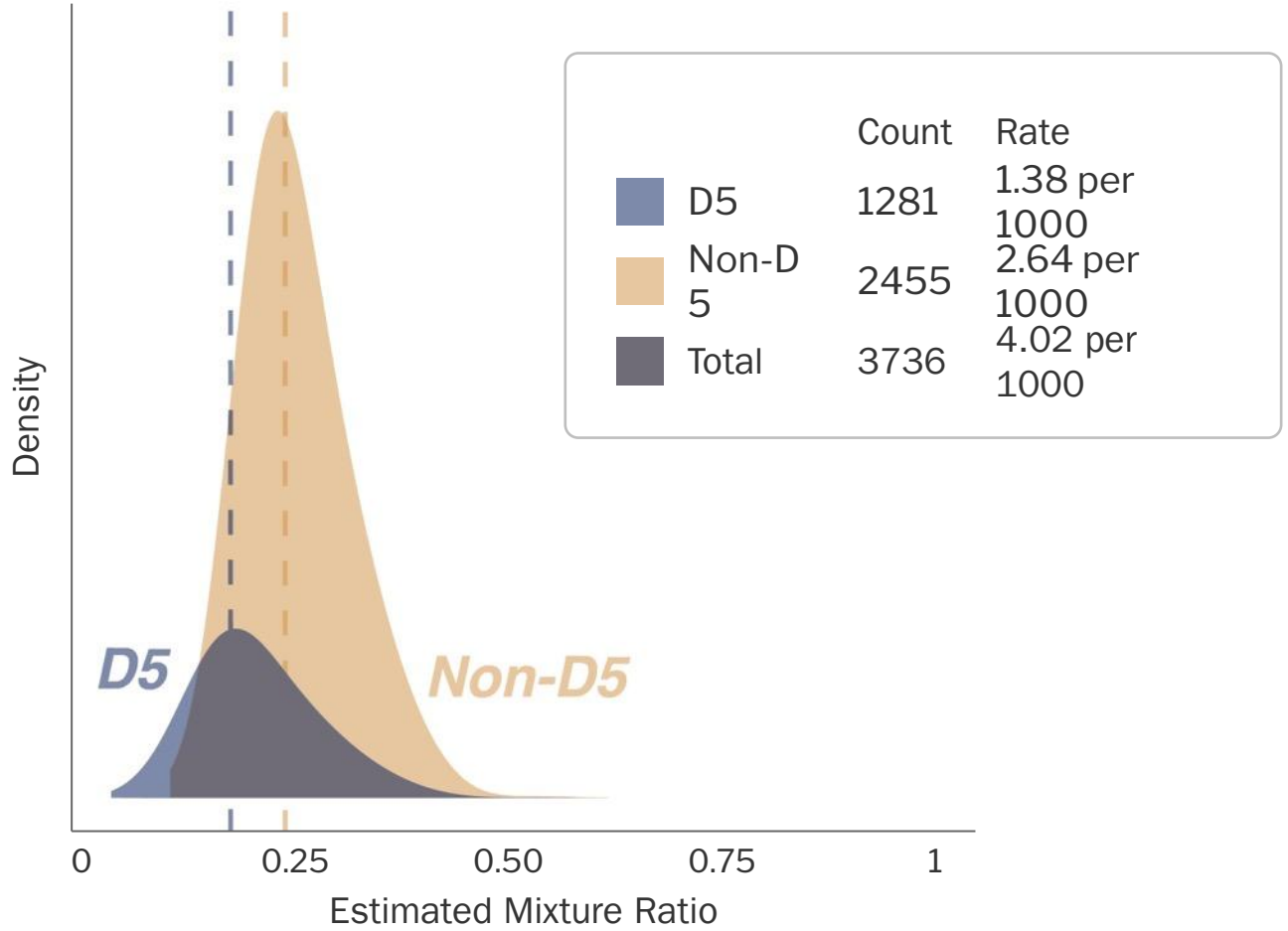
Identifying underperformers using your laboratory data

- Collectors across all units are captured using PPID
- Collector associated with the hemolysis index for each specimen
- Assess the frequency of hemolyzed samples

Farnsworth CW Zaydman M, Internal Data

Humans are bad at detecting IVF contamination

- BMP results as contaminated (specimen redrawn within 4 h)
- 18% (IQR 9-27%) for dextrose containing fluids
- 24% (IQR 16-38%) for non-dextrose fluids

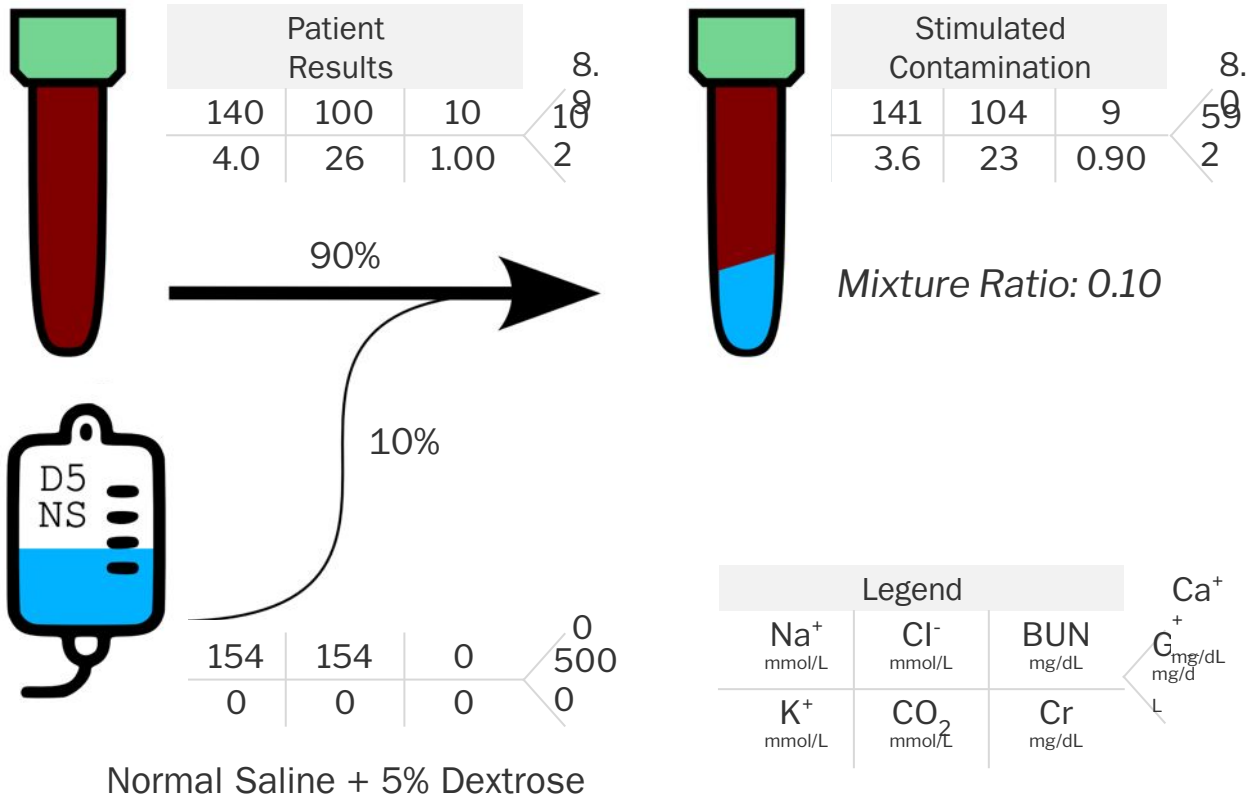


Spies NC & Farnsworth CW, Jour of Laboratory Medicine. 2024;48:29-36.

How much contamination is too much?

928,742
BMP results

- Simulated mixing study
- Assessed # results exceeded
  - Total Allowable Error (TEa)



Spies NC & Farnsworth CW, Jour of Laboratory Medicine. 2024;48:29-36.

Total allowable error (TEa) exceeded at ~10% normal saline (NS)

Minimum Significant Mixtures

50% of results contaminated at this ratio will exceed TEa thresholds.

	Sodium	Chloride	BUN	Calcium	Potassium	CO2	Creatinine	Glucose
Normal Saline (NS)	30%	7%	12%	12%	14%	10%	29%	6%
CLIA TEa	4mmol/L	3mmol/L	2mg/dL	1mg/dL	0.5mmol/L	2mmol/L	0.3mg/dL	6 mg/dL

Spies NC & Farnsworth CW, Jour of Laboratory Medicine. 2024;48:29-36.
Spies NC et al. Clinical Chemistry 2024;70:444-52.
Spies NC et al. Clinical Chemistry 2024;70:444-52.

Harnessing your own data to establish single analyte delta checks

Most predictive single-analyte delta check and cutoff value	Decreased calcium; $\Delta Ca\% \leq -24\%$
Sensitivity (95% CI) at the cutoff	76.4% (70.7%–82.0%)
Specificity (95% CI) at the cutoff	99.2% (98.7%–99.8%)

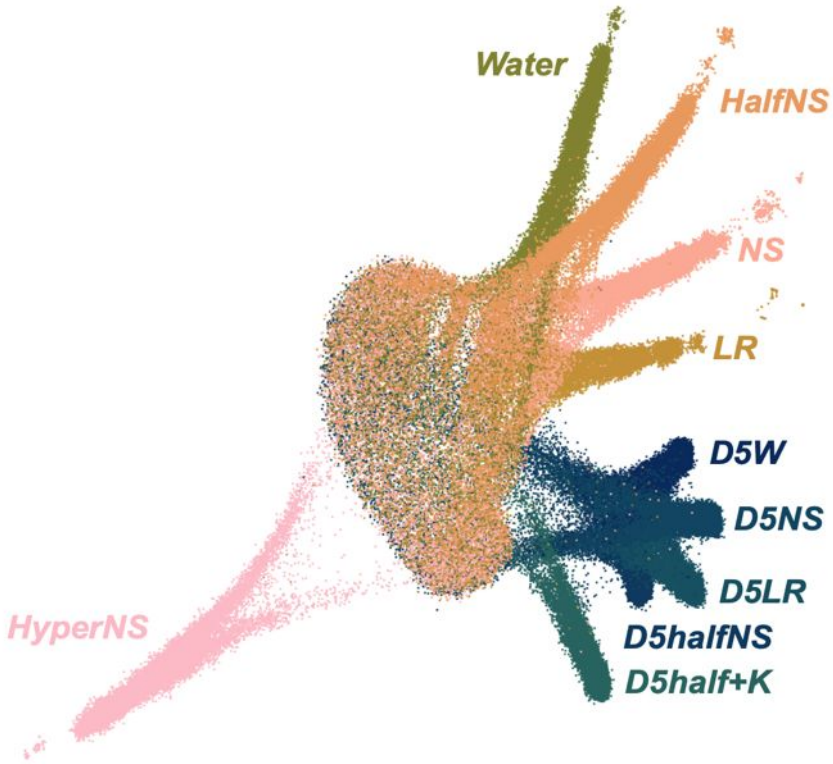
- 326,103 BMP/CMPs
- Used changes in the RCV to identify potential contaminants
- Chart review performed on 1,489
- Use logistic regression to identify ideal delta thresholds

Data sets	Sample size	Parameters	Logistic regression models	Single-analyte delta checks
Labeled training data set	1489	Sensitivity	77.2% (95% CI: 73.5%–80.9%)	70.3% (95% CI: 66.3%–74.4%)
		Specificity	98.7% (95% CI: 98.1%–99.4%)	97.2% (95% CI: 96.2%–98.2%)
		PPV	91.8% (95% CI: 89.2%–94.4%)	82.3% (95% CI: 78.7%–86.0%)

Yang J et al. JALM 2024 3:jfae066.
doi: 10.1093/jalm/jfae066.

Simulated results are outliers from the main embedding

A. Simulated Contamination
Fluid Type

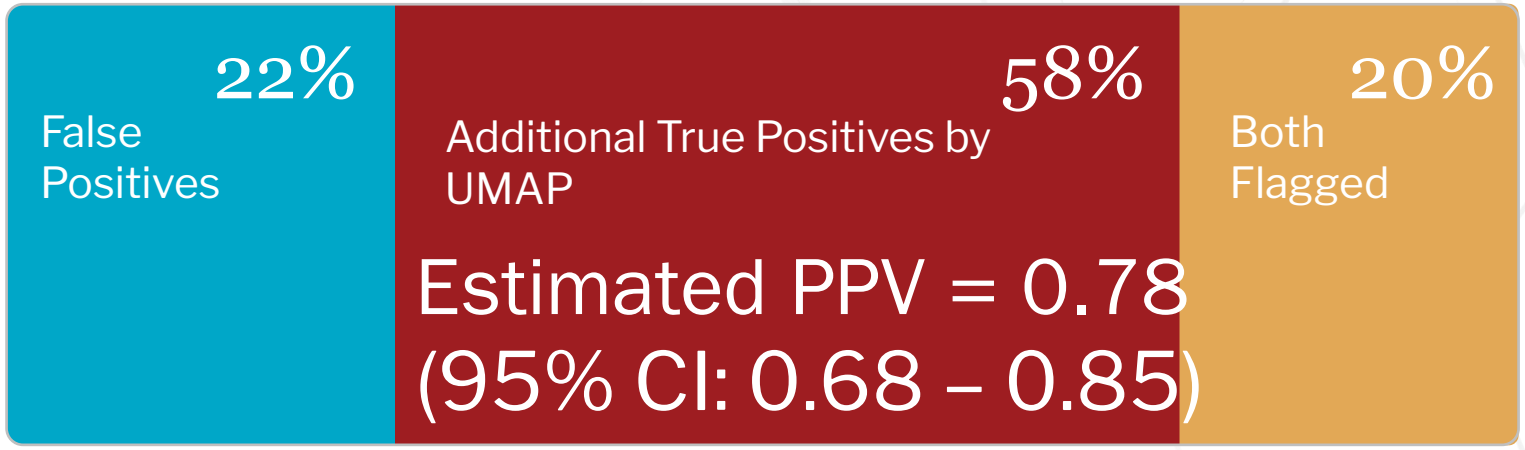


B. Simulated Contamination
Mixture Ratio

Spies NC et al. Clinical Chemistry 2024;70:444-52.

Unsupervised machine learning to detect IVF contamination

100 Consecutive UMAP Flags



Future Directions:

01

Can we create better models

02

Does it generalize to other hospitals

03

How do you implement?

Spies NC et al. Clinical Chemistry 2024;70:444-52.