Twists, Turns and Accelerations:

The Effect of Pneumatic Tube Transport on Clinical Laboratory Testing

Christina Pierre, Ph.D., DABCC, FAACC

Clinical Chemist- Penn Medicine Lancaster General Hospital

Disclosures

Christina Pierre, Ph.D.

- Nothing to disclose

Learning Objectives

At the conclusion of this presentation, learners will be able to:

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2. Discuss the impact of pneumatic tube transport on specimen integrity and mitigation strategies

3. Design and implement a pneumatic tube system validation plan

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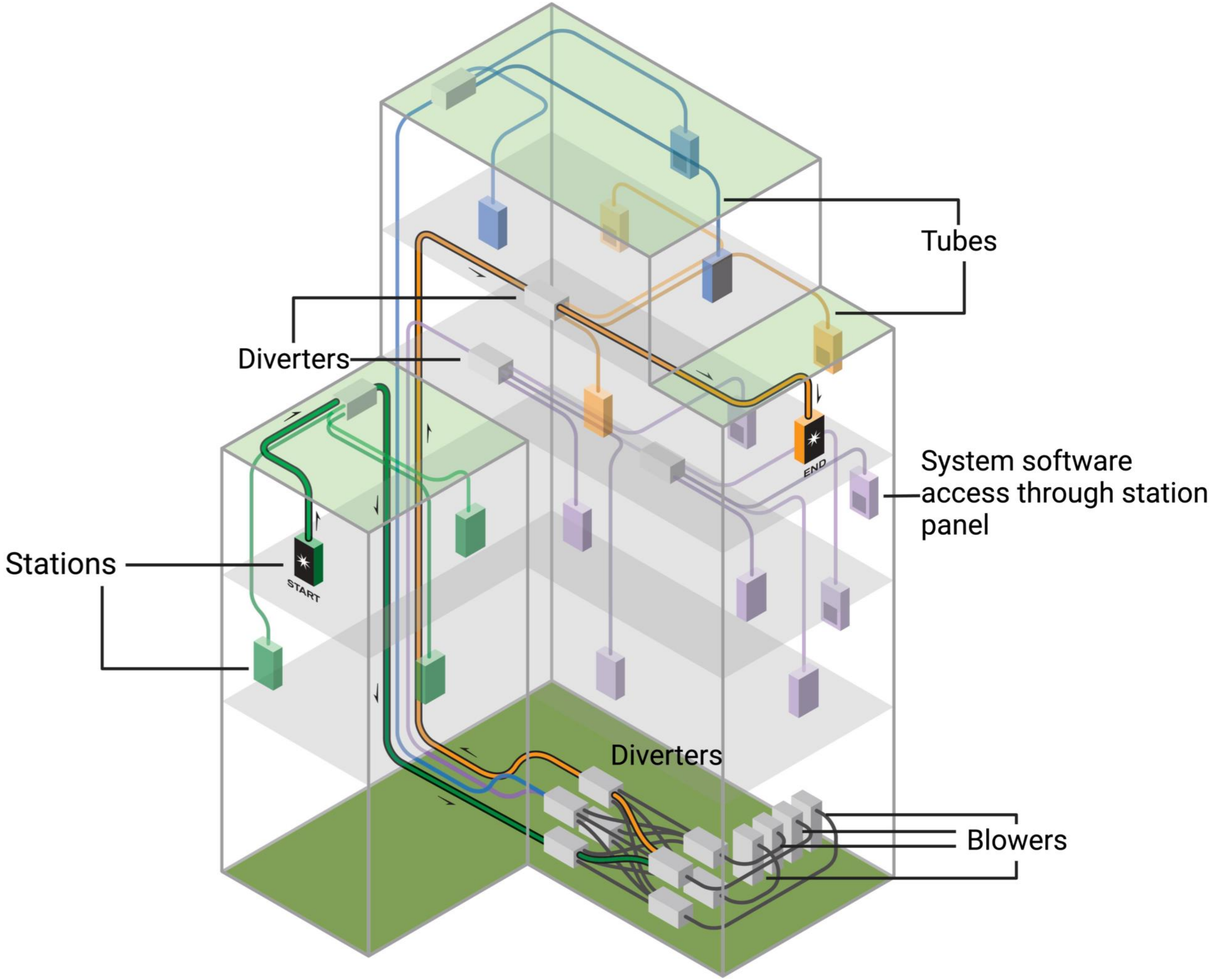
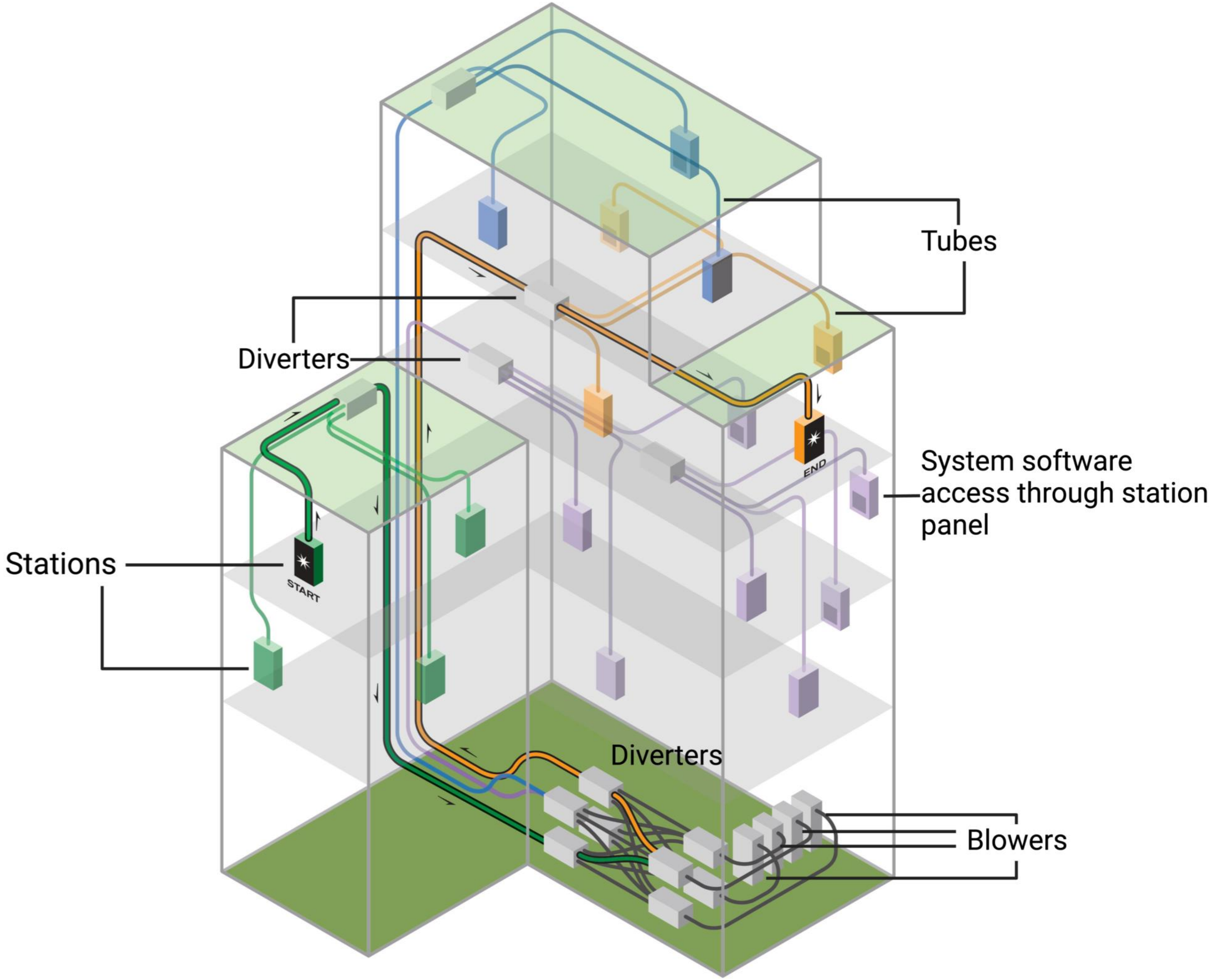
Network of air-pressurized tubes
Core elements:



Pierre & Wiencek, Under Review- Clinical Biochemistry

Network of air-pressurized tubes
Core elements:

- Blowers
  - Create pressure and vacuums



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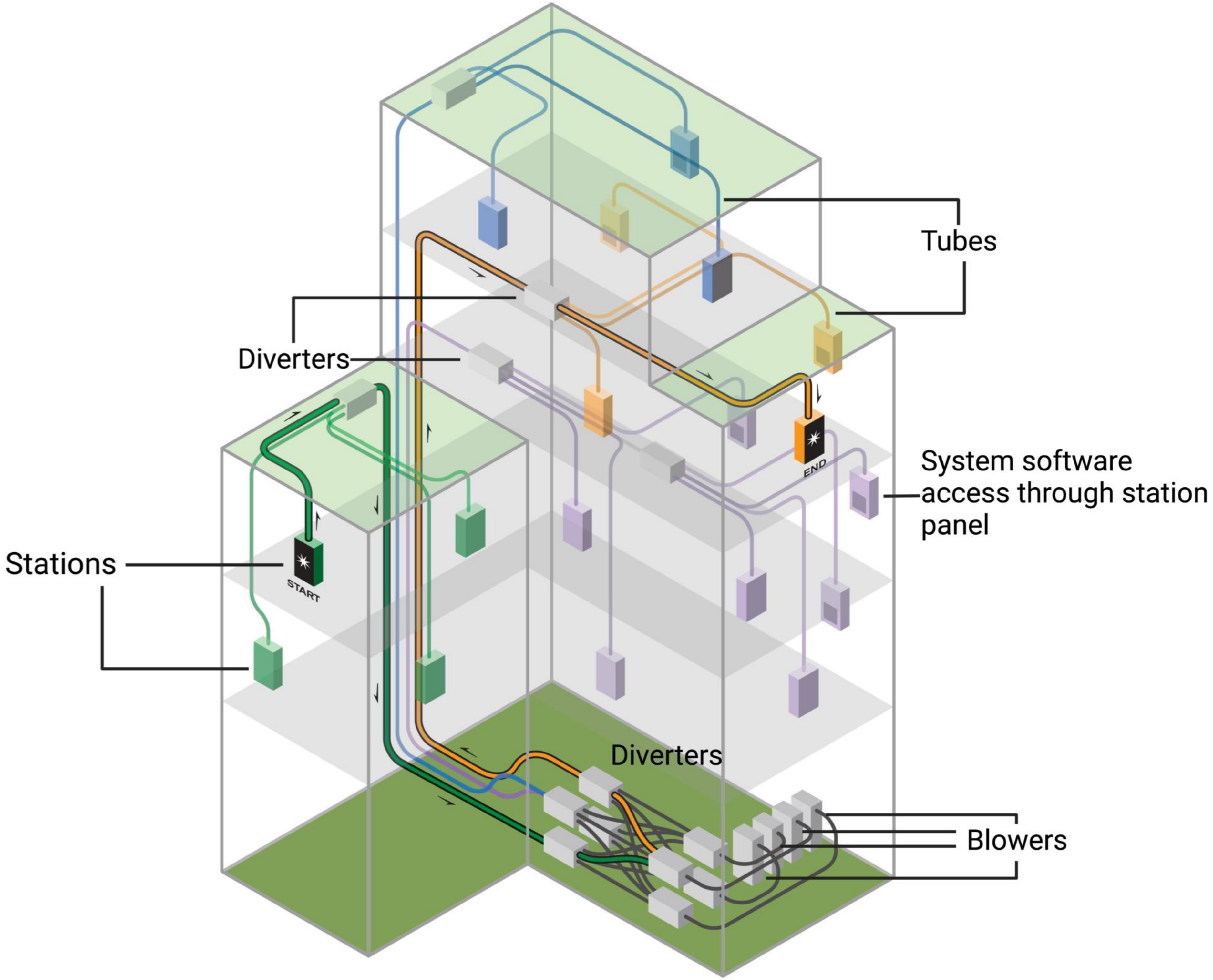

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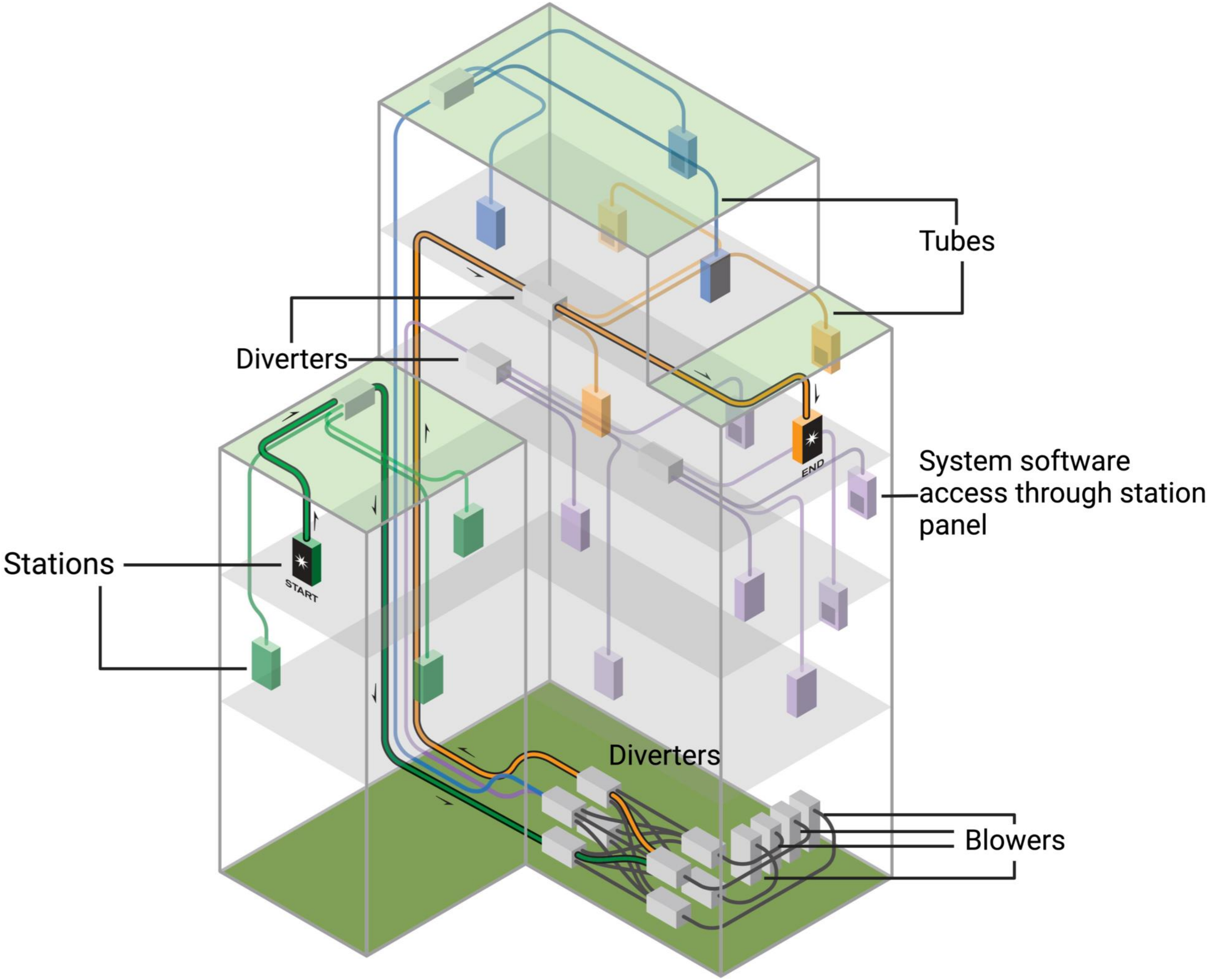
Network of air-pressurized tubes
Core elements:

- Blowers
  - Create pressure and vacuums
- Tubes
- Stations



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Network of air-pressurized tubes
Core elements:

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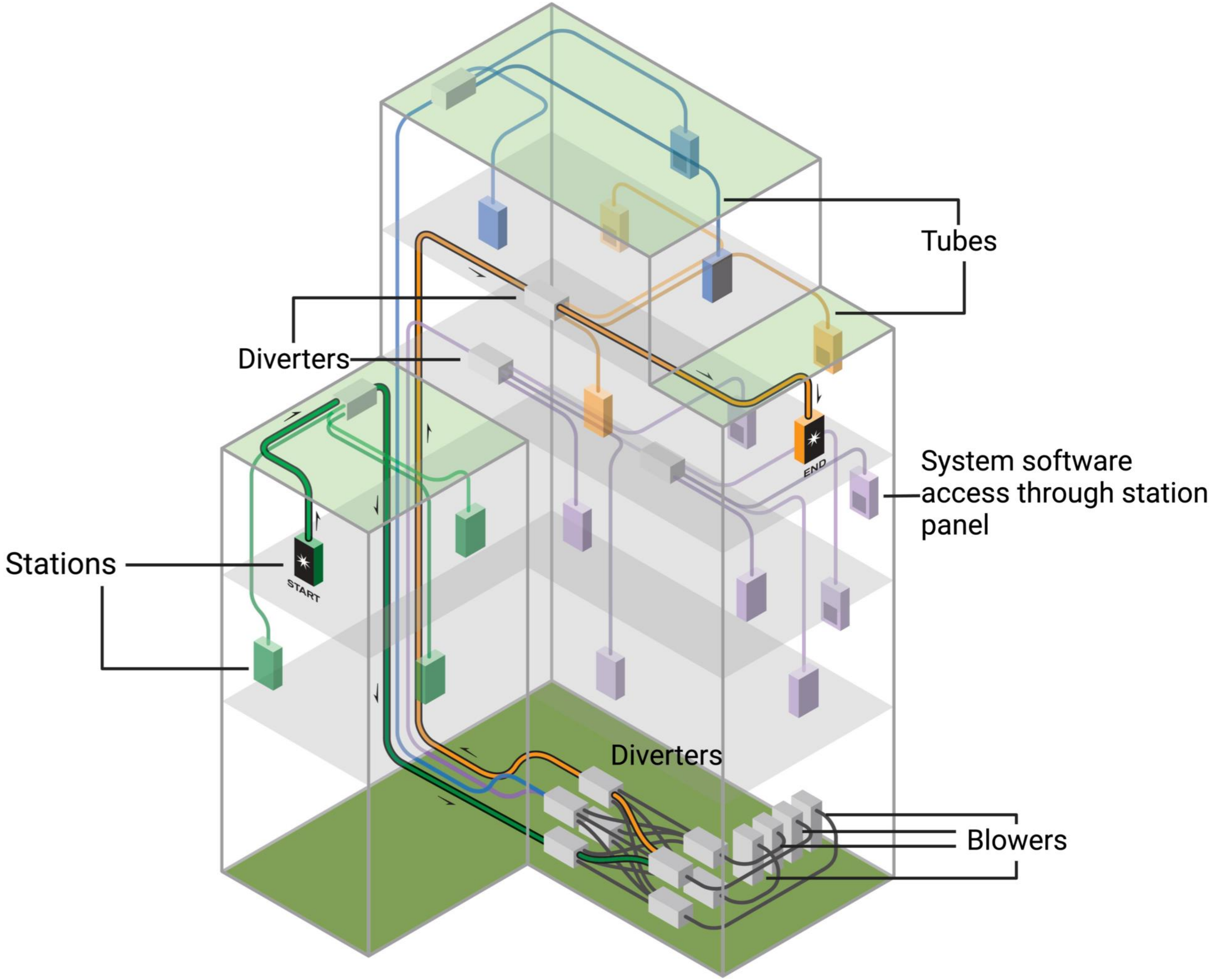
- Tubes
- Stations
- Diverters
  - Allow tubes to change direction



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Network of air-pressurized tubes

Core elements:

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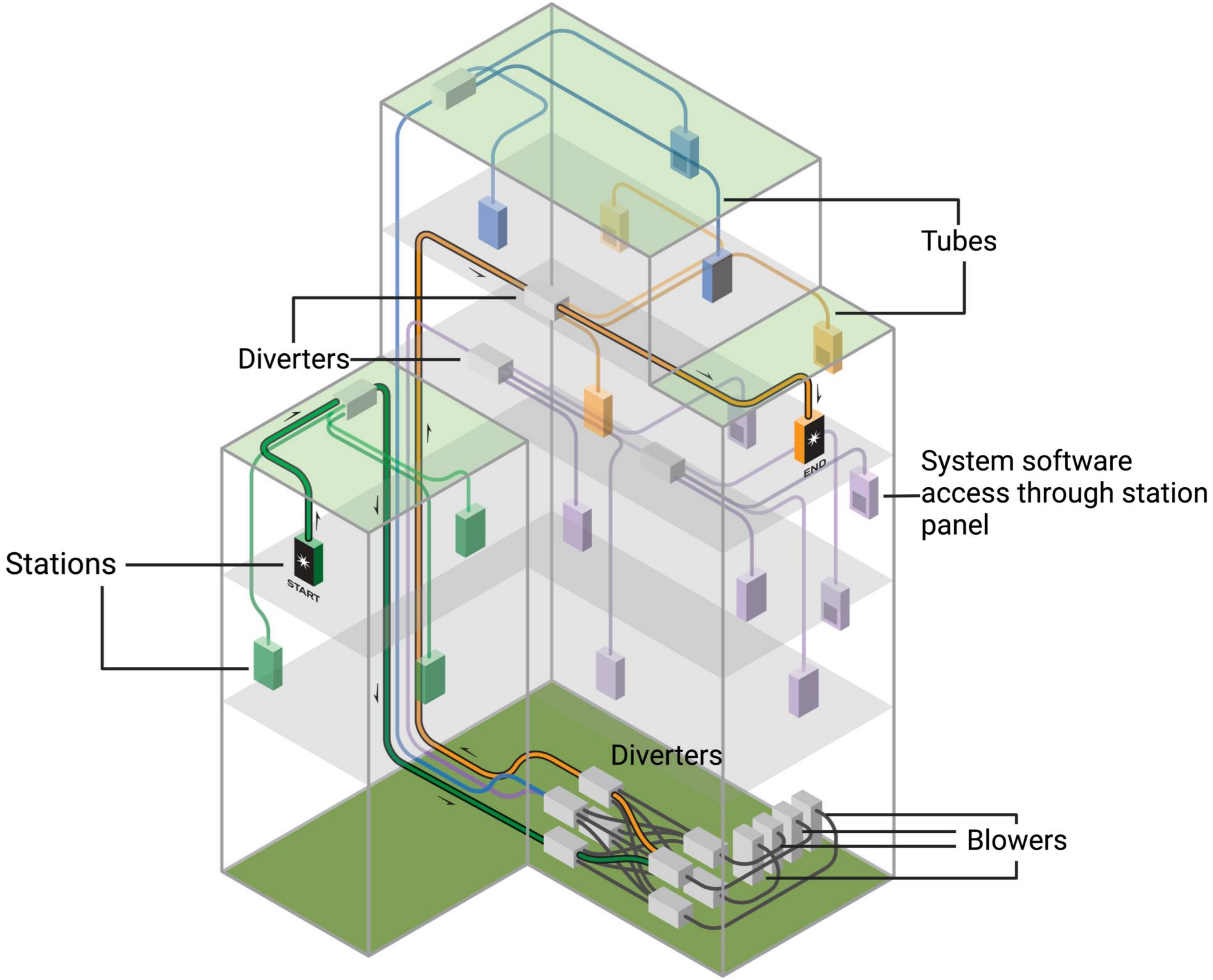
- Tubes
- Stations
- Diverters
  - Allow tubes to change direction
- Carriers



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Network of air-pressurized tubes
Core elements:

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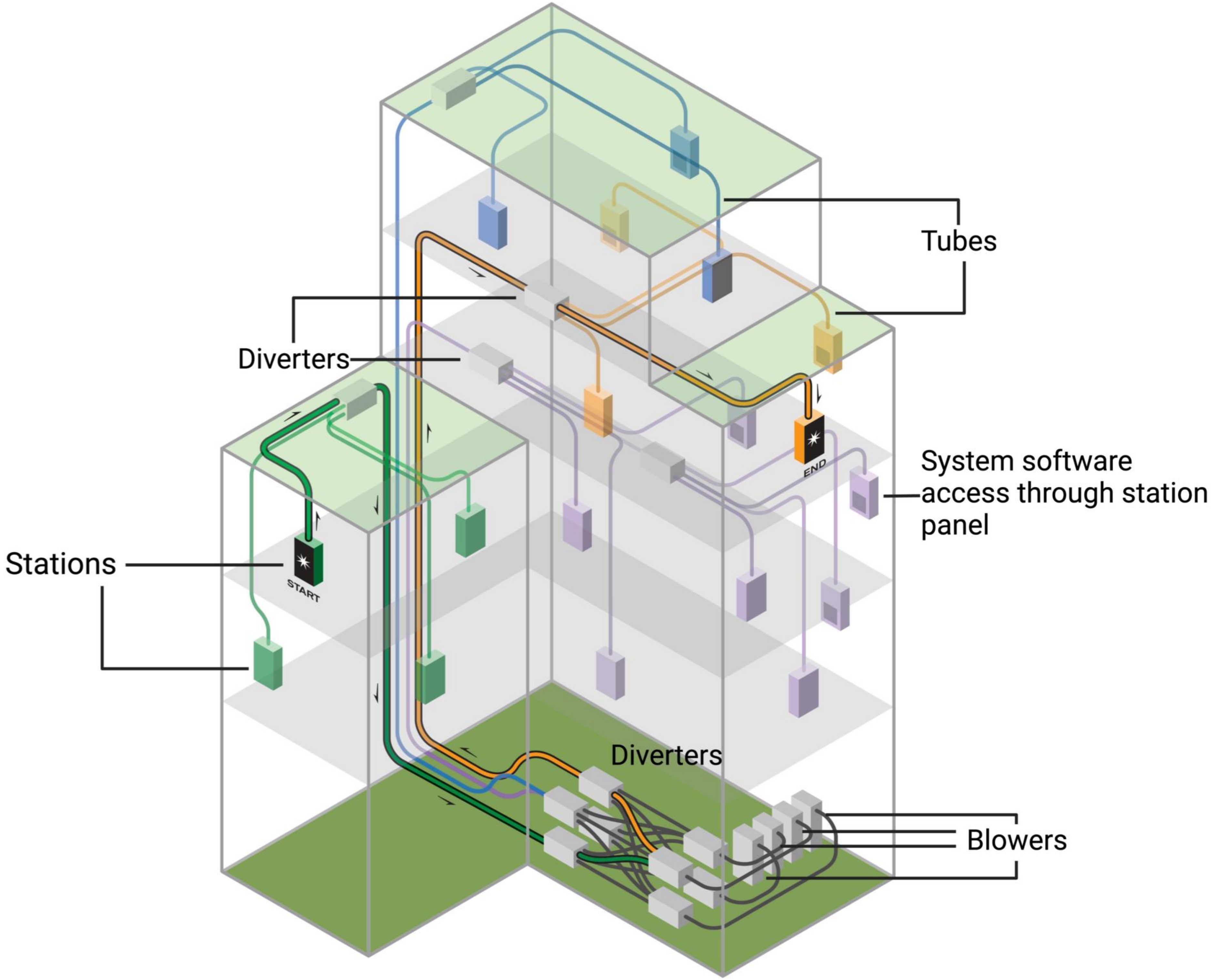
- Diverters
  - Allow tubes to change direction
- Carriers
- System software



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Garrett R Mullins, James H Harrison, David E Bruns, Smartphones Can Monitor Medical Center Pneumatic Tube Systems, Clinical Chemistry, Volume 62, Issue 6, 1 June 2016, Pages 891–893, https://doi.org/10.1373/clinchem.2016.257063

Pneumatic Tube Systems are Highly Customized

- Tube length
- Tube diameter
- Number of vertical drops
- Number of twists
- Number of turns
- Turning radii
- Air pressure
- Sending speed
- Tube and carrier materials and design

Specimen Environment During PTS Transport

- Vibration/agitation
- Rapid and large acceleration changes or shock forces (m/s^2 or g)
- Pressure changes
- Temperature extremes – poorly insulated areas of PTS

Thomas Streichert, Benjamin Otto, Claudia Schnabel, Gerhard Nordholt, Munif Haddad, Mario Maric, Astrid Petersmann, Roman Jung, Christoph Wagener, Determination of Hemolysis Thresholds by the Use of Data Loggers in Pneumatic Tube Systems, Clinical Chemistry, Volume 57, Issue 10, 1 October 2011, Pages 1390–1397

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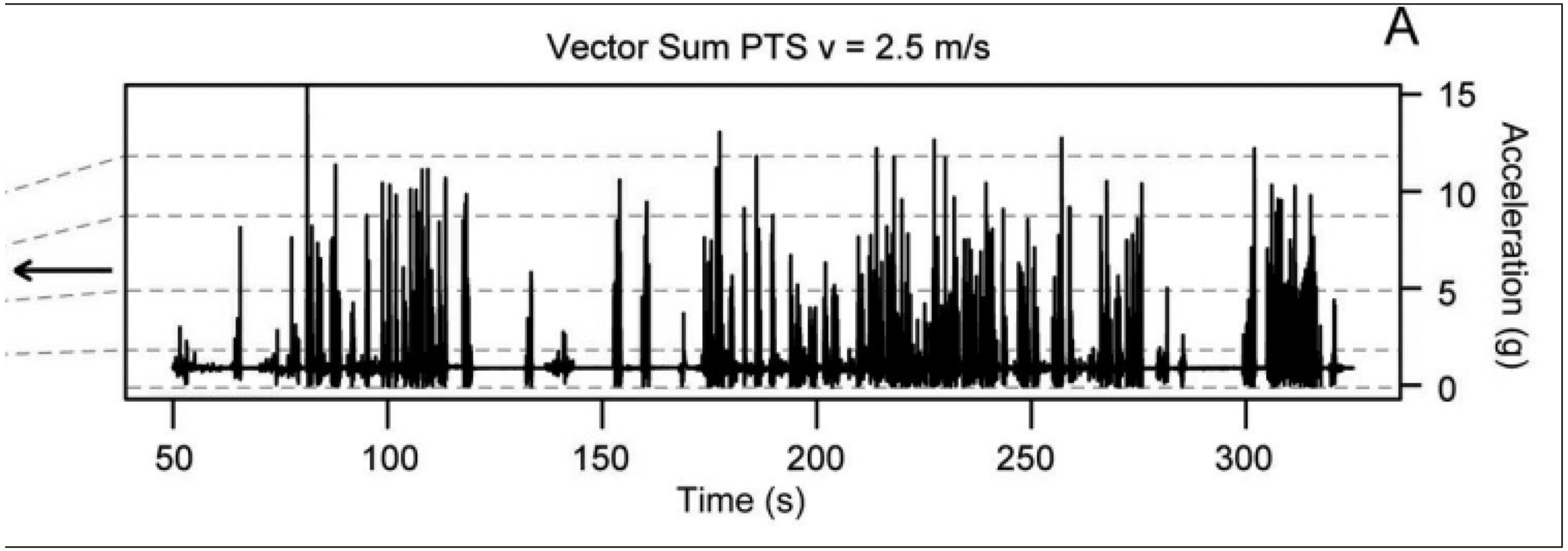

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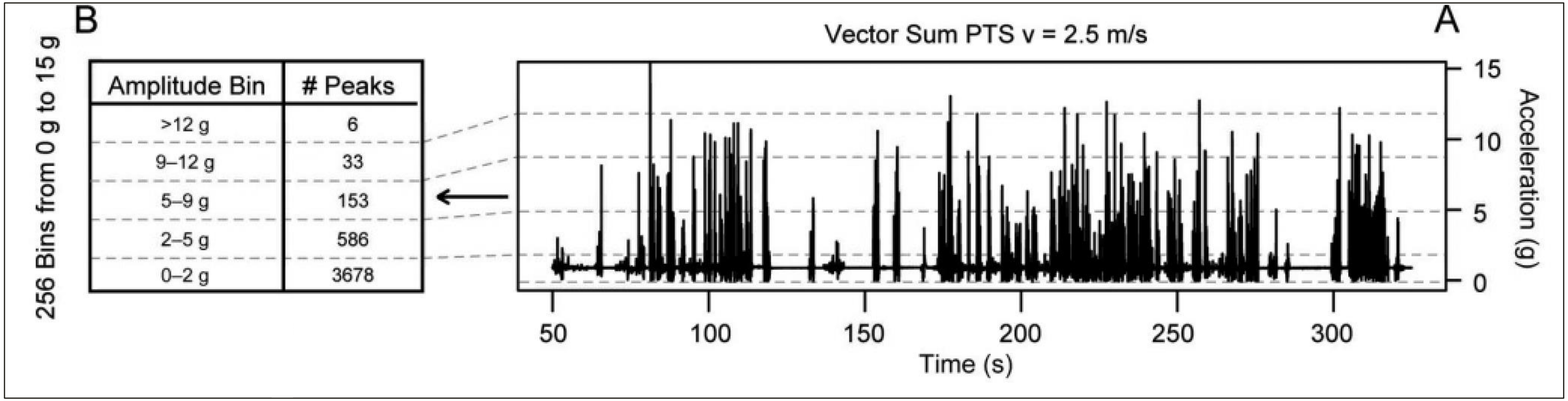

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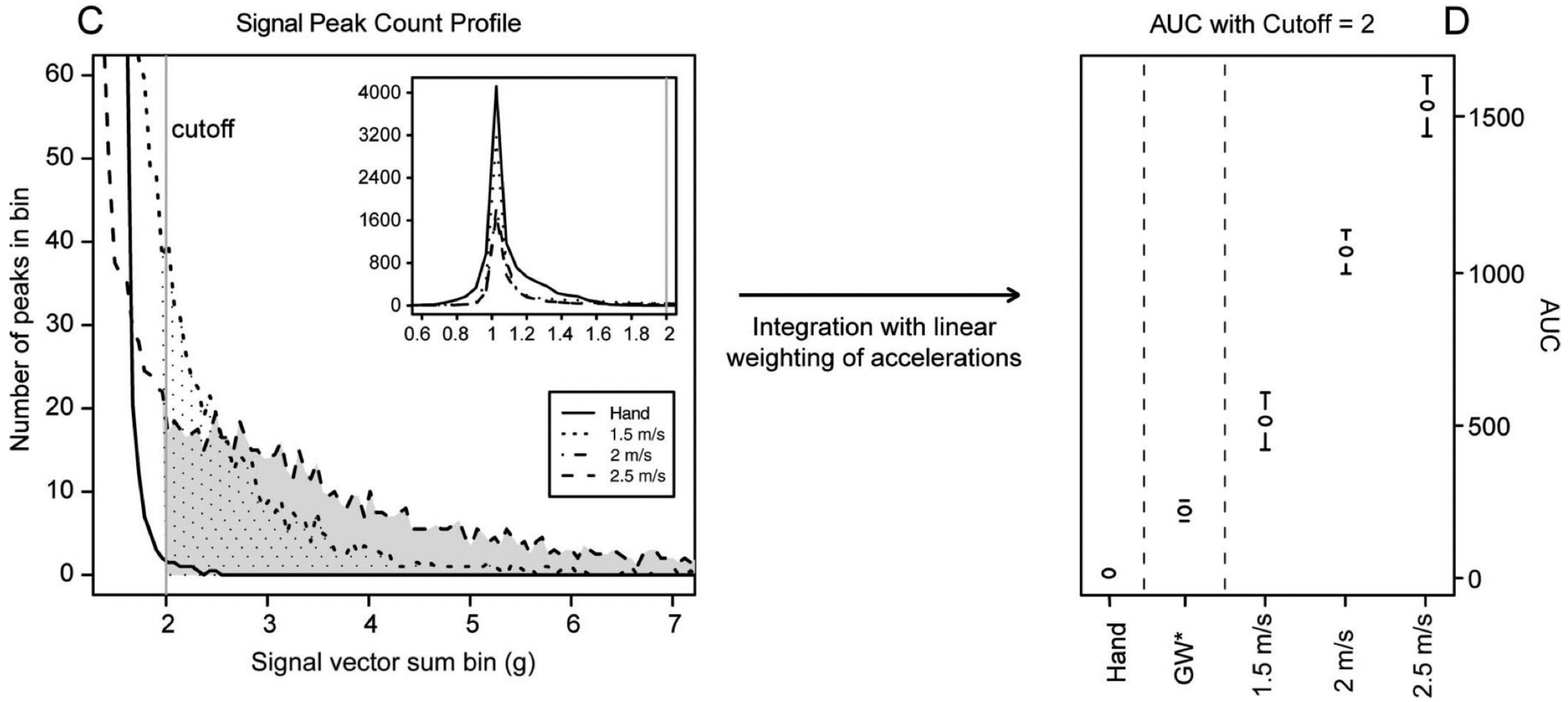
Area Under the Curve as a Measure of Cumulative Accelerations



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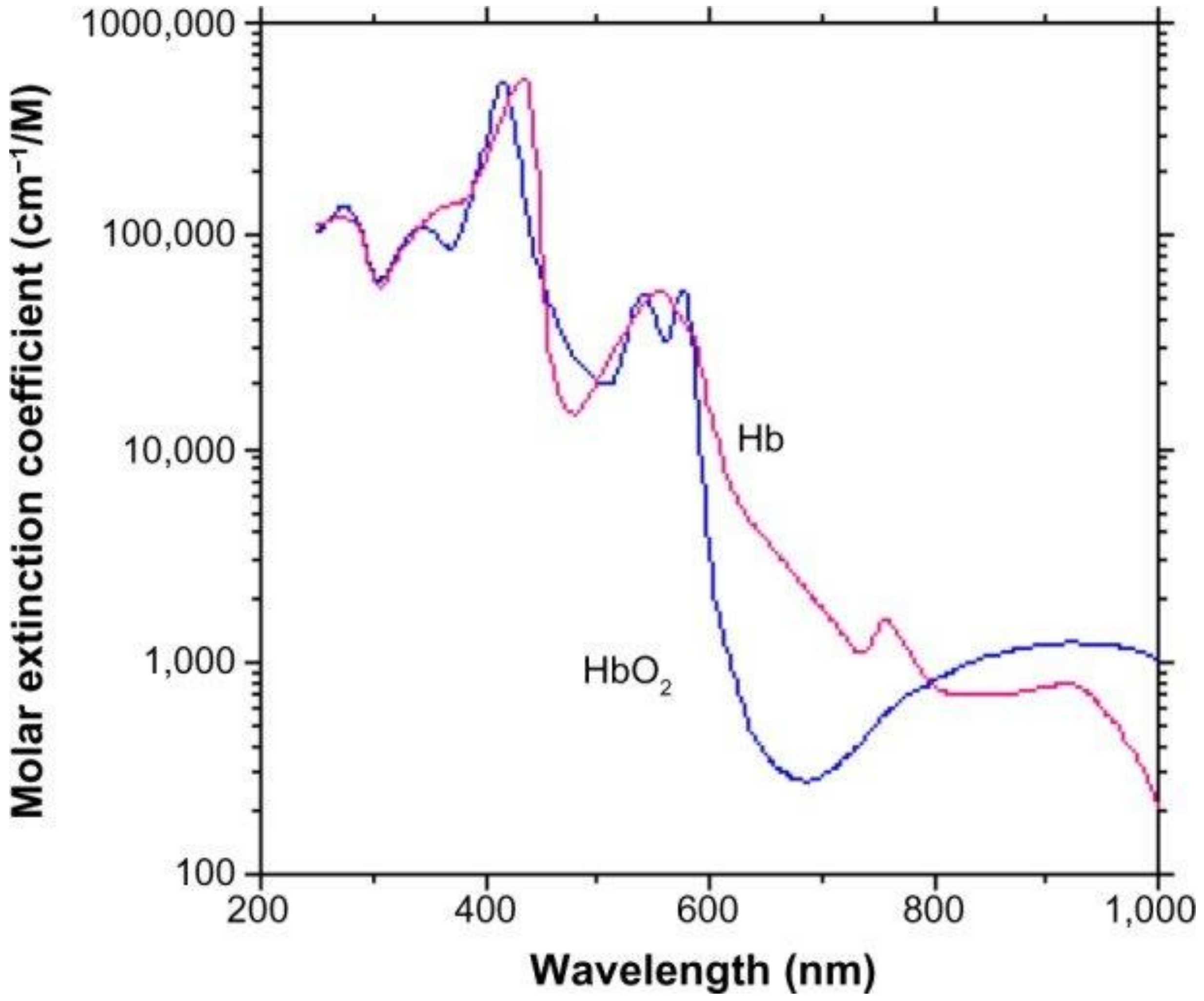
PTS-induced hemolysis



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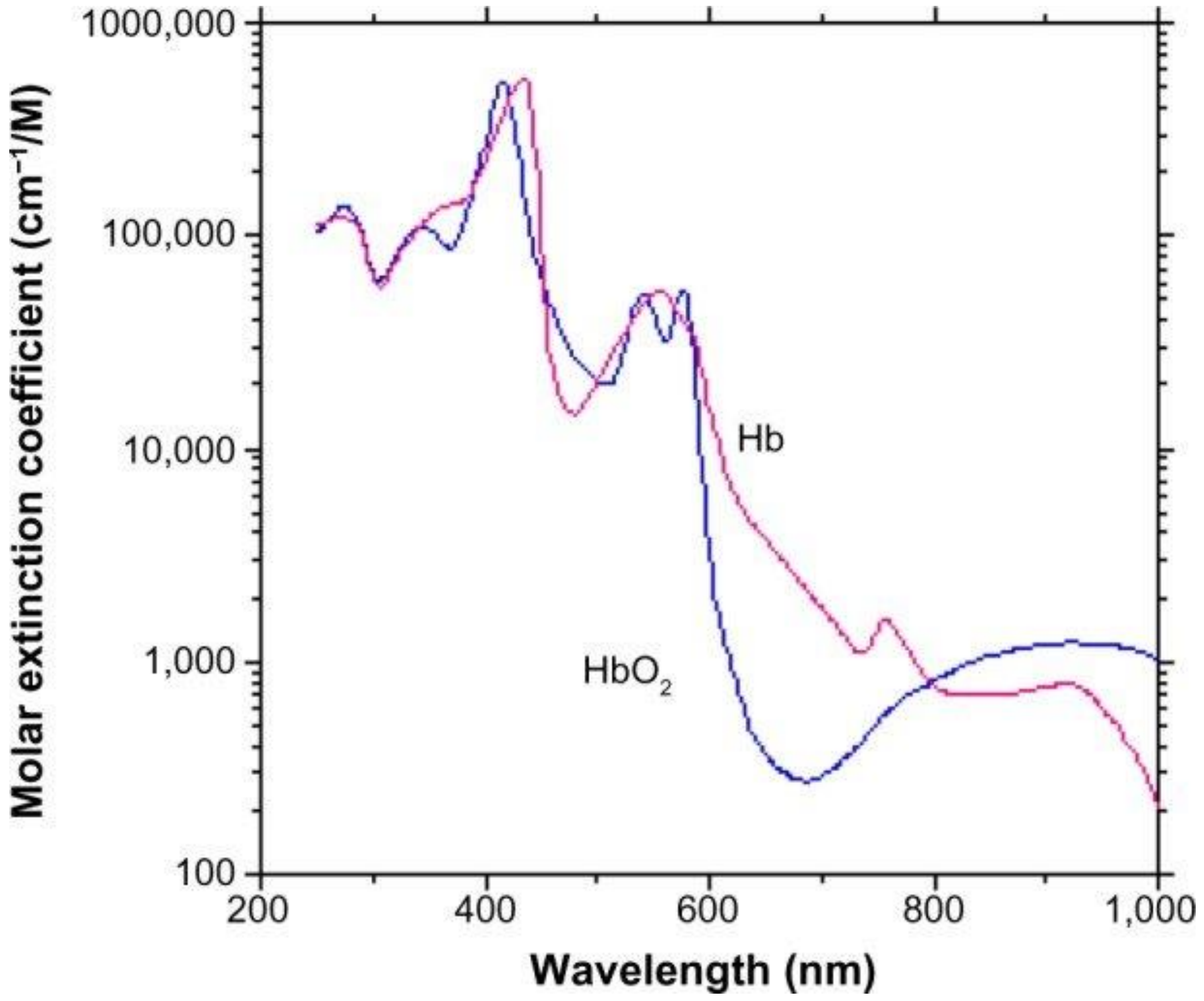

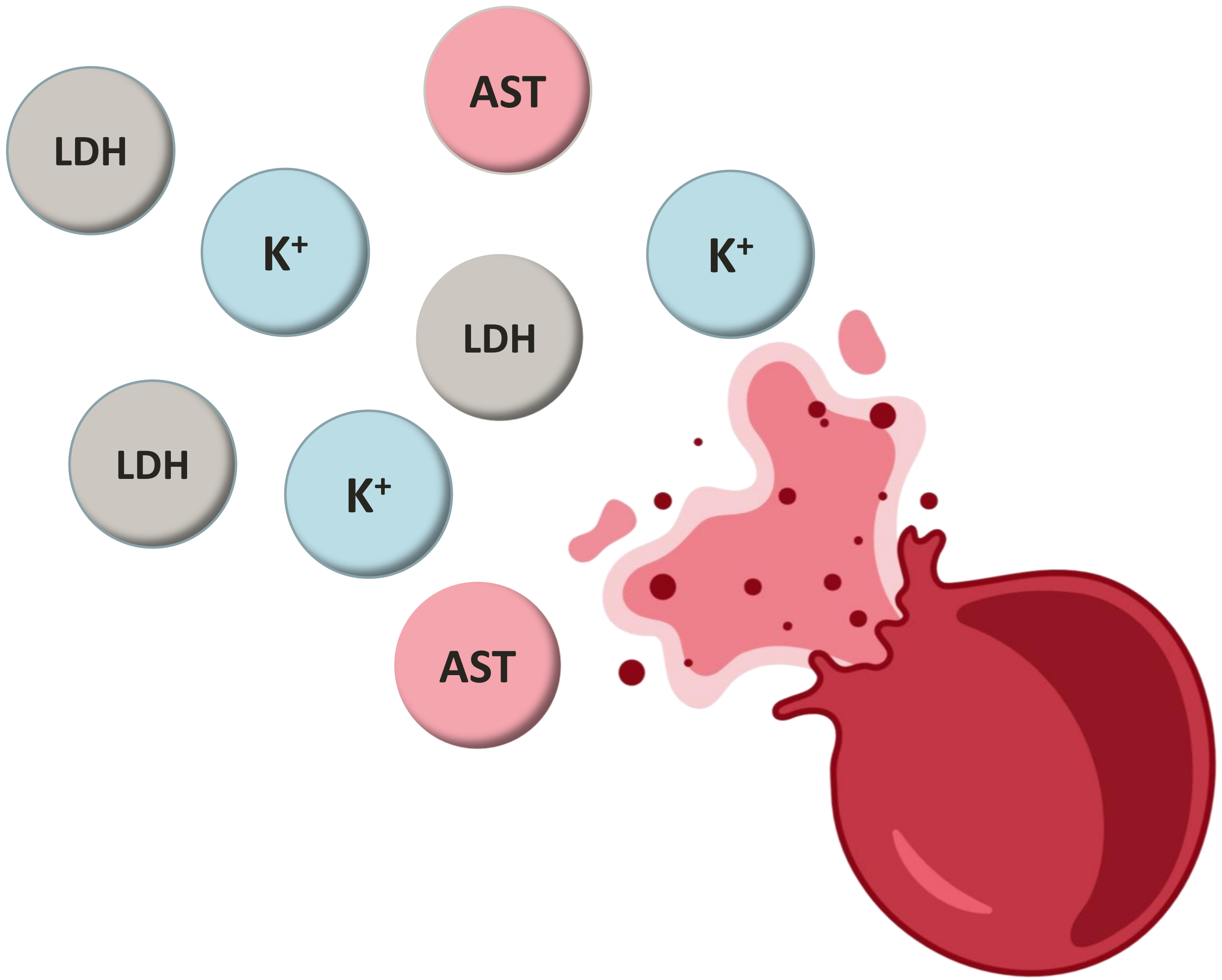

Hemolysis Index

Flag	Frequency of Hemolysis flags					
+++++						**0**
++++					**15**	
+++				**10**		
++			**24**	3		
+		**30**	8			
N	**359**	26				
	< 50	50-99	100-199	200-299	300-499	≥ 500
	Hemoglobin Concentration (mg/dL)					

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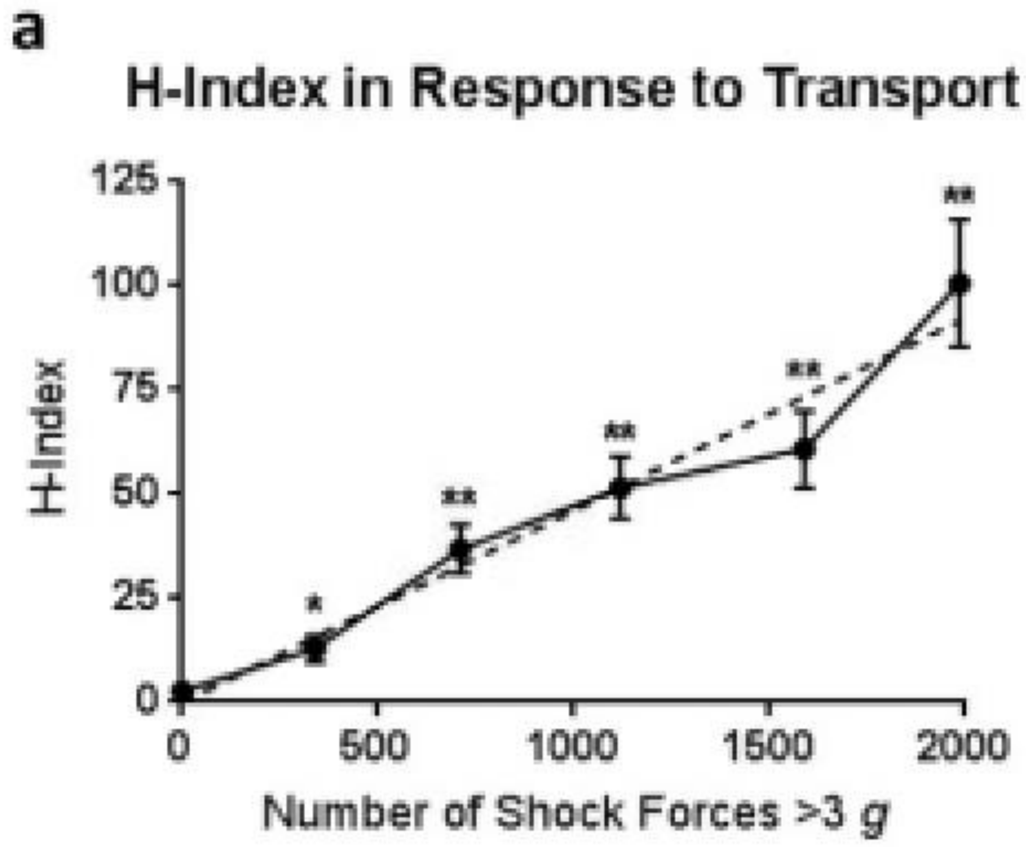
Which Analytes are Affected?

Test	Hemolysis Threshold
Alkaline phosphatase	≥ 4+
Alanine amino transferase	≥ 4+
Amylase	≥ 3+
Aspartate amino transferase	≥ 1+
Total cholesterol	≥ 4+
Creatine Kinase	≥ 4+
Direct bilirubin	≥ 1+
Iron	≥1+
Gamma glutamyl transferase	≥ 4+
Potassium	**≥ 1+**
Lactate Dehydrogenase	≥ 1+
Magnesium	≥ 2+
Phosphorous	≥ 4+
Tobramycin	≥ 4+
Albumin	≥ 4+
Vancomycin	≥ 4+

Number and Magnitude of Shock Forces Correlates with Degree of Hemolysis



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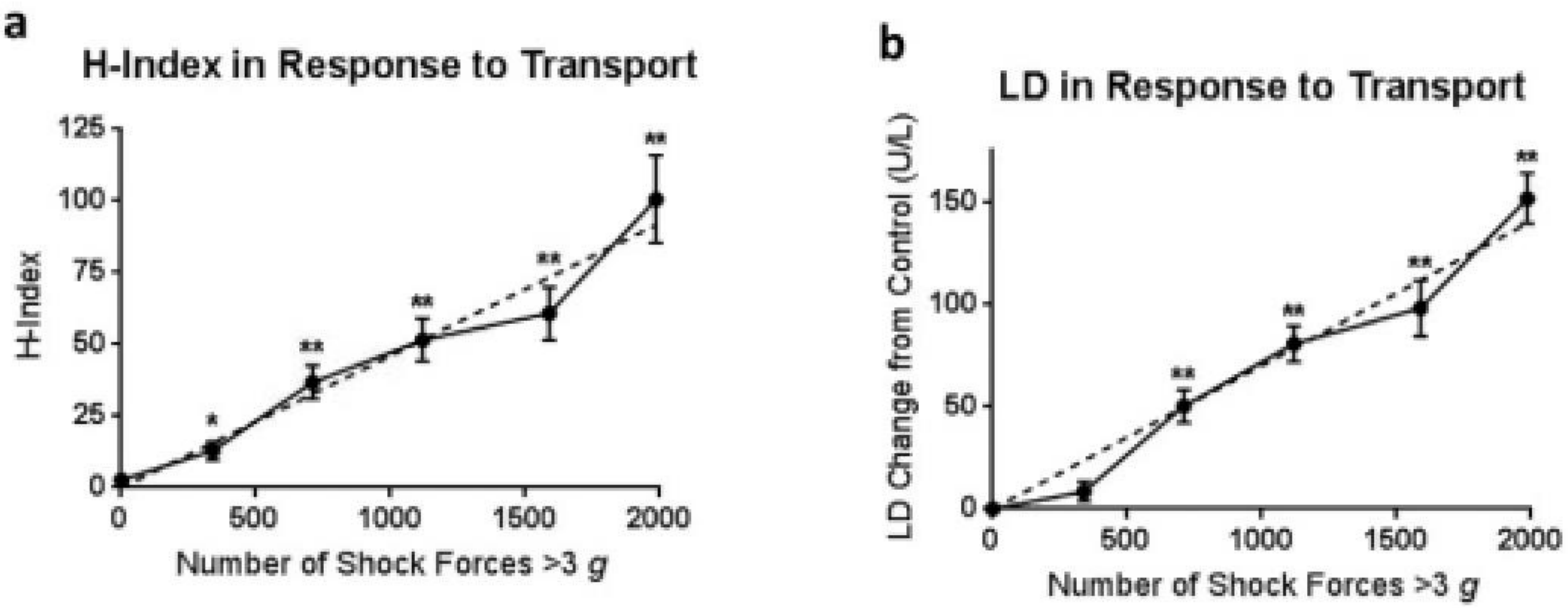

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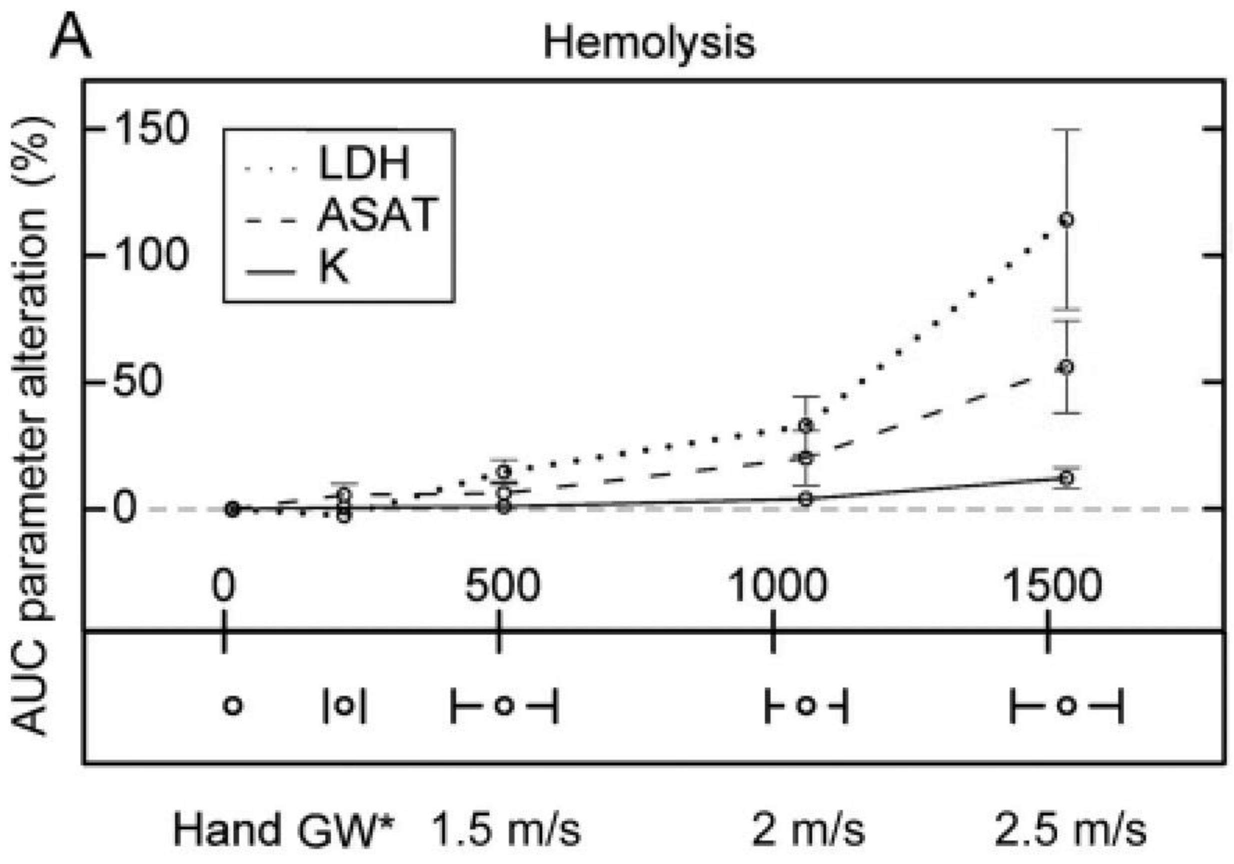
Specimen Hemolysis Correlates with PTS Transport Speed



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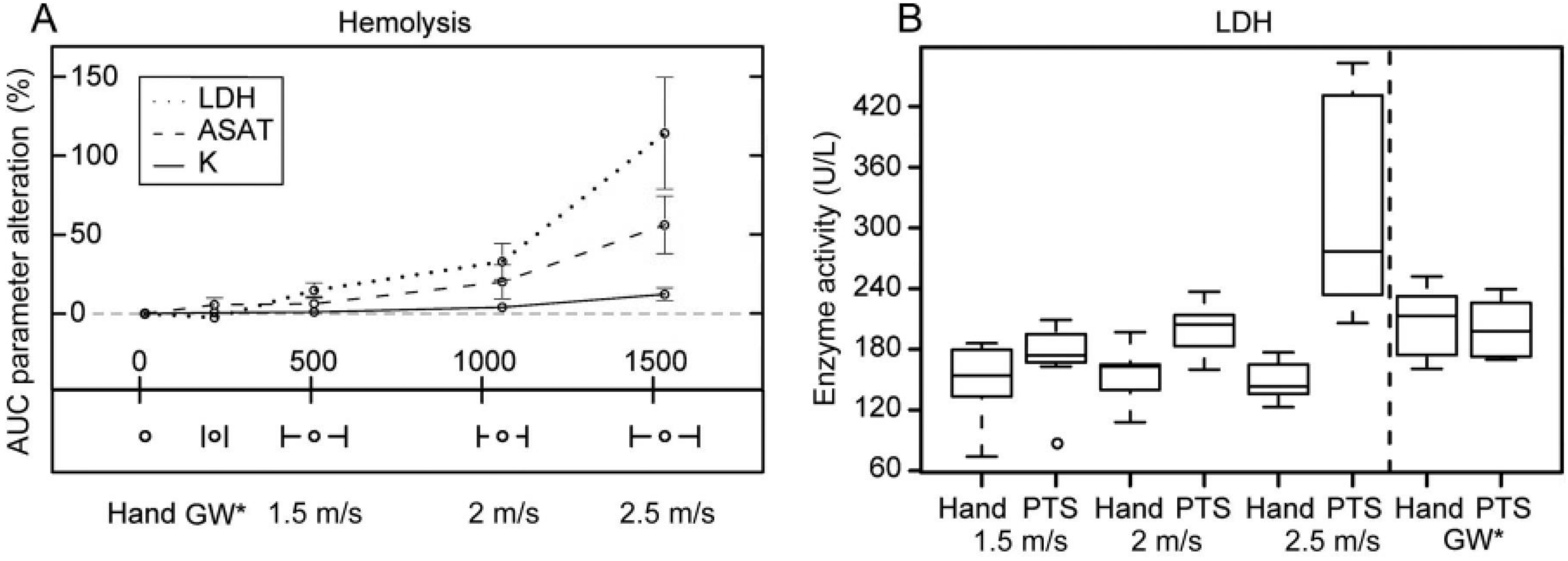

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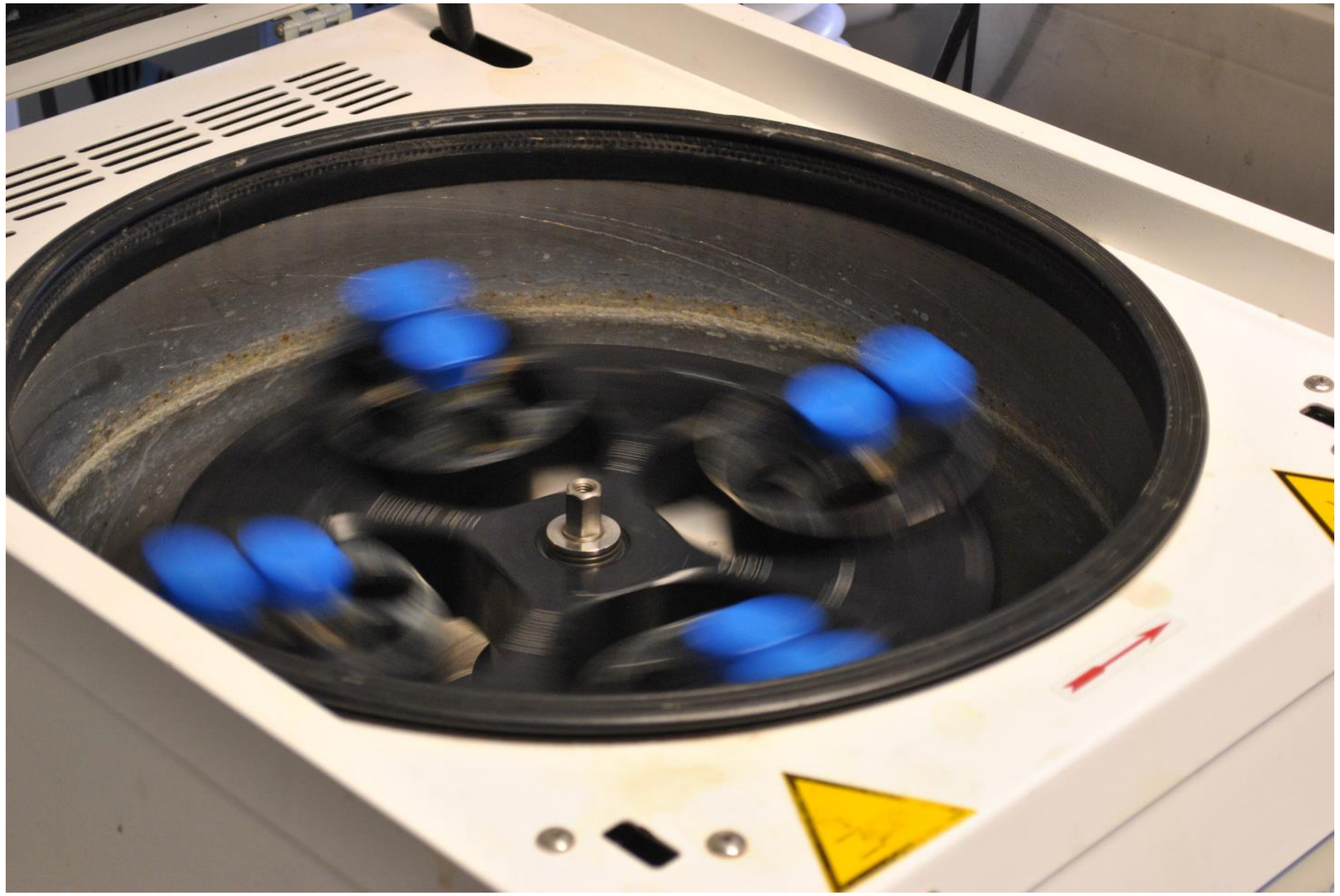
How Do Low g-Forces During PTS Transport Cause Hemolysis?



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How Do Low g-Forces During PTS Transport Cause Hemolysis?

B

256 Bins from 0 g to 15 g

Amplitude Bin	# Peaks
>12 g	6
9–12 g	33
5–9 g	153
2–5 g	586
0–2 g	3678

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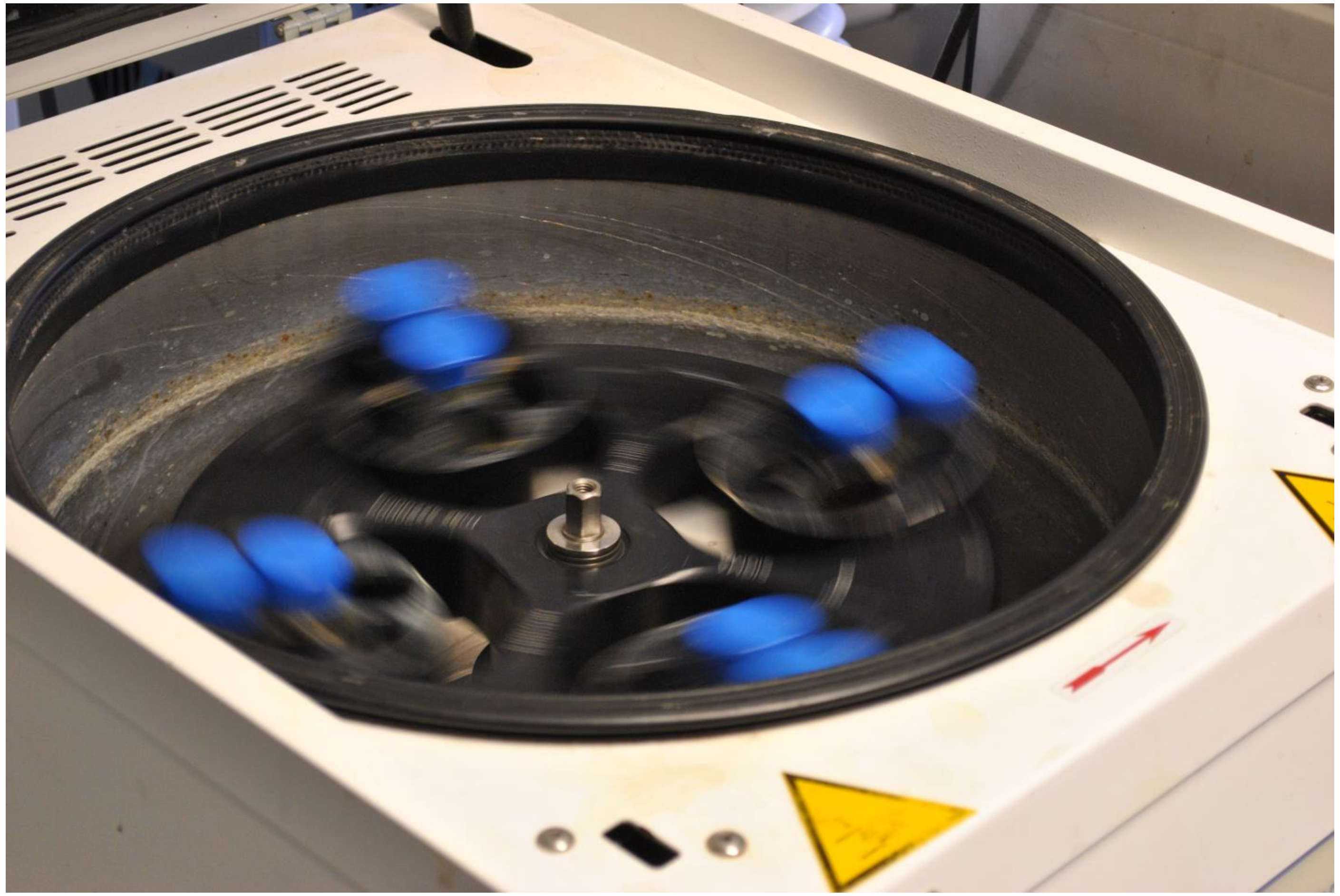

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Air Bubbles May Cause PTS-induced Hemolysis

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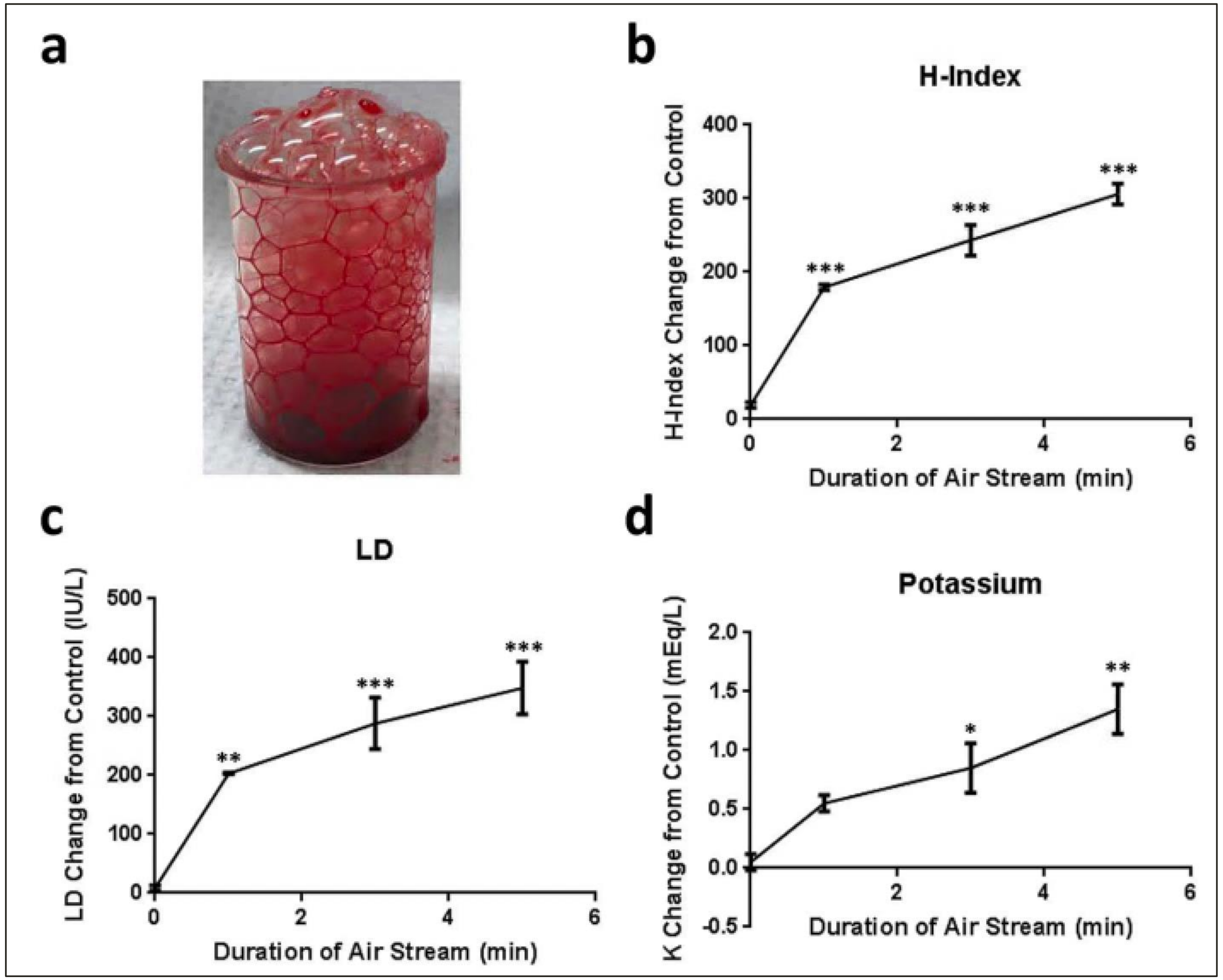

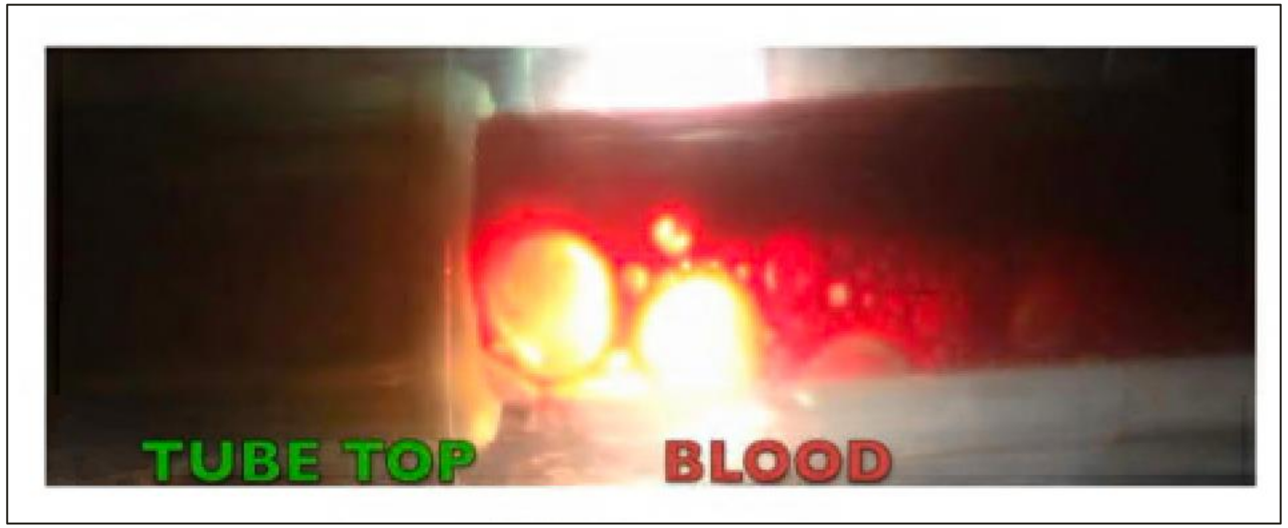

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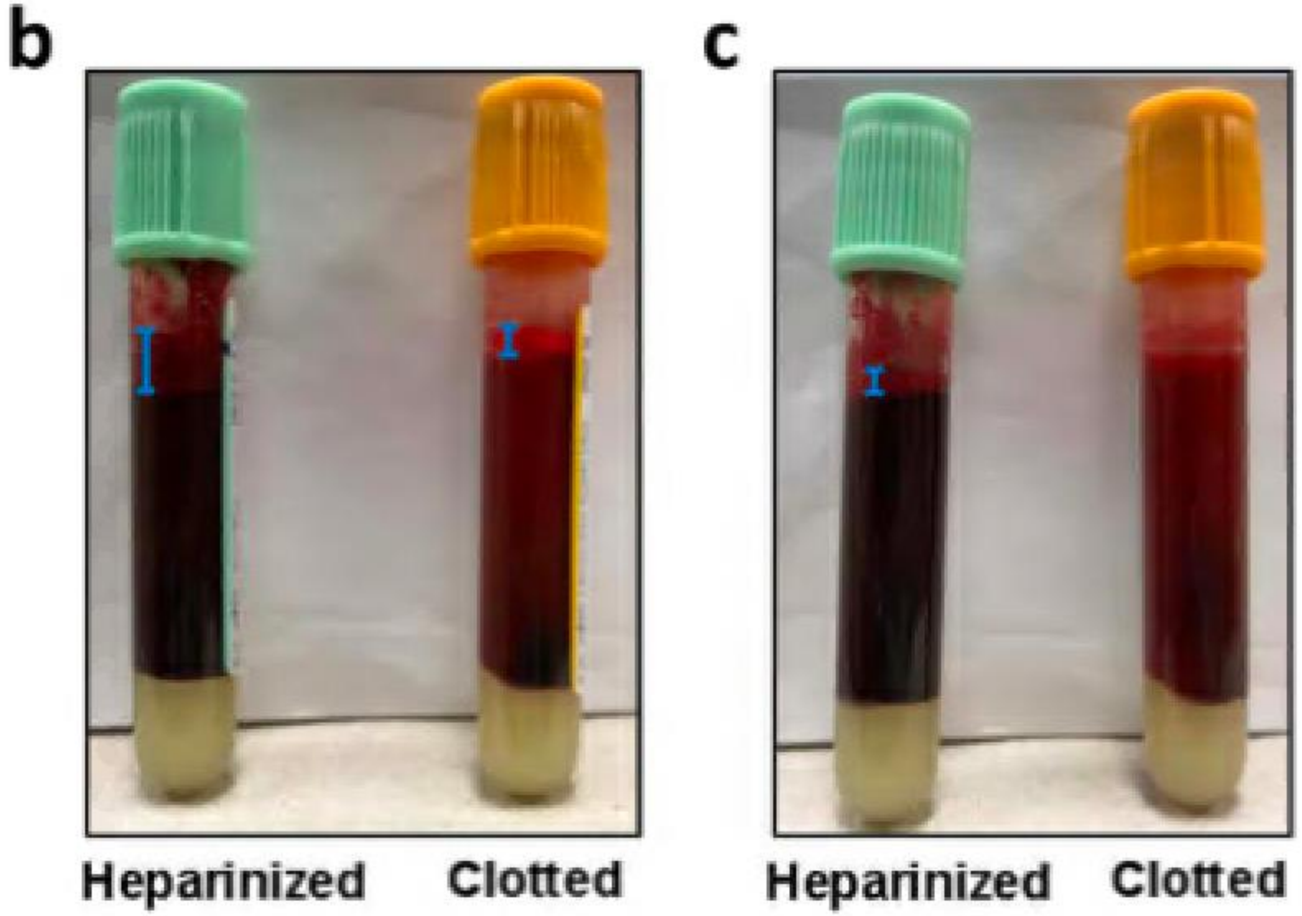
Clotted Blood is More Resistant to PTS-induced Hemolysis



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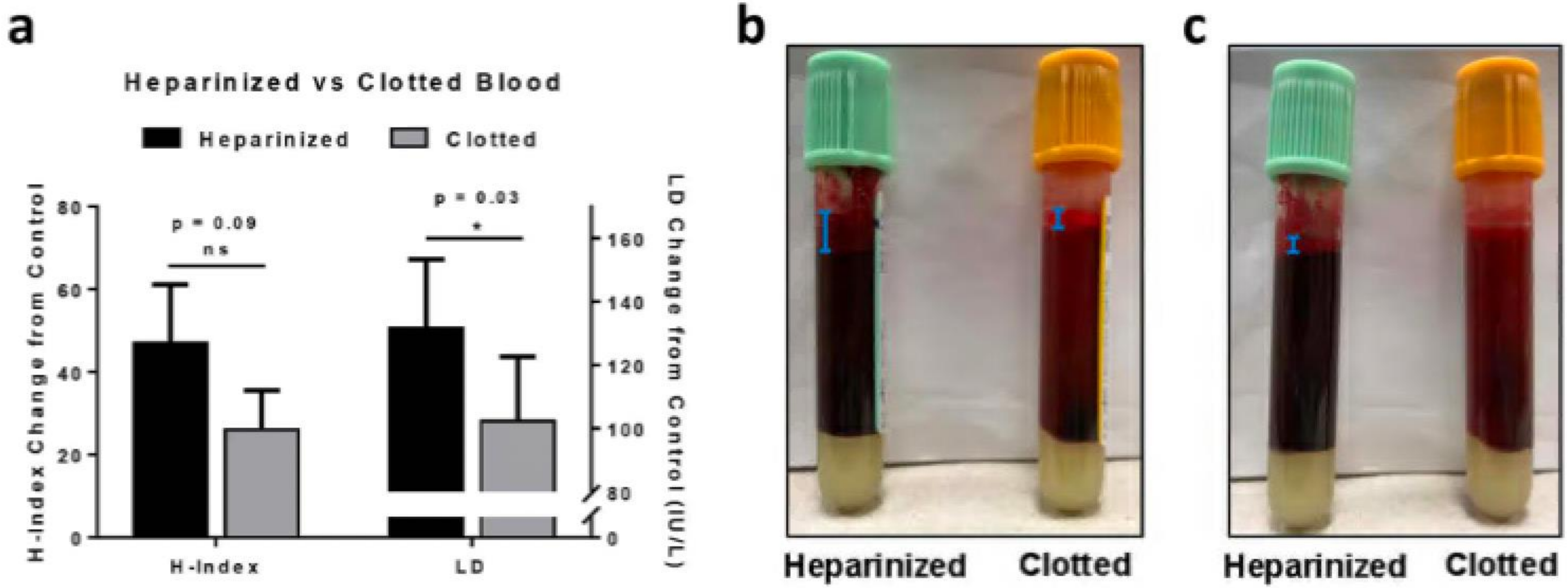

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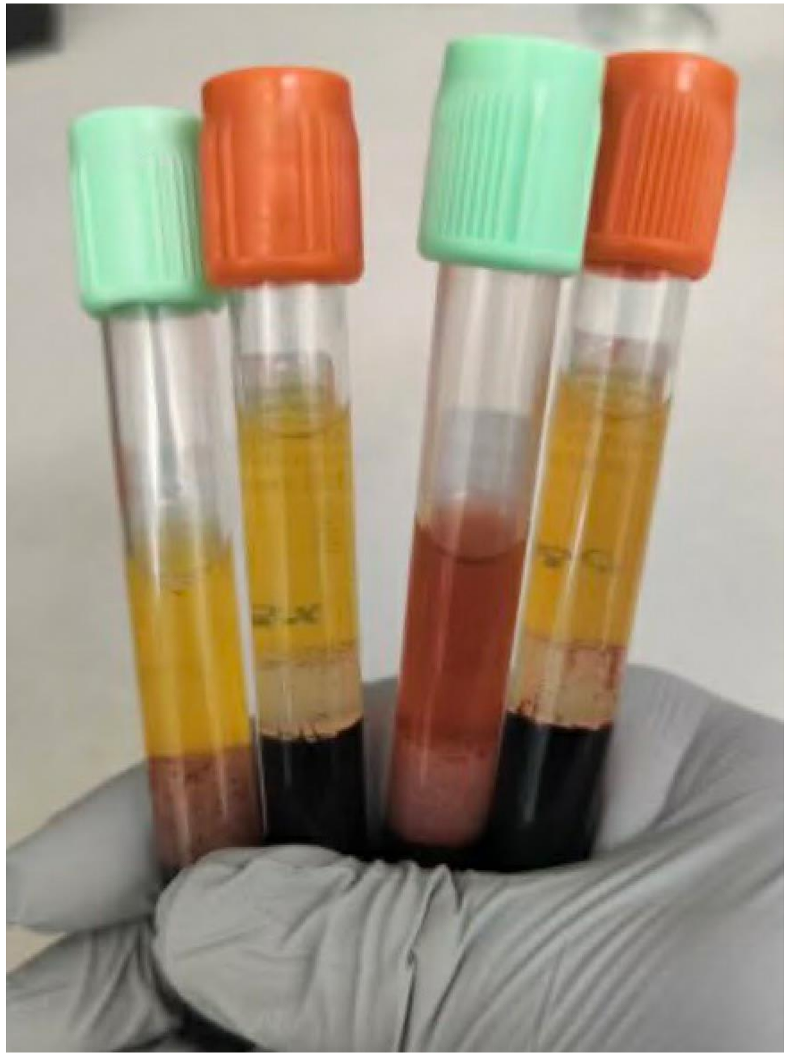

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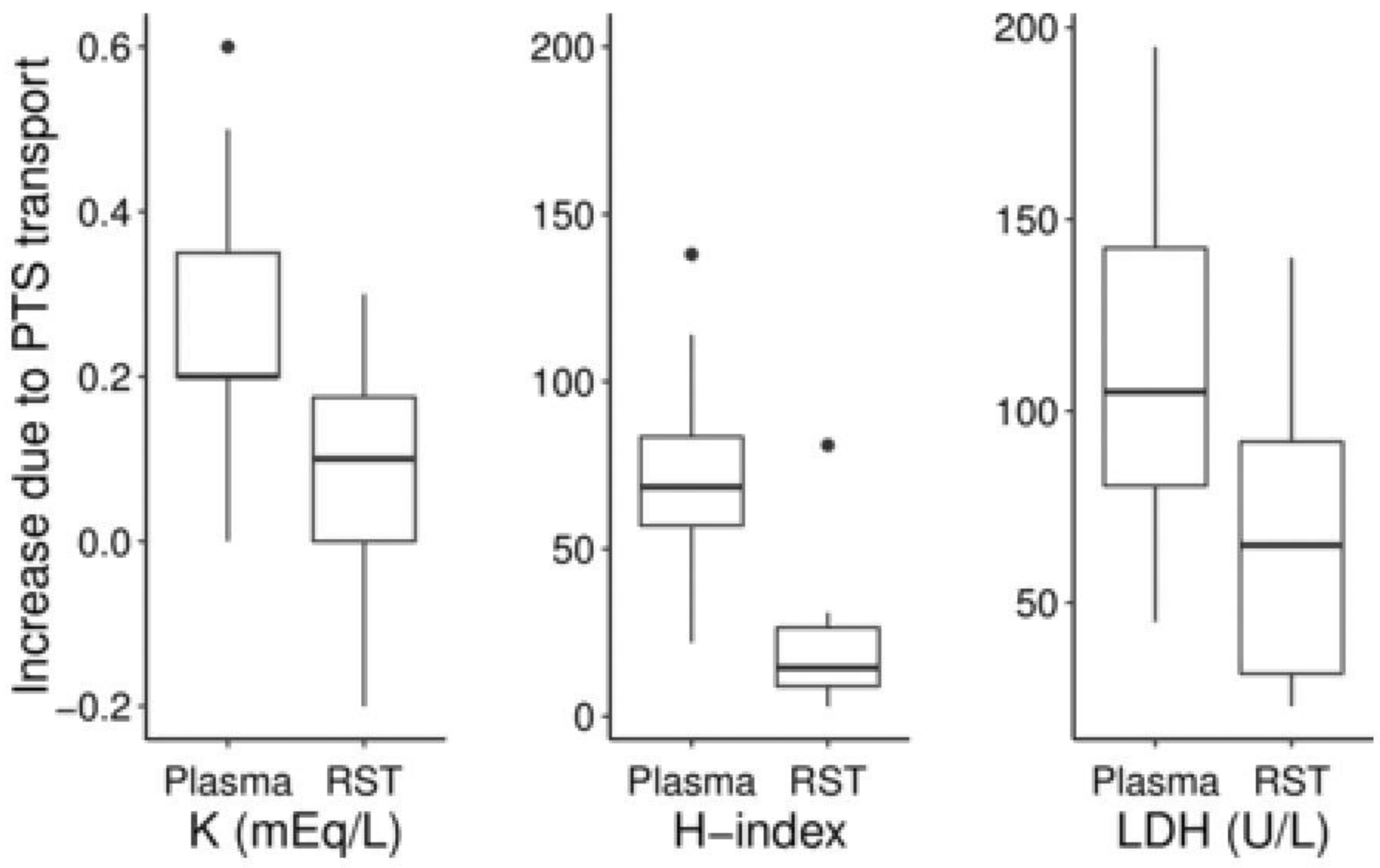

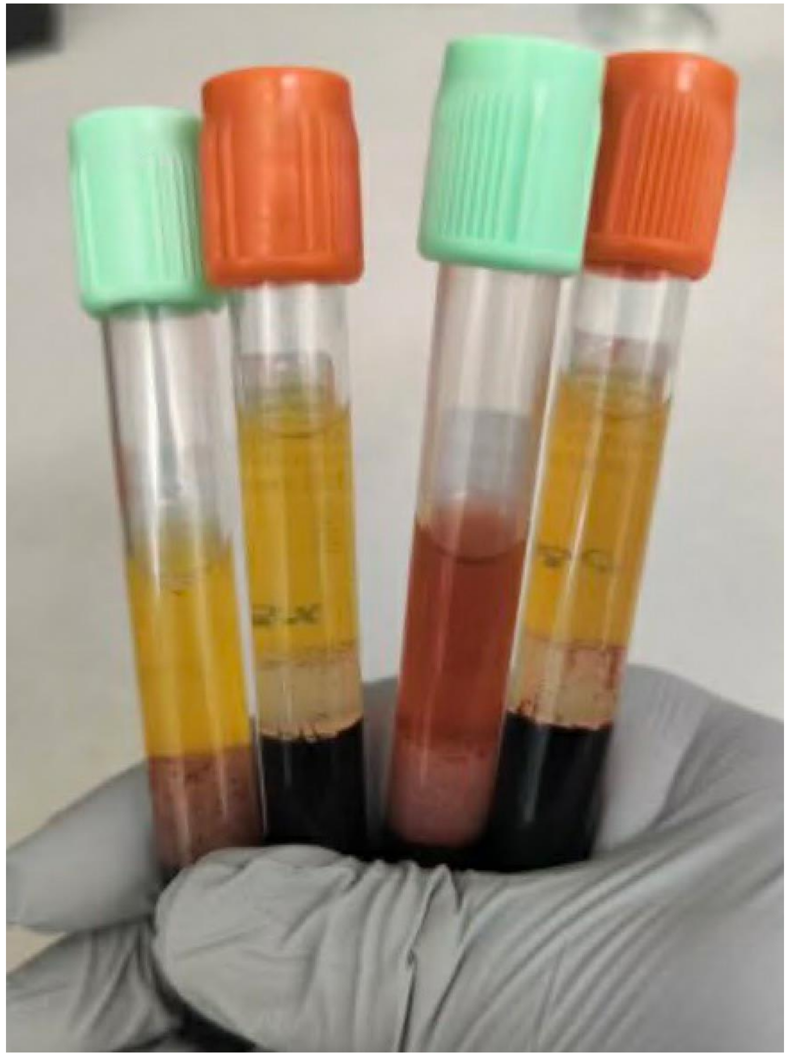

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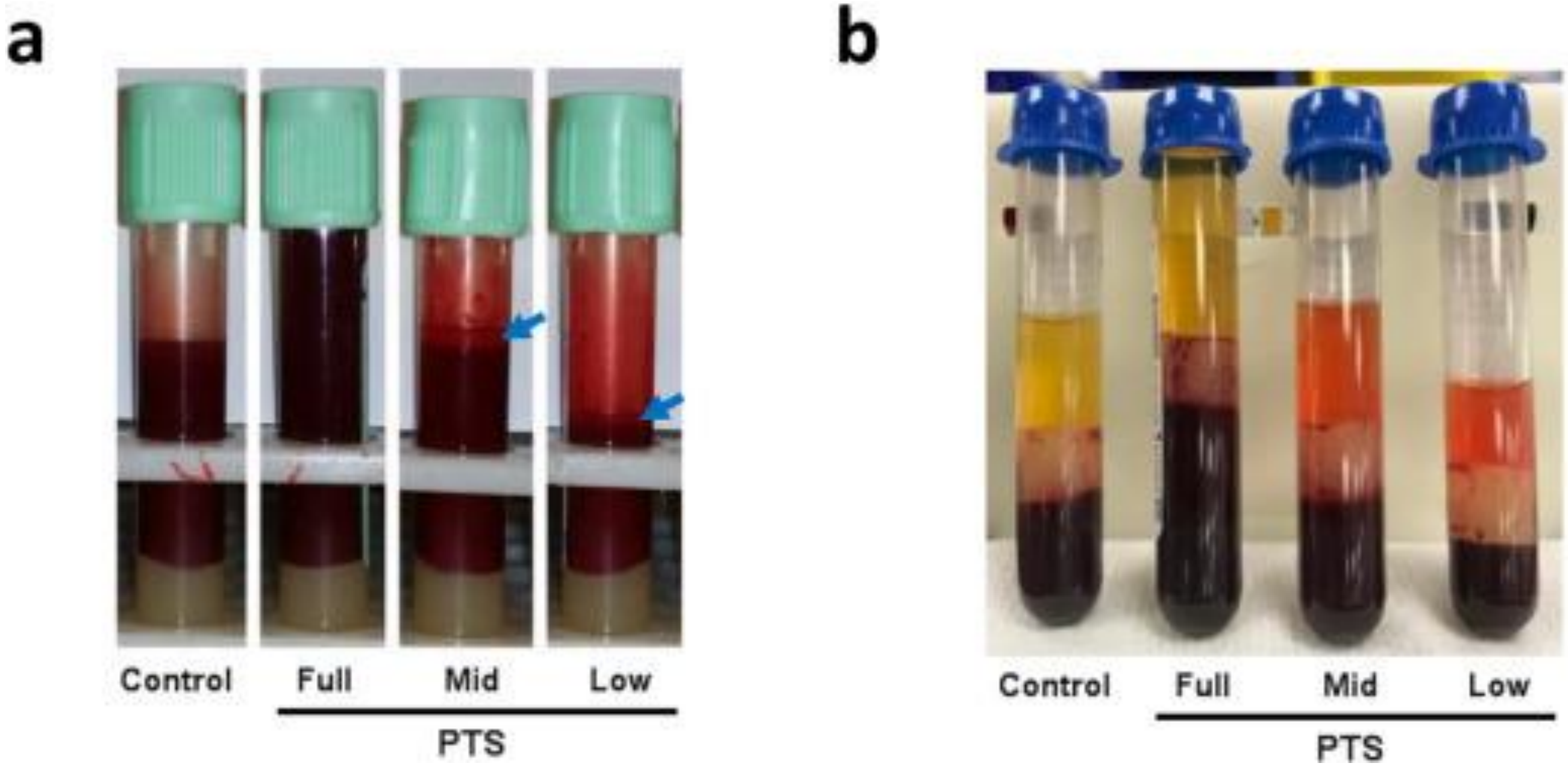
Full blood tubes are less prone to hemolysis



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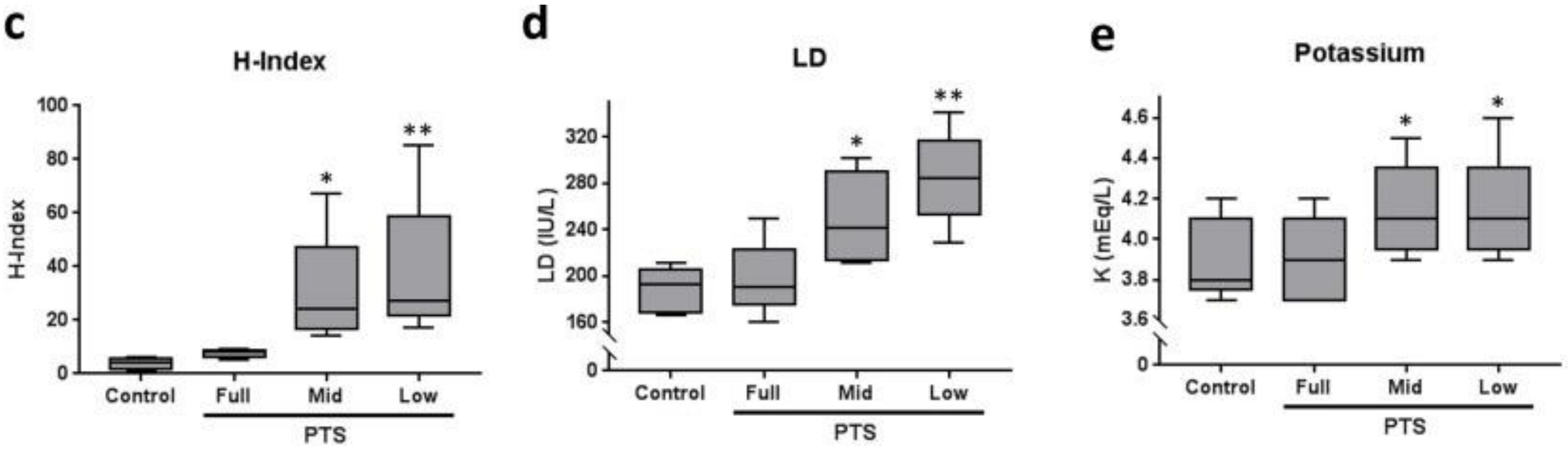

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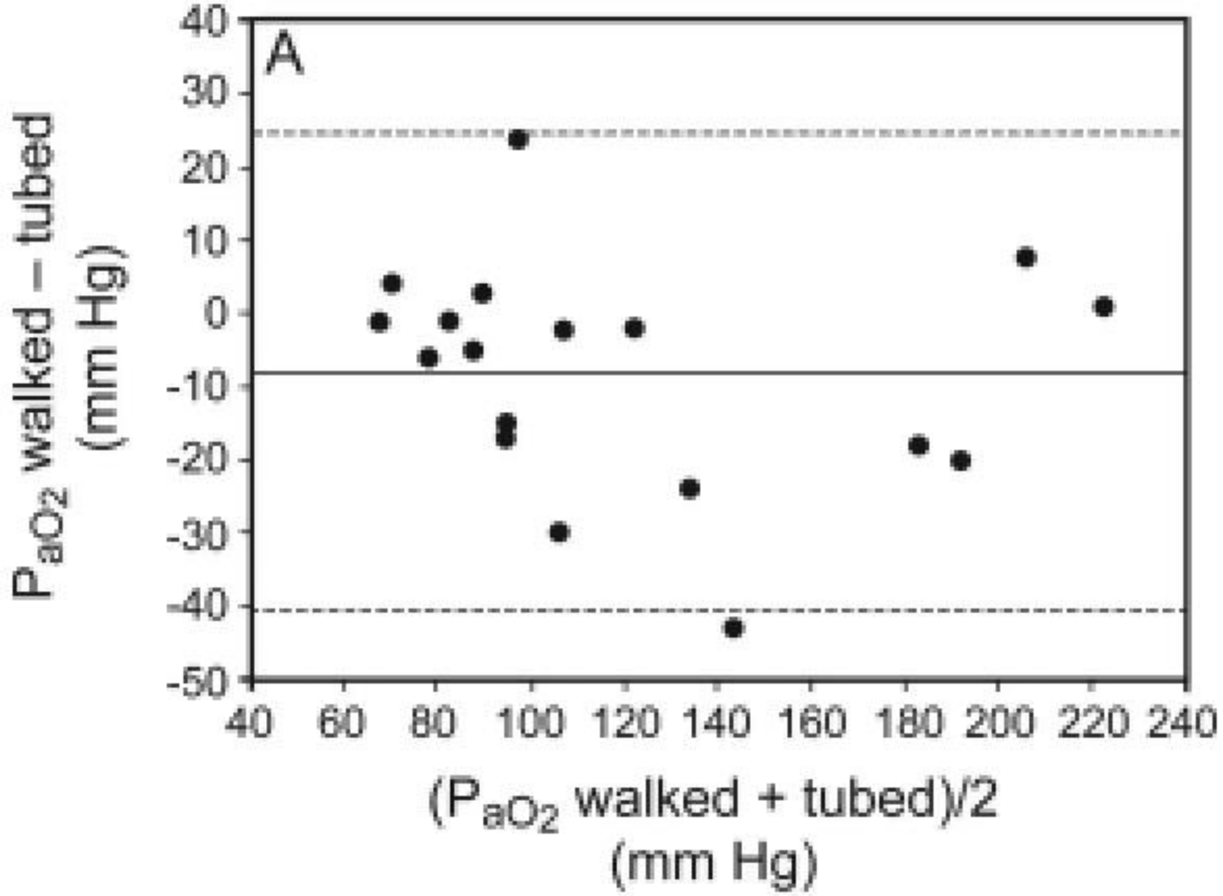
pO_2 is Impacted by PTS Transport



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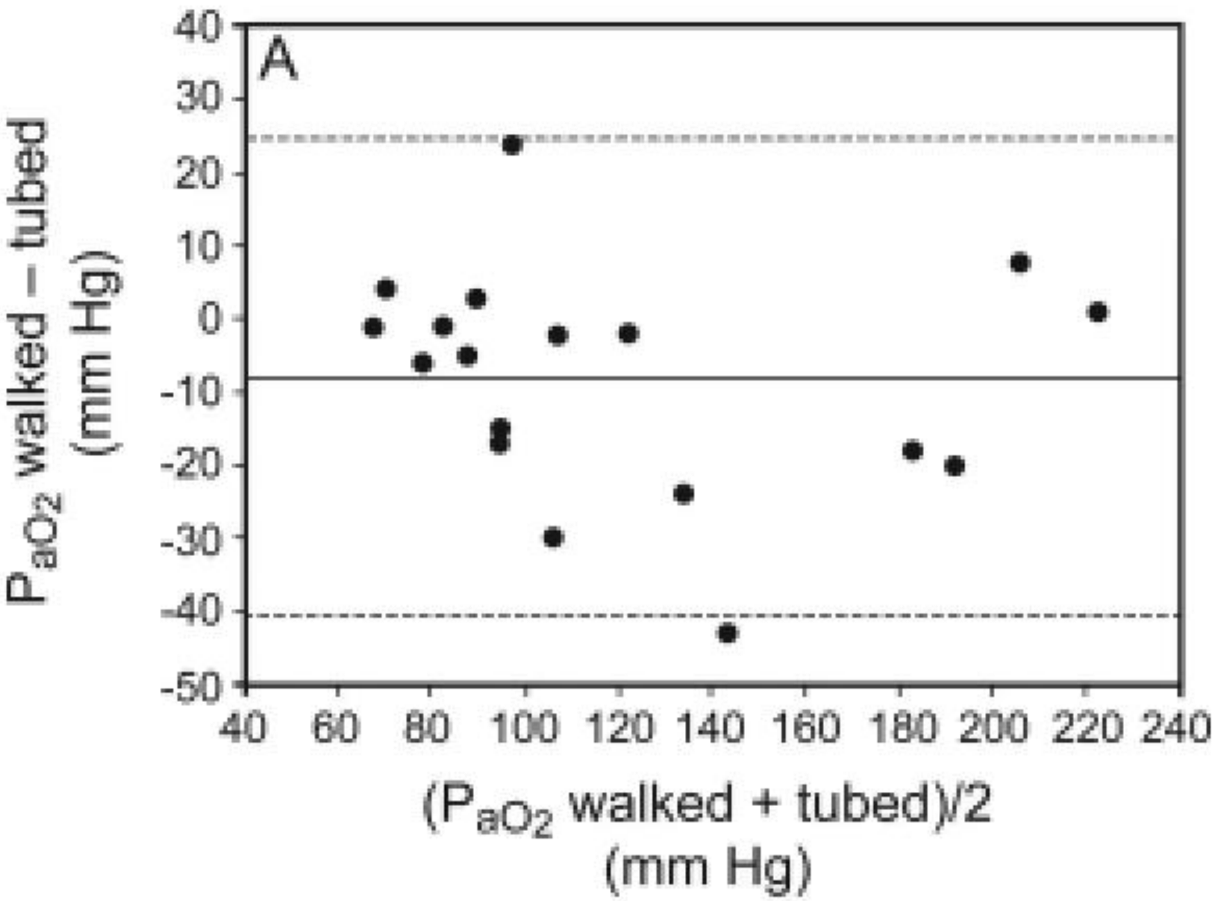

Transport in pressure-sealed containers may mitigate PTS-induced changes in pO_2

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Hemolysis Impacts Blood Gas Analytes

Table 3. Variation of blood gas parameters in mechanically hemolyzed specimens.

Parameter	Desirable specifications (%)	Non-hemolyzed blood	Hemolyzed blood	*p* Value	Bias
pH	±1.0	7.29 ± 0.01	7.33 ± 0.01	<.01	0.2 % (0.0 % to 1.2 %)
pO_2, mmHg	±1.8	49.2 ± 4.7	55.3 ± 4.7	<.01	12.4 % (−9.7 % to 80.9 %)
pCO_2, mm Hg	±1.8	52.6 ± 1.4	45.1 ± 1.4	<.01	−14.3 % (−26.7 % to −5.3 %)
HCO_3^-, mmol/L	±1.6	24.6 ± 0.5	23.2 ± 0.5	<.01	−3.2 % (−11.7 % to −2.2 %)
Na^+, mmol/L	±0.2	139.6 ± 0.8	137.4 ± 0.6	<.01	−1.6 % (−17.2 % to 6.2 %)
K^+, mmol/L	±1.8	4.4 ± 0.1	5.2 ± 0.8	<.01	18.2 % (−0.5 % to 117 %)
Cl^-, mmol/L	±0.5	99.7 ± 0.6	99.9 ± 0.6	.08	0.2 % (−1.8 % to 2.1 %)
Ca^{2+}, mmol/L	±0.6	1.3 ± 0.02	1.2 ± 0.02	<.01	−7.7 % (−13.7 % to −0.4 %)
Anion gap, mmol/L	±3.5	18.9 ± 0.4	19.6 ± 0.4	<.01	3.7 % (−14.2 % to 22.3 %)
Glucose, mmol/L	±1.8	5.9 ± 0.3	5.8 ± 0.3	<.01	−0.6 % (−16.3 % to 3.3 %)
Lactate, mmol/L	±8.0	3.95 ± 0.31	4.31 ± 0.31	<.01	−1.5 % (−2.8 % to 66.7 %)
Hemoglobin, g/L	±1.8	10.4 ± 0.4	10.4 ± 0.5	.68	15.6 % (−19.5 % to 37.1 %)
Hct, %	±1.7	33.2 ± 1.2	33.6 ± 1.3	.06	13.5 % (−22.3 % to 65.7 %)

Casati M, Intra J, Rossi W, Giacobone C, Brivio R. Hemolysis and blood gas analysis: it's time for a change! Scand J Clin Lab Invest. 2022 Apr;82(2):138-142

Robot carriers may be an alternative to PTS-transport

- Already in use in some health systems for various tasks including transport of specimens to lab
    - Temperature control
    - Agitation control
    - Rapid
    - Reduces need for hand delivery

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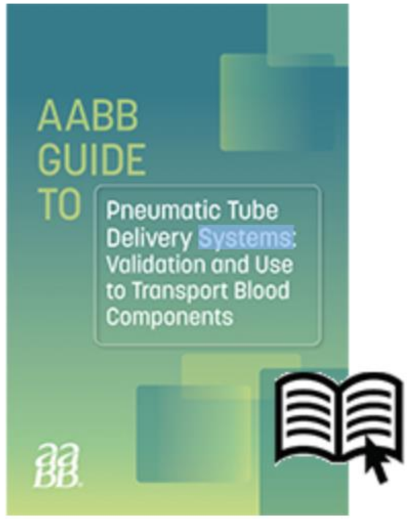
Validation of PTS for Specimen Transport

- No clear regulatory guidance on how to validate PTS for specimens destined for clinical laboratory analyses

AABB GUIDE TO PNEUMATIC TUBE DELIVERY SYSTEMS: VALIDATION AND USE TO TRANSPORT BLOOD COMPONENTS - DIGITAL



Pneumatic tube delivery systems are an integral component of the contemporary day-to-day functioning of many blood banks and transfusion medicine services. In recent years, reliance on their speed has increased and the software used to operate them has become highly sophisticated. Adequate staffing at receiving stations is an increasing concern, as is the overall system workload. This *Guide to Pneumatic Tube Delivery Systems* details the "nuts and bolts" of system planning, operation, and maintenance for facilities considering a pneumatic delivery system, those needing to expand an existing system, or those wanting to increase efficiency of operations. Highlights include:

https://www.aabb.org/aabb-store/product/aabb-guide-to-pneumatic-tube-delivery-systems-validation-and-use-to-transport-blood-components---digital-15175121

Clinical Chemistry 65:5
694–702 (2019)

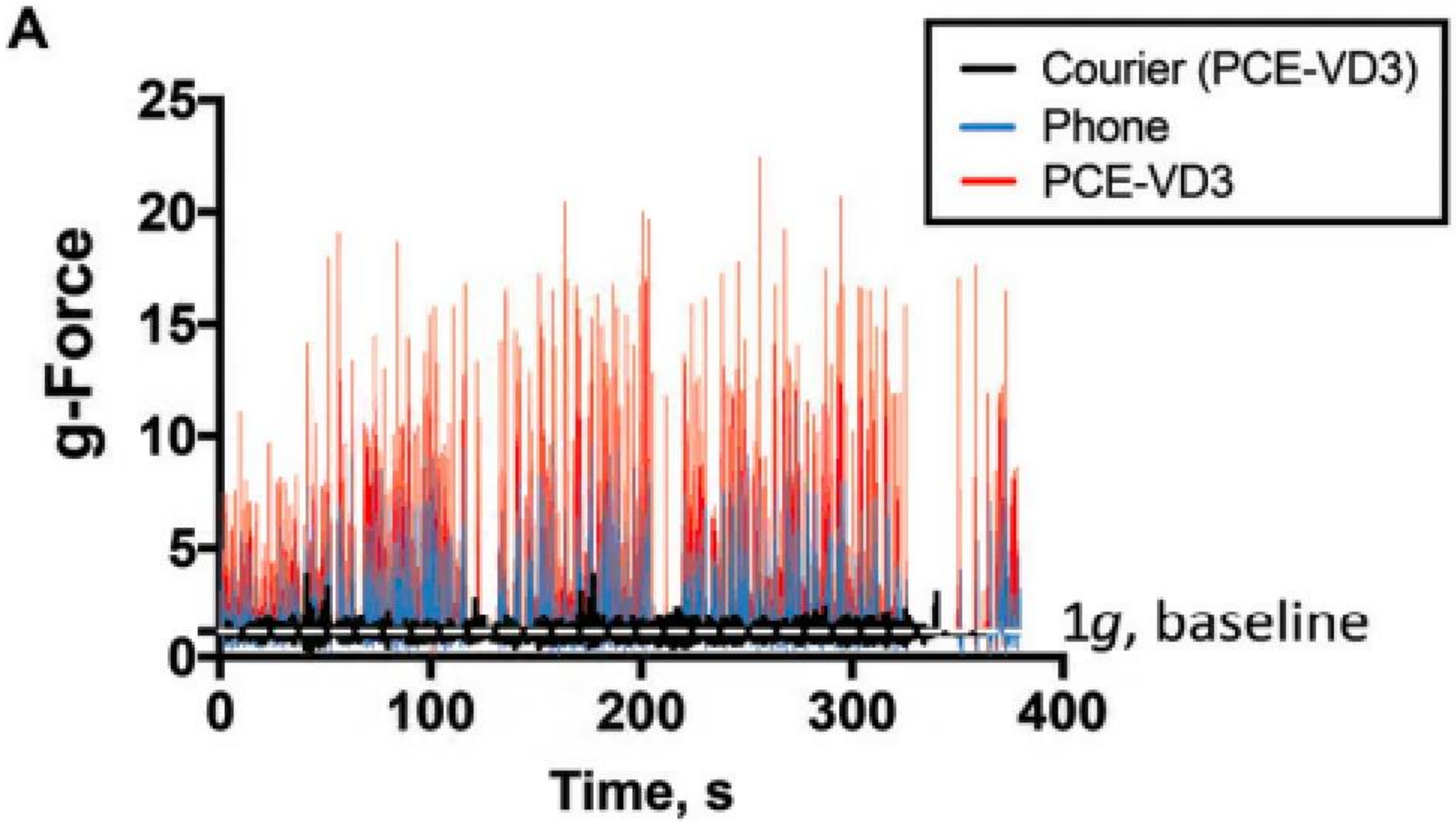
Other Areas of Clinical Chemistry

Parameters for Validating a Hospital Pneumatic Tube System

Christopher W. Farnsworth,[1] Daniel M. Webber,[1] James A. Krekeler,[1] Melissa M. Budelier,[1] Nancy L. Bartlett,[2] and Ann M. Gronowski[1*]

Validation of PTS for Specimen Transport

Accelerometers Are Better Suited for Validation Studies



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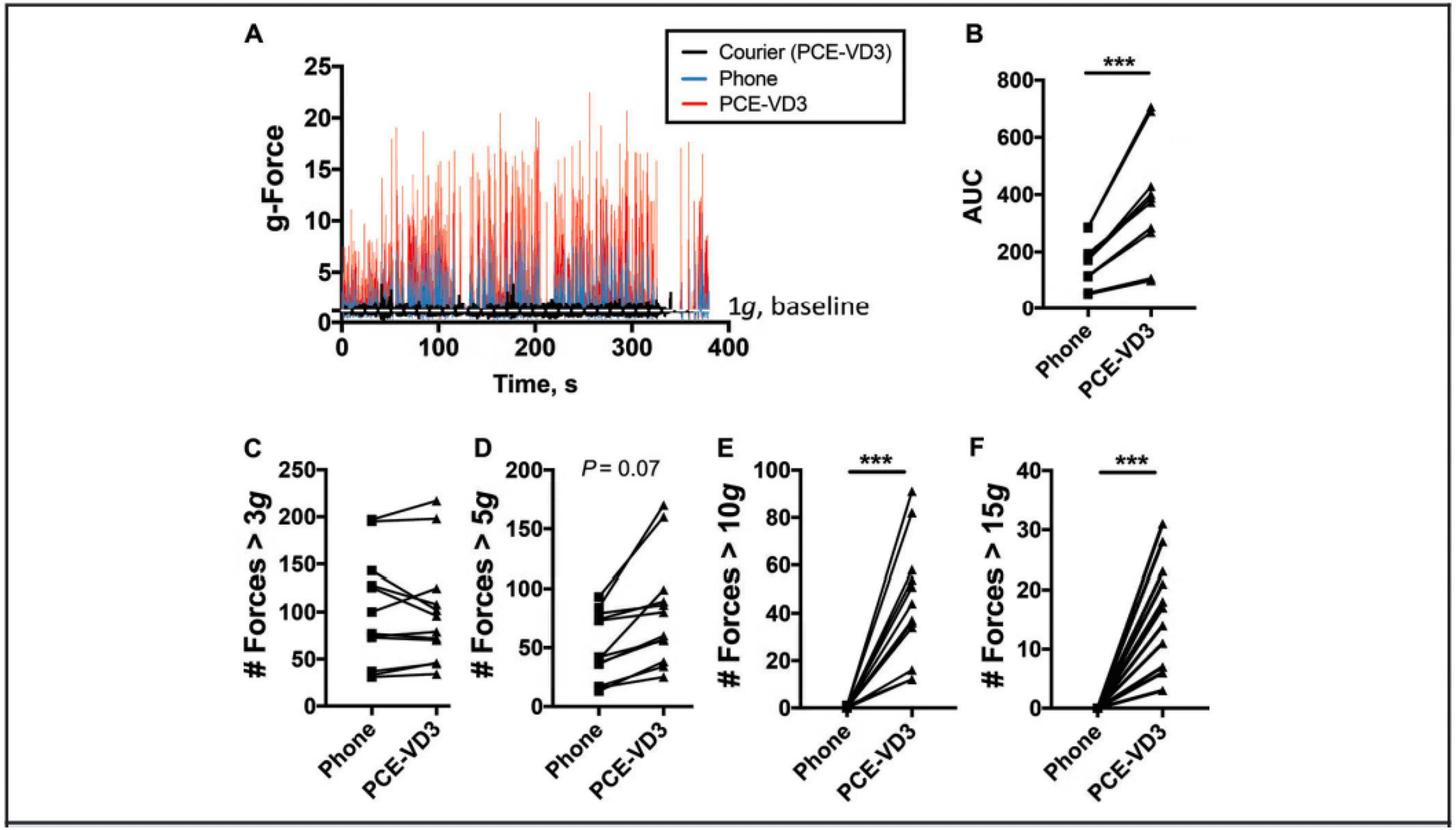

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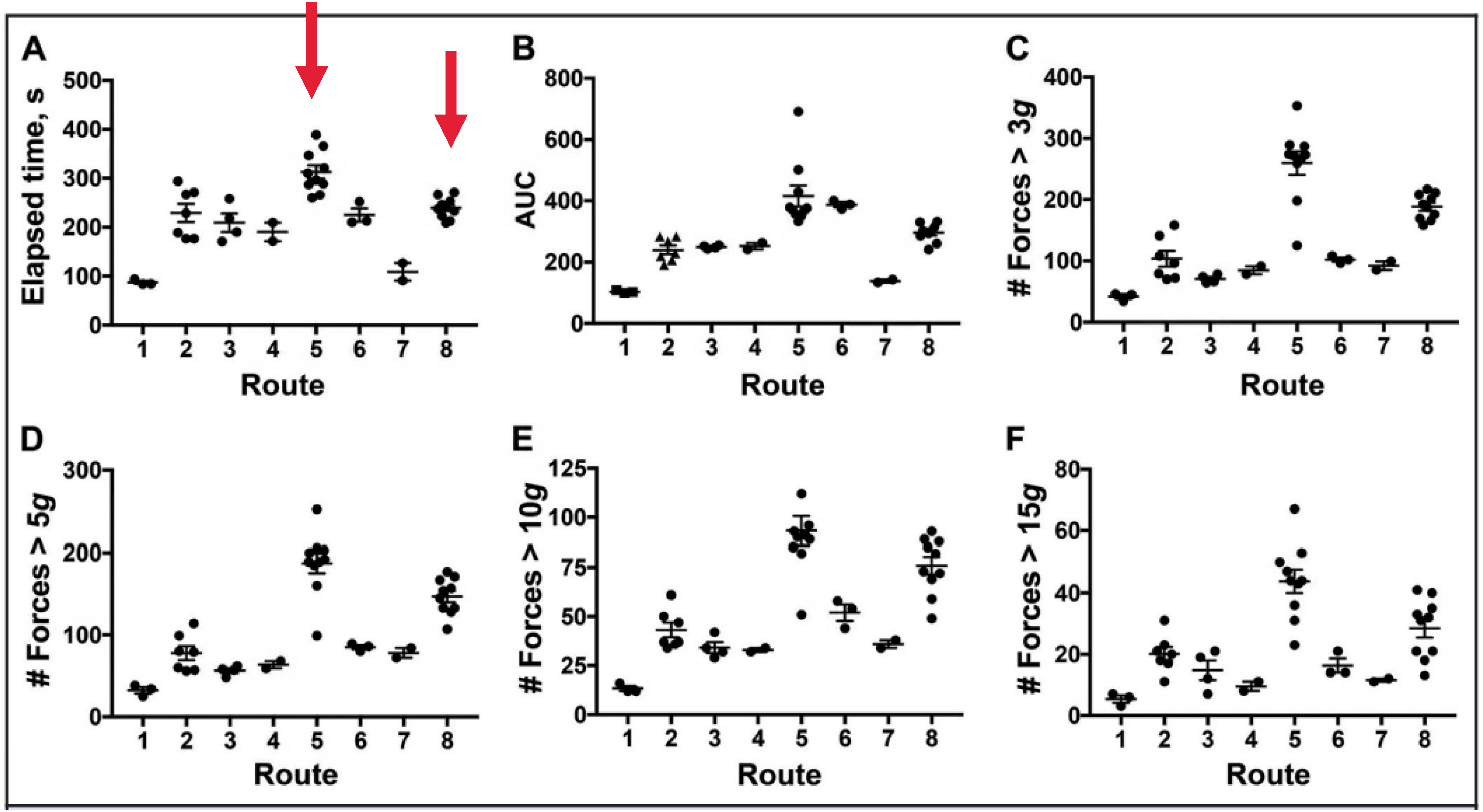
Validation of PTS for Specimen Transport

Different Transport Routes Must Be Evaluated



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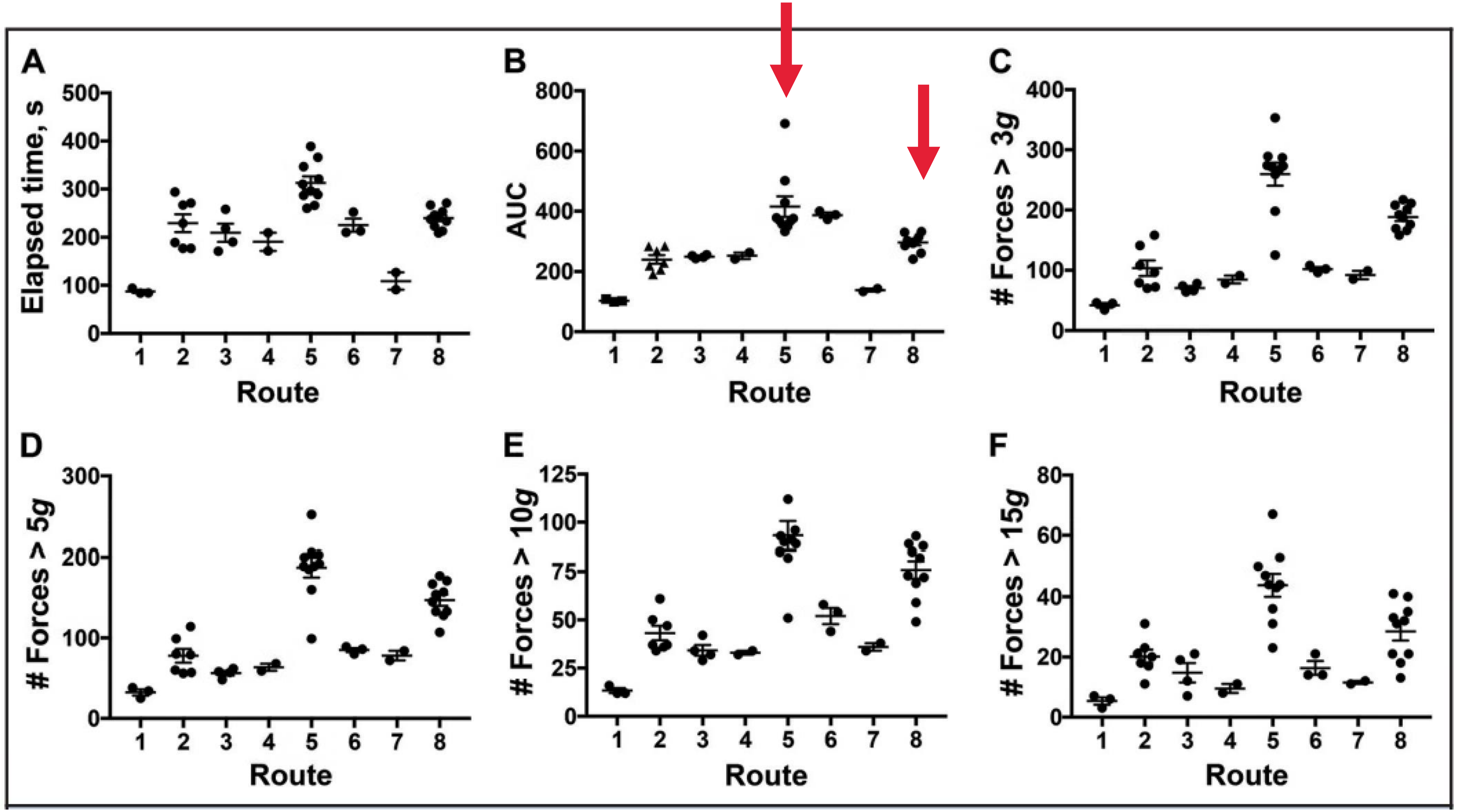
Validation of PTS for Specimen Transport

Different Transport Routes Must Be Evaluated



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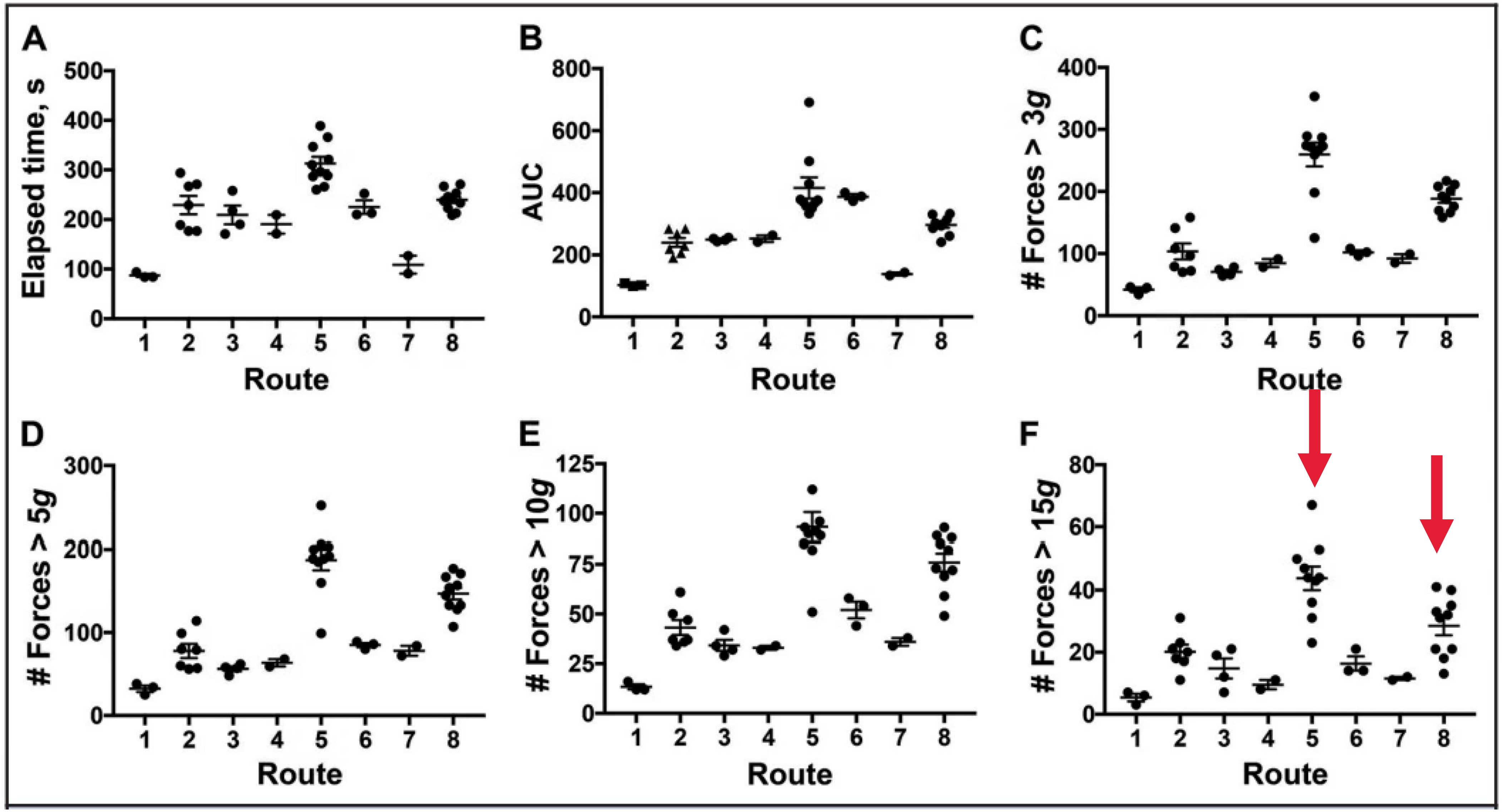

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Precision Must Be Evaluated

Table 1. Intraday and interday variability in 2 routes of a hospital PTS.[a]

	Intraday variation			Interday variation		
	Mean	SD	CV, %	Mean	SD	CV, %
Route 5						
Elapsed time (s)	316	31	10	310	56	18
AUC	359	19	5	472	134	28
Number of g-forces >3	272	10	4	248	88	35
Number of g-forces >5	192	7	4	183	57	31
Number of g-forces >10	91	4	4	96	34	35
Number of g-forces >15	44	6	14	44	17	39
Route 8						
Elapsed time (s)	249	14	6	245	15	6
AUC	339	9	3	340	47	14
Number of g-forces >3	235	15	6	214	9	4
Number of g-forces >5	186	10	5	172	11	6
Number of g-forces >10	109	5	5	98	13	13
Number of g-forces >15	51	4	8	45	12	27

[a] Intraday n = 5; interday n = 5 over 5 separate days.

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Additional Considerations

- Acceptability criteria based on changes in LDH, K^+ and H-index relative to hand-transported specimens.

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  - May be testosterone mediated

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- Special patient populations:
  - Patients with anemia
  - Patients with high blood cell counts
  - Critically ill patients

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What about temperature?

AABB Recommendation

- Assess temperature changes that blood components may be exposed to during transport
    - Temperature strips
    - Digital thermometers
    - Temperature loggers
    - Built in temperature sensors

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Packed red blood cells experience temperature variations during PTS-transport

Parameter	PTS[a]	CRR[a]	*p*-value
Temperature variation (°C)	8.3 (5.3 – 10.7)	4.1 (1.5 – 8.5)	0,085
Ht variation	0.6 (-1.05 – 0.95)	0 (-0.8 – 0.6)	0.336
Hb variation	0 (-0.15 – 0.2)	-0.1 (-0.03 – 0.1)	0.369
Supernatant Potassium variation	1.6 (0.1 – 2.45)	0.1 (-1.85 – 2.25)	0.345
AST variation	2 (1 – 7.5)	3 (1 – 7.5)	0.796
LDH variation	58 (17.5 – 149.5)	108 (29.75 - 157)	0.666
Variation in Hemolysis Index	37 (5.5 – 73.5)	51 (27 – 132.5)	0.554
Variation of Visual Hemolysis	169 (80.5 – 415.75)	142.5 (81.5 - 321)	0.412
Free Hb variation	0.03 (0.005 – 0.0925)	0.01 (0 – 0.1)	0.114

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- Hemolysis can occur during PTS transport and correlates with the number and magnitude of shock forces, duration of transport, and transport speed
- Hemolysis can be mitigated by proper tube filling, use of clotted specimens, and reduced transport speeds
- Validation of pneumatic tube systems should be performed using 3-axis accelerometers, assessing different transport routes and precision
  - Male specimens should be included
  - Special patient populations must be considered

Thank you

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