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Exploring realistic haptics for 3D printed organ phantoms in surgery training in VR and AR

T. Lück[1], H. Nopper[1*], O. Schendel [1], Prof. Dr. D. Weyhe[2], Dr. D. Salzmann[2], Dr. V. N. Uslar[2], A. V. Reinschluessel [3], Dr. T. Döring [3], T. Muender[3], Prof. Dr. R. Malaka[3], Dr. A. Schenk[4], and C. Schumann[4]

[1] cirp GmbH, department research and development, Heimsheim, Germany
[2] University hospital for visceral surgery, Pius hospital Oldenburg, Oldenburg, Germany
[3] University of Bremen, Digital Media Lab, Bremen, Germany
[4] Fraunhofer institue for Digital Medicine MEVIS, Bremen, Germany
[*] Corresponding author, email: hans.nopper@cirp.de

Abstract: Virtual (VR) and Augmented reality (AR) represent excellent tools for surgeons to understand spatial relationships, exercise anticipated workflows and hence improve surgery results. By providing realistic haptic feedback, implementing 3D-printed organ phantoms to those tools, their benefit becomes even more compelling, increasing their immersion. In this work we have investigated the resemblance of organ phantoms to the originals regarding physical hardness, touch and palpation. In a user study involving 12 surgeons, we evaluated cast liver phantoms in a 50 % scale. Results allowed the configuration of measurement tools for exact exploration of realistic haptics within this context.

I. Introduction

Tools of virtual reality (VR) and augmented reality (AR) possess the potential to improve training within surgery for all involved parties.

The "VIVATOP" project (**V**ersatile **I**mmersive **V**irtual and **A**ugmented **T**angible **OP**), which is funded by the Federal Ministry of Education and Research, targets, among other goals, to sharpen the immersion within those tools by introducing 3-D printed organ phantoms as spatial comprehensible interaction objects. Therein visceral surgery was selected domain of focus.

In case of VR, while interacting with VR-glasses or a 3D display in a VR environment, abstract gestures or handles [1, 2, 3] are used as interface for the hands. These do not possess the haptic and shape of the real object.

In case of training with AR realistic organ phantoms are preferably used to create the most vivid experience of the intended surgical scenario.

Surgeons and physicians rely heavily on their tactile sensations in everyday work hence a realistic simulation of these properties would lead to a major breakthrough in enhancing surgical skills and results.

Starting point for achieving realistic properties is of course to quantitatively measure the exact hardness of the targeted "in vivo" organs and to render these in the respective 3D-printed or cast phantom. A key problem subsequently is that neither a standardized measurement procedure nor a proper organ hardness data base exists in this very range of soft solids e.g. food, animal tissue or "in vivo" organs not to mention complex pathological samples. This applies especially to the very soft range of the material scale which could be found in various examples of visceral surgery.

One of the main project targets entails closing this gap and generating robust measurement results as a basis for producing realistic haptic interaction objects.

The lack of state-of-art 3-D printing technology to display, to a large extent, the realistic soft material properties of "in vivo" phantoms [4] led to the application of gelatine as preliminary phantom sample material. As a first step, gelatine liver phantoms in a 50% scale with accompanying reference measuring bodies (Figure 1) in a broad tactile hardness range have been created for evaluation through "touch and feel" by surgeons (Figure 2).

Figure 1: cast gelatine liver phantom sample in a 50% scale for evaluation and a reference measuring body.

Our contribution in this context is two-fold: (1) to encompass the relevant hardness measurement range by generating and evaluating gelatine test samples (2) based on the results to configure a measurement tool tailored to the intended application.

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Figure 2: physician at Pius Hospital, Oldenburg evaluating a cast liver phantom sample in a 50% scale

These two steps serve as a preparation for “in vivo” organ measurements during laparotomies at a later stage. The generated, relevant hardness data base, can subsequently be balanced out with 3-D printed or cast organ phantoms. Measurements for inorganic polymers are preferably conducted within the Shore-hardness scale.

II. Material and methods

Five different liver phantoms in a 50% scale have been evaluated by a group of 12 surgeons (5 residents, 1 fellow, 5 consultants and 1 superintendant). The samples have been measured beforehand with a durometer type Shore 00. The measurement range in each Shore area e.g. Shore 00 or 0 stretches from 0 – 100. Following values have been detected: Probe A = not quantifiable, out of measurement scale; Probe B = 2-5; Probe C = 10-11; Probe D = 26; Probe E = 39.8. In terms of measurement precision it has to be stated that Shore values below 10 and above 90 within this scale cannot be considered as dependable. The samples have been presented to the physicians in a random sequence. Each physician was requested to evaluate the liver phantoms on a Likert-scale starting from 1 (very realistic) up to 6 (not realistic at all) in terms of haptic consistency, haptic surface tension as well as the cutting sensation (only senior- and chief physicians; Figure 3) using authentic “in vivo” organs as a reference. Additionally the haptic comparability to a relevant organ or pathology could be described verbally. The data analysis was conducted using descriptive statistics.

Figure 3: Surgical consultant at Pius Hospital, Oldenburg conducting a cutting test for evaluation of realism of different 50% scaled liver phantoms

III. Results and discussion

Sample B received the highest ratings in terms of haptic consistency (mean: 2.9; SD=2) and surface tension (mean: 3.14; SD=3): Sample A received the highest rating in terms of cutting sensation (mean: 3.07; SD=2.5). The samples B (n=6) and C (n=4) were compared most frequently with a healthy liver, sample D most frequently to a fibrous respectively cirrhotic liver (n=5) sample E with a cirrhotic liver (n=5) and sample A with a fatty liver (n=5).

IV. Conclusions

The soft samples A and B reproduced the haptic characters of a healthy liver to the greatest extent. As those two samples exceeded the dependable measurement scale on the soft side, it is indicated to apply a scale in the softer range like Shore 000 or even below. The containment of the exact measuring range requires further research. There is further need for optimization in terms of surface tension and cutting sensation. The description of the haptic comparability with an “in vivo” organ or pathology varied depending on the sample, viz. different pathologies can be represented by varying the hardness grade. The corresponding measuring range spans across different Shore hardness areas, hence has to be addressed by different durometers. All observations were summarized to form a specification sheet for an adequate measurement tool. A subsequent test with a sample set adapted on the results will be executed to narrow down the measurement range. Arising from the questionnaire this adapted sample set should include integration of hard tumors in fatty or healthy liver, representation of pathological surface textures e.g. cirrhotic texture improvement of the cutting sensations by added outside skin, addition of a liquid film, integration of arteries within the organ, if possible and a more realistic color scheme.

AUTHOR’S STATEMENT

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