PelvisVR: Recreating Pelvic Trauma Surgery in Virtual Reality

Students:
- Han Zhang
- Zixuan Liu
- Liam Wang

Mentors:
- Benjamin Killeen
- Mathias Unberath

Background Presentation

Johns Hopkins Whiting School of Engineering

ARCADE

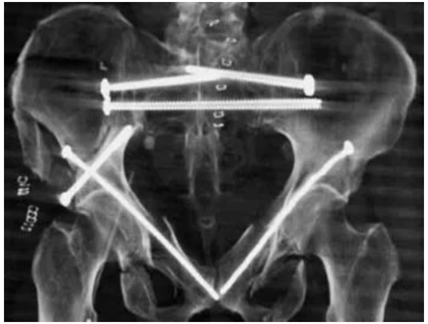
Background

Percutaneous pelvic fracture surgery is a **minimal invasive surgery**.

- ➔ Inadequate visualization
- ➔ Require more training for surgeons
- ➔ More radiation exposure for surgeons when k-wire insertion.

Open Pelvic Fracture Surgery(a)

Percutaneous Pelvic Fracture Surgery with C-arm(b)

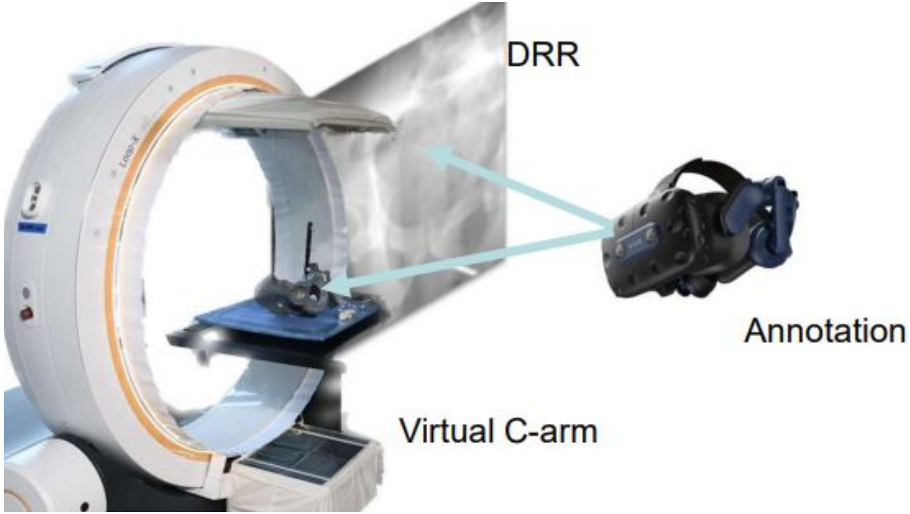


K-wires in Pelvis shown in Intraoperative Fluoroscopy

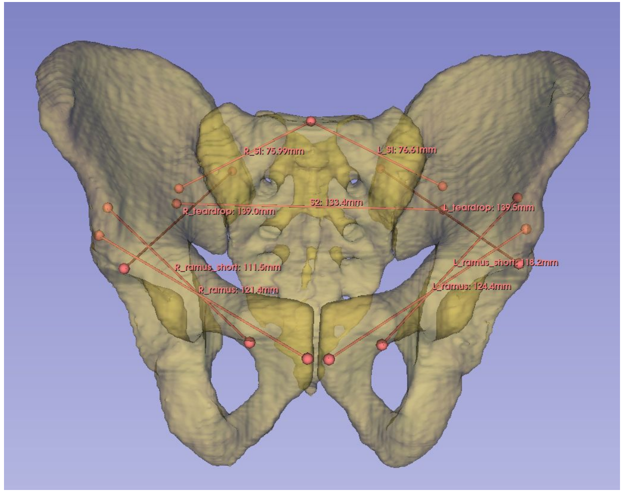
(a)Wang, Z.-h. and Li, K.-n. (2019), Regional Injury Classification and Treatment of Open Pelvic Fractures. Orthop Surg, 11: 1064-1071. https://doi.org/10.1111/os.12554
(b)Rami Mosheiff, Chip Routt.Percutaneous fixation of pelvic fractures. orthoinfo - aaos. OrthoInfo. (n.d.). Retrieved February 8, 2023, from https://orthoinfo.aaos.org/en/treatment/internal-fixation-for-fractures

Goal

- Creating a **virtual training environment** for percutaneous pelvic fracture surgery.



Training Environment with DRR
https://www.brainlab.com/surgery-products/overview-platform-products/



Annotation of operative plan:

Paper 1: Development and evaluation of an open-source virtual reality C-Arm simulator

Daniel R. Allen, Collin Clarke, Terry M. Peters & Elvis C.S Chen

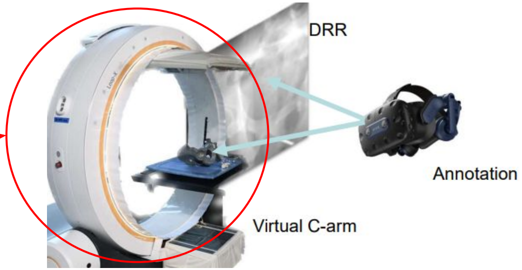
[1] D. R. Allen, C. Clarke, T. M. Peters, and E. C. S. Chen, "Development and evaluation of an open-source virtual reality C-Arm simulator," *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–6, Dec. 2022, doi: 10.1080/21681163.2022.2152374.

Why do we choose this paper?

ARCADE

- ➔ Discusses a virtual reality simulator for **C-arm positioning** in interventional spine procedures
- ➔ Provides a **complete architecture** for building the virtual training system
- ➔ Evaluates the **effectiveness** of the C-arm simulator with medical residents and expert clinicians

Help build this!



Our system

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

[1] D. R. Allen, C. Clarke, T. M. Peters, and E. C. S. Chen, "Development and evaluation of an open-source virtual reality C-Arm simulator," *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–6, Dec. 2022, doi: 10.1080/21681163.2022.2152374.

Methods

ARCADE

- ➔ System built in **3D Slicer** with generating **digital reconstruct radiography.**
- ➔ CT model achieved **3-DoF** rotations using forward kinematics with **homogeneous transformation**.
- ➔ User study conducted with 12 residents and 2 expert users to obtain 3 standard views **before/after VR training**
- ➔ Performance metrics: total **procedure time**, angular and translation **accuracy**, and number of **shots**

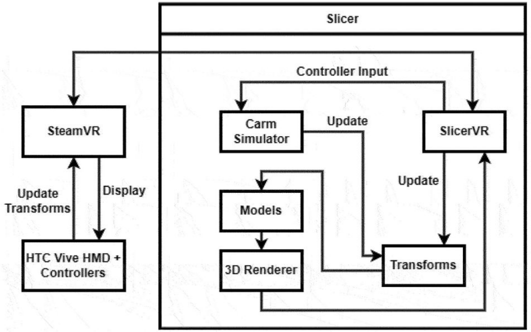


Figure The high-level system architecture overview.(Allen et al. 2022)

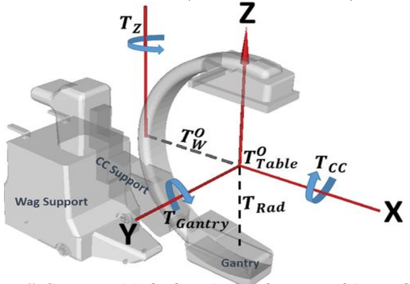


Figure 4 C-arm model(Allen et al. 2022)

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

[1] D. R. Allen, C. Clarke, T. M. Peters, and E. C. S. Chen, "Development and evaluation of an open-source virtual reality C-Arm simulator," *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–6, Dec. 2022, doi: 10.1080/21681163.2022.2152374.

Results

- ➔ Overall performance of each user **improved** after completing training
- ➔ Average number of virtual fluoroscopic **shots decreased** from 42.33 ± 22.29 to 26 ± 13.27 ($p > 0.05$)
- ➔ Average procedure **time decreased** from 20.71 ± 5.43 min to 9.72 ± 4.38 min ($p < 0.05$)

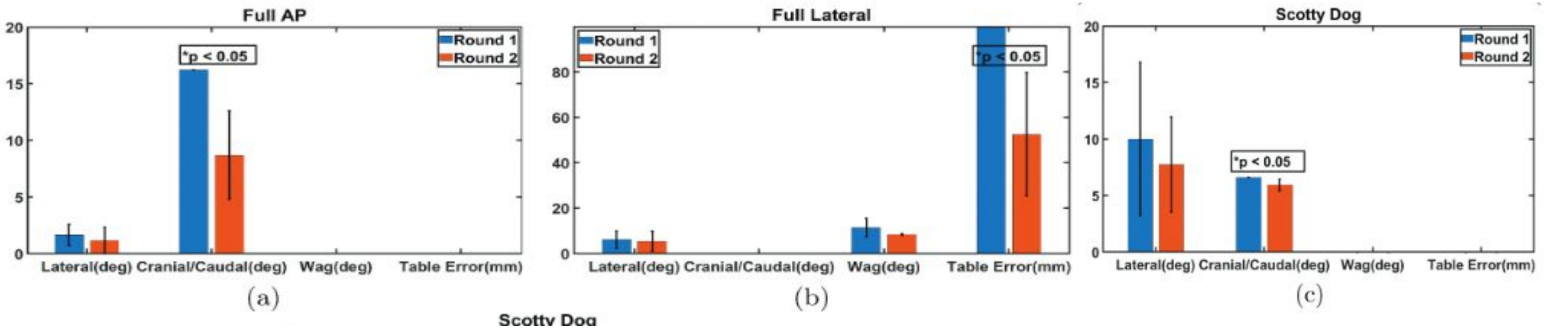


Figure: Novice User Study Result(Allen et al. 2022)

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

[1] D. R. Allen, C. Clarke, T. M. Peters, and E. C. S. Chen, “Development and evaluation of an open-source virtual reality C-Arm simulator,” *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–6, Dec. 2022, doi: 10.1080/21681163.2022.2152374.

Results

➔ Questionnaire showed **positive feedback** from users

Table 1. Questionnaire results (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree).

Face Validity (n = 14 (12 novices, 2 experts))	Mean	Min	Max
The simulator realistically represents an X-ray image	4.6 ± 0.5	4	5
The X-ray image is representative of the virtual C-Arm and patient position	4.6 ± 0.6	3	5
Interaction with the C-Arm in the VR environment was user friendly	4.3 ± 0.9	2	5
Integration of simulator into medical education would be useful	4.7 ± 0.6	3	5
Your spatial understanding of the movement of the C-Arm in VR was more intuitive than on a 2D display	4.5 ± 0.6	3	5
Content Validity (n = 2 experts)			
The simulator is suitable for training novices	5.0 ± 0.0	5	5
The simulator is suitable for training experts	5.0 ± 0.0	5	5

Figure. Questionnaire Results(Allen et al. 2022)

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

[1] D. R. Allen, C. Clarke, T. M. Peters, and E. C. S. Chen, "Development and evaluation of an open-source virtual reality C-Arm simulator," *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–6, Dec. 2022, doi: 10.1080/21681163.2022.2152374.

Assessment

- **Pros:**
  - Used 3D Slicer with integrating medical research modules
  - Verified feasibility of VR training with DRR
  - Provided an architecture suitable for building other VR-related training environments
- **Cons:**
  - Only 3 DoF manipulation for the C-arm
  - No direct interaction with C-arm for users
  - No any interaction with surgical tools
- **Future Works:**
  - Enable all degrees of freedom for the C-arm
  - Add surgical tool simulation
  - Enable interaction with model and tools

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

[1] D. R. Allen, C. Clarke, T. M. Peters, and E. C. S. Chen, "Development and evaluation of an open-source virtual reality C-Arm simulator," *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–6, Dec. 2022, doi: 10.1080/21681163.2022.2152374.

Significance

- Virtual reality simulator provides **safe and effective** way to learn without radiation and **unlimited training time**
- Simulator can be used outside fluoroscopy suite, increasing **training availability and accessibility**
- Results show **significant improvement** in C-arm placement, potential to improve outcomes for medical residents

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

[1] D. R. Allen, C. Clarke, T. M. Peters, and E. C. S. Chen, “Development and evaluation of an open-source virtual reality C-Arm simulator,” *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–6, Dec. 2022, doi: 10.1080/21681163.2022.2152374.

Paper 2: DeepDRR – A Catalyst for Machine Learning in Fluoroscopy-guided Procedures

Mathias Unberath, Jan-Nico Zaech, Sing Chun Lee, Bastian Bier, Javad Fotouhi, Mehran Armand, and Nassir Navab

[2] M. Unberath et al., “DeepDRR -- A Catalyst for Machine Learning in Fluoroscopy-guided Procedures,” arXiv.org, https://arxiv.org/abs/1803.08606v1 (accessed Mar. 13, 2023).

Why do we choose this paper?

ARCADE

- ➔ Our virtual reality C-arm X-ray imager simulation needs to be realistic to provide useful training for surgeons
- ➔ The X-ray images taken by the C-arm is the primary way surgeons guide their tools during orthopedic surgery
- ➔ This paper describes an open-source algorithm for generating realistic synthetic X-ray images in real-time, which is required for our interactive virtual simulation

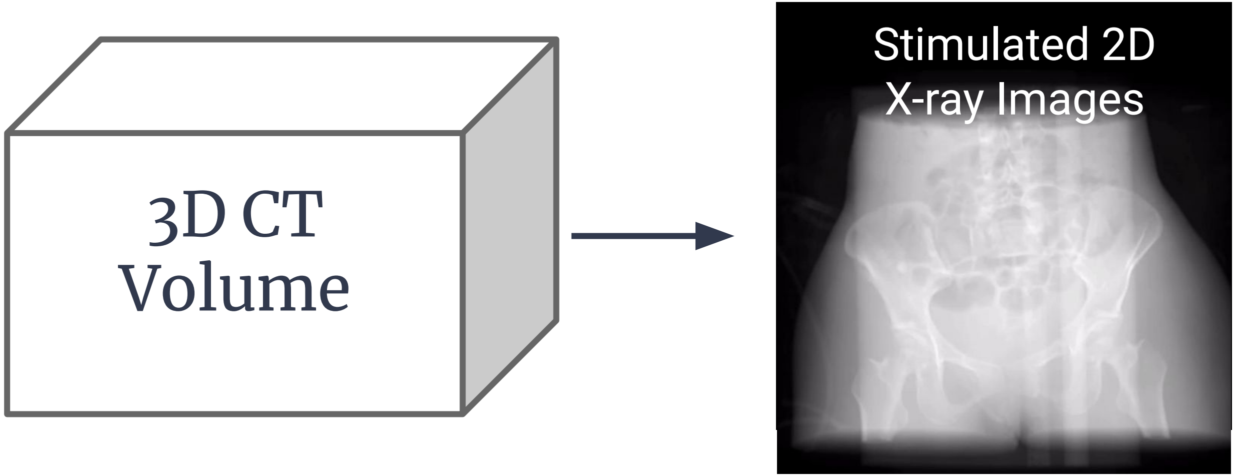
JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

[2] M. Unberath et al., “DeepDRR -- A Catalyst for Machine Learning in Fluoroscopy-guided Procedures,” arXiv.org, https://arxiv.org/abs/1803.08606v1 (accessed Mar. 13, 2023).

Background

ARCADE

- Digitally Reconstructed Radiograph (DRR): A 2D X-ray image generated using an algorithm that simulates the path of X-ray beams through a patient CT volume



JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

[2] M. Unberath et al., “DeepDRR -- A Catalyst for Machine Learning in Fluoroscopy-guided Procedures,” arXiv.org, https://arxiv.org/abs/1803.08606v1 (accessed Mar. 13, 2023).

Methods

➔ DeepDRR uses a 4 stage pipeline for DRR generation

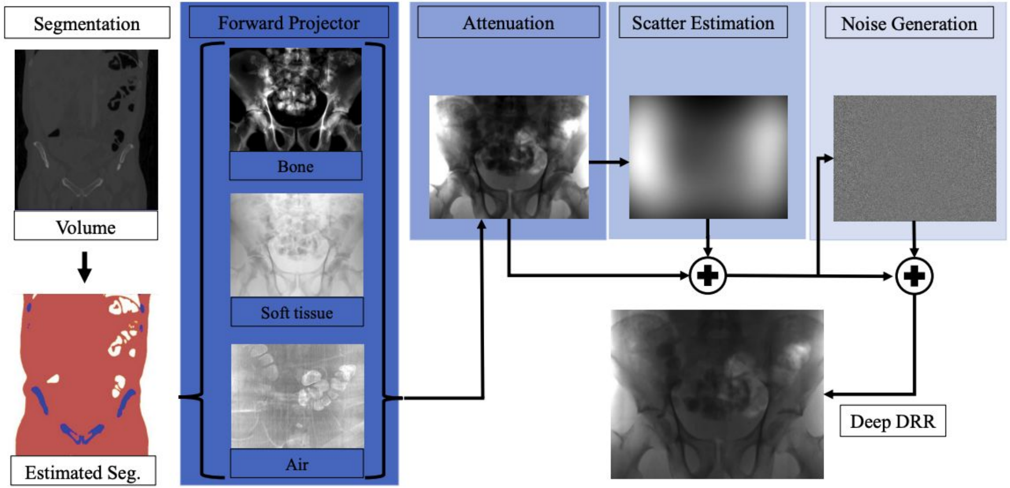


Fig. 1. Schematic overview of DeepDRR.

[2] M. Unberath et al., “DeepDRR -- A Catalyst for Machine Learning in Fluoroscopy-guided Procedures,” arXiv.org, https://arxiv.org/abs/1803.08606v1 (accessed Mar. 13, 2023).

Results

➔ Deep learning landmark detection model trained on DeepDRR images performed much better on real-world data

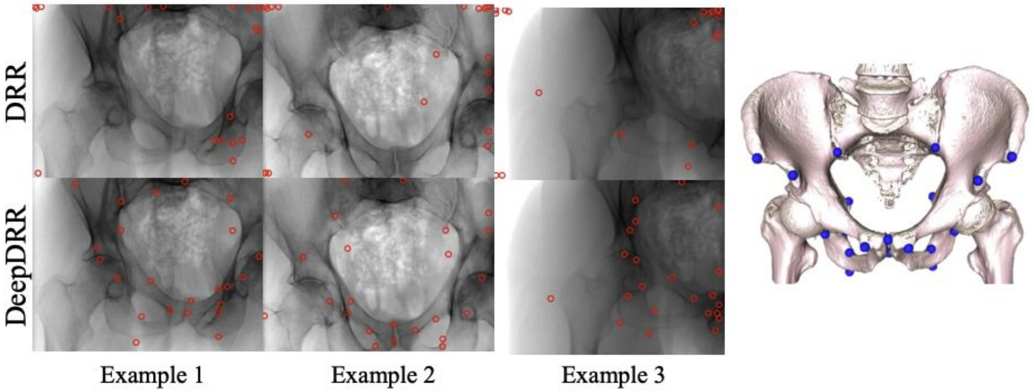


Fig. 3. Anatomical landmark detection on real data of cadaveric specimen using the method detailed in [9]. Top row: Detection results of a model trained on conventional DRRs. Bottom row: Detections of a model trained on the proposed DeepDRRs. No domain adaption or re-training was performed. Right-most image: Schematic illustration of desired landmark locations shown on a training set sample.

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

[2] M. Unberath et al., "DeepDRR -- A Catalyst for Machine Learning in Fluoroscopy-guided Procedures," arXiv.org, https://arxiv.org/abs/1803.08606v1 (accessed Mar. 13, 2023).

Assessment

- **Pros:**
  - Novel method for generating fast realistic DRR images
  - Each stage of DRR generation pipeline is clearly explained
  - Use-case for generating training data for other deep learning algorithms is demonstrated
- **Cons:**
  - Lacks side-by-side qualitative comparison of conventional DRR and DeepDRR X-ray images with real X-ray images

[2] M. Unberath et al., "DeepDRR -- A Catalyst for Machine Learning in Fluoroscopy-guided Procedures," arXiv.org, https://arxiv.org/abs/1803.08606v1 (accessed Mar. 13, 2023).

Significance

ARCADE

- Previous methods for generating X-ray images using the DRR technique either **lacked realism** or were too **slow** to run in real-time
- With this technique, it is now feasible to generate **realistic X-ray images in real-time**
- Directly applicable to our project– will allow orthopedic surgeons to practice using highly realistic X-ray images from a virtual C-arm and patient

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

[2] M. Unberath et al., "DeepDRR -- A Catalyst for Machine Learning in Fluoroscopy-guided Procedures," arXiv.org, https://arxiv.org/abs/1803.08606v1 (accessed Mar. 13, 2023).

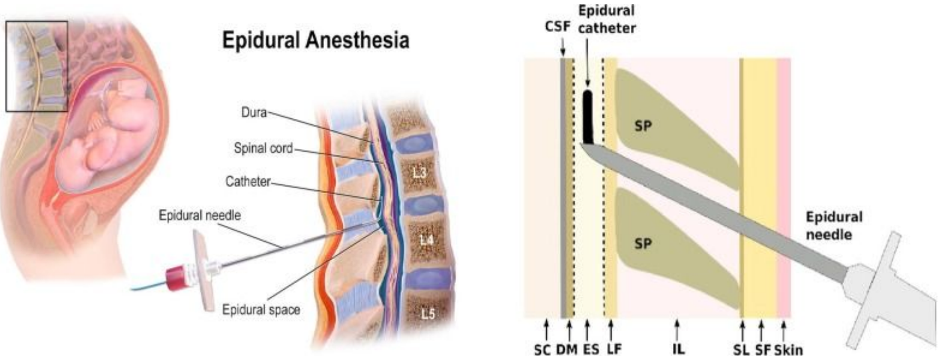
Paper 3:
Haptic forces and gamification on epidural anesthesia skill gain.

André Luiz Brazila, Aura Concib, Esteban Cluab,
Leonardo Kayat Bittencourtc, Lúcia Blondet Baruqued,
Nathalia da Silva Concie

Why do we choose this paper?

ARCADE

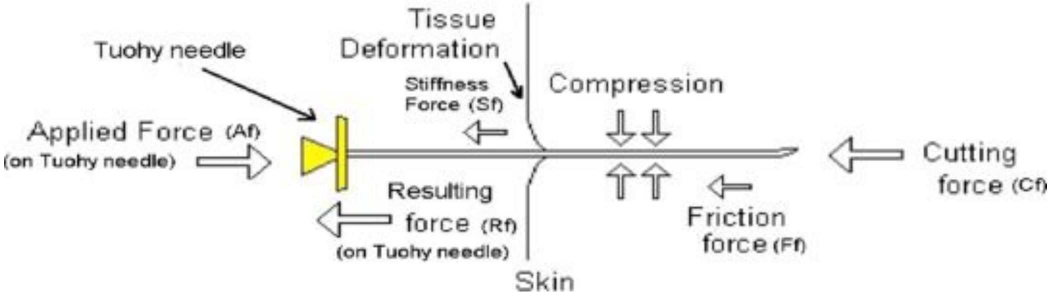
- For the tissue simulation/K-wire insertion, the main difficulty with simulating K-wire insertion is determining how to realistically navigate the wire from outside the patient's body, through the tissue, and ultimately into the bones.
- We do not have prior knowledge of insertion simulation in virtual reality
- The haptic feedback of VR controllers is critical to make a realistic simulation
- Although the paper is focusing on simulating epidural insertion, our K-wire simulation is essentially a simplified version of it.



A. L. Brazil, A. Conci, E. Clua, L. K. Bittencourt, L. B. Baruque, and N. da Silva Conci, "Haptic forces and gamification on epidural anesthesia skill gain," Entertainment Computing, vol. 25, pp. 1–13, Mar. 2018, doi: 10.1016/j.entcom.2017.10.002.

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

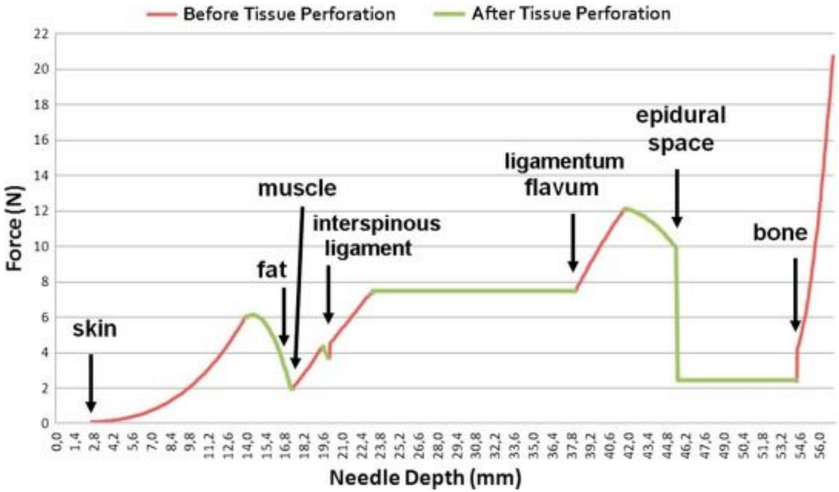
Methods



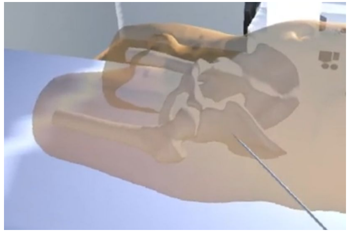
A. L. Brazil, A. Conci, E. Clua, L. K. Bittencourt, L. B. Baruque, and N. da Silva Conci, “Haptic forces and gamification on epidural anesthesia skill gain,” Entertainment Computing, vol. 25, pp. 1–13, Mar. 2018, doi: 10.1016/j.entcom.2017.10.002.

- ➔ Applied force must be greater than the resulting force
- ➔ The stiffness force, which represents the elastic force of the skin tissue surface
- ➔ The cutting force, which is the resistance produced by the tissue as the needle tip rotates and advances
- ➔ The friction force, which represents the frictional force exerted on the surface of the needle by the body tissues as it advances

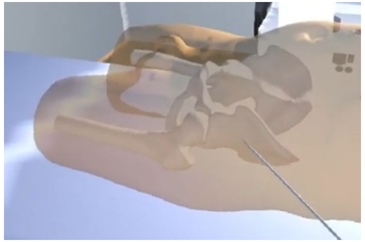
Results

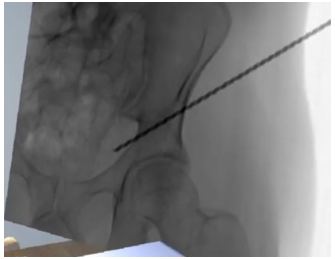


A. L. Brazil, A. Conci, E. Clua, L. K. Bittencourt, L. B. Baruque, and N. da Silva Conci, "Haptic forces and gamification on epidural anesthesia skill gain," Entertainment Computing, vol. 25, pp. 1–13, Mar. 2018, doi: 10.1016/j.entcom.2017.10.002.



➔ When the K-wire inserting into the skin, we constrain the rotation for a range and provide haptic feedback





➔ When the K-wire touches the bone, we constrain the k-wire can only move forward or backward.

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

Assessment

- **Pros:**
  - The study uses the haptic device to simulate the needle insertion process. It can achieve very realistic physical simulation.
  - The study also measured the penetration limit strength of various tissues through experiments, thus providing a strong guarantee for the scientific nature of the entire simulation process.
- **Cons:**
  - The precise rendering haptic device is not very portable and is also very expensive, which is not conducive to the adoption of the entire training paradigm around the world.
  - Only needle insertion process, the user is always sitting on the seat

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

[1] D. R. Allen, C. Clarke, T. M. Peters, and E. C. S. Chen, "Development and evaluation of an open-source virtual reality C-Arm simulator," *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–6, Dec. 2022, doi: 10.1080/21681163.2022.2152374.

References

[1] D. R. Allen, C. Clarke, T. M. Peters, and E. C. S. Chen, “Development and evaluation of an open-source virtual reality C-Arm simulator,” *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–6, Dec. 2022, doi: 10.1080/21681163.2022.2152374.

[2] M. Unberath et al., “DeepDRR -- A Catalyst for Machine Learning in Fluoroscopy-guided Procedures,” *arXiv.org,* https://arxiv.org/abs/1803.08606v1 (accessed Mar. 13, 2023).

[3] A. L. Brazil, A. Conci, E. Clua, L. K. Bittencourt, L. B. Baruque, and N. da Silva Conci, “Haptic forces and gamification on epidural anesthesia skill gain,” *Entertainment Computing*, vol. 25, pp. 1–13, Mar. 2018, doi: 10.1016/j.entcom.2017.10.002.

[4] J. Moo-Young, T. M. Weber, B. Kapralos, A. Quevedo, and F. Alam, “Development of Unity Simulator for Epidural Insertion Training for Replacing Current Lumbar Puncture Simulators,” *Cureus*, vol. 13, no. 2, p. e13409, doi: 10.7759/cureus.13409.

JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING