

# Pressure-Driven Blood Metering for Improved Sepsis Diagnosis with BD

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## Motivation



**BACTEC™ Bottles** Sepsis detection requires the use of vacuum-sealed bottles containing bacteria culture broth

“Blood volume is the most important variable for the detection of microorganisms in blood cultures”

Journal of Clinical - Microbiology, 2019

Consistent BACTEC™ Fill between 8ml - 10ml of blood is crucial for accurate diagnosis

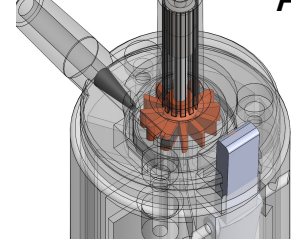
### Drawbacks of Current Blood Metering

Manual Filling (Current Practice)



“Eye test” for fill volume  
Human error: ~50% of bottles are underfilled & subject to false negatives

BD Paddlewheel Patent  
AU2020324538A1

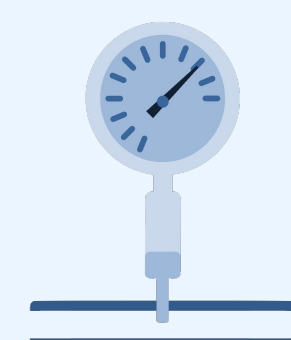


Tracks RPM as blood flows through to calculate volume

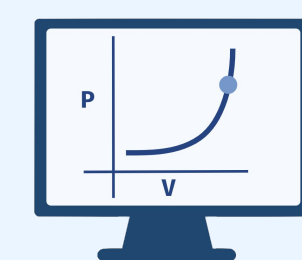
Efficacy issues with varying blood viscosities due to different hematocrit compositions

## Objectives

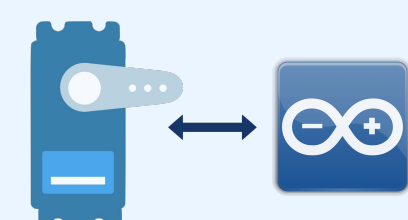
Develop a Proof of Concept for Pressure Sensor + Servo Cutoff Pairing



Develop Testing Set-up that Accurately Measures Pressure



Identify Cutoff with Pressure/Volume Modeling

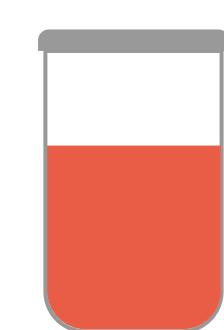


Develop Code to Shut off Valve at 9 mL Pressure



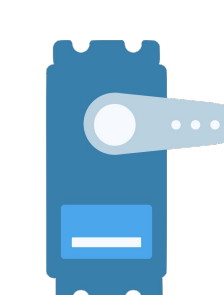
Determine a Solution that Mimics Blood for Experimentation

## Model Design Requirements



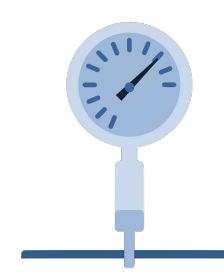
### Reservoir Pressure Control

- Pressure leaving the reservoir should emulate venous pressure, (8-10 mmHg)
- Pressure from the reservoir to the tube needs to be regulated to ensure a consistent and controlled flow of blood



### Servo Motor Control

- Program servo motor to respond to real-time pressure measurements
- Specify the specific pressure value at which the blood flow should be cutoff to prevent overfilling of the vial



### Accuracy & Consistency

- Measures volume within +/- 1 mL of target volume (9 mL)
- Repeated results observed during testing

## Results

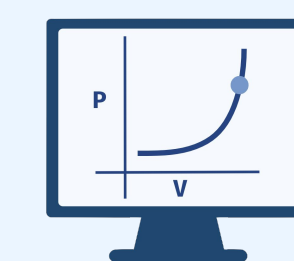
### Pressure/Volume Modeling

Hydrostatic pressure to drive blood flow:  $P_{\text{Blood}} = \rho gh_{\text{Reservoir}}$

Modeling dynamic flow behavior with Reynolds Transport Theorem

Characterizing blood flow with Navier-Stokes

Boyle's Law to calculate final pressure for shut off  $P_{\text{cutoff}} = (P_{\text{Initial}} \cdot V_{\text{Initial}}) / V_{\text{Initial}} + 9 \text{ mL}$



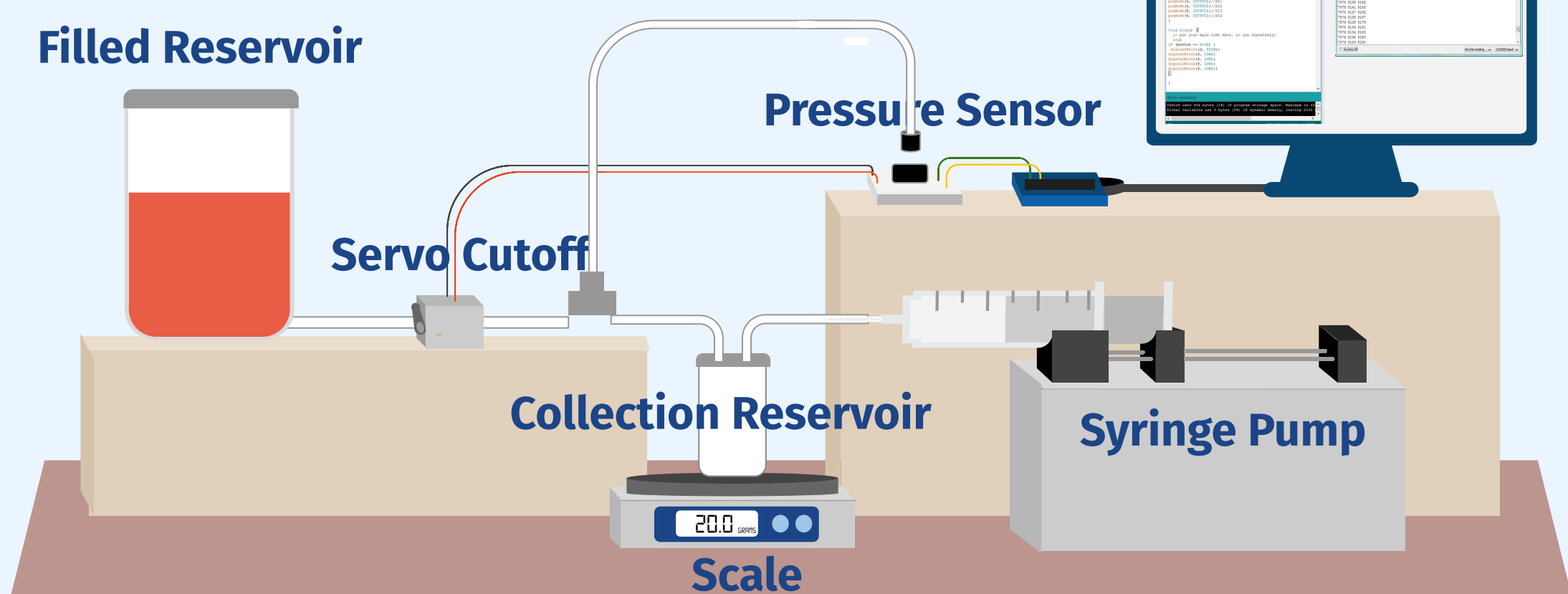
### Blood Mimicry

35% Glycol + 65% Water Solution Proves Similar Viscosity Behavior

Effective for Proof Of Concept Testing

Arduino Code & Serial Monitor

### Testing Set-up



Utilizing Pressure Sensor readings to extract 8ml-10ml from the Filled Reservoir to the Collection Reservoir

### Testing Procedure



### Data

#### Volume vs. Pressure Difference in Water & Glycol/Water Testing

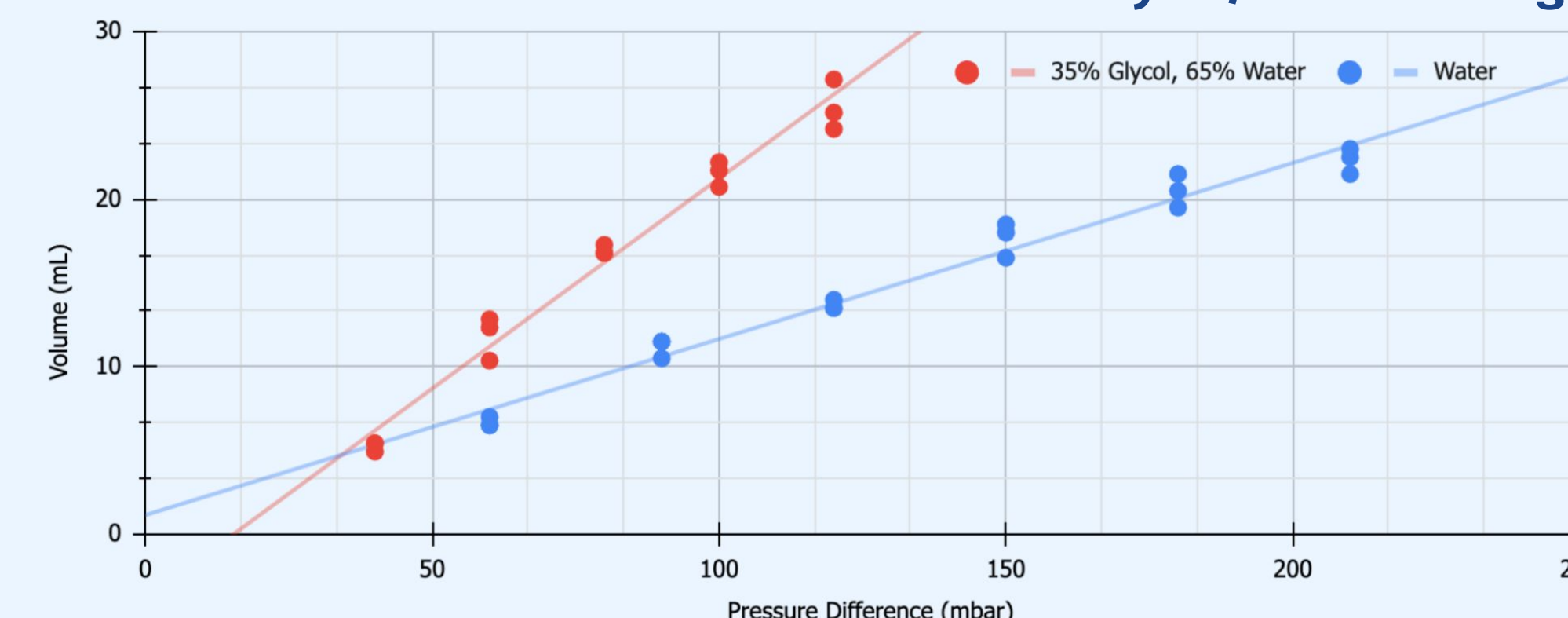


Figure 1: Comparison of water and 35% glycol/65% water viscous solution tests relating pressure and volume. The relationship between pressure difference and water is linear. The pressure difference needed to fill the same volume of glycol/water solution is less than the pressure difference needed for water. The estimated pressure difference to obtain 9mL for the glycol/water solution is 51.195 mbar while the estimated pressure difference for water is 74.762 mbar.

## Conclusion

### Accuracy Testing with 35% Glycol + 65% Water Solution

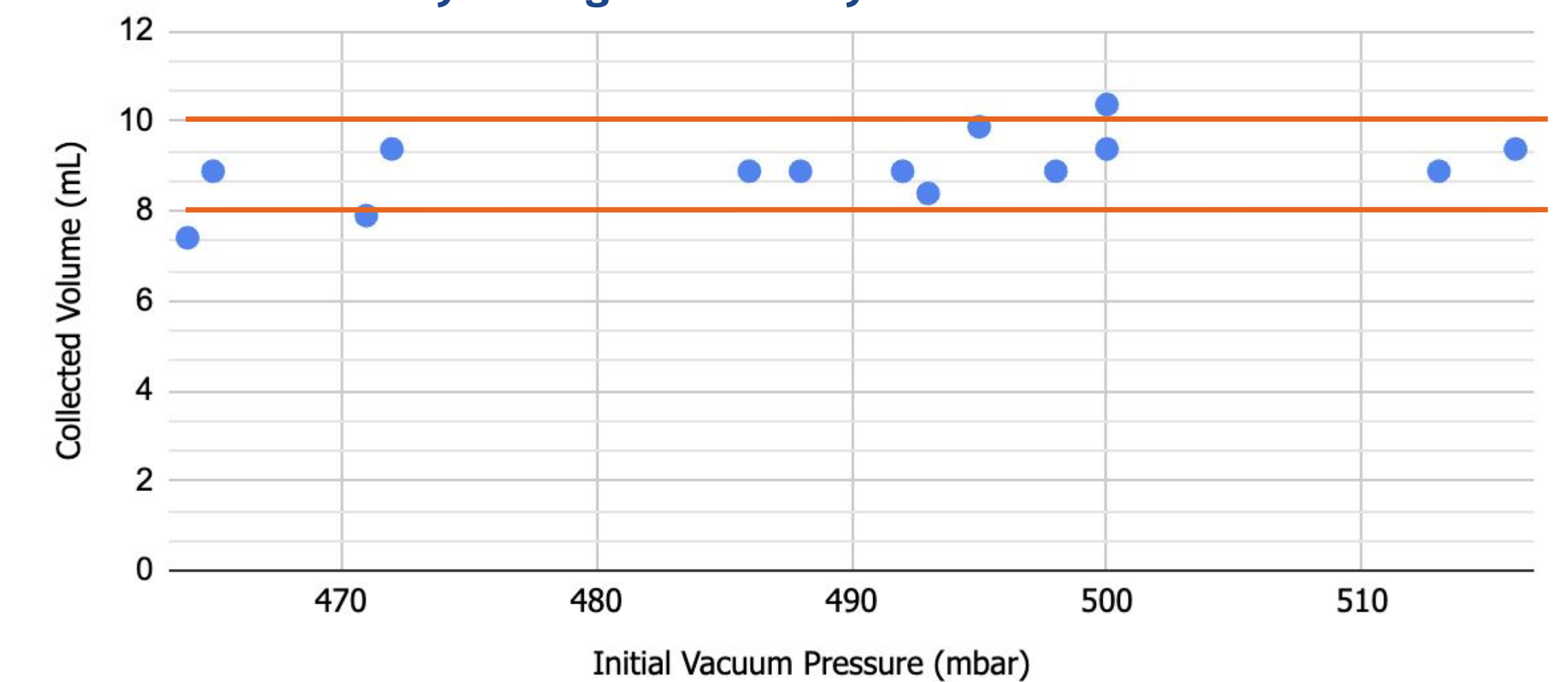


Figure 2: Final Volume of 35% glycol/65% water in collection reservoir calculated from proportioned weight difference

Standard Deviation = ± 0.72 mL → Confidently within ±1 mL of 9 mL

Confidence in the conclusion can be built through further investigation of:

### Improved Testing Set Up

- Improve vacuum sealing
- Replace tubing between testing
- More precise scale

### Increased # of Trials

- Testing at varying pressure differences
- Increase trials per pressure

## Future Work

Design a prototype BACTEC™ bottle cap with pressure sensor integration

Designed for disposability to align with BD's business model & ensure compatibility with other BACTEC™-related equipment

Design for bottle preservation for further processing

Affordability to increase accessibility

- Currently: ~ \$10.50 per BACTEC™ bottle + medical service fees
- Ensure pressure sensor cost is minimized while maintaining or improving system sensitivity of 84.6% and specificity of 94.1%<sup>3</sup>

## References

- BD (Becton, D. and C. (2022, October 18). Bd, Magnolia Medical Technologies Retrieved December 13, 2022, from <https://www.prnewswire.com/news-releases/bd-magnolia-medical-technologies-announce-commercial-collaboration-to-help-reduce-blood-culture-contamination-and-improve-testing-accuracy-301651747.html>
  - Henning, Claes et al. "Detailed Analysis of the Characteristics of Sample Volume in
  - Blood Culture Bottles." Journal of clinical microbiology vol. 57,8 e00268-19. 26 Jul. 2019. doi:10.1128/JCM.00268-19
- Sepsis > Fact Sheets. (2023). Yale Medicine. Retrieved December 13, 2023, from <https://www.yalemedicine.org/conditions/sepsis>