DEVELOPMENT OF AN OPEN-SOURCE 3D VIRTUAL SIMULATOR WITH INTEGRATED MOTION-TRACKING AS A TEACHING TOOL FOR PEDICLE SCREW INSERTION

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INTRODUCTION

Pedicle screw insertion techniques are traditionally taught with limited hands-on training, using artificial or cadaveric models, prior to guided supervision within the operating room. With technology shifting towards less invasive, navigated procedures, requirements for surgical expertise (and training) are expanding. Unfortunately, this evolution in surgical technology has left gaps in the current surgical education curriculum, leading to unprepared trainees. Furthermore, as residency programs move to competency-based curricula, more authentic and accessible teaching tools are required to evaluate next generation spine surgeons. Virtual simulation can provide a valuable tool for practicing challenging surgical procedures; however, its potential depends on effective integration into student learning. Surgical simulation tools have recently gained traction in orthopaedic training for safe and effective teaching outside the operating room (Atesok 2012).

Our group previously developed a simulation program on the commercial AMIRADev platform (VSG, France) which allowed the insertion of virtual pedicle screws into 3D models of CT-based patient-specific spines with visual and quantitative feedback (Klein 2009). Feedback on this software was very positive, but suggested that a more accessible and robust version would be of even greater value (Podolsky 2010). The objectives of this work were to develop a freely accessible virtual pedicle screw simulator and to improve the clinical authenticity of the simulator through integration of a low-cost motion tracking sensor.

MATERIALS AND METHODS

The open-source medical imaging and visualization software, 3D Slicer, was identified as the most appropriate development platform for the virtual simulation (Federov 2012). Available for all major operating systems, 3D Slicer is capable of displaying CT-DICOM images, volume rendering 3D anatomy, incorporating 3D models of virtual devices and allows for measurement and calculation of anatomic parameters. The software is also capable of adding custom-written modules or extensions, coded in Python scripts, to create the desired functionality and workflow.

The developed software includes both pre-operative planning and intra-operative pedicle screw insertion workflows. Pre-operative planning utilizes CT imaging to identify the vertebral levels requiring instrumentation and take anatomic measurements. The intra-operative screw insertion workflow requires identification of the correct entry point and trajectory to create a safe screw tract with a pedicle probe. This requires skill in complex 3D spatial perception and interpreting 2D images into real-world 3D positioning.

To address this required skill development, virtual monitoring of the surgeon's simulated tool positioning was incorporated into the simulator with a Leap Motion motion tracking sensor in real-time (LeapMotion, San Francisco). The Leap Motion is a low-cost (~$100), hardware sensor that tracks 3D hand motion with accuracy up to 1/100th of a millimeter. This allows a pedicle probe surrogate to be physically tracked as the surgeon defines a virtual screw's insertion point and trajectory on a 3D spine model.

RESULTS

Using a combination of existing and custom-written 3D Slicer Python scripts, an interactive virtual pedicle screw simulator was created. The surgical planning and operative screw insertion were simulated in a six step workflow. In Step 1, the user identifies the vertebral levels from a series of CT-DICOM imaging, loaded to Slicer via DVD or USB. The user identifies the location of a known level (i.e., L1) and adjacent level labels are automatically assigned. In Step 2, a region of interest (ROI) box is expanded around the vertebrae that are to be instrumented and, in real-time, a 3D rendering of the bony anatomy within the ROI is generated. In Step 3, the user identifies the start points for screw insertion via fiducials which attach to the surface of the 3D anatomy rendering; help videos were included to guide novice users. In Step 4, anatomic measurements of each pedicle are made and recorded to later determine appropriate screw sizing. CT slice reconstruction angle can be adjusted to allow measurements in non-orthogonal planes (i.e., where the spine is curved). In Step 5, the screw diameter and length are chosen. Using the LeapMotion, the screw's trajectory is then physically controlled via the surrogate tool and the user can insert the screw once the desired trajectory is achieved. In final step, qualitative evaluation of screw positioning and cortical breaches can be conducted in 2D CT images and in a 3D translucent rendering of the spinal column (Heary 2004). Quantitative evaluation is calculated based on the screw-bone contact area. Visualization of the contact is shown as a density gradient on the screw model.

Initial surgeon feedback of the virtual simulator with integrated motion tracking was positive, with no noticeable lag and high accuracy between the real-world and virtual environments. The software yielded high fidelity 3D visualization of the complex geometry and the tracking enabled coordination of motion to small changes in both translational and angular positioning.

DISCUSSION

Significant interest from surgical residency programs and international organizations to access a virtual spine surgery simulator as a training/evaluation tool motivated transitional development of the current commercial AMIRAdev-based pedicle screw simulator to the open-source 3D Slicer platform (Klein 2009). Residents and staff surgeons evaluating the original simulator felt such technology would be best used in a sustained manner over a longer time period (Podolsky 2010). The 3D Slicer-based virtual simulation developed in the current work overcomes these previous issues by allowing for distribution of the simulation without the need for commercial software, enabling trainees to practice instrumentation techniques anywhere they have access to a computer. Further the interactivity provided by the low-cost LeapMotion represents a significant advancement in terms of the simulator's task authenticity.

Future evaluation of the simulator will be conducted via a pilot study with University of Toronto Orthopaedic Surgery residents over the course of a spine rotation (Gallagher 2005). Ultimately, free global access to this simulation module will be provided through the 3D Slicer extension manager. Most importantly, the integration of this simulator at teaching hospitals should translate into a benefit to surgical safety. Consistent use of this patient specific simulation will provide surgical trainees with increased competence for each surgical case and has the potential to improve the safety of pedicle screw insertions in teaching hospitals.

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