Design and Validation of a 3D Printed Simulator for Posterior Cervical Laminectomy

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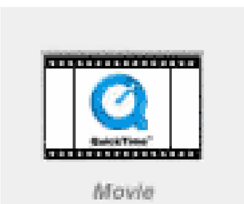
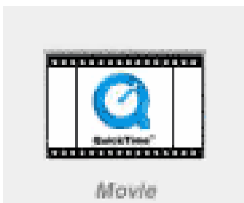
Introduction Technical skills for a laminectomy are traditionally acquired through intraoperative learning and cadaveric courses. These methods provide little objective assessment, involve financial and biohazard considerations, and may not incorporate desired pathology. We aimed to develop and assess face, content, & construct validity of a high-fidelity, inexpensive cervical laminectomy simulator.

Video 1: Model Development



Methods Computer models generated from CT imaging of a patient with cervical spondylytic myelopathy were 3D printed into negative molds. Molds were used with Polyvinyl Alcohol hydrogels, plaster, and fiber glass to replicate tissues and bleeding. Intra-thecal pressure, simulated by a pressurized balloon in the spinal canal connected to a pressure transducer, was used as a proxy for cord manipulation. Twelve surgeons (novices designated by prior laminectomies <100) performed full-procedure C4-C6 posterior laminectomy simulation. Post -simulation surveys assessed face & content validity. Construct validity was assessed by comparing procedural metrics (thecal-sac pressure wave count, amplitude, slope, time of elevated pressure, operative times, EBL, incision length, complications) between groups.

Video 2: Compilation of Surgical Steps



Results The simulator received average face and content validity ratings of 4/5. Significant differences between experts and novices were found in total intra-thecal pressure wave count (84 vs 153, $p = 0.023$), amplitude (4% vs 12% >2SD above expert mean, $p < 0.001$), area under curve (4% vs 11% >2SD above expert mean, $p < 0.001$), & procedure time (35 vs 69 min $p = 0.003$). Insignificant differences were found in mean pressure wave slope or blood loss. There was a significant difference in complication rate between novices (3 incorrect levels decompressed, 1 dural tear) & experts ($p = 0.03$).

Conclusions This full procedural laminectomy simulator received excellent validity ratings and successfully measured operator performance. Further studies are needed to determine the role of this simulator in the training and maintenance of surgical skills.

Excerpt of Pressure Wave Prior to Smoothing

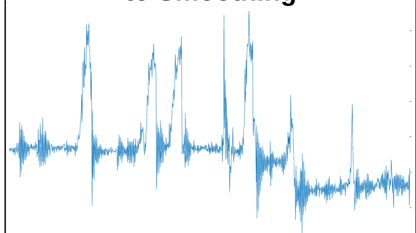
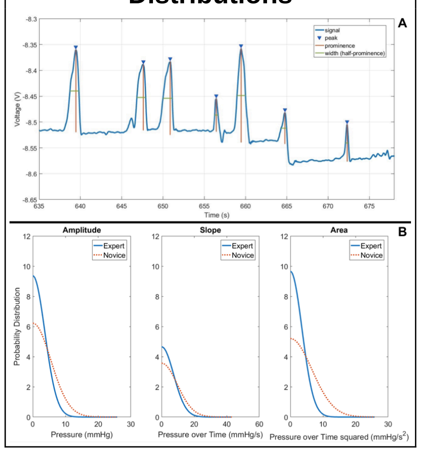


Fig. 1. A) Analyzed Pressure Wave Excerpt and B) Expert and Novice Probability Distributions



Face and Content Validity Results

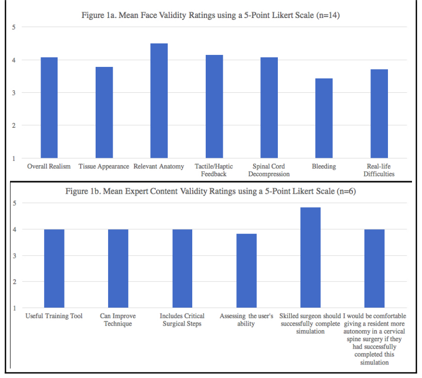
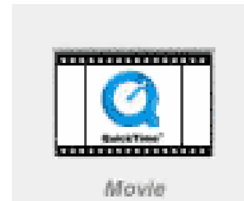
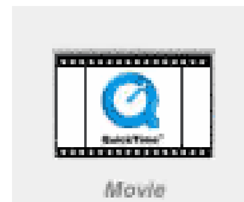


Fig. 1 (left) **A.** Excerpt of pressure wave curve from simulation. Waves coincide with Kerrison use. Frequency, amplitude (measured in volts and converted to mmHg) and slope (mmHg/s) were measured. A decrease in baseline pressure was seen with progression of decompression. **B.** Probability distributions of the characteristics of novice and expert intra-thecal pressure waves. Distributions of amplitude, slope, and area under curve of each pressure wave found in the intra-thecal pressure logs for experts and novices. Significant difference was seen between experts and novices in the amplitude of pressure waves (mmHg) and the area under curve (mmHg/s2). An insignificant difference was seen in the slope of the onset of each pressure wave (mmHg/s).

Video 3: Excerpt of Expert Decompression with Pressure Waveform



Video 4: Excerpt of Novice Decompression with Pressure Waveform



Learning Objectives

1. Understand how 3D printing can be used to create high fidelity low cost surgical simulators.

2. Discuss various forms of validation for simulation and describe how to conduct a simulation study.

3. Recognize how the incorporation of sensors into simulation permits the evaluation of technical performance.