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Utility of 3D Reconstruction of 2D Liver Computed Tomography/ Magnetic Resonance Images as a Surgical Planning Tool for Residents in Liver Resection Surgery

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OBJECTIVE: A fundamental aspect of surgical planning in liver resections is the identification of key vessel tributaries to preserve healthy liver tissue while fully resecting the tumor(s). Current surgical planning relies primarily on the surgeon's ability to mentally reconstruct 2D computed tomography/magnetic resonance (CT/MR) images into 3D and plan resection margins. This creates significant cognitive load, especially for trainees, as it relies on image interpretation, anatomical and surgical knowledge, experience, and spatial sense. The purpose of this study is to determine if 3D reconstruction of preoperative CT/MR images will assist resident-level trainees in making appropriate operative plans for liver resection surgery.

DESIGN: Ten preoperative patient CT/MR images were selected. Images were case-matched, 5 to 2D planning and 5 to 3D planning. Images from the 3D group were segmented to create interactive digital models that the resident can manipulate to view the tumor(s) in relation to landmark hepatic structures. Residents were asked to evaluate the images and devise a surgical resection plan for each image. The resident alternated between 2D and 3D planning, in a randomly generated order. The primary outcome was the accuracy of resident's plan compared to expert opinion. Time to devise each surgical plan was the secondary outcome. Residents completed a prestudy and poststudy questionnaire regarding their experience with liver surgery and the 3D planning software.

SETTING AND PARTICIPANTS: Senior level surgical residents from the Queen's University General Surgery residency program were recruited to participate.

RESULTS: A total of 14 residents participated in the study. The median correct response rate was 2 of 5 (40%; range: 0-4) for the 2D group, and 3 of 5 (60%; range: 1-5) for the 3D group ($p < 0.01$). The average time to complete each plan was 156 ± 107 seconds for the 2D group, and 84 ± 73 seconds for the 3D group ($p < 0.01$). A total 13 of 14 residents found the 3D model easier to use than the 2D. Most residents noticed a difference between the 2 modalities and found that the 3D model improved their confidence with the surgical plan proposed.

CONCLUSIONS: The results of this study show that 3D reconstruction for liver surgery planning increases accuracy of resident surgical planning and decreases amount of time required. 3D reconstruction would be a useful model for improving trainee understanding of liver anatomy and surgical resection, and would serve as an adjunct to current 2D planning methods. This has the potential to be developed into a module for teaching liver surgery in a competency-based medical curriculum. (J Surg Ed ∎:∎∎∎-∎∎∎.

KEY WORDS: liver surgery, computer-assisted surgery, medical education, surgical education

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COMPETENCIES: Practice-Based Learning and Improvement, Medical Knowledge

INTRODUCTION

The 5-year survival for primary and secondary liver cancer without resection is approximately 3%. Surgical resection with negative margins increases 5-year survival rates from 20% to 30%.[1,2] The challenge lies in removing enough tissue to achieve negative margins, while sparing healthy liver tissue to reduce the risk of postresection liver failure. A fundamental aspect of surgical planning is the identification of vascular tributaries that are key in preserving healthy liver tissue and their relation to the tumor(s).[3,4]

Current surgical planning primarily relies on the surgeon's ability to interpret and mentally reconstruct 2D computed tomography/magnetic resonance (CT/MR) images into 3D while planning resection margins. This is mentally strenuous and increases cognitive load, especially in trainees, as it relies on CT/MR interpretation, anatomical and surgical knowledge, experience, and spatial sense.[5,6] Prior research has shown the benefit of 3D reconstruction with hepatobiliary specialized surgeons in planning complex liver resections with unconventional resection planes,[7] but no studies exist evaluating the use of 3D reconstruction as a surgical planning tool for trainees. The objective of this study is to determine if 3D reconstruction of preoperative CT/MR images will assist trainees in selecting appropriate surgical plans for liver resection surgery.

MATERIAL AND METHODS

Study Design

This was a prospective cohort study (2016). The study was approved by the Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board. Voluntary enrollment and signed consent was obtained from each participant.

Study Participants and Setting

Senior level general surgery residents in postgraduate year (PGY) 3 to 5 were recruited from the Queen's University General Surgery residency program. Junior level trainees (PGY 1 and 2) were excluded from the study as exposure and knowledge expectation at that level does not include liver resection planning. The participants performed the study on a standard personal computer without access to the internet or textbooks. An investigator was present to facilitate the study and answer technical questions about the use of the 3D visualization software, but questions related to surgical planning were not answered during the study.

Study Protocol

Liver resection cases completed at our institution from 2011 to 2016 were reviewed. Preoperative patient CT/MR images were chosen on the basis of quality images that provided adequate visualization for surgical planning. Inclusion criteria for liver resection cases were single stage operative interventions with preoperative imaging that accurately reflected the intraoperative findings and the final surgery performed was in keeping with the preoperative plan. Each preoperative image was independently reviewed by 2 hepatobiliary surgeons to provide expert opinion on the optimal surgical plan, and cases with differing opinions were excluded. Cases with 2 stage resections, radiofrequency ablation, or preoperative portal vein embolization were also excluded. A total of 10 cases were selected and patient data were anonymized.

Five cases were allocated to the 2D method and 5 cases were allocated to the 3D method. Both groups were case-matched so that similar types of resections and level of difficulty were assigned to each planning method. Each group had one of the following: left lateral segmentectomy, right posterior segmentectomy, left trisegmentectomy, right hepatectomy, and wedge resection of segment 8. The 2D group consisted of raw CT/MR images without the radiologist report. The 3D group consisted of digital reconstructions that can be manipulated 360° to view the tumor(s) in relation to the hepatic structures from any viewpoint (Fig. 1). These were created using an open source segmentation module in 3D Slicer (www.slicer.org).

Residents were given a sample 3D case to orient them to the technology and allow them to learn how to manipulate the model. They were then asked to evaluate the images from the 10 cases, and write down the optimal surgical approach for each. This was defined as the type of liver resection they would perform to obtain negative margins while still maintaining adequate hepatic function (i.e., left lateral segmentectomy). Residents had to devise the plans de novo, they were not aware that the groups were case-matched, or that there were only 5 different types of resections. Each resident alternated between 2D and 3D cases in a different predetermined randomized order (https://www.random.org/lists/). Their surgical plan and time (seconds) to devise each plan was recorded. Residents did not know that their times were being recorded. Residents completed a prestudy and poststudy questionnaire regarding their level of training, prior experience with liver surgery, and their experience with the 3D planning software (Appendix Table A).

Data Analysis

Residents received a score of 1 for a correct response and 0 for an incorrect response. A correct response was based on expert opinion, and can be defined as the optimal surgery to obtain clear margins while maintaining hepatic function. This was tallied for a score out of 5 per resident for each group. The

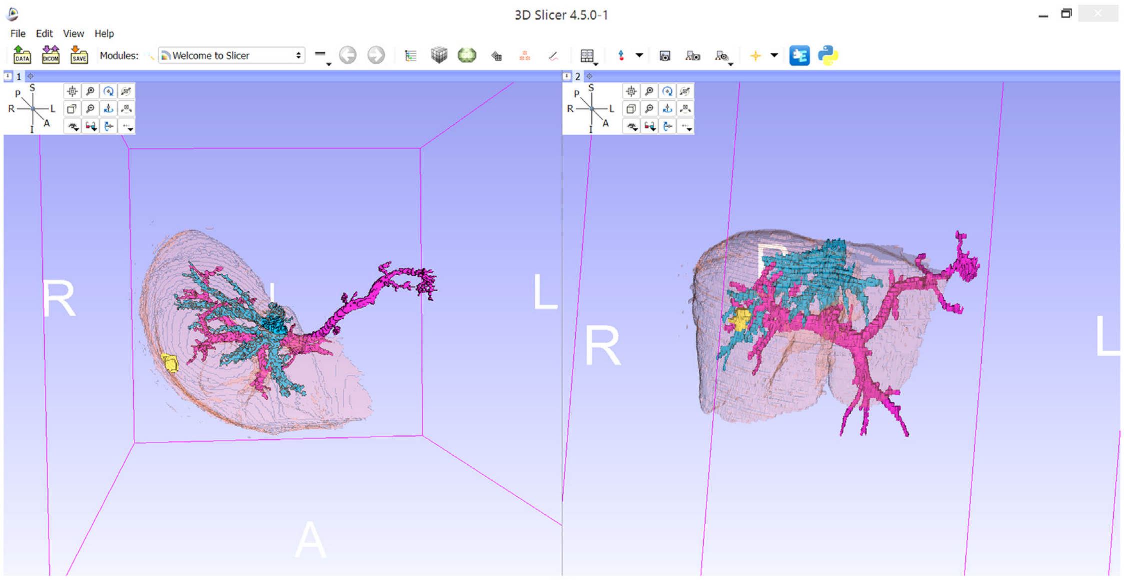

FIGURE 1. 3D reconstructed liver image with parenchyma (beige), tumor (yellow), hepatic vessels (blue), and portal vessels (pink).

response data are presented as median (range) and the Wilcoxon signed-rank test was used to analyze the difference in scores between the 2D and 3D groups. Time to assess image and devise an operative plan was recorded in seconds. Time data are presented as mean ± standard deviation and was analyzed using the paired *t*-test. The data were stratified by PGY and the analysis for correct responses and time was repeated. Kruskal-Wallis test was used to determine stochastic dominance between PGY. Significance was determined a priori as $p \leq 0.05$. Statistical analysis was performed using MedCalc version 9.2.1.0.

RESULTS

A total of 14 senior general surgery residents (PGY 3-5) were recruited from Queen's University in 2016 (Table 1). A prestudy survey assessed the number of liver cases residents were exposed to, and level of comfort according to PGY.

TABLE 1. Participant Demographics

	N **= 14**
Postgraduate year	
PGY 3	4
PGY 4	5
PGY 5	5
Sex	
Male	9
Female	5
Estimated number of liver cases assisted with	Median (range)
PGY 3	<5 (<5-10)
PGY 4	<5 (<5-10)
PGY 5	10-20 (<5 to >20)

Residents further into their training had more experience and comfort with liver surgery (Table 1 and Fig. 2). The median correct response rate was 2 of 5 (40%; range: 0-4) for the 2D group, and 3 of 5 (60%; range: 1-5) for the 3D group ($p < 0.01$, Fig. 3). The average time to complete each plan was 156 ± 107 seconds for the 2D group, and 84 ± 73 seconds for the 3D group ($p < 0.01$, Fig. 4). Data were further stratified by PGY (Table 2). A total 13 of 14 residents found the 3D reconstructions easier to use than the 2D images. Among them 5 residents noticed "somewhat" of a difference between the 2 modalities, whereas 9 residents responded with "very," and 8 residents found that the 3D model "somewhat" improved their confidence with their surgical plan, whereas 6 residents responded with "very."

DISCUSSION

Most liver resection surgeries can be divided into the following 2 major categories: anatomical (Couinaud segments) and nonanatomical (wedge).[8] Couinaud divided the

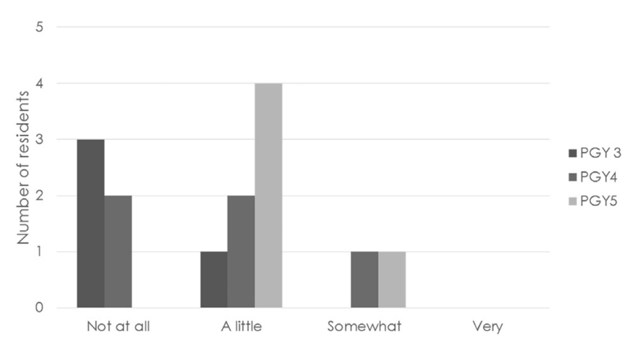

FIGURE 2. Level of comfort with liver surgery.

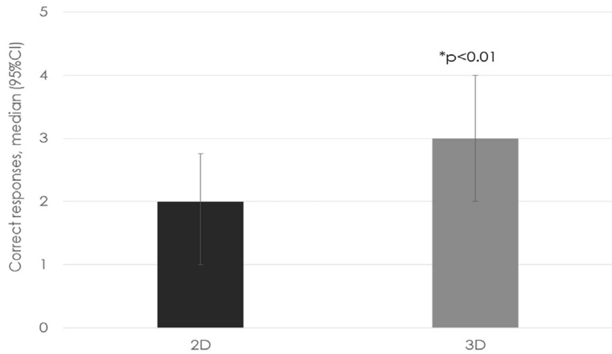

FIGURE 3. Median correct responses (of 5).

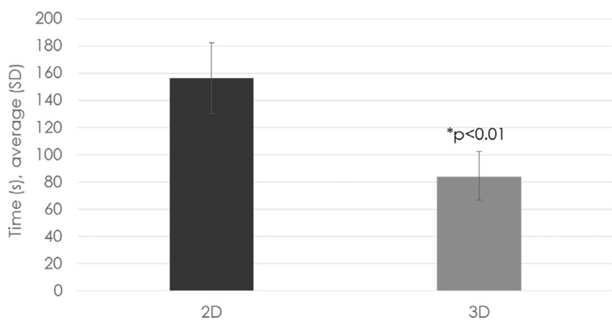

FIGURE 4. Average time to complete plan.

liver into 8 functional segments based on the blood supply from the hepatic artery and portal vein.[20] Understanding this complex anatomy is critical to planning resections, as the goal is to obtain negative tumor margins while preserving maximal volume of liver parenchyma to prevent postoperative liver failure. This is especially important in the setting of neoadjuvant chemotherapy with potential associated liver injury, or in patients with underlying liver disease.[9] The surgeon is required to identify vessel tributaries and dependent liver parenchyma by mental determination of 3D structures based on 2D images.[10]

At the end of residency training, a general surgeon is expected to have an understanding of liver anatomy as determined by their ability to develop surgical plans to resect hepatic tumors. This is a challenging process as the resident must be able to identify and interpret CT/MR images, mentally reconstruct the anatomy into a 3D structure, and then create a surgical plan for liver resection. This results in high element interactivity and a split-attention effect, where the resident has to incorporate multiple sources of information simultaneously.[11-13] This creates a significant amount of cognitive load. Cognitive load is the amount of information being processed by the working memory at any one time.[14] Limiting the amount of information decreases the demands on mental processing and allows better interpretation and retention of information.[15]

Removing the aspect of 2D CT/MR image interpretation and mental reconstruction allows the trainee to focus on understanding the tumor's relation to key anatomical structures and creating a surgical plan. This reduces the cognitive load on the working memory, where conscious processing occurs, by reducing the extraneous cognitive load.[16] Extraneous cognitive load refers to information presented to the learner in a manner that increases the demand on working memory unnecessarily thus distracting the processing capability from the remainder of the learning activity.[17] By removing the process of CT/MR interpretation the working memory is not overwhelmed thereby allowing the trainee to optimally use their processing capability for the learning task. It breaks down the learning experience into a smaller, more manageable processes.[18] The interpretation of CT/MR can be taught elsewhere in the curriculum.

Our results show that 3D reconstruction improves the residents' ability to devise the correct surgical plan. This is beneficial across all 3 residency years, with the more advanced residents performing better at 3D planning than the more junior residents. When the results were stratified by PGY, the PGY 5 residents did not show any difference from the PGY 3 and 4 residents when creating surgical plans for the 2D cases. For the 3D cases, there appears to be an improvement in number of correct cases in the more advanced residents, but the numbers were too small to determine significance.

The stratified results suggest that PGY 3 residents may not have enough exposure to liver surgery to correctly determine surgical plans regardless of 3D adjuncts. It also suggests that despite more advanced liver surgery knowledge the PGY 5 residents struggle with interpretation of 2D images. This highlights a possible curricular gap in our residency training program. Our current residency curricu-

TABLE 2. Data Stratified by Resident Postgraduate Year

	Correct Response			Time (s)		
	2D	**3D**		**2D***	**3D****	**p Value**
PGY 3	2 (0-3)	2 (2–4)	p value not available as *n* is too small	171 ± 101	105 ± 88	0.02
PGY 4	2 (0-4)	3(1–4)		177 ± 127	96 ± 79	<0.01
PGY 5	2 (1-3)	4 (2–5)		122 ± 75	56 ± 32	<0.01

Kruskal-Wallis test for stochastic dominance.
*p = 0.12.
**p = 0.02.

lum includes longitudinal exposure to hepatobiliary surgery with 1 to 3 months on the hepatobiliary service per year, starting in PGY 1. During senior years this includes in-depth patient-centered discussions with hepatobiliary surgeons, including review of imaging and surgical approaches. Residents also receive some didactic teaching on hepatic anatomy and resection as part of the academic curriculum. These results also highlight that residents at the PGY 5 level are not able to consistently develop correct surgical plans using the 2D images, thus supporting the current requirements for hepatobiliary fellowship training.

The survey results show that residents notice a difference between the 2 modalities and the 3D models improve their confidence in their surgical planning ability. The literature suggests that students prefer leaning with a combination of both 2D images and 3D interactive models compared to using only 2D or 3D information alone.[19] Thus we feel that 3D reconstruction could serve as a very useful teaching tool in a competency-based curriculum where residents would first learn about liver anatomy and 2D CT/MR image interpretation, followed by liver surgery planning using 3D models. After these skills are learned residents then can combine both CT/MR image interpretation and 3D models to develop more advanced skills of mental reconstruction and surgical planning.

The study by Radtke et al.[7] found that 3D reconstruction allowed hepatobiliary specialized surgeons to more accurately determine liver perfusion, allowing them to alter their 2D strategy for better resection. Although residents are required to have basic knowledge of liver resection, they would not be expected to execute such plans in their practice without further specialized hepatobiliary fellowship level training. Given the potential benefit of 3D reconstruction at the resident level, as well as the fact that 3D models have shown benefit with hepatobiliary specialized surgeons planning complex liver resections,[7] it is conceivable that this teaching tool would also have educational and practical value for fellowship level training.

The most significant limitation to this study is that it is a single center study with a small number of participants. Thus the data may not be generalizable to other programs with varying degrees of MR/CT interpretation and hepatobiliary exposure. Future studies aim to explore if these results are replicable at other centers where the training volumes are different.

CONCLUSIONS

The results of this study show that 3D reconstruction for liver surgery planning increases accuracy of resident surgical planning, and decreases amount of time required to plan the resection. The interface is reported by residents as easy to use and improves their confidence in surgical planning.

3D reconstruction is useful as a teaching tool to augment current curriculums. It has the potential to reduce the cognitive load required to interpret and mentally reconstruct a 2D CT/MR image allowing the resident to focus on the surgical planning component. 3D reconstruction can be a useful model for improving trainee understanding of liver anatomy and surgical resection and can serve as an adjunct to current 2D planning methods. This has the potential to be developed into a module for teaching liver surgery in a competency-based medical curriculum.

APPENDIX

For prestudy and poststudy questionnaire see Table A.

TABLE A. Prestudy and Poststudy Questionnaire

Prestudy survey				
PGY:	3	4	5	
Level of comfort with liver surgery:	Not at all (1)	A little (2)	Somewhat (3)	Very (4)
Number of liver cases assisted:	<5	5-10	10-20	>20
Poststudy survey				
	Not at all	A little	Somewhat	Very
Did 3D navigation improve your confidence in your answers?	(1)	(2)	(3)	(4)
Did you find a difference between the 2D and 3D planning?	(1)	(2)	(3)	(4)
Which one did you find easier to use?	2D		3D	

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