Tangible Organs – Introducing 3D Printed Organ Models with VR to Interact with Medical 3D Models

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ABSTRACT

Medical images contain important information for diagnosis and preoperative planning in modern medicine. Interacting with these images still happens mostly with a mouse, abstract gestures or handles. In a focus group with five surgeons, we evaluate the possibilities of 3D printed organ models for interaction in VR for the use case of surgery planning. The surgeons rate the approach as highly useful and highlighted the advantage of easier grasping the space relations, which would greatly improve the planning phase of surgery.

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CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **Haptic devices**; • **Applied computing** → **Health care information systems**; • **Hardware** → **Haptic devices**.

KEYWORDS

Medical Imaging; Image Navigation; Spatial Interaction; Virtual Reality; VR; 3D printing; 3D Model; Surgery; Focus Group

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INTRODUCTION

Medical imaging such as MRI (magnetic resonance imaging) and CT (computed tomography) produces a vast amount of 3D and 2D data. These images contain very important information for diagnosis and preoperative planning in modern medicine and aid the surgeons in novel and more complex treatments. Yet, interacting with these images, on the other hand, happens mostly on a 2D screen with a mouse. In case of a 3D display or virtual reality (VR) environment abstract gestures or handles [1, 4, 5] are used. But surgeons and physicians rely heavily on their tactile sensations in everyday work and their visual thinking, which is needed to put everything in relation to each other. One essential ability is to match what they know and see on the images to the real case in their hands. To be best prepared for the real case, the surgeons plan their interventions, which is also a critical stage in decision making [3]. Research suggests, that this activity depends on the level of expertise. In the specific circumstances of surgery the surgeons have to cope with (potential) conflicts between their goal and the biological laws governing the patient's body, who's anatomy might differ from the text books [3]. Therefore, achieving a better knowledge of the individual patient by using all available visualization possibilities beforehand is important to handle potentially critical situations during the intervention.

As 3D printing is on the rise for nearly 20 years now [7], we aim at giving the surgeons an interaction device that matches what they will experience in the operating room (OR) - an organ (model). We will print out the organ model based on the image data and integrate it with a VR viewer for the 3D model, additional information, and the raw images. Using a tracking framework to track the organ model and the hands, the surgeons will be able to naturally interact with the model, e.g., by turning, pressing or pointing onto the model and thereby inform themselves about the specific case. In order to investigate the potential of this approach, we run a focus group with five experienced visceral surgeons from a local university hospital to discuss the idea and requirements. We use the liver with tumors as an example case. The surgeons see great potential in the approach and state the usefulness especially for the liver, because of its complex internal structure which is hard grasp by visual thinking solely based on image data.

RELATED WORK

Researchers investigated the use of virtual environments to show medical image data. One example is the VR by Reinschluessel et al. [4], who evaluated different gestures to interact with 2D images shown on a screen in a virtual setting. King et al. [1] explored showing 2D images of MRI and CT scans in the complete field of view in the virtual space and thereby allowing for more images to compare at once. As an interaction modality they used a Gamepad controller. A similar approach was done by Sousa et al. [6], as they developed a virtual reading room for radiologists, allowing for "touch" on a table using infrared to scroll through the images. Reitinger et al. [5] went one step further and allowed for investigation of a 3D model in VR based on the images taken and further added a surgery planning option. The exploring and planning is done by an "Eye of Ra input device". These examples have in common, that they all use either gestures or a device to explore the images or model. The use of 3D printing in medicine has been increasing since 2000 [7]. A literature review by Martelli et al. [2] for the period of time between 2005 and 2015 showed that 71.5 % used it to produce anatomical models. The main advantage reported was better preoperative planning (48.7 %) and that it saved time in the operating room (32.9 %). As 3D printing is an expensive endeavor, there are efforts to make it more cost effective and affordable as published by Witowski et al. [8]. One example of using 3D printed organ models is by Zein et al. [9]. They used 3D printed livers or parts of the liver for planning of a transplantation to make sure they discover potentially unsuitable patients based on the anatomical structure or that they are aware of any anomalies. Their aim was to decrease complications during the actual surgery. This extra knowledge can be important, as Morineau et al. [3] showed that the expert's strategy to handle critical situations in surgery is knowledge based.

The VR misses the "realistic"sensation of what the users see, but offers a variety of options to show the important information from and in the image data. The 3D prints just show a selected view of the images and does not provide any further displaying options. Therefore, we aim at combining both modalities to match the haptic perception and the rich visualization possibilities of a VR to increase the knowledge of the surgeon.

METHOD & PARTICIPANTS

We performed a focus group with five physicians from a local university hospital. The experts were a head physician (**P1**), two chief residents (**P2, P3**) and two residents (**P4, P5**) of the visceral surgery department. We presented our idea using three approaches:

- a VR application using HTC VIVE[1] and controllers (see Figure 1)
- a solid transparent 3D print of an actual liver with a tumor and blood vessels (see Fig. 2 - scale ca. 1:4)
- six material probes of different softness to discuss the tactile properties (see Fig. 3)

In the VR environment, we attached the same liver model, which was printed as a 3D model, to one of the controllers. The physicians could inspect the model from all sides by turning the controller. The second controller is equipped with a simple line drawing tool to annotate the model. The physicians used this application before the discussion to spark the initial idea in their minds. We further explained that instead of a Vive controller they will use a 3D printed model to control the view in the VR. As the model was not of realistic size, one of the main questions was which size they would like to have it. Additionally, we asked for material properties in terms of softness using the material probes. As gaining knowledge to prepare the surgery is the central focus, we were interested in what are the essential parts in the 3D print as well as in the visualization in VR. Questions about the relevant planning steps and the derived planning features were related to this topic.

RESULTS & DISCUSSION

The discussion of the focus group was recorded and analyzed using thematic analysis. We identified three themes: application & interaction, organ visualization, and haptic properties.

Application & Interaction: This theme summarizes the two main application areas as they were discussed by the surgeons: surgery planning and training. The haptic model in combination with detailed visualization could provide surgeons with the important feeling for the spacial relation before surgery and it could be used to plan the volume of a resection. For this, the participants expressed the need to mark areas which will be removed, to scale the model to different sizes for more detailed views and to hide different vessels. The surgeons also saw a potential to use the tool for more precise discussions between multiple doctors. Observations during the focus group showed that turning the model in one's hand and pointing with fingers was used to show colleagues specific parts. The surgeons suggested that a surgery which is planned digitally could be used to automatically produce a short film to inform surgical nurse and other staff about the procedure. The second application which was discussed is the use of haptic models with different visualizations for the training of surgeons. The tool could provide the possibility to learn the connection between haptic feeling and the image data.

Organ Visualization: For all physicians, it was most relevant to have a correct perception of the distance and spatial relation between tumors and vessels in order to plan the surgery correctly. The main vessels are the most important ones to visualize in detail as they are critical for the surgery while smaller vessels were considered less important. For surgery planning the surgeons were most

[1]https://www.htcvive.com/

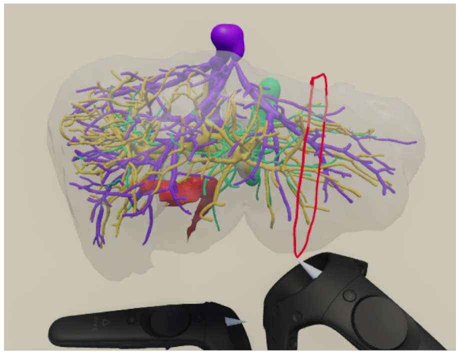

Figure 1: The view on the liver in the VR application

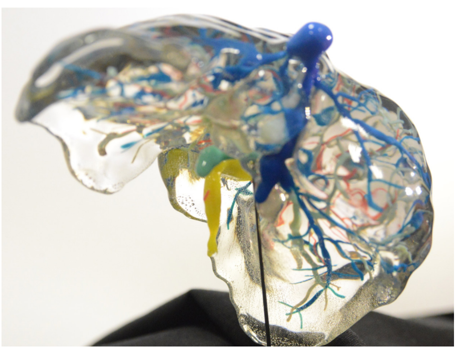

Figure 2: The 3D printed model

Figure 3: The material probes

interested in an abstract visualization with a see-through organ and vessels highlighted by colors based on standard color schemes. They were also interested in visualizing the near surrounding structures for spatial orientation. For training purposes, two different visualizations were requested: an abstract visualization and a realistic visualization. The abstract one should be used mainly for the surgery planning in order to learn about the spatial arrangement of structures in the organ. The realistic visualization aims at forcing users to use their haptic senses to explore the model. In both training and planning scenarios, it was requested to be able to display the CT/MRT images together with the model.

Haptic Properties: The surgeons discussed the size of the model, as for the realistic assessment of the position of blood vessels and a tumor the real size would be optimal. But as the model is an interaction device as well, they ended up in agreement that the real size might be too big in the presented example case of the liver and would be too heavy as well. They would prefer a model that fits the hand well. One idea of surgeons was instead of using patient individual 3D prints to use standard models of organs for interaction to save material, especially for the less complex cases. All physicians agreed that the model should have distinct haptic landmarks for orientation (e.g. ligament). For the material softness, the surgeons were not so much interested in a fluent gradient of material softness but rather distinct material softness for different kind of tumor entities. This is due to the fact that pre-existing conditions of the real organ can change its overall softness, so there is no standard softness which has to be matched.

All surgeons were enthusiastic about the idea to use a 3D printed model in combination with VR to discuss and plan interventions. As suggested by the literature, the surgeons highlighted the benefit of better spatial perception by using a 3D model. Based on their interaction with the model and how they discussed the model at hand, it came clear that this way of visualization and interaction encourages exchange between the experts. As the model was solid and the inner structures will not be reachable by pointing from the outside, the question of how to interact with them arises. This aspect has to be investigated in further discussions and studies, to find an intuitive and well-integrated solution. The surgeons also immediately thought about how the model can be used further for training purposes and how the different visualizations used for planning can aid this purpose. Depending on the application domain, the preferences for the appearance of the 3D print might differ – as an interaction device, a transparent model as shown in Figure 2 was not rated as important as for training purposes. Finally, the surgeons saw the potential to shift important decisions about resections to the planning phase. In the current workflow, the decision about what needs to be removed is made during the surgery. With the here presented possibilities the decision could be made before and therefore could reduce surgery time or the need for surgery at all and thereby increase the survival rate.

CONCLUSION

In a focus group with five surgeons, we evaluate the possibilities of 3D printed organ models for interaction in VR for the planning and training of surgeries. The surgeons rate the approach as highly useful and highlighted the advantage of easier grasping the spatial relations, which would greatly improve the planning phase of surgery. The next steps will be to design a 3D printed organ as an interaction device for a VR environment, as informed by the here presented research. We will conduct user studies with surgeons to further investigate the idea of combining 3D printing with VR.

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