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Study Protocol

Effectiveness of an Immersive Virtual Reality Environment on Curricular Training for Complex Cognitive Skills in Liver Surgery: A Multicentric Crossover Randomized Trial

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1. General description of project

1.1 Introduction

Continual advancements in technology have dramatically changed the ways of surgical education. Multimedia-based technologies and different computer-based simulators have been studied to enhance the efficacy of training and to improve the quality of care by reducing surgical complications.[1,2] The adoption of web technologies for cognitive online training can be a useful way of optimizing educational programs, allowing for anytime/anywhere training.[3] Computer-based surgical simulation, including three-dimensional (3D) models and virtual reality (VR) immersive environments, also hold enormous potential in surgical education.[4]

Liver surgery is considered an essential part of the general surgery curriculum, and trainees in this field need guidance to learn the complex liver anatomy, pathophysiology, patient management and necessary operative skills to successfully manage patients. Despite the implementation of various training models to improve skills, there is currently absence of high-qualitative research that really demonstrates that training results in improvement of skills in the clinical setting.

1.2 Rationale and Objectives

In liver surgery, to perform safe and accurate hepatectomy, it is important to understand the complex liver anatomy and the relationship between the tumor and the intrahepatic structures. To date, preoperative assessment of patients with liver tumors have been

mainly reliant on Computerized Tomography scan (CT scan) and Magnetic Resonance (MR) images. These modalities are limited to 2D displays, which require surgeons to reconstruct 3D spatial images based on their clinical knowledge and experience. This process needs a vast cognitive knowledge of liver anatomy and pathophysiology, and possibly leads to a significant amount of cognitive load. Cognitive load refers to the amount of information being processed by the working memory resources at any point in time.[5,6] To address this cognitive load in liver surgery, different desktop interface (DI) based 3D models and VR solutions have been developed.[7,8] Evidence suggests that for experts 3D reconstruction is beneficial for planning complex liver surgery but also for improving residents' understanding of liver anatomy and surgical planning.[6,9,10] The presentation of these 3D models is mostly as 3D PDFs on 2D screens and, therefore, it still has the limitation of depending on the viewer's mental ability to reconstruct images into 3D structures. In light of recent developments in digitalization of the healthcare system and surgical education, affordable VR solutions have been introduced for reviewing 3D models. Recently, immersive VR environments with context-sensitive presentation integrating relevant patient data have been introduced as a possible solution to improve surgical training and preoperative liver surgery planning.[11-13] While these studies provide subjective data on the potential of VR to enhance complex cognitive skills training, objective data to demonstrate its effectiveness as it relates to high judgmental skills are lacking.

1.3 Hypotheses

- We hypothesize that an immersive VR experience is superior to 3D imaging reconstruction to understand the complex liver anatomy and to devise precise pre-operative planning for general surgery residents.
- We hypothesize that a stepwise training model will enable general surgery residents to understand liver anatomy, surgical approach to liver tumors and pre-operative evaluation of patients.

2. Material and Methods

2.1. Training and assessment methods

- Basic cognitive training: by means of 3 web-based learning modules.
- Three-dimensional anatomy training and operation planning: by means of 3D modeling for planning liver surgery (Synapse 3D workstation *vs* Immersive VR environment)
- Assessment: by means of MCQs and real case scenarios

2.2. Basic cognitive training

Module 1. Liver anatomy

Module 2. Surgical approach to liver tumors

Module 3. Pre-operative evaluation

2.3. Three-dimensional anatomy training and decision making

The trainees will be trained individually by an investigator in order to be able to interact with 3D software and VR environment. To orient them to the technology and allow them to learn how to manipulate the model, a sample 3D model will be provided in both environments. The familiarization will be considered enough if they can perform the following features independently:

- Rotating of 3D model 360 degrees in both vertical and horizontal axes.
- Making the liver surface transparent to show the intrahepatic structures in relation to the liver surface.
- Isolating each intrahepatic structure to better analysis their configuration.
- Labeling all the structures (portal vein, hepatic artery, hepatic vein, tumor).
- Volumetry of liver base on portal branches.
- Virtual hepatectomy based on portal branches.
- Virtual hepatectomy using extract scoop region (wedge resection).
- Decision-making based on reviewed data

2.4. Assessment tools

1. A validated multiple choice questionnaire (MCQ) will be used to test whether residents will acquire the appropriate cognitive knowledge.

Proficiency level is defined as 80% of the average expert score (≥ 12 of 15-MCQs correct).

2. Ten real patient cases will be used as an assessment tool to test whether residents will acquire the appropriate skills in clinical decision making.

Proficiency level is defined as 80% of the average expert score (≥ 8 of 10 cases correct).

2.5. Study population

All surgical residents at Ghent University, Belgium, and Federico II University, Naples, Italy, irrespective of their postgraduate level (1-6), will be invited to participate in the program. Participation of residents will be on voluntary basis, and they are free to withhold their data from the research data set.

2.6. Sample size calculation

For alpha of 0.05, power of 0.80, an estimated standard deviation of 0.6, and moderately expected effect size that is compatible with pooled analysis of previous studies comparing VR with other digital training environments,[14] a sample size of 46 trainees is required to be able to show a statistically significant difference in results. Considering a potential dropout rate of 10%, a total sample size of 50 participants is needed.

2.7. Statistical analysis

Data analysis will be performed using R version 3.6.1 (2019, The R Foundation for Statistical Computing). Categorical data will be presented as absolute frequency and associated percentage rate. Symmetrically distributed data will be presented as mean ± standard deviation (SD). For independent samples, t-Test or Mann–Whitney U test, and for dependent samples, paired t-Test or paired Wilcoxon signed-rank test will be used to compare the performance differences according to the type and distribution

of variables. Reckoning with the study's crossover design, the comparison of continuous outcomes will be conducted using a linear mixed model, which assumes treatment (VR vs DI-based training) and period as fixed effects and resident as a random effect. To evaluate the risk of a carryover and learning effect between two sequences of tests, an interaction term *treatment x period* will be included in the mixed model to test for the presence of a carryover effect. Finally, the influence of resident gender and level (senior *vs* junior) on the outcomes will be explored by including in turn these variables into the model as fixed effects. An α level of $P < .05$ will be considered statistically significant and P values will be calculated 2-sided.

2.8. Randomization

Using computer-generated randomization stratified by postgraduate (PG) level (Junior (PG 1-2) *vs* Senior (PG ≥ 3)) and institution, residents will be randomized in a 1:1 allocation to one of two assessment sequences to devise a surgical plan for 10 clinical scenarios. In group A, the first five cases will be evaluated via a DI, and the second five cases will be evaluated in the VR environment; while in group B, the sequence of cases will be reversed. We consider one-hour washout time between the first and the second sequence of cases.

2.9. Criteria for selecting the radiologic imaging

CT scans used in this study will be taken from a library of CT scans of patients with liver tumors who underwent liver surgery at Ghent university hospital. Ten patient

cases weill be selected based on quality images that provide adequate visualization for surgical planning and reflect the intraoperative findings, as the final surgery performed was in line with the preoperative plan. Each preoperative image will be independently reviewed by two hepatobiliary surgeons to provide expert opinion on the optimal surgical plan, and cases with differing opinions will be excluded.

A total of 10 cases will be selected and patient data will be anonymized.

CT images will be imported into the FUJIFILM synapse 3D software, to produce 3D surface renderings of the liver surface, hepatic veins, portal veins, hepatic arteries and tumor. The same 3D model will be uploaded to the VR environment.

Various liver cases (benign and malignant) will be considered, and the final 10 cases will include the following surgical plan:

1. Left lateral resection
2. Left hepatectomy
3. Right hepatectomy
4. Extended right hepatectomy
5. Multiple wedge resection (cherry-picking metastasectomy)
6. Right posterior sectionectomy
7. Unresectable tumor due to main portal vein invasion
8. Central hepatectomy
9. Anatomical resection of segment 7
10. Unresectable tumor due to low volume of future liver remnant

3. Endpoints

3.1. Primary outcome

- The difference in accuracy of the residents' decision-making when reviewing patient data along with 3D liver models visualized via DI or VR, measured by comparing their performance to experts' opinion.

3.2. Secondary outcomes:

- Percentage of residents achieving proficiency in clinical decision-making after completing the training curriculum
- The difference in the timing to devise treatment plans using DI or VR
- Percentage of correct anatomical landmark and liver segments identification using DI or VR
- Knowledge retention assessed by comparing MCQs score before and after e-learning training

4. Cross-over randomized trial

After signing informed consent, all participants will complete a pre-training questionnaire to determine their demographic information and their experience in liver surgery. Then, they will answer a set of 15 MCQs to assess their baseline cognitive knowledge. Subsequently, they will receive the 3 e-learning models to study. After completion of e-

learnings, 15-MCQ will be provided. When the average MCQ score (i.e. at least 80%) of the experts (benchmark) has been achieved, they can progress to the next training step. If they will not accomplish the required score, they are referred to the e-learning platform and once they feel ready, a second different set of MCQ should be completed until they reach the benchmark score. They will have one month time to study the modules and associated tests on their own pace.

For the next step, residents will be invited to an individualized training session for 3D anatomy training and clinical decision-making. Participants will be trained individually by an investigator to be able to interact with SYNAPSE VINCENT and LiVeR Trainer. After completing the training session, the two groups will be compared for accuracy of their surgical planning when they used DI or VR to review 3D models of liver during surgical planning. Group A will receive the first 5 cases along with 3D models via DI and the second 5 cases in the VR environment, while group B will receive a reverse sequence of cases.

5. Ethics

The institutional review board at Ghent University Hospital reviewed and approved the protocol (IRB approval No. B6702020000275). Participation of trainees will be voluntary and informed consent will be obtained from all of them.

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