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Clinical value of 3d printing and virtual reality tools in pre-surgical planning of pancreatic cancer respectability

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RESEARCH

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ABSTRACT

Background

Pancreatic cancer has a high mortality rate and the only definitive management currently available is tumour resection. A patient-specific 3D model such as 3D-printed and virtual reality may be useful as an adjunct planning tool to the standard preoperative planning stages of pancreatic cancer resections.

Aim

This study aims to assess the clinical value of patient-specific 3D printed models and virtual reality visualisation in pre-surgical planning of pancreatic cancer respectability.

Methods

A CT scan of an anonymised pancreatic cancer case was selected with images post-processed segmented, and converted into a 3D printed model as well as a virtual reality visualisation. Both were presented to a group of 6 clinicians who specialise in the diagnosis and treatment of pancreatic cancer. Expert opinions were obtained by asking the participants to complete questionnaires on the clinical value of these models as a preoperative planning adjunct.

Results

Five out of six (83 Per Cent) participants agreed that the virtual reality tool was of more valuable compared to the 3D printed model when it comes to preoperative planning of pancreatic cancer resections. Similarly, 83 Per Cent also agreed the virtual reality was more useful in understanding the depth perception and spatial relationship between anatomical structures. There is potential for patient-specific 3D models to increase surgical safety, overcome minute anatomical discrepancies and plan complex surgical procedures.

Conclusion

This study demonstrates the clinical value of patient-specific models (3D printed and virtual reality) in the preoperative planning stages of pancreatic cancer resection. The models enhance understanding of the tumour's location and its relation to the surrounding anatomy. The models offer the option of manipulating the anatomy in a 3D plane, either tactilely (3D printed) or via controllers (virtual reality). Future research could include assessing the clinical value of 3D models in pancreatic cancer patients with complex anatomical discrepancies.

Key Words

3D printing, Virtual reality, Surgery, Pancreatic cancer

What this study adds:

1. What is known about this subject?

3D printing and virtual reality are increasingly used in medical applications with reports showing promise in assisting medical education, surgical planning and simulation of surgical procedures, as well as enhancing doctor-patient communication.

2. What new information is offered in this study?

This study compares 3D printing and virtual reality technologies in pre-surgical planning of pancreatic cancer resectability instead of investigating individual 3D visualisation tools, thus it adds valuable information to the existing literature.

3. What are the implications for research, policy, or practice?

3D virtual reality visualisation could serve as a useful pre-surgical planning tool in pancreatic cancer resection by enhancing understanding of complex anatomical structures and tumour.

Background

Pancreatic cancer has the highest mortality rate amongst the main types of cancer and is predicted to the be second leading cause of cancer death by 2030. It has a poor prognosis, with a 5-year survival rate of 8 Per Cent in Australia[1]. As the population ages, the burden of pancreatic cancer relative to other types of cancer is predicted to increase[2].

Currently, the only cure for pancreatic cancer is complete resection of the primary tumour which is linked to a long-term survival of about 25 Per Cent. Surgeons currently use 2-dimensional (2D) Computed Tomography (CT) or Magnetic Resonance Imaging (MRI) images to plan preoperatively for surgical resection. For surgeons with less experience in spatial perception, particularly trainees, accurately visualizing the 3-dimensional (3D) relationship between the tumour and surrounding vasculature is particularly challenging[3].

In recent years, three dimensional (3D) printing and virtual reality (VR) tools have been increasingly used in the medical field[4,5]. Applications of 3D printing and VR include education of medical students and doctors-in-training, simulation of surgical procedures for trainees, preoperative planning and refinement of anatomical diagnosis in patient-specific procedures[6-8].

Song et al. conducted a study showing that patient-specific 3D printed models improved surgeons' preoperative planning and understanding of patients' pancreatic cancer[9]. Sampogna et al. found that VR can be adapted for patient-specific procedure rehearsal and planning before any interventions is performed on the patient[10]. It can be used as an advanced tool for planning anatomically complex surgeries and rehearsing procedures that involve challenging or high-risk anatomical variances. A systemic review by Stott et al. found that augmented reality allowed better visualization and planning of complex steps in pancreatic tumour resection prior to conducting the actual resection[11].

Therefore, 3D printed and VR models may give surgeons the ability to physically orientate themselves with the tumour, pancreas and surrounding structures before operation3. It is an emerging approach that could enable surgeons to familiarize themselves with patient-specific anatomy and enhance spatial perception[12,13]. However, investigation comparing both 3D printing and VR in the preoperative planning of pancreatic cancer resection is lacking in current literature. Thus, the purpose of this study is to compare the clinical value of 3D printing and VR technologies in pre-operative planning of pancreatic cancer resection.

Materials and Method

Data processing

An anonymized case of a 62-year old male patient with pancreatic cancer was selected for generation of 3D printed models and VR demonstration. The CT scan of the selected case was performed on a 128-slice CT scanner, Siemens Definition Flash (Siemens Healthcare, Forchheim, Germany). The CT dataset in Digital Imaging and Communications in Medicine (DICOM) format was first imported into an open source software 3D Slicer (Brigham and Women's Hospital (BWH), Boston, MA, USA) for image processing and segmentation. Each slice of the pancreas and tumour was segmented manually due to its close location to the adjacent anatomical structures, with special attention due to being of similar density to the surrounding soft tissues. Blood vessel segmentation was obtained using the Flood Filling function in the 3D Slicer.

Generation of 3D printed models and VR models

All three segmented structures were then assembled using 3D rendering in MeshLab (ISTI-CNR, Italy) to allow visualization of the intended final object. The segmented volume data was then converted into Standard Tessellation Language (STL), which enabled printed by 3D printer. Abdominal aorta and arterial branches were printed using Anycubic Photon S. Pancreatic tumour was printed using Raise3D N2 Plus. Abdominal aorta and arterial branches were printed with PU80A; while pancreatic tumour was printed with Polylactic Acid (PLA). The total cost of printing the models was USD 20. Abdominal aorta and arterial branches were printed at a resolution of 47 µm at x, y and z-axis planes. Pancreatic tumour was printed at resolution of 12.5 µm at x, y and z-axis planes. The total time of printing is around 20 h.

The pancreas, tumour and vasculature were printed in separate colours and materials to provide better visual differentiation and representation of anatomical structures (Figure 1). This enabled the most accurate representation of the spatial relationship between the pancreas and pancreatic tumour. The ratio of the model size to the patient's anatomical measurements was 1:1. This enabled the participants to accurately view the 3D printed pancreas and tumour within the branches of the main blood vessels (between the celiac trunk and mesenteric artery). Participants were also able to freely manipulate the models in a tactile manner.

Unity (Unity Technologies, Inc., San Francisco, CA, USA) was used to upload the segmented structures into a VR headset. When using the VR headset, the user can walk around the virtual model. An interactive toggle box enabled the user to make all three structures individually disappear and reappear at their will, allowing for better visualization of the blood vessels within the parenchyma of both the pancreas and tumour (Figure 2).

Participant recruitment and data analysis

To assess and compare the clinical value of the 3D printed *vs* the VR model, both models were presented to six clinicians: four pancreatic surgeons, one surgical registrar and one gastroenterologist (Figure 3). An interview and questionnaire for each participant were carried out over a three-month period.

Each participant was asked to reflect on which model was more useful in 1) the pre-operative planning of pancreatic tumour resection and 2) understanding the spatial relationship and depth perception between the patient's anatomical structures. They were then asked to provide opinions on whether 3D printed and VR models provided additional benefits compared to the current imaging modalities used in preoperative planning of pancreatic cancer resection.

Data analysis mainly focused on the percentages or frequencies regarding participant's response on the clinical value and usefulness when compared 3D printed model and VR with original DICOM images.

Results

Overall, 83 Per Cent of participants agreed that the VR model was more useful in the preoperative planning of pancreatic tumour resection (Figure 4). Seventeen percent said they were unsure of which model was more useful. Eighty-three percent of participants also said that the VR model was more useful in understanding the depth perception and spatial relationship between anatomical structures (Figure 5). Seventeen percent indicated that both 3D printing and VR tools were equally useful.

When asked about the additional benefits patient-specific 3D models (either 3D-printed or VR) provided compared to the current 2D imaging modalities used, 83 Per Cent of participants agreed that 3D models could improve spatial resolution and spatial awareness between anatomical structures. They also indicated the 3D models could help plan complex surgery and increase surgical safety. One participant emphasised that the VR model specifically could provide additional benefit, whilst another responded saying that these models could provide additional value by marginally overcoming minute anatomical discrepancies.

Overall, participants agreed that the 3D models could provide better anatomical representation of the tumour in relation to the surrounding structures.

Discussion

The use of patient-specific 3D printed models as a preoperative planning tool has been demonstrated by Bati, et al. Reporting that 3D printed models improved surgical planning by enhancing spatial perception and pancreatic biliary anatomy. A study conducted by Seyama, et al. demonstrated the effective use of VR simulation in laparoscopic pancreatic tail resection[14]. Unlike previous studies, this study investigates and compares the clinical value of both 3D printed and VR models in preoperative pancreatic tumour resection. Our results showed that whilst both enhance preoperative planning of pancreatic cancer resection, the VR model was of higher clinical value, specifically when it came to understanding the depth perception and spatial relationship between anatomical structures.

Whilst not explored extensively, participants agreed that these models, particularly the VR model, could enhance the teaching and training for pancreatic surgical trainees. Sampogna, et al. States that further studies are necessary before mandating these new techniques into surgical training programs; however, the benefits of adapting these technological advances into abdominal surgical training are worth the extra time, cost and effort. Sampogna, et al. suggests that VR offers an eco-sustainable method of learning about interventional procedures that may solve some of the medico-legal and ethical issues of medical education. A study conducted by Aoki et al. found that using virtual reality as a preoperative simulation of pancreatic tumour resection is an extremely useful tool for the initial learning phase of junior surgeons[15]. Specifically, it provides a precise 3D reconstruction of vessels surrounding the pancreas. Song et al. found that the use of 3D printed models for teaching trainees scored higher than the use of conventional CT scans for teaching doctors in training.

Song, et al. found that 3D printed models scored higher than conventional CT imaging when it came to educating patients about pancreatic tumour resections and what the surgery would entail9. We did not investigate which model (3D printed or VR) surgeons preferred for patient education and consent, or which model would have scored higher patient satisfaction when used for obtaining informed consent for pancreatic tumour resection. This could be addressed in future studies.

Current systematic reviews such as Perica and Sun and Rossi et al. discuss the value of 3D printed models in liver tumours [16,17]. For example, Perica and Sun suggest 3D printed models can assist with preoperative planning and may be used in the simulation of malignant hepatic tumour resection. Rossi et al. suggests that further research could be conducted to investigate the relationship between patient-specific 3D printed models and patients' intra- and postoperative outcomes. However, there is a lack of similar reviews on the clinical value of both 3D printing and virtual reality in surgical planning of pancreatic cancer treatment.

There were several limitations in this study. The 3D printed model was not printed with the vasculature incorporated inside the pancreatic tissue and tumour, which would have been a more accurate representation of the patient's anatomical structures. One of the VR model's main limitations is the inability to pick up the virtual model and manipulate it with one's virtual hands (using the VR controllers) which would be similar to the actual surgery. Users are only able to walk around the virtual model and toggle the pancreas and tumour on and off. The ability to pick up and translate the model would be a better simulation of the surgery.

Additionally, both the 3D printed model and virtual model did not include the surrounding parenchyma and anatomical borders. Small sample size is another limitation. Future studies with inclusion of more sample size are needed. Furthermore, impact of using 3D printed models and VR on surgery outcomes (such as reducing operating time, reducing risks or complications) could be investigated in future studies.

Conclusion

This study demonstrates the potential value of 3D printing and VR in the pre-operative planning of pancreatic cancer resections. The VR model provides surgeons with a better understanding of depth perception and spatial relationship between anatomical structures. Further research, ideally with a larger number of participants of different clinical experience/expertise and more anatomically challenging cases will enable further insight into the clinical value of 3D printed and VR models in pre-operative planning of pancreatic tumour resections.

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CONFLICTS OF INTEREST

Authors declare that they have no competing interests.

Figures

Figure 1: 3D printed pancreatic model and abdominal aorta. Left image: aorta and arterial branches and pancreatic tumour placed together. Right image: 3D printed aorta model and pancreatic model separately. Reprinted with permission under the open access from Sun et al[8].

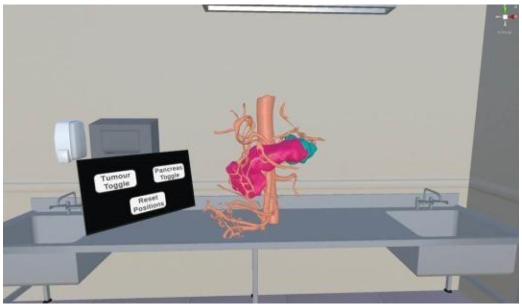

Figure 2: Virtual reality showing 3D visualisation of segmented models. Reprinted with permission under the open access from Sun et al[8].

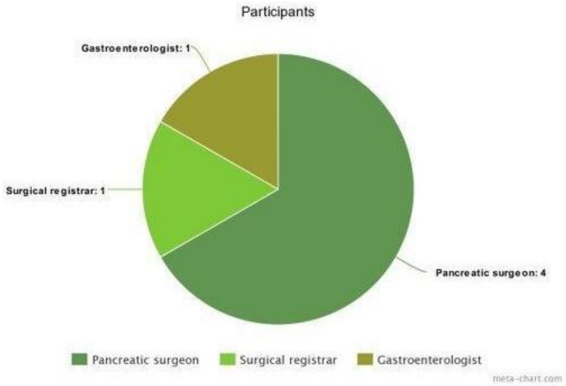

Figure 3: Participants' clinical background.

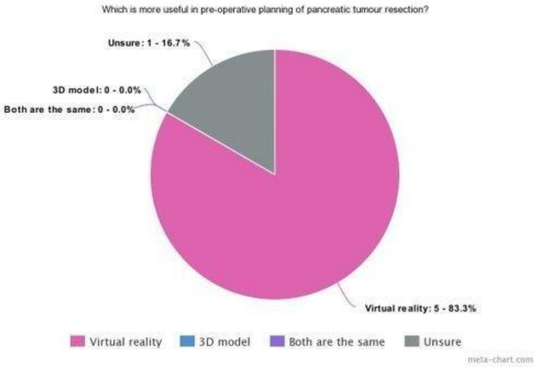

Figure 4: Participants' responses on the usefulness of 3D printed models and VR in pancreatic tumour resection.

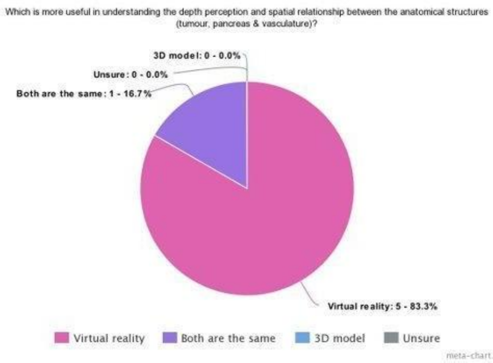

Figure 5: Participants' response on the value of 3D printed models and VR in understanding spatial relationship.

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