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Towards next generation cannulation simulators

Abdulrahman Mahmoud[1], Uzair Khurshid[1], Aiman Abducarim[1], Sakib Mahmud[1], Omrane Abdallah[1], Elshaikh Mohamed[1], Abdullah Alsalemi[1], Faycal Bensaali[1], Abbes Amira[1], Ali Ait Hssain[2], Guillaume Alinier[3], Ibrahim Hassan[2]

Address for Correspondence:
Abdulrahman Mahmoud
[1]College of Engineering, Qatar University, Doha, Qatar
[2]Medical Intensive Care Unit, Hamad General Hospital, Hamad Medical Corporation, Doha, Qatar
[3]Ambulance Service, Hamad General Hospital, Hamad Medical Corporation, Doha, Qatar
Email: am1510247@qu.edu.qa

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ABSTRACT

Background: Cannulation, in extracorporeal membrane oxygenation (ECMO), is the act of inserting a cannula through the body[1]. For femoral veins, femoral arteries, and the jugular vein, the cannula stops at the inferior vena cava (IVC) beside the hepatic vein and at the beginning of the distal aorta, and the superior vena cava at the right atrium, respectively. Cannulation is considered a critical operation and requires intensive training. Simulation-based training (SBT) is the gold standard, allowing for training in risk-free, versatile, and realistic environments[2]. A research collaboration was established between Hamad Medical Corporation and Qatar University College of Engineering to support the development of the ECMO training programme. Initially an ECMO machine simulator was developed with thermochromic ink to simulate blood and modules that simulate common emergencies practitioners may face during ECMO runs[3]. This cannulation simulator is now being designed to close the gap in the market in relation to cost and fidelity[4,5].
Methods: The cannulation simulator is composed of several modules. Firstly, a 3D-printed femoral pad mold was constructed to facilitate the production of

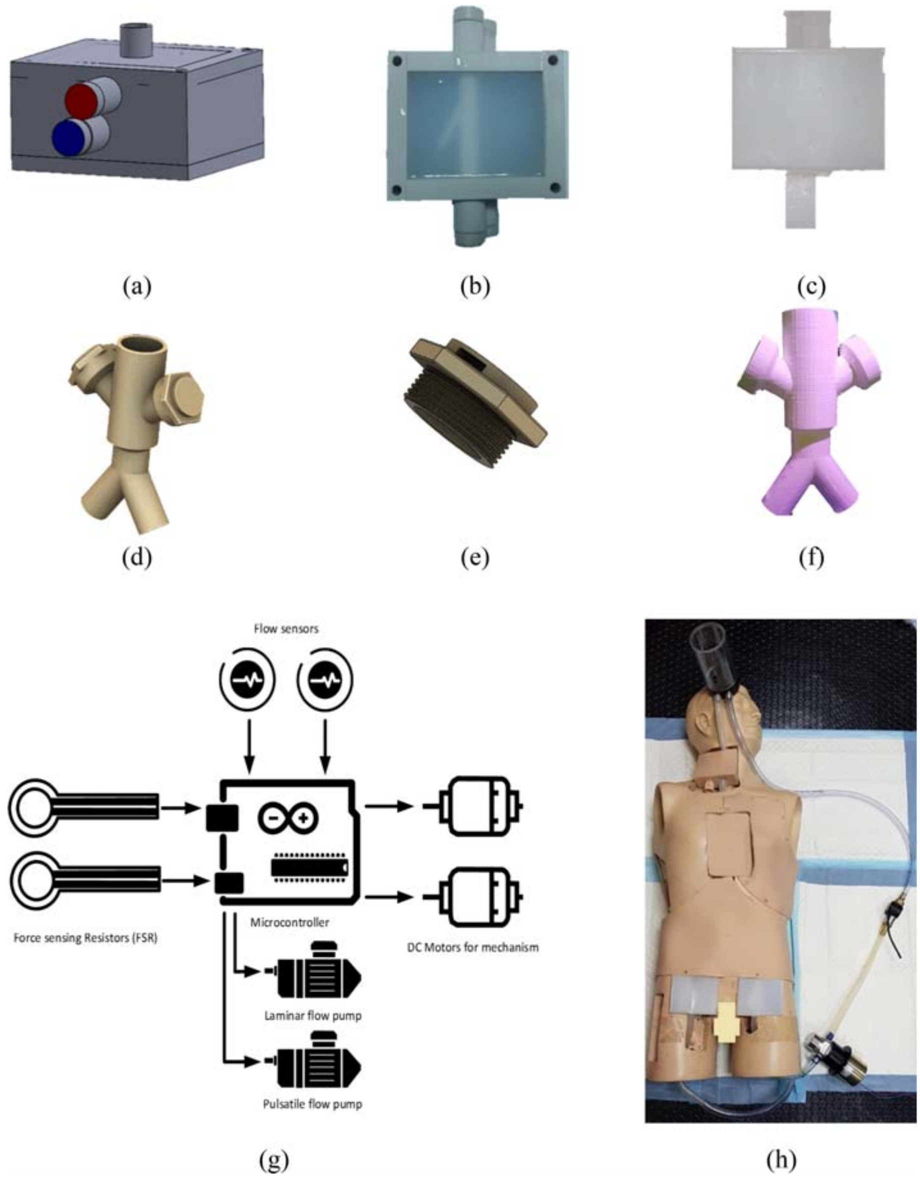

Figure 1. (a) Pad mold design, (b) 3D printed mold with poured EcoFLEX™ showing superficial artery, (c) Sample of cannulation access pad, (d) Meeting point IVC connector, (e) Meeting point IVC screw showing space for FSR, (f) 3D printed Y-connector, (g) Embedded system block diagram, (h) Improved prototype cannulation simulator.

cannulation pads (Figure 1(a), (c)). Secondly, cannulation pads were designed so they are anatomically correct and ultrasound compatible. For the arteries, the superficial artery was added at the access point to simulate possible incorrect routes for the cannula. Furthermore, the orientation of the veins and arteries were set to further resemble the human anatomy, where the arteries are situated above the veins (Figure 1(a), (b)). In addition to the implementation of a closed loop linking the jugular to the femoral, cannulation access points with a pump connected to a tank between them to regulate the flow.
The blood flow in the arteries was enhanced with a pump to simulate a pulsatile flow while the flow in the veins is laminar as seen in the single loop implementation (Figure 1(h)). The connection of the pump to the embedded system is shown in Figure 1(g). The junctional point in the IVC was designed in the venous loop to allow for two cannulas to pass and an alternative path simulating the renal vein was added. A force sensing resistor (FSR) was connected to detect and measure incorrect entry of the guide-wire as this, in real-time scenarios, could cause internal bleeding to the patient (Figure 1(g)). Lastly, the Y-connector showing the renal vein entry is shown in Figure 1(d) and (e).

Results: Tests were done on the system namely on the FSR to recalibrate it in the presence of liquid. Tests on the pulsatile flow were conducted to optimize for realism in terms of pressure. Since both jugular and femoral cannulation access points are included, the simulator can be used for training for all ECMO modes including veno-arterial and veno-venous. After testing, the main limitations of the current prototype include the flexibility of the tubes, limits on FSR measurements, and the rigidity of the available 3D printing material.
Conclusion: After implementing the stated features, the anticipated outcome is a realistic and cost-efficient ECMO cannulation simulator.

Keywords: extra-corporeal membrane oxygenation, cannulation, simulation-based training, embedded systems, human circulatory system simulation

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