Haptic and Virtual Reality Surgical Simulator for Training in Percutaneous Renal Access: a Feasibility Study

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Percutaneous renal access (PCA)

Preliminary step to PCNL (percutaneous nephrolithotomy)

Steep learning curve → 24 procedures are needed to get competency

Only 11% of the urologists perform PCA by themselves

Percutaneous renal access is challenging and training is inadequate
Anatomical considerations

Puncture should not be too close to the rib, to preserve nerves and muscles.

The best spot to insert the needle is medially to the posterior axillary line.
Anatomical considerations

- **Posterior calix** is preferred, to better handle the guide wire.

- **Puncture along the infundibulum of the calix of choice** to reduce bleeding and traumas.

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Fluoroscopy

- Standard guidance for PCA
- Exposure to radiation
- Difficulty in interpreting 2D images with respect to 3D anatomy

A. without contrast  B. with contrast
Training models

Easily accessible, but anatomically inaccurate, degradable and subject to bioethical concerns
Training models

A new approach to urology training: a laboratory model for percutaneous nephrolithotomy, L. Hammond

Soft 3D-Printed Phantom of the Human Kidney with Collecting System, F. Adams

https://www.3dsystems.com/medical-simulators/simbionix-perc-mentor

BIOLOGICAL   NON-BIOLOGICAL   VIRTUAL REALITY

Accurate and with reliable haptics, but degradable, time consuming and sometimes expensive
Training models

A new approach to urology training: a laboratory model for percutaneous nephrolithotomy, L. Hammond

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BIOLOGICAL NON-BIOLOGICAL VIRTUAL REALITY

Accurate, with performance evaluation, but high priced and haptics is unavailable
Problem statement

Current training models for PCA are anatomically inaccurate, high-priced and/or easily degradable.
Ideal requirements

• Anatomically accurate
• Radiation-free
• Non-degradable
• Commercially viable and relevant
Approach

VISUAL
- Fluoroscopy guidance

HAPTICS
- Tactile feedback from the models
- Transparency

Haptic and virtual reality surgical simulator
3D models

VOLUME SEGMENTATION
automatic + manual

GENERATION OF THE MODELS
as 3D meshes

SMOOTHING AND DECIMATION
improving graphics and haptics rendering performance
3D models

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New software development kit

- Visualization Library (VL) 3D Graphics rendering
- QuickHaptics (QH) Haptics rendering
- Wykobi (WK) Mathematical computation
- Ascension (ASC) EM tracking system
Implementation

HAPTIC DEVICE

MOUSE & KEYBOARD

ANATOMICAL MODELS

FLUOROSCOPY

STEREOSCOPIC DISPLAY
Haptics rendering

VOLUMETRIC EFFECTS
Fulcrum point effect inside the skin
Damping and friction inside the models

\[ \text{Force}(n) = (\text{Position}(n) - \text{Position}(n-1)) \times \text{Gain} [N] \]

SUPERFICIAL EFFECTS
Haptic properties associated to each mesh (stiffness, damping, friction and pop through)
Experimental protocol

1. Set the useful projections of the virtual fluoroscopy
2. Insert the virtual needle inside the patient
3. Avoid undesired contacts with the organs in the scene
4. Place the needle within the left renal pelvis
5. Freeze the needle and check the performance
Performance metrics

• duration of the task, expressed in seconds

• fluoroscopy time, in seconds

• distance from a desired target, in centimetres

• number of undesired contacts with spleen, lungs, spine and major vessels
Results – Quantitative evaluation
Results – Qualitative evaluation

1. Assessment questionnaire

**Ease of use**

- How easily have you learnt how to interact with the simulator?
  - Fairly: 71.4%
  - Very: 14.3%
  - Somewhat: 9.52%
  - Extremely: 4.76%

**High satisfaction**

- How satisfied were you when using the simulator?
  - Very: 52.4%
  - Fairly: 23.8%
  - Extremely: 23.8%

**Adoption as a training tool**

- To what extent do you think the simulator would be useful for training in PCA?
  - Extremely: 33.3%
  - Very: 47.6%
  - Fairly: 19%
Results – Qualitative evaluation

2. System Usability Scale – **Good usability**

\[ SUS_{avg} = 71 \pm 4.6 \]

<table>
<thead>
<tr>
<th>N</th>
<th>Statement</th>
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<tbody>
<tr>
<td>1</td>
<td>I think that I would like to use this system frequently.</td>
</tr>
<tr>
<td>2</td>
<td>I found the system unnecessarily complex.</td>
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<tr>
<td>3</td>
<td>I felt very confident using the system.</td>
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<tr>
<td>4</td>
<td>I found the various functions in this system were well integrated.</td>
</tr>
<tr>
<td>5</td>
<td>I thought the system was easy to use.</td>
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<tr>
<td>6</td>
<td>I thought there was too much inconsistency in this system.</td>
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<tr>
<td>7</td>
<td>I found the system very cumbersome to use.</td>
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<tr>
<td>8</td>
<td>I would imagine that most people would learn to use this system very quickly.</td>
</tr>
<tr>
<td>9</td>
<td>I think that I would need the support of a technical person to be able to use this system.</td>
</tr>
<tr>
<td>10</td>
<td>I needed to learn a lot of things before I could get going with this system.</td>
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Conclusions

• Accurate reproduction of human anatomy
• Radiation-free fluoroscopy guidance
• Unlimitedly repeatable
• Performance assessment
• Low-cost
Benefits

Potential to improve **PSYCHOMOTOR SKILLS** and **IMAGE INTERPRETATION** in a **SAFE ENVIRONMENT** for trainees during the learning process
Future research and development

Simulation of the respiratory cycle while performing the surgery

Integration of a virtual ultrasound guidance for a better visualization of the soft tissues
Acknowledgments

Mixed Reality Lab

Collaborators