A Mixed Simulator for Subclavian Central Venous Access

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Introduction

- During central venous access (CVA), a central venous catheter is typically inserted into the internal jugular (IJ) or subclavian vein.
- While ultrasound (US) guidance is recommended for IJ central venous access, subclavian vein access is almost universally performed without US, as a “blind” procedure.
- Clinicians rely on anatomical landmarks such as the sternal notch and the clavicle and heuristics to establish the entry point and trajectory to target the subclavian vein and a 3D mental model of the anatomy to safely steer the needle tip into the subclavian vein.
- It is difficult to get sufficient experience during training to achieve subclavian vein catheterization expertise.
- We designed a mixed simulator (one that mixes physical and virtual components such that users generally cannot tell when they are interacting with the physical or the virtual components) to provide realistic practice for placing the needle tip into the subclavian vein without striking the artery or the lung.
- In contrast to existing CVA part task trainers, our simulator detects lung strikes, displays the margin of safety, i.e., the distance by which artery and lung puncture was avoided and offers recording and playback of the needle’s path.
- The entire access procedure showing the 3D needle path relative to surrounding structures is captured and can be replayed for after action review (debriefing).

Methods

- We physically modeled the torso, neck and head of an actual human including anatomical landmarks such as the palpable sternal notch and the clavicle and selected ribs, as well as the feel of the skin and underlying tissue to user touch and resistance to puncture at specific regions where the needle is usually inserted.
- The remainder of the simulator was virtually modeled and registered to the physical component (the torso) with sub-millimeter accuracy.
- The 3D physical model for the torso and neck and the vein, artery and lung came from a CT scan and MRI scan respectively of a colleague.
- The individual components (vein, artery, lungs) from the MRI scan were manually reconstructed into separate 3D virtual objects.
- We converted the CT scan of the torso, neck and head to a 3D model that was then used to create a full scale, anatomically correct, physical model via a 3D printer (zPrinter 310, Z Corporation, Rock Hill, SC).
- The simulated skin is actually punctured by the instrumented 18 ga Raulerson needle from a commercial central venous access kit (TeleFlex Medical, Research Triangle Park, NC).
- The tip of the 18 ga Raulerson needle was instrumented with a magnetic sensor tracked in real time by a 3D tracking system (Ascension Technology Corp., Burlington, VT) relative to the virtual 3D structures surrounding the subclavian vein.
- We implemented a scoring algorithm to automatically score performance at the end of a training session.
- A video of the CVA simulator is at http://simulation.health.ufl.edu/research/cvl_intro.wmv

Vigilance... Gator Style

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Results

- Surgeons not involved with development evaluated the simulator and judged it anatomically authentic.
- The simulator was evaluated in a study with 28 anesthesia residents who each used the simulator 3 consecutive times. From Run 1 to Run 3, performance score (0 to 100 scale; lower score is better) for all participants was improved, on average, by 28% and a 71.9 seconds reduction in average time to achieve subclavian venous access was obtained.
- We performed repeated measure ANOVA on the outcomes from the three waves of data collection with follow-up pairwise dependent sample t-tests. There were reductions in average time ($F=14.28$, $p<.0001$), the number of attempts ($F=10.77$, $p=.0001$), number of skin punctures ($F=6.59$, $p=.004$) and score as determined by the scoring algorithm ($F=14.59$, $p<.0001$). For all outcomes, there were significant differences between Run 1 and Run 2 and between Run 1 and Run 3 ($p<.05$), but not between Run 2 and Run 3. The increased success rate from 82.1 (Run 1) to 92.9% (Run 3) was not significant ($p=.08$).
- Complication rates for pneumothoraces and subclavian arterial punctures were reduced from 11% to 7% and 13% to 7%, respectively.
- On a five point scale (1=strongly disagree to 5=strongly agree), on average, participants agreed that the simulator was realistic (M=4.1) and strongly agreed that the simulator should be used as a training/educational tool (M=4.8).
- In preliminary trials, the skin insert could be used for at least 100 punctures.

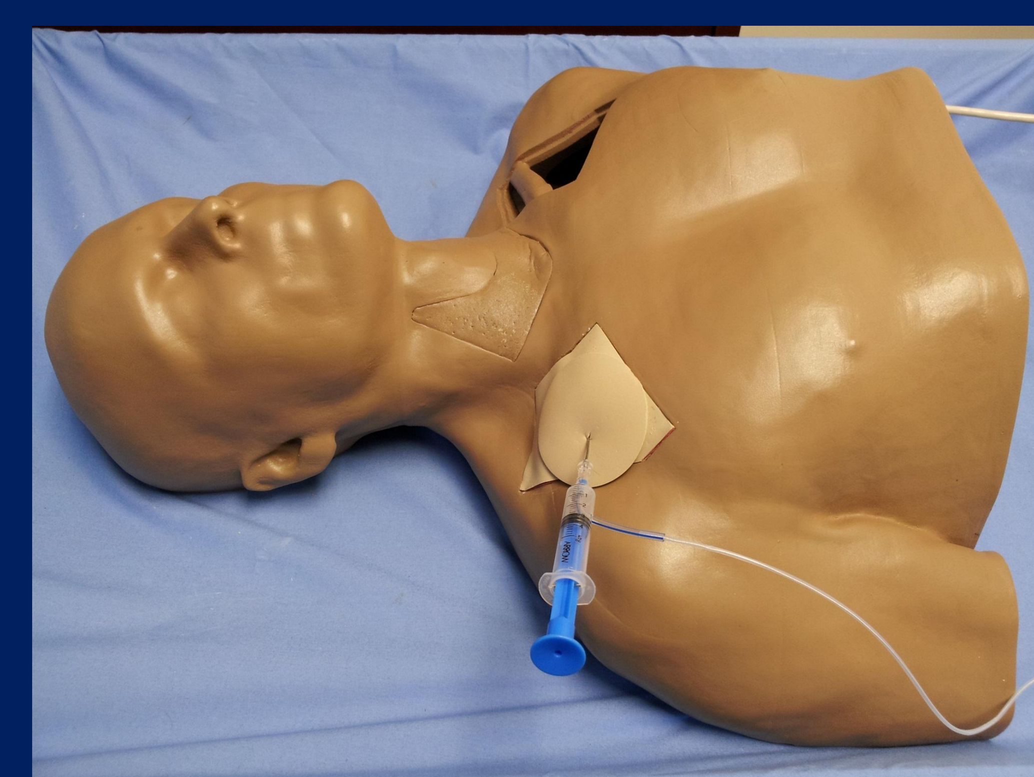

Figure 1. The mixed reality central venous access simulator; a needle (tracked in 3D space) is inserted via the skin patch to access the subclavian vein

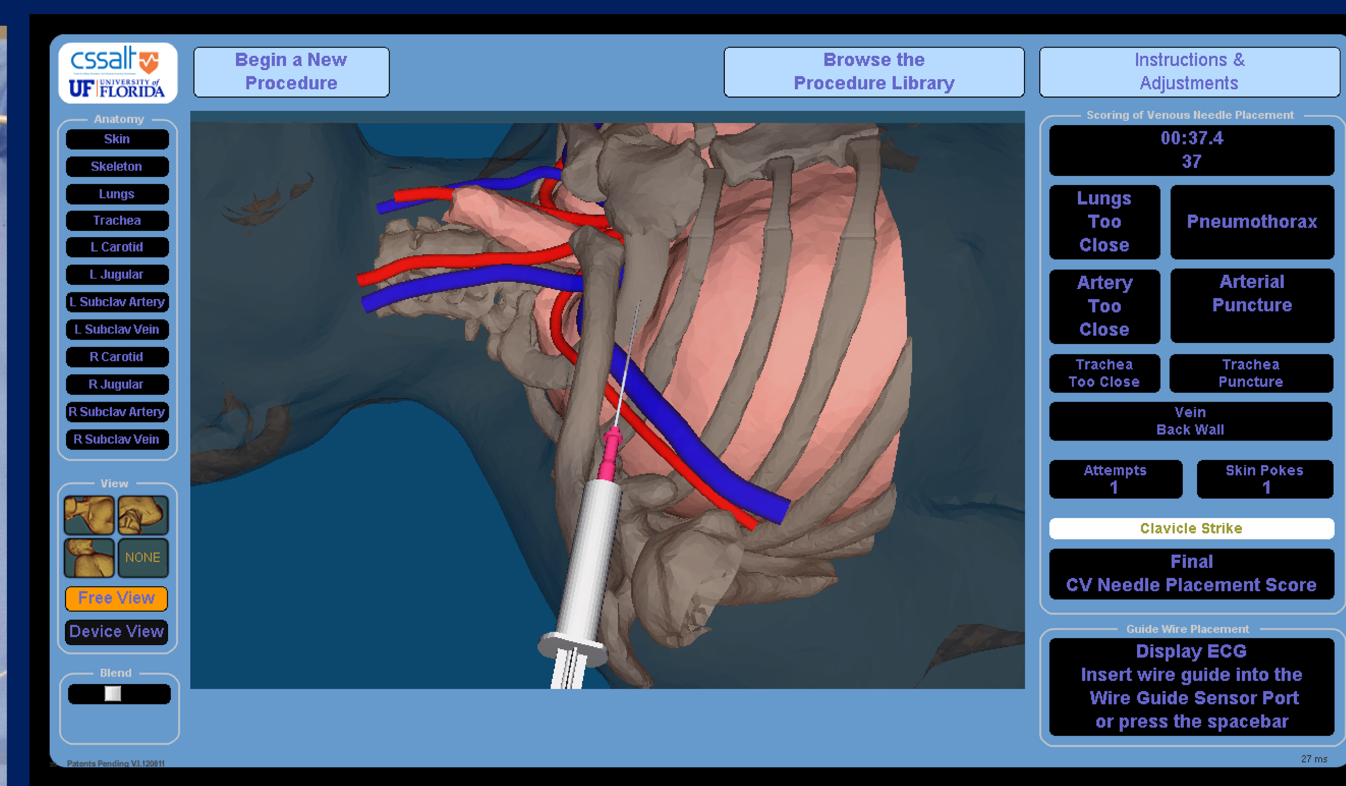

Figure 2. The virtual relevant soft tissues (vein, artery, lungs) are displayed collocated to virtual representations of the physical needle, syringe and torso. The skin opacity has been set by the instructor to transparent, in this view.

Conclusions

- A mixed simulator to teach a procedure with potential for significant complications, i.e., subclavian vein catheterization, has been created and ‘face’ validated and provides a unique new tool to allow novices to gain useful experience and confidence without risk to patients.
- We anticipate it can be combined with other technologies/simulations to tackle the entire spectrum of modern quality considerations surrounding percutaneous central vascular access or other “blind” procedures.
- We are currently working on adding simulated ultrasound guidance to this new simulation technology.