Neonatal ABG Trainer

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Introduction

Arterial Blood Gas (ABG) sampling is a medical procedure that allows for collection and testing of blood samples from patients in critical condition, with examples seen in **Figure 1** [1]. High risk techniques such as this require adequate and efficient training of medical personnel and simulation devices provide a reliable way for practicing these procedures and consequently ensure patient safety.

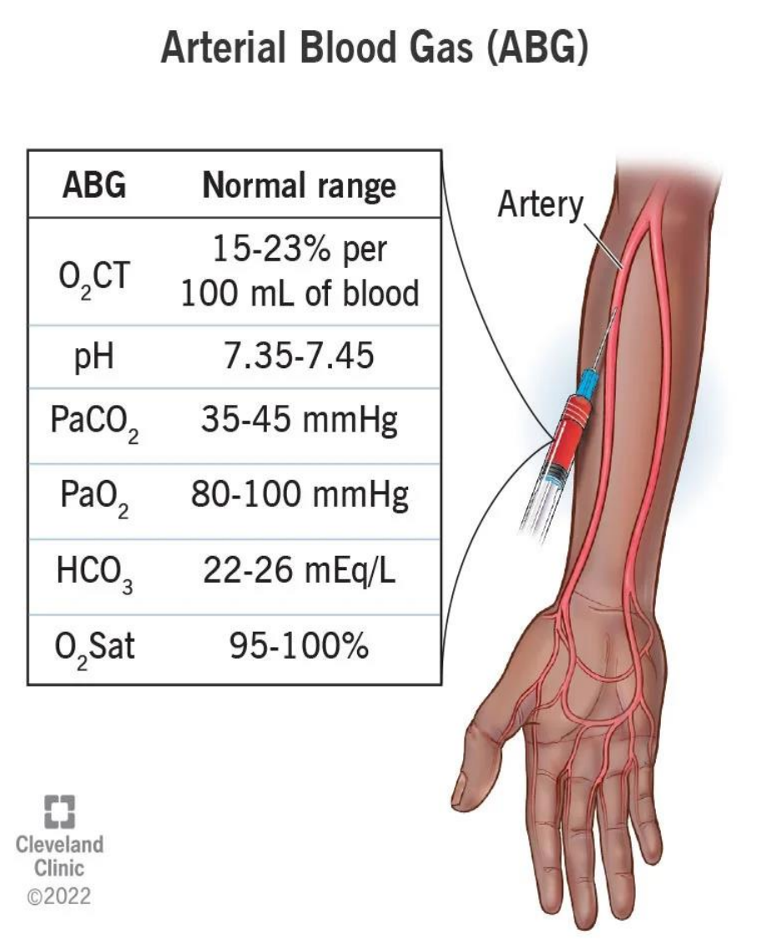

Figure 1: ABG Sampling test measurements

Purpose and Scope

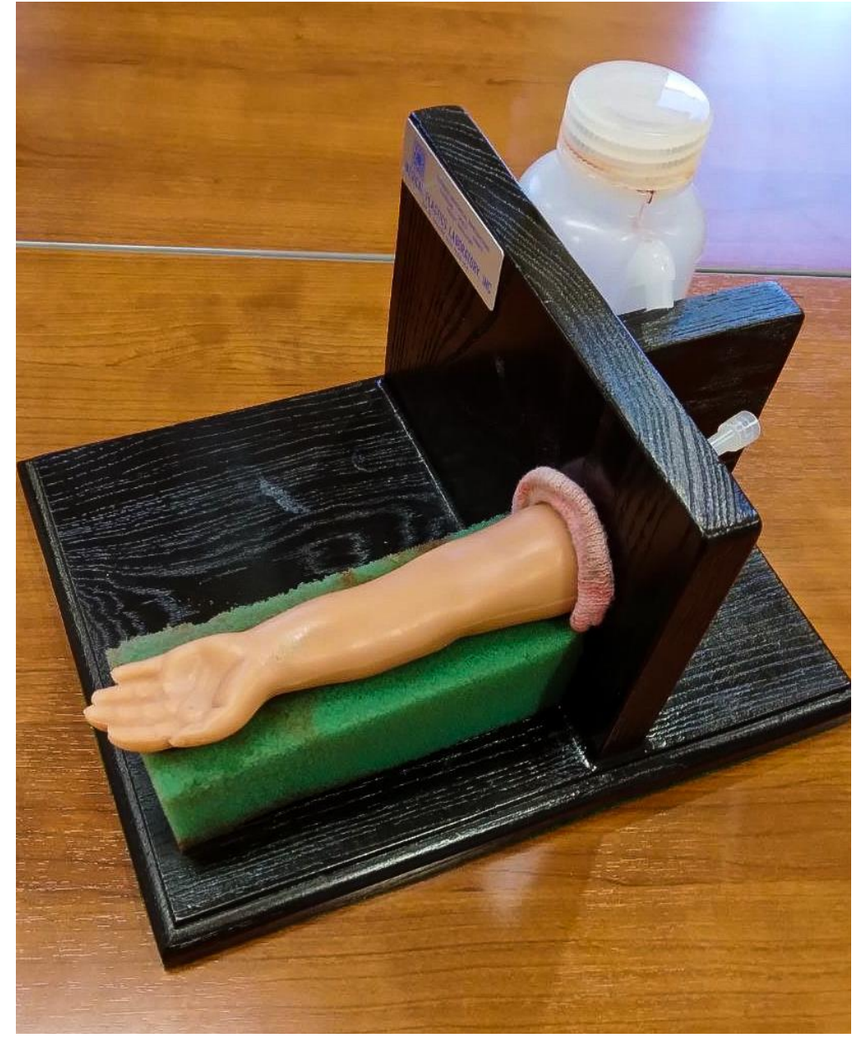

Figure 2: Current Neonatal ABG Trainer

Challenge: There is a lack of neonatal ABG trainers on the market. The available trainer is not functional: leaks, uses a manual pump and lacks a proper drainage system **(Figure 2).**

Purpose & Scope: Design a neonatal ABG trainer that is automated, has replaceable and pierceable skin patches with ultrasound capabilities.

The trainer will be used for ABG sampling at variable heart beats and the drainage system will be a closed loop system.

Technical Specifications

Customer requirements were assessed, and a list of technical specifications was generated alongside the target literature values and measurement methods as shown on **Table 1**.

Specification	Target Value	Measurement Methods/Equipment
Realistic feel of skin	Shore hardness of 10A-30A	Durometer
Pierceable skin	0.5-0.6N	Penetration testing
Adjustable heart rate	90, 120, 140, 160 BPM	Peristaltic pump calibration
Realistic arm length	140-145mm	Meter rule
Realistic skin thickness	1.3 ± 0.7mm	Calipers
Ultrasound capabilities	N/A	Qualitative analysis

Table 1: Technical specification of primary and secondary customer requirements

Methods and CAD Design

A selection grid was created to inform design and material selection based of various criteria such as cost-effectiveness, feasibility and durability.

Arm design consisted of a 3D printed arm (Elastico), a shelf connector, a barbed plastic fitting, and a mesh with integrated tube Guides (**Figure 3**).

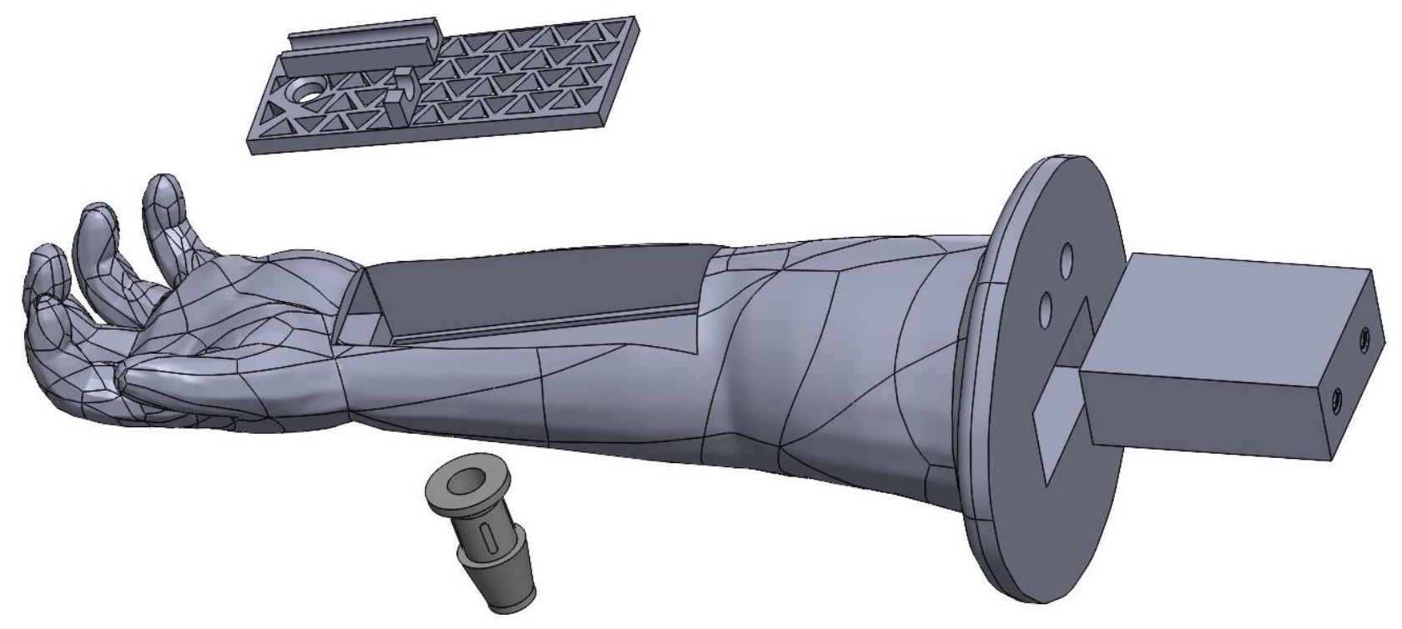

Figure 3: Exploded view of the neonatal arm

A mold for the silicone patches was designed to fit flush across the arm cavity (**Figure 4**).

The Acrylic Shelf was designed to house the peristaltic pump (**Figure 5**) and the reservoirs. A plastic arm support was integrated into the shelf assembly to hold up the arm during the procedure (**Figure 6**).

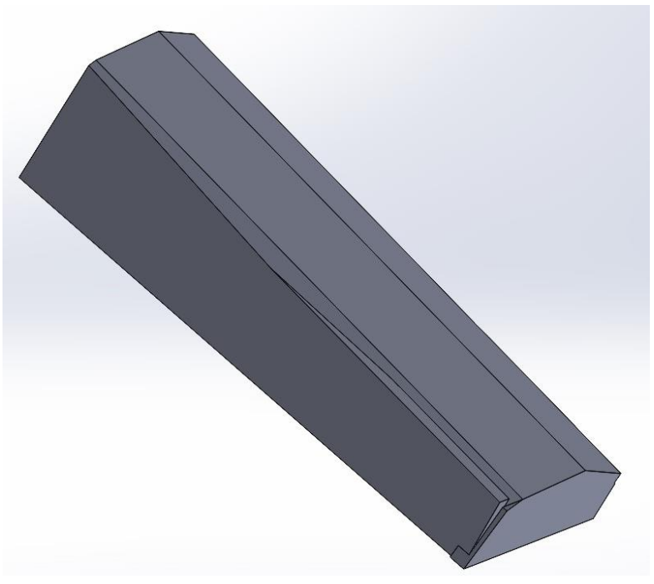

Figure 4: Silicone patch mold

Figure 5: Peristaltic pump

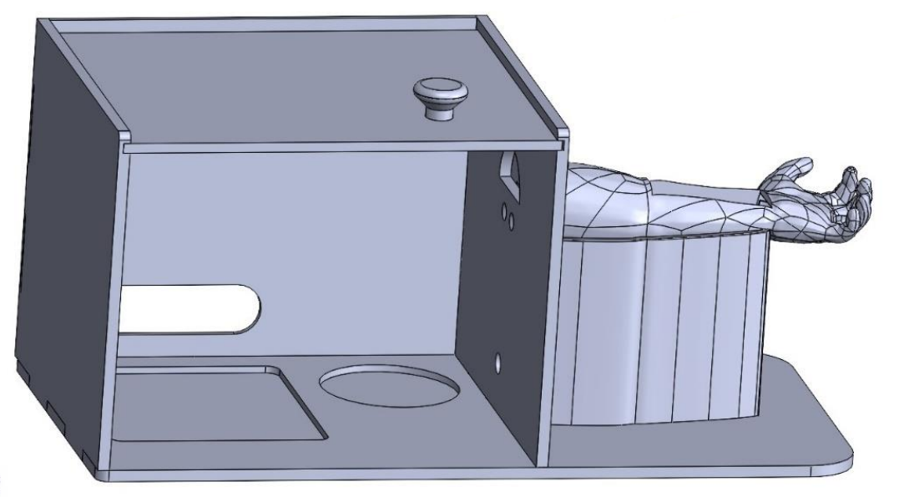

Figure 6: Shelf Assembly with arm and arm support

Mathematical Modeling

Mathematical model was used to establish the flow as laminar (**Figure 7**) in the system. Bernoulli equation (**Figure 8**) which establishes a relationship between speed, area and pressure was used to model the flow of fluid through the tubes. Fluid flowing horizontally from an area of high pressure to low pressure will increase speed , a phenomena also known as Venturi effect. The models informed our design, and a constriction was added to the silicone tubes to increase the velocity of "blood" to be drawn into the needle.

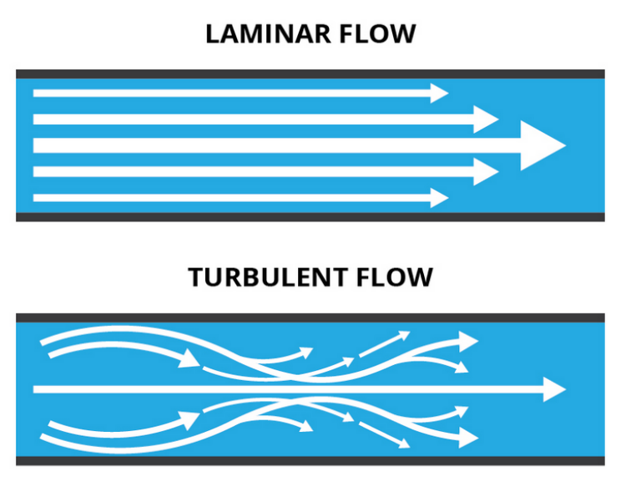

Figure 7 : Comparison of Lamina and Turbulent Flow[2]

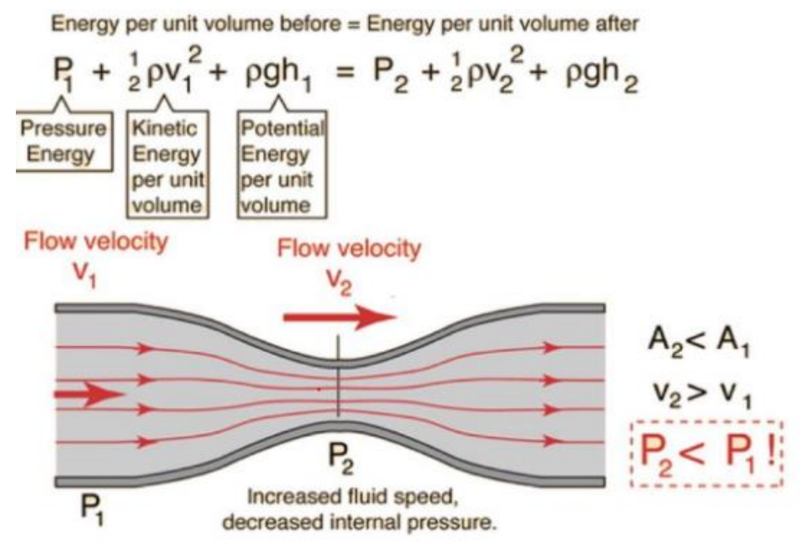

Figure 8 : Example of Bernoulli's Theorem [3]

Pump Validation

Pump Validation was performed using a timer, tap counter on a mobile device and the ABG simulation device. Pulse was measured at four different speeds. A Pearson Correlation test (**Figure 9**) indicated a positive correlation between speed (rpm) of the pump and pulse(bpm) with r =0.950. A boxplot was used to determine corresponding ranges of pulse to specific speed settings (**Figure 10**).

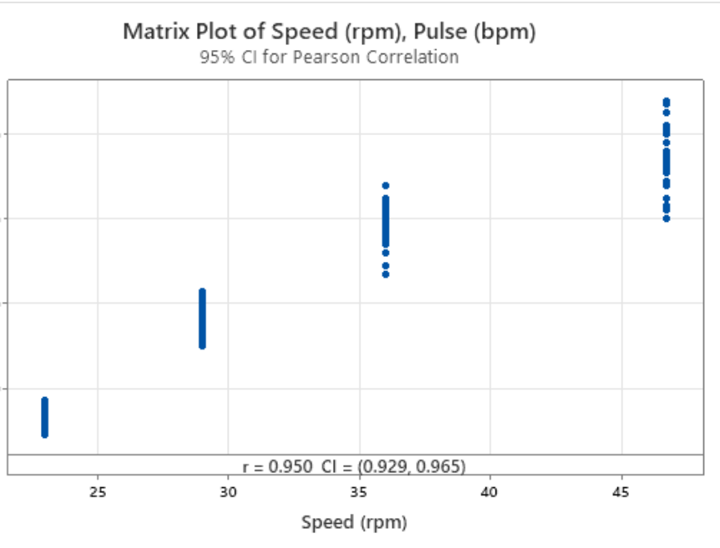

Figure 9: Pearson correlation test of speed (rpm) vs pulse (bpm)

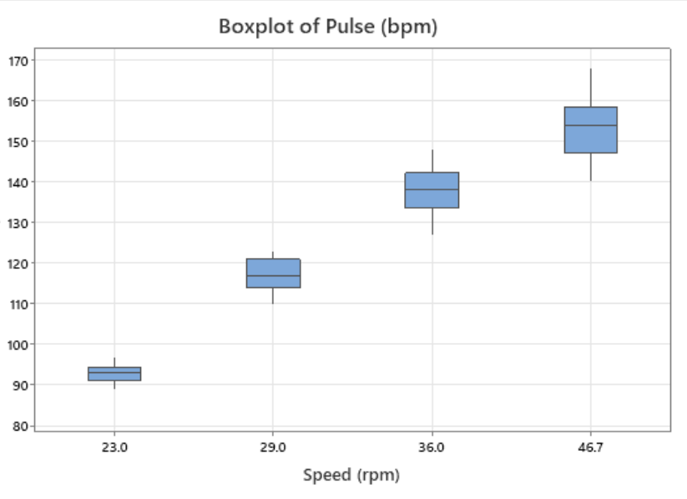

Figure 10: Boxplot of BPM values compared to RPM

Ultrasound Testing

Qualitative analysis was achieved using a survey where different ultrasound images (**Figure 11 and 12**) with varying mixing ratios of silicone and scattering agent (1:1:0.2, 1:1: 0.1, 1:1:0.05 & 1:1:0.03) were ranked on a pseudo-binary scale of -1, 0, 1. Relative frequencies of scaling factors were evaluated and a target of 95%

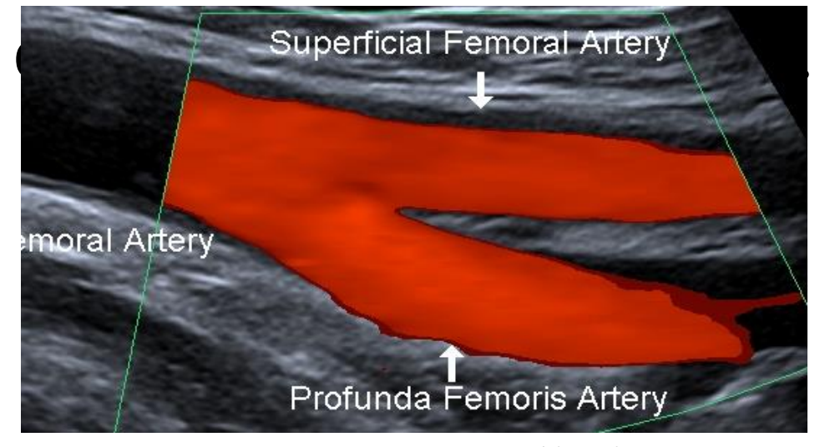

Figure 11: Realistic ultrasound reading of artery [4]

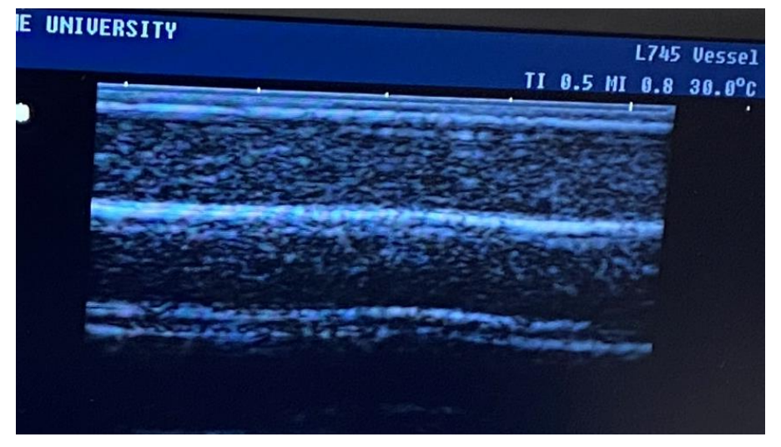

Figure 12: Ultrasound Image at 1:1:20 mixing ratio

Puncture Testing

Puncture testing was performed according to ASTM F2878-19 [5]. **Figure 13** demonstrates the data found with an average max force of 1.194N. Our statistical analysis in **Figure 14** demonstrate our results were statistically significant compared to the ideal value of 0.60N.

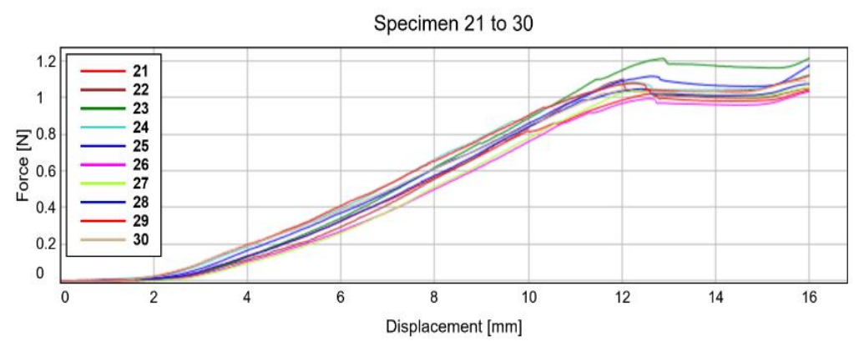

Figure 13: Force v. Displacement of samples 21 to 30

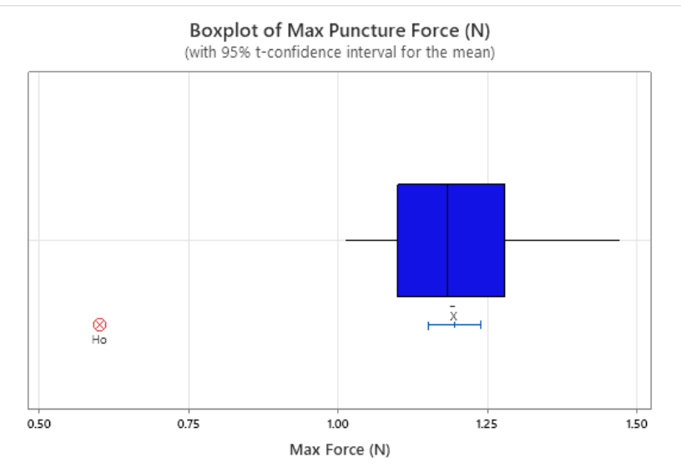

Figure 14: Boxplot Results of Puncture Testing

Hardness Testing

Hardness testing was performed according to D2240-15[6]. **Figure 15** shows the frequency and distribution of values, with an average of 20.44. The statistical analysis in **Figure 16** demonstrates that the results were statistically significant compared to the ideal value of 55.

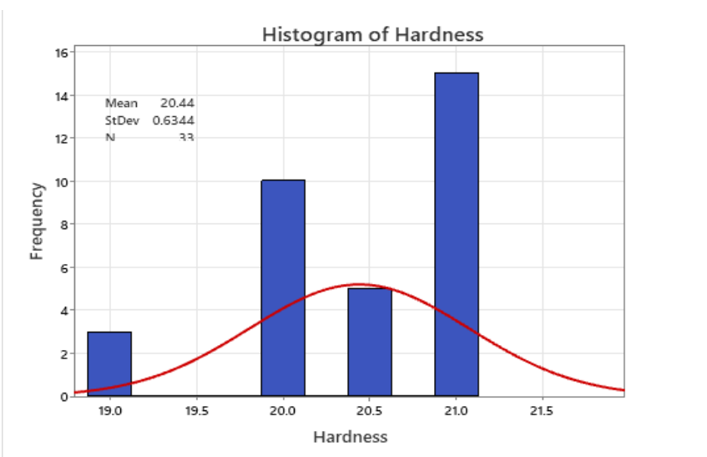

Figure 15: Histogram of Silicone Sample Shore Hardness

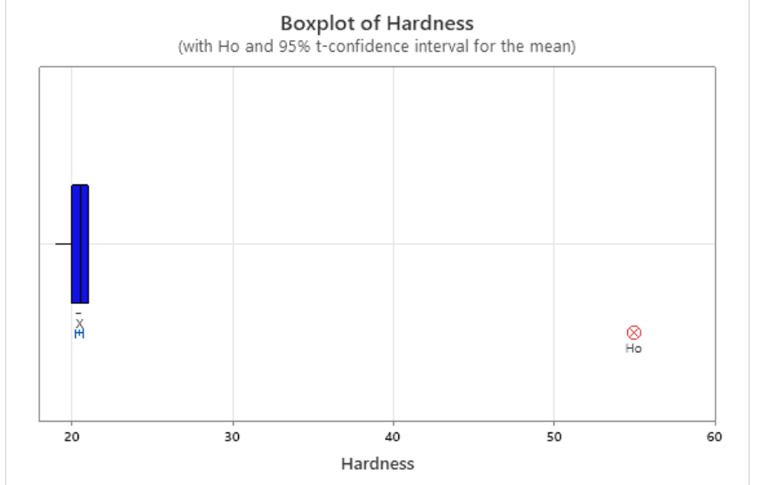

Figure 16 : Boxplot Results of Hardness Testing

Conclusion

The neonatal ABG trainer provides an efficient way for medical staff to practicing and training in ABG sampling and ultrasound guided arterial line insertion. The device integrates a resin arm, replaceable silicone tubing and silicone skin patches, with flow driven by a peristaltic pump, a closed loop drainage system and an acrylic shelf to contain all components that simulate the target processes (**Figure 17).** This design met and surpassed customer requirements and some phase II designs are being considered to improve the simulation device.

Figure 17 : Final Design of Neonatal ABG Trainer

Phase II Recommendations

Phase II will encompass improvements on the arm resin material that will be rigid enough to withstand repeated use and still maintain a realistic feel of human skin. An option of allowing the arm to be interchanged for multiple sizes of pediatric arms could also be explored as well as developing a method to create variable heart rates on a continuous flow. The shelf design can be optimized further to separate the liquid components from the electrical (pump) components.

References

[1] *Arterial blood gas (ABG): What it is, purpose, procedure & levels*. Cleveland Clinic. (n.d.). Retrieved April 24 2023, from https://my.clevelandclinic.org/health/diagnostics/22409-arterial-blood-gas-abg#:~:text=An%20arterial%20blood%20gas%20(ABG,Lab%20Appointments%20%26%20Locations

[2] F. Elizalde, "Laminar flow vs. turbulent flow - what is laminar flow?," Cleatech Scientific, 26-Oct-2021. [Online]. Available: https://www.cleatech.com/laminar-flow-vs-turbulent-flow/. [Accessed: 20-Nov-2022].

[3] D. Poole, "1738: Hydrodynamica and bernoulli's principle," Safe Swiss Cloud, 10-Aug-2022. [Online]. Available: https://safeswisscloud.com/en/blog/1738-hydrodynamica-and-bernoullis-principle/. [Accessed: 15-Mar-2023].

[4] "Peripheral arterial evaluations," *Pacific Vascular*. [Online]. Available: https://pacificvascular.com/peripheral-arterial-evaluations/. [Accessed: 25-Apr-2023].

[5] "Peripheral arterial evaluations," *Pacific Vascular*. [Online]. Available: https://pacificvascular.com/peripheral-arterial-evaluations/. [Accessed: 25-Apr-2023].

[6]ASTM, "Standard Test Method for Rubber Property—Durometer Hardness," ASTM International, West Conshohocken, PA, Jul. 2021.

Acknowledgments

The Neonatal ABG team would like to thank the following for their contributions, facilities, and resources:

- Trine University Biomedical Engineering Department
- Innovation One Department
- Parkview Mirro Center