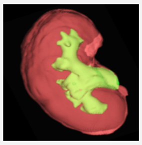


Organ Phantom for the Assessment of Robotic Surgeries

D. Y. Kim[1], D. Li[1,2], X. Tan[1,3], M. Jeong[1], E. Choi[1,2], K. Ruffieux[2], A. Miernik[4], P. Fischer[2], T. Qiu[1,2,*]
1 Cyber Valley Group – Biomedical Microsystems, University of Stuttgart, Stuttgart, Germany;
2 Micro Nano and Molecular Systems Lab, Max Planck Institute for Intelligent Systems, Stuttgart, Germany;
3 Department of General, Visceral and Transplant Surgery, University Hospital Tübingen, Tübingen, Germany;
4 Department of Urology, Faculty of Medicine, University of Freiburg - Medical Centre, Freiburg, Germany;
* Corresponding author: T.Q., tian.qiu@ipc.uni-stuttgart.de

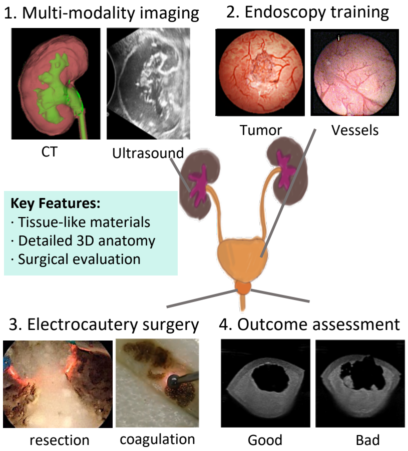
HAMLYN SYMPOSIUM ON MEDICAL ROBOTICS 2021

Introduction

Minimally-invasive robotic surgery is growing and its impact is being felt in many areas, including urology. However, the training standards to ensure the safe and effective implementation of optimal surgical procedures have not yet been fully established. One of the most important reasons is **the lack of a realistic in vitro training environment for minimally-invasive surgery.**

A virtual reality-based surgical environment offers a digital, interactive, instructor-free and safe surgical training environment. However, its level of realism is lacking. For instance, it suffers from slow or inaccurate estimates for the deformation of organs, a limited interaction between the medical instruments and soft biological tissues, such a general lack of realistic haptic feedback. **To tackle this, we combine a soft, anatomically accurate physical phantom with digital interface to build a cyber-physical organ phantom for the realistic simulation and assessment of robotic surgeries.**

In this poster, we report a full urinary tract phantom model (**Fig. 1**) that perfectly resembles the anatomical structures with sub-millimeter detail. The kidney, the bladder and the prostate are built with soft materials that show the correct appearance in common medical imaging modalities. The model possesses accurate surface textures an haptics of the corresponding human organs. We validated their fidelity and used the model for ‘real’ surgical procedures with clinical instruments. New sensing methods permit the quantitative assessment of the surgeons’ performance. These can also be used to score robotic procedures.



Key Features:
- Tissue-like materials
- Detailed 3D anatomy
- Surgical evaluation

Figure 1. An overview of the full urinary tract model that consists of the kidneys[1], bladder[2] and prostate[3].

Method

The 3D shapes of the organs were obtained by reconstructing human computer tomography (CT) data [1]. The surface textures of the organs, including blood vessels and tumors, were first endoscopically recorded and then extracted to develop a custom digital model. This data was processed to develop negative molds, which were then 3D-printed. The soft organ phantom were made by injection molding of polymeric materials (and custom material combinations), to reproduce the elasticity, as well as the correct electrical and heat conductivity. Similarly the acoustic (ultrasound scattering and absorption) contrast and the optical properties (transparency and colors) were adjusted to match those of the real organs [2]. **Our method allows for high-resolution structures as well as the use of realistic biomimetic materials that can be imaged, cut, coagulated and sutured [3]. The human-like organ phantom ensures a realistic and precise deformation as well as the interaction with the clinical instruments.**

For the performance assessment of the trainee or the robotic device, **our system utilizes quantitative computational analysis, based on multiple sensing modalities** embedded in the phantom, for example:

- Pressure sensing [2]
- Ultrasound imaging [3]
- Electrical sensing [4]
- Computer vision [5]

Results

Our physical phantom models were validated with multiple medical imaging methods, such as CT, ultrasound imaging and endoscopy (**Fig. 1**). The anatomy replicates the human organ in details with sub-millimeter resolution [1,4]. The soft materials allow the deformation of the phantom during the surgery to offer realistic visual and haptic feedback to the surgeons. The fine details of blood vessels and bladder tumor models are included on the inner wall of the phantom. The vascular network allows the surgeons to visually track structures and orient themselves while operating the endoscope, and to perform biopsy and resection procedures on tumors. The practice is an essential training component to learn the haptic feedback and to strengthen their hand-eye coordination.

The full urinary tract model is suitable for many types of urological surgeries, for example, open surgery, transurethral endoscopy, and laparoscopy including robotic surgery. One example of **the urethrovesical anastomosis (UVA) procedure in a radical prostatectomy** was successfully performed with laparoscopy (**Fig. 2**). Essential physical parameters are sensed with the embedded sensors to provide quantitative data to evaluate the success of the procedure and the computation model offers useful feedback to the surgeons to optimize their skills in specific aspects (**Fig. 3**), for instance, the safe preservation of adjacent nerves, the consistency and smoothness of tissue resection, and the strength and symmetry of the sutures.

Realistic Surgical Simulation

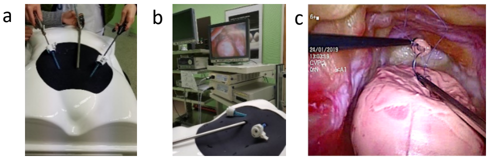


Figure 2. Laparoscopic UVA training system. (a-b) Surgical simulation set-up; (c) The suturing between the urethra and the bladder neck was performed to train the laparoscopic skills.

Surgical Performance Matrix

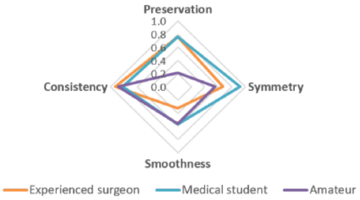


Figure 3. Example parameters to score the performance of a trainee. [3]

Discussion

We present the full urinary tract model with detailed features and tissue-like soft materials for the simulation of minimally-invasive surgical procedures. The model allows the evaluation of the performance of instruments, surgeons or surgical robots. **The same phantom models can be reproducibly obtained, which is essential for the quantitative assessment. Our models are suitable for endoscopic as well as laparoscopic procedures. The embedded sensing features enable the quantitative evaluation of the “surgical” outcome, which results in a steeper learning-curve of medical students, and will facilitate the development of surgical robots.** The combination of, what we believe are the most realistic physical organ models with digital imaging, sensing and tracking features makes for novel cyber-physical organ phantoms.

Cyber-physical Organ Phantom

MAX-PLANCK-GESELLSCHAFT
Universität Stuttgart
UNIVERSITÄTS KLINIKUM FREIBURG
CyberValley

References

[1] F. Adams, *et al*. Soft 3D-printed phantom of the human kidney with collecting system. ***Annals Biomed. Eng.***, https://doi.org/10.1007/s10439-016-1757-5 (2017).
[2] E. Choi, *et al*. Soft urinary bladder phantom for endoscopic training. under revision (2021).
[3] E. Choi, *et al*. A high-fidelity prostate phantom for surgical simulation and quantitative evaluation. ***Annals Biomed. Eng.***, https://doi.org/10.1007/s10439-019-02361-7 (2020).
[4] X. Tan, *et al*. Soft liver phantom with a hollow biliary system. ***Annals Biomed. Eng.***. https://doi.org/10.1007/s10439-021-02726-x (2021).
[5] D. Y. Kim, *et al*. Computer-assisted quantitative assessment of endoscopic skills based on a urological phantom. under revision (2021).