Integration of a Virtual Reality Environment for Percutaneous Renal Puncture in the Routine Clinical Practice of a Tertiary Department of Interventional Urology: A Feasibility Study

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Correlatori: Prof. Marco Elli, Prof. Maurizio Vertemati, Dr. Gianluca Sampogna
Laureando: Greta Mondino (mat. 859232)
The thesis, affiliated to the NearLAB of the Politecnico di Milano, was created in collaboration with:

- **the Department of Biomedical Sciences and Clinics "Luigi Sacco", University of Milan at ASST Sacco Fatebenefratelli, Milan;**
- **the Departments of Radiology and Interventional Radiology** of the Department of Advanced Diagnostic Therapeutic Technologies at the ASST Grande Metropolitan Hospital Niguarda, Milan.
Clinical Background: Kidney

**Anatomy**

Kidneys (or renal cavities) are parenchymal excretory organs, shaped bean, mainly composed by renal calyces and renal pelvis. They lie inside the abdominal cavity **at the level of the 12th thoracic** and first three lumbar vertebrae.

The renal anatomy is constituted by a rich vascularization characterized by some differences between different individuals called anatomical **intersubjective variabilities**. There is not an ideal patient: each patient is unique.
Clinical Background: Kidney Pathologies

There are some pathologies of the kidney, which if suspected, require a histological examination of a sample taken by biopsy.

**Kidney Stones Disease**
It is a clinical condition characterized by the presence of one or more variable-size stones (normally of around 4-5 mm) contained within the urinary system. Between 1% and 15% of people in the world have been hit by urinary calculus at some point in their life.

**Renal Tumors**
It is a neoplasia of this organ. There are several types of this. It affects about 330 thousand new cases every year in the world.
Clinical Background: Percutaneous Renal Puncture for Renal Biopsy

The Renal Biopsy is a diagnostic technique that permit to take a tissue sample to be able to analyze it. The access to the kidney is realized thanks to a procedure called **Percutaneous Renal Puncture**. It is a _mini-invasive approach that permit to minimize the surgical trauma_.

The access to kidney is realized piercing the skin with a very thin needle, behind the axillary axis and immediately above the 12\textsuperscript{th} rib, until it reaches a calyx in the kidney cavities.

The procedure is performed using a double guide:
- the **ultrasound guide**
- and the **radiological** one.
Clinical Background: Related Issues and Possible Solutions

The difficulty is due to the possible associated adverse effects, which sometimes may be fatal as haemorrhage, pleural injury or sepsis.

Because of potential complications, trainees have difficulty gaining experience and they usually end their academic curriculum performing just few percutaneous renal punctures.

HOW TO FACE THESE PROBLEMS?

A virtual reality simulator for a percutaneous renal puncture might be an appropriate solution.

Simulation is used in many branches of medicine to support the activity of the professionals and try to reduce human errors.
State of the Art: Virtual Reality Medical Simulators

“Virtual Reality (VR) can make learning surgical anatomy easier by allowing the student to explore the interrelations of various organ systems in perspectives not available through other standard teaching techniques”
(Satava, 1993)

“VR-Simulation is defined as a technique to replace or amplify real experiences with guided experiences, often immersive in nature, that evoke or replicate substantial aspects of the real world in a fully interactive manner”
(Riaz A. Agha, 2015)

“Perceiving the needle interaction forces could allow the surgeon to better estimate the position of the needle inside the tissue, enhance the accuracy in soft tissue identification”
(Enayati et al., 2016)
State of the art: Limitations & Percutaneous Renal Puncture Simulators

<table>
<thead>
<tr>
<th></th>
<th>PERC Mentor™</th>
<th>LACE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of simulator</strong></td>
<td>Workstation: Virtual Reality Simulator with a Flank Box</td>
<td>Virtual Reality Environment Software</td>
</tr>
<tr>
<td><strong>Tactile feedback</strong></td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Conspicuous</td>
<td>Negligible</td>
</tr>
<tr>
<td><strong>Possibility of became patient-specific</strong></td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td><strong>Integration in clinical practice</strong></td>
<td>NO</td>
<td>YES</td>
</tr>
</tbody>
</table>

- **Percutaneous Renal Puncture Simulator**
  - PERC Mentor™
  - LACE Virtual Reality Environment
The chosen simulator is called LACE. It is a virtual reality environment developed by four students of the NearLAB in collaboration with the University of Chicago.

Properties:
- Platform developed in C++;
- Physical configuration → computer with Windows, mouse, keyboard and haptic device (Phantom Omni®, Geomagic);
- Implementation configuration → integration of four libraries:
  - Visualization Library
  - Quick Haptics
  - Computational geometry Library
  - Electromagnetic tracking Library

LACE consists of several classes in which the variables and functions used to allow virtual simulation are declared.
WHAT WE HAVE DONE

Healthcare  |  Medicine  |  Tech  |  Biomedical Devices
Science  |  Engineering  |  Biology
Aim of the Thesis

- CT Images Collection and Patient-Specific 3D Models Reconstruction
- Standardization of LACE
- Development and Optimisation of a Simulation Process to make it possible to use as a patient-specific simulator
- Development of a standardized workflow for the integration in the clinical practice
- Evaluation of LACE as a patient-specific simulator and in terms of Ease of Use
- Evaluation of the simulator as a Medical Device
LACE as a Patient-Specific Simulator

PATIENT CT EXAMS FROM NIGUARDA HOSPITAL

3D SLICER

Conversion of the file

PATIENT CT SAMPLING

EXTRACTION OF TARGET COORDINATES

3D SEGMENTATION OF EACH ORGAN

CREATION OF MESHES AND DECIMATION

Conversion of the file

DATA ENTRY IN THE Patient FOLDER

SIMULATION

EVALUATION OF THE USER PERFORMANCE

USER PERFORMANCE DATA

Conversion of the file
CT Image Collection

PATIENT CT EXAMS FROM NIGUARDA HOSPITAL

3D SLICER

- 3D SEGMENTATION OF EACH ORGAN
- CREATION OF MESHES AND DECIMATION
- EXTRATION OF TARGET COORDINATES
- CT SAMPLING

Conversion of the file

Conversion of the file

DATA ENTRY IN THE Patient FOLDER

SIMULATION

EVALUATION OF THE USER PERFORMANCE

USER PERFORMANCE DATA
CT Images Collection

CT Images
CT Images are based on a grey scale in which each value is proportional to the tissue density. To work on an anatomical district such as the abdomen, it was necessary to acquire a certain clinical eye to identify the regions of interest (abdomen organs and circulation pathway).
Post-processing Phase

Conversion of the file

PATIENT CT EXAMS FROM NIGUARDA HOSPITAL

3D SLICER

3D SEGMENTATION OF EACH ORGAN ➔ CREATION OF MESHES AND DECIMATION ➔ EXTRACTION OF TARGET COORDINATES ➔ CT SAMPLING ➔ Conversion of the file

DATA ENTRY IN THE Patient FOLDER ➔ SIMULATION ➔ EVALUATION OF THE USER PERFORMANCE ➔ USER PERFORMANCE DATA
LACE as a Generic Simulator

LACE as a Patient-Specific Simulator
To realize a 3D Reconstruction with 3D Slicer it is necessary to perform for each organ of the abdomen cavity basically four steps:

1. Uploading of the CT file in DICOM format from the Directory
2. Performing a Semi-Automatic Segmentation
3. Choice of the Volume Rendering Effect
4. Data (Meshes files) back-up as .stl format

For the Semi-Automatic Segmentation we decide to use almost entirely a Thresholding Effect to select the regions of interest. For the Volume Rendering instead we have chosen to perform a Superficial Rendering based on triangulation. There are several ways to perform this process: the proposed one is what, in our opinion, provides a good result in the face of user-friendliness.
**3D Slicer: Extraction of Target Coordinates and CT Sampling**

**Extraction coordinates**

It is necessary to identify a target inside the 3D models to insert in LACE. Obviously, the **operative target is different according to the patient of his pathology**.

We have used the function Place some Fiducials to extract and save point coordinates in mm.

**CT Sampling**

From the CT are extracted the information related to the fluoroscopy image, needed to perform the Percutaneous Renal Puncture. However, because of a limitation in LACE implementation choices, it is necessary to reduce the dimension of the CT files to permit a faster and optimized uploading of these on LACE Virtual Reality Environment.
Simulation on VRE and Outcomes

Conversion of the file

PATIENT CT EXAMS FROM NIGUARDA HOSPITAL

3D SLICER

EXTRACTION OF TARGET COORDINATES

CT SAMPLING

CREATION OF MESHES AND DECIMATION

DATA ENTRY IN THE Patient FOLDER

SIMULATION

EVALUATION OF THE USER PERFORMANCE

USER PERFORMANCE DATA

Conversion of the file
Simulation and Outcomes

Before opening the Virtual Reality Environment, the user has to locate the files created previously inside the folder 'Patient' specially created inside the directory.

The VRE requires the access to ten different files:

• the sampled CT called CT sample.mhd
• the original CT called CT.mhd
• the needle mesh called Needle.3ds
• and the organ meshes of the abdominal cavity that must be those of:
  - the kidneys, named kidneys.stl;
  - the spleen, named spleen.stl;
  - the lungs, named lungs.stl;
  - the skin, named skin.stl;
  - the liver, named liver.stl;
  - the ribs, named bone.stl;
  - and the circulation pathway, named circulation.stl.
Integration in Clinical Practice: Pre-operative Workflow Development

The workflow has been developed mainly by interviewing surgeons who deal with the type of intervention we talked about previously. We can identify two pools, the Clinical Activity and the Surgical Unit Activity, divided in three different phases:

- Acceptance and Decision Making Phase (in green);
- Simulation Phase (in blue);
- Operative Block Activity and Immediate Post-Operative Phase (in yellow and orange).

Several actors participate to this workflow, in particular: interventional radiologists, anesthesiologists and nurses.
Experimental Validation Protocol

<table>
<thead>
<tr>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td>Male</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>62</td>
<td>64</td>
<td>63</td>
</tr>
<tr>
<td><strong>Pathology</strong></td>
<td>Tumour of the left kidney: Upper Calix</td>
<td>Suspected Right Renal Neoplasm: Lower Calix</td>
<td>Hypodense alteration of the Right Kidney to the Middle third</td>
</tr>
<tr>
<td><strong>Intervention</strong></td>
<td>Thermo-ablation</td>
<td>Renal Biopsy</td>
<td>Renal Biopsy</td>
</tr>
<tr>
<td><strong># slices along longitudinal axes</strong></td>
<td>916</td>
<td>156</td>
<td>138</td>
</tr>
</tbody>
</table>
Evaluation of the Work in terms of Ease of Use and Utility

This evaluation was performed on the base of the questionnaire developed by us. It is a 13-points questionnaire based on a Likert Scale.
Conclusions and Future Developments

In conclusion, for our knowledge, this simulator represents the **first patient-specific virtual reality simulator to perform Percutaneous Renal Puncture access**, representing a solid base for future studies like this. A big advantage of this work is the **standardization** of the processes because:

- The simulation workflow is valid for numerous applications of LACE;
- The integration workflow represents a good models for the integration of other technologies

**Future Developments**

Possible Developments can regard both software development and clinical trial:

- Implementation of ultrasound guide;
- Implementation of scene visualization through **3D glasses**
- Improvement of number of clinical subjects and professionals
THANKS FOR YOUR ATTENTION!