Transactions on Additive Manufacturing Meets Medicine
Trans. AMMM, Vol 3, No 1, 2021, Article ID 502

Infinite Science | Publishing

Advanced training scenarios for liver surgery with realistic interactive 3D-printed phantoms

H. Nopper[1*], O. Schendel [1], F. Karayagiz [1], U. S. Freitas[1], T. Lueck[1], T. Stadie[2], M. Lampe[2], A. V. Reinschluessel [3], T. Doering[3], D. Salzmann[4], D. Weyhe[4]

[1] *cirp GmbH, Department Research and Development, Heimsheim, Germany*
[2] *SZENARIS GmbH, Bremen, Germany*
[3] *Digital Media Lab, University of Bremen, Bremen, Germany*
[4] *University Hospital for Visceral Surgery, Pius-Hospital Oldenburg, Oldenburg, Germany*
[*] *Corresponding author, email: hans.nopper@cirp.de*

Abstract: Realistic surgery phantoms possess the potential to improve medical training and as a result improve surgery outcomes, reduce operation time and minimize patient risks. In this work, we developed a training scenario within visceral surgery, implementing lifelike liver phantoms using a hybrid manufacturing approach combining collagen-based casting and 3D-printing. Being equipped with integrated sensors, we developed a feedback system to assess the performance of the trained procedure. This could lead to a new paradigm within visceral surgery training.

I. Introduction

The use of simulation has established itself in training and further education such as flight simulation. At present, surgical simulations have not yet found their way into structured visceral surgical training, though providing the possibility to systematically train relevant and customised cases. They could improve and complement structured visceral surgical training, offering a safer and more practical alternative to observation in a first step of a training [1]. However, a lot of modern technologies, such as Virtual Reality, lack the crucial haptic feedback. With the recent progress, lifelike organ phantoms in contrast, enable learning surgical palpation skills and motoric abilities and thus possess the potential to create a paradigm shift in medical training. The “VIVATOP” project (**V**ersatile **I**mmersive **V**irtual and **A**ugmented **T**angible **OP**) – funded by the Federal Ministry of Education and Research – is focused on the development of comprehendsive training scenarios for surgeons in visceral surgery. To create realistic surgery phantoms, it is vital to ensure the compatibility with sonography and high-frequency (HF) devices. Establishing a feedback system to evaluate the procedure was another target. Our contribution in this context is three-fold: (1) to develop corresponding phantom manufacturing methods, (2) to integrate interactive sensors compatible with a HF-device, and (3) to implement a comprehensive training scenario, compromising the requests of surgeons.

I.I General manufacturing considerations

State-of-the-art printing technology cannot meet the targeted characteristics, majorly owed to the fact that the determined liver hardness scale encompassed values on the soft side, even below the Shore 00 range [2]. Our aim to be displayable by modern imaging technologies and compatible with a HF-device required a certain water content in the material. Standard UV-curable plastics lack those features. Therefore, we decided to apply a hybrid approach combining collagen-based casting and 3D-printing.

Figure 1: Liver phantom in 50 % scale with transparent tissue material showing embedded blood vessels (left). Liver phantom with opaque tissue material (right).

I.II. Integration of feedback sensors

To achieve our objective to monitor the performance of the trainee with a feedback system, we equipped critical structures of the phantom with an electronic sensor system. This enables the training system to detect vessel damage live during training and to generate corresponding changes in the patient’s vital signs. Respective blood discharge could be presented by Augmented Reality glasses, if desired.

I.III Implementation into a training scenario

Based on interviews with our target groups, personas were created. These led to an advanced training concept, which is designed to be conducted in a skills lab (Fig. 2). Embedded into a realistic surgery environment, the trainee can monitor vital parameters of the patient. The liver phantom, which is embedded in a dummy, can be adapted exactly to the targeted pathology. During the surgical simulation, additional stress can be created via an interface

DOI: 10.18416/AMMM.2021.2109502

on a tablet (e.g., add telephone ringing). An interactive feedback system monitors the performance of the trainee and emits a signal in case of violation of a critical vessel. This leads to a change of the patient's vital parameters. The trainee then has to develop exit strategies to overcome the critical situation and to continue the operation.

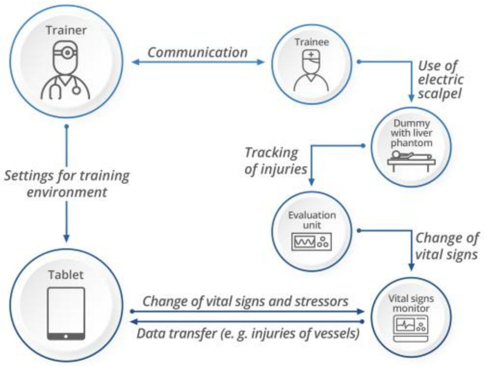

Figure 2: Interactive training scenario overview

This kind of training enables to experience rare situations which trainees may have never encountered in real life.

II. A hybrid manufacturing method

Our hybrid manufacturing approach enables the realization of organ tissue with a collagen-derived material that emulates the bespoke hardness of the corresponding living tissue, while maintaining compatibility with a HF-device. It can be realized in transparent or opaque color (Fig. 1). A 3D-printed mold serves as a framework to cast the outer shape. Corresponding model components such as blood vessels and tumors are 3D-printed with flexible TPU material and placed in the mold prior to casting, seamlessly integrating them into the resulting phantom. Critical components are supplementary prepared with a newly developed process to serve as combining collagen-based casting and 3D-printing feedback system within the phantom (Fig. 3). The surgery phantoms were based on real patient cases. The magnetic resonance imaging (MRI) or computed tomography (CT) images were segmented in relevant anatomical features, to provide the geometrical data of target organs in form of triangular meshes. These meshes are used in two ways: first of all, to support the design of the mold, based on the organ's geometry and secondly to provide geometric data for additive manufacturing, to print the inherent features like vessels and tumors. In this process the later placement of the features in the mold has to be prepared with diligence to assure precision. Due to its geometric accuracy, support-free construction and large building space, the Selective Laser Sintering (SLS) process was selected. In this powder bed-based process, the thermoplastic is melted with a laser beam and the component is manufactured layer by layer. Blood vessels and tumors are built in a soft thermoplastic polyurethane (TPU) material (>Shore 80 A) in order to keep these parts flexible. A harder material, Polyamide 12 (PA12), is used for the mold.

III. Results and discussion

In the future, the hybrid approach, being a relatively elaborate process, may be substituted by a direct 3D-printed approach. This especially applies to customized preoperative training cases, where timing is a critical driver. Current state-of-the-art 3D-printing technology lacks the capabilities to do so. In the training and education phantom realm, those drivers are less critical and a certain amount of standardization may enable an optimized benefit to cost ratio.

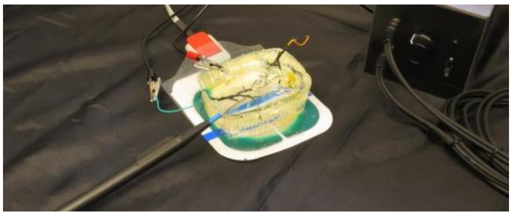

Figure 3: Sensor implementation test on a casted test phantom

IV. Conclusions

In general, simulations in medical education offer the advantage of training standardization, integrating evidence-based guidelines and eliminating time and place constraints. Being independent from the occurrence of real relevant operations, training gets more systematically plannable. Hence surgeons could be appropriately prepared for specific cases, which can result in reduced task completion time and better performance [3].With the new training concept developed here, it is also possible that students focus on the skills needed to make the most of valuable training time and get better and more effective feedback from the trainer. The training phantoms developed within this project possess the abilities to practically train and learn the fundamental surgical palpating and motoric skills, due to lifelike material properties. Procedure and surgical performance evaluation through feedback systems might pave the way to revolutionize the future of surgical training. The efficiency of our training approach will be determined as part of an evaluation, which is planned for the near future.

Acknowledgments

The phantoms described here were only made possible by the support of the Fraunhofer Institute for Digital Medicine MEVIS, Bremen, Germany. In addition to the generation of the CAD shells from CT data, their help enabled the generation of surface textures, e.g., for cirrhotic livers.

Author's statement

Research funding: Funded by the Federal Ministry of Education and research (BMBF); project VIVATOP; funding code 16SV8082 Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

References

[1] R. Kneebone & D. ApSimon, Surgical skills training: simulation and multimedia combined, in Medical Education, vol. 35, issue 9, 2001, pp. 909–915.

[2] T. Lueck, H. Nopper, O. Schendel, D. Weyhe, D. Salzmann, V. Uslar, A. V. Reinschluessel, T. Doering, T. Muender, R. Malaka, A. Schenk & C. Schumann, Exploring realistic haptics for 3D-printed organ phantoms in surgery training in VR and AR. Transactions on Additive Manufacturing Meets Medicine, vol. 2, issue 1, 2020.

[3] David T Wong, Arpan Mehta, The effect of virtual reality bronchoscopy simulator training on performance, European Journal Anaesthesiology, 2019 Mar; 36(3):227-233.