Central Line Trainer

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PARKVIEW MIRRO CENTER FOR RESEARCH AND INNOVATION

Motivation

A central venous catheter (CVC) is a vital tool for vascular access, commonly utilized across various medical specialties. The insertion of a CVC can be performed via the internal jugular vein or the subclavian vein. Given the potential risks associated with CVC placement, such as infections, arterial punctures, and pneumothorax, it is imperative for medical residents, physician assistant students, and other healthcare professionals to undergo regular recertification. A medical training device serves as an essential resource for practice, enabling healthcare professionals to refine their skills and ensure preparedness for recertification in the central venous catheter insertion procedure.

The aim is to develop a comprehensive central line training device for the hospital that is cost-effective, durable, and designed to enhance the skills of medical residents and physician assistant students. The proposed device addresses limitations in existing training models by integrating essential functionalities into a single system, streamlining the training process, and improving the overall learning experience.

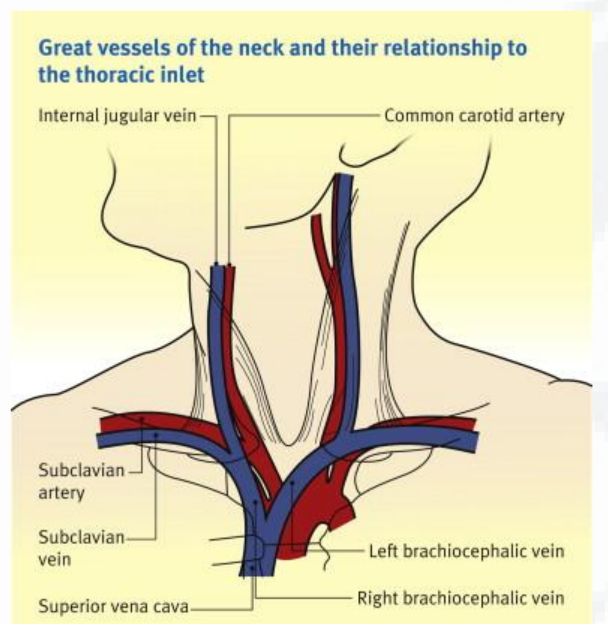

Image 1: Subclavian and Internal Jugular vein

Customer Expectation

Parkview Mirro Center for Research and Innovation requested various components to be integrated into a single trainer for use by upcoming medical professionals. Emphasis was placed on reusability, durability of material, an anatomically correct model, and an all-in-one trainer.

Table 1: Project Scopes

Expectation	Significance
Battery Powered	Critical
Internal Sensors	Desirable
Alert System	Desirable
All-in-One Trainer	Essential
Average Adult Male Measurements	Essential
Artery and Vein Path Plus Length	Essential
Meltable Material	Critical
Easily Re-Assembled	Critical

Final Tranier

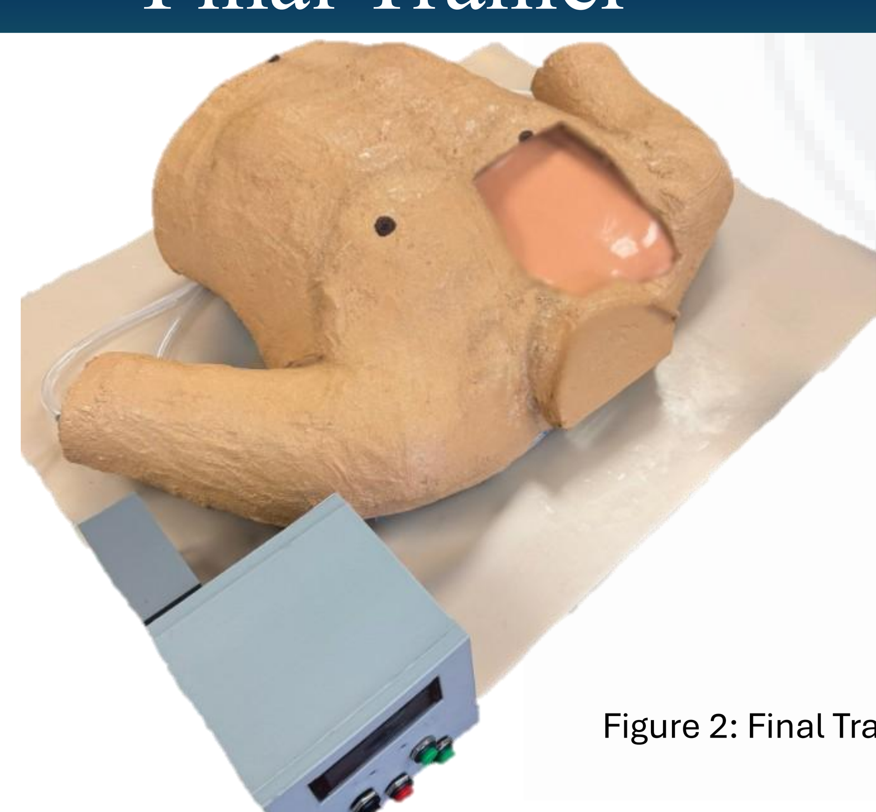

Figure 2: Final Tranier

Design Components

3D Modeling

Reverse Mold: The reverse mold was produced using a 3D scanner, with the scan data processed and refined in Artec Studio. The secondary component was designed in Siemens NX and both parts were fabricated via 3D printing. Final assembly was completed using caulk and hot glue to securely bond the components.

Image 3: Fully Assembled Reverse Mold

Mold: The mold was fabricated using Mold Max 60 silicone rubber. A 5-gallon bucket served as the mold container, with Mold Max 60 poured around the reverse mold to form the final cast.

Image 4: Completed Mold

Circuit Box: The circuit box was designed using Siemens NX, with each component modeled individually before being assembled virtually. STL files were then exported for 3D printing, enabling the physical fabrication and final assembly of the complete unit.

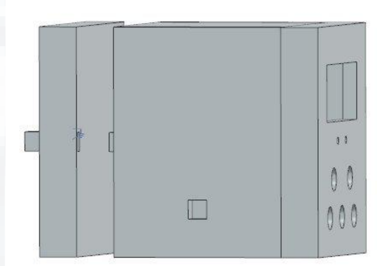

Image 5: Fully Assembled NX Circuit Box

Consumables

Image 6: Artificial Skin and Ballistics Gelatin mold

Artificial Skin: The artificial skin was fabricated using Shore OO-30 silicone, reinforcing mesh, and silicone pigment to replicate the appearance and tactile properties of human skin. Designed for needle insertion practice, the skin features a three-layer structure—epidermis, dermis, and hypodermis—totaling a thickness of 6.35 mm. Each skin patch is capable of withstanding 15 to 20 needle insertions before replacement is required.

Ballistics Gelatin: Ballistics gelatin is used to simulate muscle tissue in the neck region. The model was created using two types of ballistics gel—Gel #1 and Gel #2—manufactured by Humimic Medical. Combining these two gel types helps replicate the realistic texture and density of muscle while maintaining enough structural integrity to support catheter insertion. The gelatin block will measure approximately 4 inches and is designed to withstand 15 to 20 uses before requiring replacement.

Fluid System

Each system includes a reservoir to hold the fluid and allow for easy fluid addition.

Arterial System:

- **Peristaltic pump:** Used for its ability to create a pulsating flow, simulating arterial circulation.
- **PVC tubing:** Used within the ballistics gel for anatomical and physiological accuracy, as it is stiffer than silicone.

Venous System:

- **Diaphragm pump:** Provides a steady flow while allowing for variations in speed and pressure.
- **Silicone tubing:** Chosen for its anatomical and physiological relevance.
- **Pressure sensor:** Monitors the pressure within the system to ensure proper functionality.

Image 7: Layout of fluid flow systems

Circuitry System

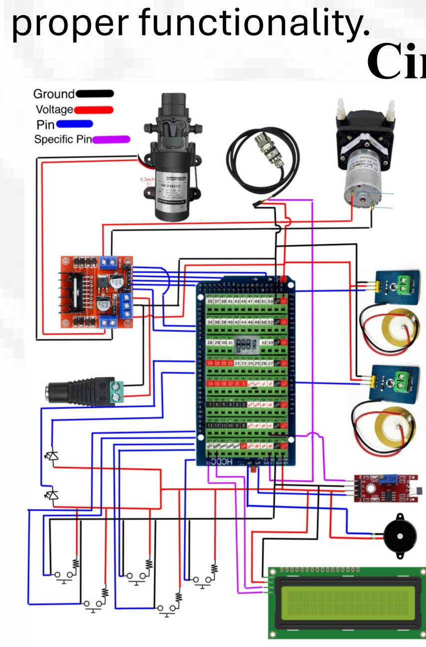

Image 8: Circuit Diagram

Pump Motors:
The pumps are powered by L298N motor drives for precise control of fluid flow and pressure.

Pressure & Heart Rate Control:
The system adjusts pressure and heart rate by varying pump speed.

Needle Detection:
Two touch sensors detect needle insertion to prevent artery puncture, with an alert if punctured.

Guide Wire Monitoring:
A magnetic hall sensor ensures the guide wire isn't inserted too far, triggering an alert if it exceeds safe depth.

Testing

Material Testing

Hardness: To verify that CLT materials mimic the mechanical properties of the human neck, a Shore hardness test was conducted on the artificial skin, ballistics gel, and tubing (n = 9 each, with varying thicknesses). Measured Shore OO hardness values ranged from OO-10 to OO-40 for skin, OO-20 to OO-80 for gel, and OO-40 to OO-70 for tubing.

Average hardness values were:

- Artificial skin: **OO-35.81 ± 3.35 ($p = 2.0\times10^{-4}$)**
- Ballistics gel: **OO-23.09 ± 2.49 ($p = 0.0059$)**
- Tubing: **OO-45.47 ± 16.82 ($p = 0.00237$)**

All results were statistically significant ($\alpha = 0.05$), as determined by a one-sample t-test.

Image 9: OO Durometer

Image 10: Puncture apparatus

Puncture Resistance: To assess puncture resistance, ASTM D3763-23 and ASTM F1306-21 standards were used to develop a testing protocol. Using an Instron machine with a 23G needle, the force required to penetrate three-layer samples (thickness: 16 mm) was measured. Across N = 9 trials, the average puncture force was **6.515 ± 0.305 N,** with a minimum threshold of 5 N. A one-sample t-test confirmed significance with a P-value of **4.08×10^{-7}**.

Durability test: A puncture durability test was performed on n = 9 three-component samples. Leakage occurred after 25 punctures, so replacement is recommended after **20 punctures** to maintain performance and prevent fluid leakage.

Ultrasound compatibility: Ultrasound compatibility of the CLT materials was assessed using n = 9 samples in a qualitative yes/no test. All samples were confirmed as "**Yes**", supporting their suitability for ultrasound-guided procedures.

Image 11: Ultrasound compatibility test

Leak Testing

The leak test consisted of the fluid flow system running for 48 hours nonstop, while constantly being monitored for leaks. The results confirmed "**NO**" leaks appeared in the system.

Conclusion

Customer Requirements	Completed
All-in-one trainer	✓
Reusable	✓
Fluid flow system	✓
Anatomically correct	✓
Feedback system	✓

Additional Features	Completed
Sensor system	✓
Self sealing material	✓
Colored fluid	✓

References

[1] A. Prakash and B. F. Matta, "Jugular Bulb Oximetry," *Elsevier eBooks*, pp. 320-326.e2, Jan. 2013, doi: https://doi.org/10.1016/b978-1-4377-0167-8.00032-7.

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