Vertebroplasty medical simulation learning environment

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Synopsis: In the recent decades, medical education has undergone a paradigm shift by embracing a competency-based approach that focuses on learner-centered training [1]. The goal for the modern learner is to arrive at the bedside of a real patient with proficiency already demonstrated in the requisite skills. In this process, the most expensive and scarce resource is the experienced clinical instructor. Educators need objective measures of performance to decide when trainees are ready to encounter a real patient [2]. In this area, the synergy between computer-assistance and real medical instrumentation can make invaluable contributions by enabling focused and deliberate practice to further motivate the trainee. Thus, clinical education specialists need a customizable medical simulation environment to experiment with new learning models and training regimens.

In this work, we outline some key aspects that we believe should characterize a customizable simulation environment. We have designed a procedural virtual reality (VR) simulator, in combination with mannequin technology, into an OR training and assessment environment. The simulator is capable of representing the entire surgical workflow including a medical imaging device simulation with the capacity to use patient-specific data, thus allowing the representation of a broad range of anatomical and pathological variety. Real surgical tools and instruments are augmented with realistic haptic feedback. Inherently, we also address a broad spectrum of human sensory channels such as tactile, auditory and visual channels in real time.

Surgical Workflow Steps and Crisis Simulation: We concentrate on vertebroplasty, a percutaneous image-guided minimally invasive surgery performed within orthopedic, trauma and radiology surgery rooms worldwide. The procedural steps were extracted from live surgery video recordings and literature [3] in conjunction with the feedback from expert surgeons. Through these surgical workflow steps the aim of our simulator is to realistically represent all sub-tasks of vertebroplasty up to cement injection and successful vertebral stabilization. Figure 1-top describes the tasks, instruments and learning objectives within three surgical workflow steps. Through a skin incision, the surgeon introduces a trocar into the virtual patient’s body and advances it further through the pedicle into the vertebral body using CT guidance. Feedback generated by the haptic device gives the surgeon tactile information on the anatomy in contact with the instrument. Bone structures are discernible and clearly distinguishable from soft-tissue. When the desired position is obtained...
with the trocar inside the vertebral body, the surgeon injects bone cement using a syringe. A cement model is used to discern the amount injected and it is consequently augmented on the CT slice images.

Crisis simulation: an “unexpected event” is induced in terms of a cement extravasation into a perivertebral vein causing a lung embolism. The aim here is to provoke communication between anesthesiologist and surgeon to relay proper response for this adverse event.

**Results:** Four surgeons participated in a user-study involving the completion of the surgical workflow steps described in the previous section, see Figure 1-bottom. The participants had varied experience: two senior experts (>150 executed vertebroplasties) and two junior experts (<150 executed vertebroplasties). Each participant was immersed individually in our VR surgical simulator in combination with a mannequin connected to the monitoring device. An independent person with knowledge of physiological responses and monitoring acted as the anesthesiologist. The surgeons were asked to give feedback using the Likert scale—a type of psychometric response and the most widely used scale in survey research. The subjects specified their level of agreement to a statement in our questionnaire. The 5-pt Likert scale format was: (1) Strongly disagree, (2) Disagree, (3) Neither agree nor disagree, (4) Agree, (5) Strongly agree. We assessed the face validity of the medical simulation environment, which is a subjective validation and usually used during the initial phase of test construction [4].

The group of surgeons thought that the modeling of workflow step 1 is realistic—4.75±0.25. The majority found that the realism is high during workflow step 2—4.00±0.66. They considered the crisis simulation realistic as well—4.50±0.33. The lowest score was assigned during workflow step 3 related to the usage of the syringe and visualization of the cement in CT—3.75±0.91. The questions pertaining to the face validity of the simulation setup were answered with an overall score of 4.50±0.33, signifying that the simulation is realistic. The complete simulation environment was ranked with an average Likert score of 4.50±0.67 when assessing all aspects of the realism of the simulation environment, specifically on whether it is suitable for the training of technical skills training.

**Conclusions:** To our knowledge this is the first VR simulator with the capacity to control the introduction of adverse events or complication yielding a wide spectrum of highly adjustable crisis simulation scenarios. Moreover, this is the first study that combines a VR simulator with a computerized mannequin simulator in an OR crisis simulation scenario in vertebroplasty. Future work will involve the improvement of: (i) haptics feedback, in particular limiting the lateral movement of the trocar inside bone tissue and (ii) CT scanner being substituted with intraoperative C-arm fluoroscopy.

**Note:** We will add (the possibility to use) fluoroscopy as a second imaging modality for guidance. Together with the research community we aim at outlining and defining pre-requisites for the ideal design of a medical simulation environment for clinical applications outside that of vertebroplasty. We hope the presented work can be the basis to catalyze such discussions.

**References**