The Role of Three-Dimensional Modeling to Improve Comprehension of Liver Anatomy and Tumor Characteristics for Medical Students and Surgical Residents

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OBJECTIVE: Studying liver anatomy can be challenging for medical students and surgical residents due to its complexity. Three-dimensional visualization technology (3DVT) allows for a clearer and more precise view of liver anatomy. We sought to assess how 3DVT can assist students and surgical residents comprehend liver anatomy.

DESIGN: Data from 5 patients who underwent liver resection for malignancy at our institution between September 2020 and April 2022 were retrospectively reviewed and selected following consensus among the investigators. Participants were required to complete an online survey to investigate their understanding of tumor characteristics and vascular variations based on patients' computed tomography (CT) and 3DVT.

SETTING: The study was carried out at the General and Hepato-Biliary Surgery Department of the University of Verona.

PARTICIPANTS: Among 32 participants, 13 (40.6%) were medical students, and 19 (59.4%) were surgical residents.

RESULTS: Among 5 patients with intrahepatic lesions, 4 patients (80.0%) had at least 1 vascular variation. Participants identified number and location of lesions more correctly when evaluating the 3DVT (84.6% and 80.9%, respectively) compared with CT scans (61.1% and 64.8%, respectively) (both $p \leq 0.001$). The identification of any vascular variations was more challenging using the CT scans, with only 50.6% of correct answers compared with 3DVT (72.2%) ($p < 0.001$). Compared with CT scans, 3DVT led to a 23.5%, 16.1%, and 21.6% increase in the correct definition of number and location of lesions, and vascular variations, respectively. 3DVT allowed for a decrease of 50.8 seconds (95% CI 23.6-78.0) in the time needed to answer the questions. All participants agreed on the usefulness of 3DVT in hepatobiliary surgery.

CONCLUSIONS: The 3DVT facilitated a more precise preoperative understanding of liver anatomy, tumor location and characteristics. (J Surg Ed 81:597−606. © 2024 The Authors. Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/))

KEY WORDS: 3D visualization technology, liver anatomy, surgical planning, liver surgery

COMPETENCIES: Medical Knowledge, Practice-Based Learning and Improvement

INTRODUCTION

The surgical treatment of liver malignancies is linked to high morbidity and mortality rates, depending on tumor

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Funding: This work was supported by the University of Verona, Verona, Italy, with the Joint Project 2019 grant.

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1931-7204/$30.00
https://doi.org/10.1016/j.jsurg.2023.12.018

location, size, stage, and complex relationships with hepatic vessels and bile ducts.[1] Having exceptional theoretical and clinical hepatobiliary and surgical abilities is crucial when performing liver resections. In particular, parenchymal-sparing liver resection is recommended to preserve the functioning parenchyma and achieve oncologic outcomes. In addition, parenchymal-sparing liver resection has demonstrated similar outcomes to anatomic resections but with better cancer-related results and higher feasibility of repeat liver resection for tumor recurrence.[2,3] However, performing nonanatomical liver resections or major resections in patients with complex relationships between tumor and vasculobiliary structures, nonperipheral lesions, or anatomical vasculobiliary variations can be very challenging. In addition, when deciding between parenchymal-sparing and anatomic resection, various factors should be considered, including the number, size, and location of the tumor.[4]

As such, when planning liver surgeries, having a thorough understanding of liver anatomy and the location of the tumor relative to the vasculobiliary structures is crucial.[5] The standard way to gather this information is through multiphase computed tomography (CT) imaging. However, bi-dimensional cross-section imaging can be challenging for medical students and surgical residents to comprehend. In the last decade, surgeons specializing in hepatobiliary surgery are utilizing 3-dimensional visualization technology (3DVT) more frequently to better understand patients' liver anatomy. This technology can also be used in conjunction with traditional imaging to plan liver resection.[5] Moreover, the use of 3DVT has proven to be beneficial for trainees, residents, and medical students in comprehending liver anatomy and surgical procedures.[6]

Studying the anatomy of the liver can be challenging because it is divided into complex functional sections that contain vasculobiliary structures in a 3D arrangement. Additionally, there are several potential anatomical variations of vessels and bile ducts to consider. However, the educational materials typically consist of anatomical books and atlases that require the student to visualize the 3-dimensional structure from 2-dimensional drawings, illustrations, or photographs. Recent findings suggest that combining 3D and 2D atlases can greatly enhance the speed and accuracy of identifying anatomical structures.[7,8] As such, 3D technology - whether used for printing, displaying on a screen, or virtual reality - improves the ability to recognize anatomical structures, their location, and morphology.[9,10]

The current study sought to assess how well medical students and surgical residents understand surgical normal liver anatomy, variations in anatomy, and the characteristics and locations of hepatic tumors, using the 3DVT. Therefore, a survey was conducted among medical students and surgical residents to compare 2D imaging with 3DVT.

MATERIAL AND METHODS

Study Design, Setting, and Participants

The study was carried out at the General and Hepato-Biliary Surgery Department of the University of Verona. Data from 5 patients who underwent liver resection for malignancy at our institution between September 2020 and April 2022 were reviewed and selected following consensus among the investigators.

Study participants were recruited from the University of Verona, remained blinded to the study aims, and were divided into 3 groups (i.e., senior-level medical students, junior-level surgical residents [Post-Graduate Year (PGY) 1-2], and senior-level surgical residents [PGY 3-5]). Participants used a standard personal computer without access to textbooks or digital educational tools to evaluate the 2D images and 3D models.

Patient Characteristics

Five patients with intrahepatic malignancy were selected (Figs. 1 and 2). Median age was 61 years (IQR 48-75) and only 1 patient (16.6%) had no vascular variations. Specifically, patient 1 had a single intrahepatic lesion in segment 4 (32 mm) in contact with the portal vein branches. Patient 2 had 2 intrahepatic lesions in segment 5 (15 mm) with a distance of 2 mm from the segmental branch of portal vein and in segment 6 (8 mm). Patient 3 had a single intrahepatic lesion in segment 5 (58 mm) with compression of the right posterior portal pedicle and gallbladder. Patient 4 had a single intrahepatic lesion in segments 6 and 7 (32 mm) in contact with the right inferior portal vein. Patient 5 had a single intrahepatic lesion in segments 5, 7, and 8 (111 mm) in contact with the middle hepatic vein and portal vein branch for segment 7. In addition, vascular variations of the hepatic artery and veins were identified (Fig, 2 c and d). Specifically, 1 patient had no variations (20.0%), while 4 patients had at least 1 variation (80.0%) (i.e., inferior right hepatic vein, right hepatic artery from the superior mesenteric artery, inferior right hepatic vein, and portal vein variation).

Three-Dimensional Models

The 3D reconstructions were performed using patient abdomen CT scans recorded between September 2020 and April 2022. The CT scans were exported in .avi video format using the Synapse Vincent medical imaging system (Fujifilm Medical Co. Ltd., Tokyo, Japan) to allow study participants to view the images using multiple

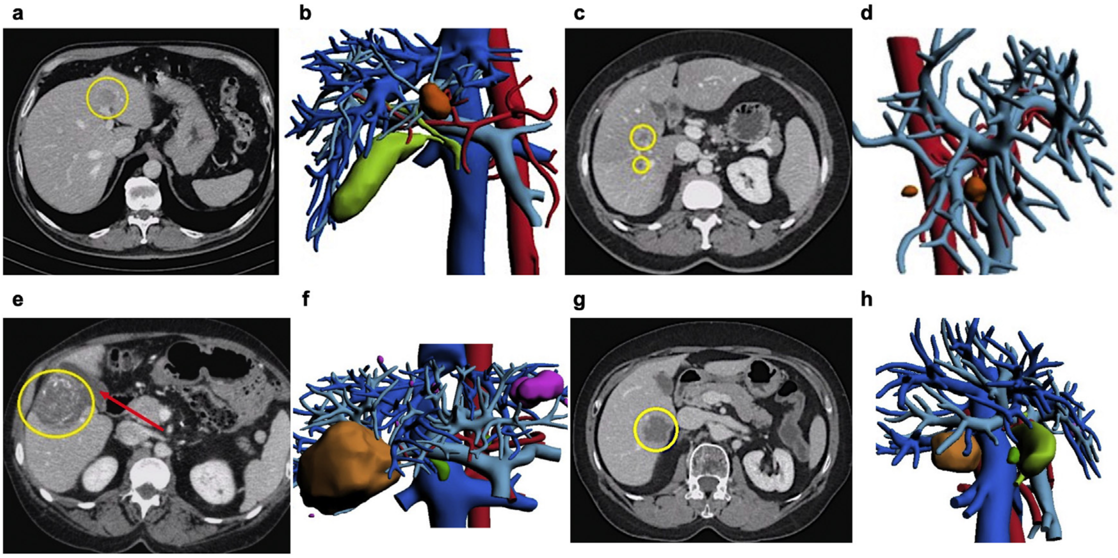

FIGURE 1. Clinical cases. Case 1: preoperative CT scan (a) and 3D reconstruction (b) of a patient with a single intrahepatic lesion in segment 4 (23 × 32 mm) in contact with the portal vein branches. Case 2: preoperative CT scan (c) and 3D reconstruction (d) of a patient with 2 intrahepatic lesions in segment 5 (15mm) with a distance of 2 mm from the portal vein segmental branch and in segment 6 (8 mm). Case 3: preoperative CT scan (e) and 3D reconstruction (f) of a patient with a single intrahepatic lesion in segment 5 (58 mm) with compression of the right posterior portal pedicle and gallbladder (red arrow). Case 4: preoperative CT scan (g) and 3D reconstruction (h) of a patient with a single intrahepatic lesion in segments 6 and 7 (32 mm) in contact with the right inferior portal vein. Lesion (yellow circle/orange), portal vein (light blue), hepatic artery (red), hepatic vein (blue), gallbladder and bile ducts (green), cyst (purple).

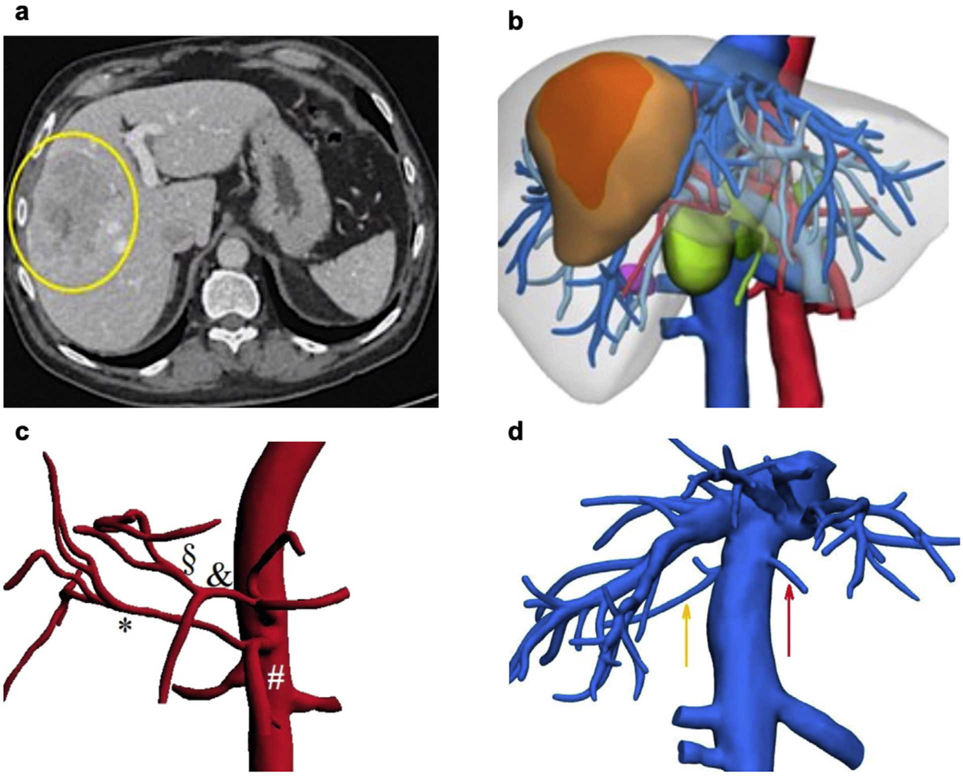

FIGURE 2. Case 5. Preoperative CT scan (a) and 3D reconstruction (b) of a patient with a single intrahepatic lesion in segments 5, 7, and 8 (111 mm) in contact with middle hepatic vein and portal vein branch for segment 7. (c), (d), Vascular anatomical variations: right hepatic artery (*) from the superior mesenteric artery (#); left hepatic artery (§) from common hepatic artery (&); inferior hepatic vein draining segment 7 (yellow arrow); hepatic vein for segment 1 (red arrow).

projections. The 3D reconstructions were performed from the DICOM format files of the CT scans. A dedicated Hyper Accuracy 3D software (HA3D^{TM}) from MEDICS (Moncalieri, Turin, Italy) provided files that allowed participants to freely manipulate, rotate and zoom in on the virtual model. Specifically, the process consisted of the rendering of a 3D virtual model, on the basis of high-resolution CT scans. The virtual models were reviewed by bioengineers and surgeons together, in order to evaluate the accuracy of the models in comparison with the obtained images. The next step was the creation of the HA3D model and an interactive 3D-PDF. The 3D-PDF file was viewed and the model was navigated next to answer the questionnaires. Participants could easily adjust the viewpoint by moving and rotating the 3D model around different axes with complete freedom, zooming in or out, and visualizing or hiding liver structures such as the hepatic parenchyma, the vascular structures (i.e., portal vein, hepatic artery, hepatic veins, and their branches), and the biliary tract. A distinct color was assigned to each anatomical structure to simplify the identification. In addition, the anatomical variations of the hepatic artery,[11] the portal vein,[12,13] and the hepatic veins were recorded and defined based on established classification systems.[14,15]

Study Protocol

The investigators, experts in hepatobiliary surgery, developed a survey regarding each patient's CT scans and 3D models. The survey consisted of 17 sections (i.e., 1 for general information, 15 for case analyses, and 1 for the Likert scale questionnaire). The first section asked for general information about the participant, such as gender, group affiliation, and video game usage (with a time estimate in hours per week). This section was used to divide participants into similar subgroups. Fifteen sections were specific to individual patient cases. Each patient case was divided into 3 sections, which included questions regarding the CT images, 3D models, and Likert-scale questions comparing 2D and 3D. The time it took to complete each section was measured.

All participants evaluated CT scans and 3D models for each of the 5 clinical cases. Specifically, each participant reviewed the CT images first and then the 3D model. The participants were instructed to identify and name the liver segment where the tumor was located. The time (seconds) needed to answer the questions on the CT scans and the 3D model was recorded for each of the 5 clinical cases, respectively. The time period to complete the first questionnaire was considered as a practice session before the other questionnaires to familiarize participants with the platform, such as a preassessment. As such, we excluded the time needed to answer the first questionnaire from the analysis. The time measurements that were excessively high were excluded from the analysis (i.e., >60 minutes, days, a week). The most common reason provided by participants was the occurrence of distractions during the survey that reflected on an untruthful amount of time recorded. To assess comprehension of CT scans and 3D models, participants were given multiple choice questions such as "How many lesions have you identified?", "Which segments are involved by the tumor?", "Have you observed any anatomical vascular variations?", "Which variations have you observed?". Correct answers were assigned 1 point each, while wrong answers received a score of 0. The Likert-scale questionnaire was submitted at the end of each patient questionnaires. Specifically, participants were asked to indicate which of the 2 methods was clearer regarding understanding liver anatomy, detecting vascular variations, and identifying lesion location. At the end of the survey, participants were asked to complete another Likert-scale questionnaire. This questionnaire sought their opinions on the usefulness of 3DVT in the clinical practice of hepatobiliary surgery.

Statistical Analysis

For descriptive statistics, categorical data were reported as frequencies (%) and were compared using χ^2 test or Fisher's exact test, as appropriate. Continuous variables were summarized as mean ± standard deviation (SD) according to the distribution of the data. The ANOVA test and paired sample t-test were used to compare the average points gained from the questionnaire and the time needed to complete the questionnaires. The reported significance levels were 2-sided and set at $\alpha = 0.05$. The software SPSS, version 25.0 (IBM Corporation, Armonk, NY), was utilized to analyze and present the data.

RESULTS

Participants and Questionnaires

Among 32 participants, a majority were male (n=21, 65.6%), with 13 (40.6%) medical students, 10 (31.3%) PGY 1-2, and 9 (28.1%) PGY 3-5 residents. A total of 324 answers were collected (162 for CT and 162 for 3D questionnaires). Specifically, medical students provided 130 (40.1%) answers, while PGY 1 to 2 and PGY 3 to 5 residents provided 102 (31.4%) and 92 (28.3%) answers, respectively. Overall, only 11 (34.4%) participants used to play video games for 0.5 to 5 hours weekly. Participant and patient characteristics are presented in Table 1.

Overall, participants identified the number of lesions more correctly when evaluating the 3D model (correct

TABLE 1. Characteristics of the Survey

Sections
1. General information of participant
Gender
Expertise (i.e., medical student, junior resident, senior resident)
Video games
Do you usually play video games?
Specify the average number of hours you spend on playing videogames weekly
2. Questions submitted for each of the 5 clinical cases
"How many lesions have you identified?" in CT scans and in 3DVT
"Which segments are involved by the tumor?" in CT scans and in 3DVT
"Have you observed any anatomical vascular variations?" in CT scans and in 3DVT
"Which vascular variations have you observed?" in CT scans and in 3DVT
5-point Likert-scale comparing CT and 3DVT
Utility in defining liver segments involved by the lesion
Utility in understanding liver anatomy
Utility in understanding vascular variations
3. Evaluate the utility of 3DVT in clinical practice for hepatobiliary surgery on a 5-point Likert scale

The same survey was given to all participants for each of the 5 clinical cases.

answers, $n = 137$, 84.6%) compared with the CT scans (correct answers, $n = 99$, 61.1%) ($p < 0.001$). Specifically, the accuracy of 3DVT answers was higher than CT scans in both groups of participants (correct answers, medical students: $n = 36$, 55.4% vs. $n = 51$, 78.5%, $p = 0.005$; residents: $n = 63$, 65.0% vs. $n = 86$, 88.7%, $p < 0.001$). Similarly, participants named more correct segments invaded by the tumor using the 3D model compared with the CT scans (correct answers, $n = 131$, 80.9% vs. $n = 105$, 64.8%; $p = 0.001$), with the 3DVT being significantly more accurate compared with CT scans among medical students (correct answers, $n = 56$, 86.2% vs. $n = 39$, 60.0%, $p < 0.001$). Conversely, the difference between the 2 methods was not statistically significant among the residents (correct answers, $n = 75$, 77.3% vs. $n = 66$, 68.0%, $p = 0.147$).

The identification of any vascular variations was more challenging using the CT scans, with only 50.6% ($n = 82$) of correct answers compared with the 3D model ($n = 117$, 72.2%) ($p < 0.001$). Specifically, the accuracy of 3DVT-answers was higher than CT scan-answers in both groups of participants (correct answers, medical students: $n = 50$, 76.9% vs. $n = 32$, 49.2%, $p = 0.001$; residents: $n = 67$, 69.1% vs. $n = 50$, 51.6%, $p = 0.013$). Consequently, the definition of the specific vascular variations was more precise while using the 3DVT compared with the CT scans (correct answers, $n = 112$, 69.1% vs. $n = 78$, 48.2%; $p < 0.001$), with higher accuracy of the 3DVT-answers compared with CT scan-answers among both medical students (correct answers, $n = 44$, 67.7% vs. $n = 27$, 41.5%, $p = 0.003$) and residents (correct answers, $n = 68$, 70.1% vs. $n = 51$, 52.6%, $p = 0.012$) (Fig. 3) (Table 2).

Scoring System and Time Analysis

The scoring system was utilized to compare the results of participant's interpretation of CT scans and 3DVT. Specifically, each participant could totalize a score between 0 (all answers wrong) and 4 points (all correct answers) in each questionnaire. Overall, using 3DVT resulted in higher scores compared to CT scans, with a mean score of 3.07 points (95%CI 2.90-3.24) versus 2.25 (95%CI 1.07-2.42) ($p < 0.001$). Medical students and residents achieved higher scores analyzing 3DVT models than CT scans. Specifically, among medical students, 67.6% ($n = 44$) scored <2 when analyzing CT images, compared to only 29.2% ($n = 19$) who scored <2 using 3DVT, ($p < 0.001$). Notably, 32.2% ($n = 21$) of students scored >2 using CT scans versus 70.7% ($n = 46$) who scored >2 using 3DVT ($p < 0.001$). The residents achieved similar results. When analyzing CT images, 56.7% ($n = 55$) of residents scored <2, compared with 29.8% ($n = 29$) with 3DVT. Meanwhile, 43.2% ($n = 42$) of residents scored >2 with CT scans versus 70.1% ($n = 68$) with 3DVT models (all $p < 0.001$) (Table 2).

The scoring system was also utilized to compare the results of participant's interpretation of CT scans and 3DVT when they were divided into groups based on the use of video games (i.e., game-players vs. not game-players). Assuming that playing video games can give an advantage in reading CT scans and 3DVT, the number of correct answers for both methods was combined. Specifically, each participant could totalize a score between 0 (all answers wrong) and 8 points (all correct answers) in each questionnaire. Notably, the use of video games did not contribute to the results of the questionnaires.

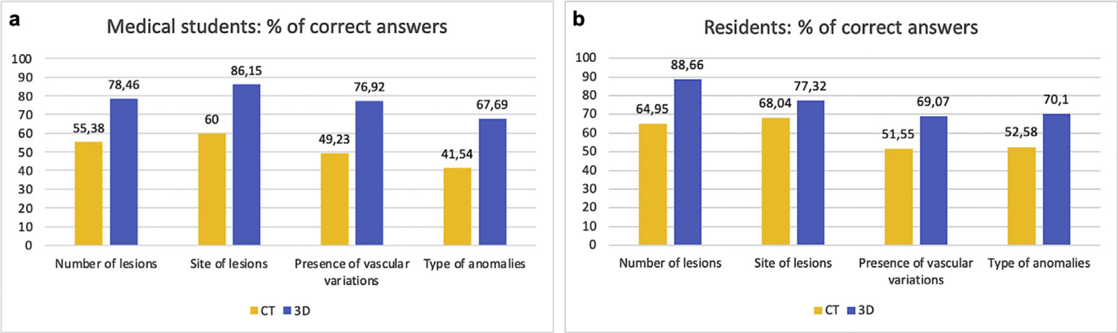

FIGURE 3. Bar graph of the percentage of correct answers provided by medical students (a) and surgical residents (b).

Participants who did not play video games had a mean score of 5.32 ± 1.75 points, while those who used to play video games weekly had a mean score of 5.29 ± 1.81 points ($p = 0.910$).

Furthermore, the difference between the percentages of correct answers to 3DVT questionnaires and the corresponding CT scan questionnaires was measured. Overall, 3DVT led to a 23.5% increase in the accuracy of the definition of the number of lesions compared with CT scans, with a higher increase among PGY1-2 residents (medical students 23.1% vs. PGY1-2 residents 29.4% vs. PGY3-5 residents 17.4%). The increase in the correctness of tumor location identification using 3DVT compared with CT scans was 16.1% (medical students 26.2% vs. PGY1-2 residents 7.8% vs. PGY3-5 residents 10.9%). The increase in the accuracy of the identification and definition of vascular variations when using 3DVT was 21.6% and 21.0%, respectively, with medical students benefitting most from using 3DVT (medical students 27.7% and 26.2% vs. PGY1-2 residents 15.7% in both identification and definition vs. PGY3-5 residents 19.6% in both identification and definition) (Fig. 4a).

The mean time needed to answer the CT scans and 3DVT sections of questionnaires were 276.6 ± 175.5 seconds and 225.8 ± 112.9 seconds, respectively ($p < 0.001$). Therefore, 3DVT allowed for a decrease of 50.8 seconds (95%CI 23.6-78.0) in the time needed to answer the questions.

Likert-scale Questionnaire

The subjective advantages of 3DVT in liver anatomy comprehension were evaluated by 3 more questions on the ability to understand liver anatomy, define tumor location, and identify vascular anatomical variations. Participant answers ranged from 1 ("CT scans interpretation was much simpler") to 5 (“3DVT interpretation was much simpler”). Medical students considered 3DVT much easier to be interpreted than CT scans relative to the understanding of liver anatomy (mean response: 4.5), the definition of tumor location (mean response: 4.4), and the identification of vascular variations (mean response: 4.5). Although 3DVT was acknowledged to provide benefits over CT scans, among the residents, the difference in advantages between 3DVT and CT scans decreased with the increase in experience from PGY1-2 residents (mean response: 4.3 in the understanding of liver anatomy location; 4.1 in vascular variations identification; 4.4 in vascular variations definition) to PGY3-5 residents (mean response: 3.6 in the understanding of liver anatomy location; 3.7 in vascular variations identification; 3.8 in vascular variations definition) (Fig. 4B).

At the end of the survey, participants were asked to express their overall opinion on the usefulness of 3DVT in hepatobiliary surgery. The answers ranged between 1 ("absolutely useless") and 5 ("absolutely useful"). All participants strongly or moderately agreed on the usefulness of 3DVT in hepatobiliary surgery.

DISCUSSION

In recent years, advanced imaging methods such as 3D visualization technology have been increasingly adopted to better understand individual liver anatomy and tumor features before surgery.[16] 3DVT is expected to offer more detailed information than traditional 2D imaging, which could lead to improved surgical treatment of liver diseases. In addition, the use of 3DVT has been shown to enhance surgeons’ comprehension of liver anatomy, assist in preoperative planning for surgical resection, and aid in making intraoperative decisions. This is achieved by providing guidance for identifying anatomical landmarks, visualizing critical areas, and accurately estimating the extent of tumor involvement in surrounding structures.[5,17,18] In addition, medical students and surgical residents often find liver anatomy challenging to study and memorize due to its complexity. The 3D branching of biliary and vascular structures, as well as liver segment definition, can be difficult to visualize without sufficient experience. In this regard, Fang et al[7] conducted a study to determine the effectiveness of 3D

TABLE 2. Evaluation of Participants' Performance

Variables	CT scans	3DVT	p-value
Number of responses, *n*			
Overall	162	162	-
Students	65	65	-
Residents	97	97	-
Correct answers, *n (%)*			
"How many lesions have you identified?"			
Overall	99 (61.1)	137 (84.6)	<0.001*
Students	36 (55.4)	51 (78.5)	0.005*
Residents	63 (65.0)	86 (88.7)	<0.001*
"Which segments are involved by the tumor?"			
Overall	105 (64.8)	131 (80.9)	0.001*
Students	39 (60.0)	56 (86.2)	<0.001*
Residents	66 (68.0)	75 (77.3)	0.147*
"Have you observed any anatomical vascular variations?"			
Overall	82 (50.6)	117 (72.2)	<0.001*
Students	32 (49.2)	50 (76.9)	0.001*
Residents	50 (51.6)	67 (69.1)	0.013*
"Which variations have you observed?"			
Overall	78 (48.2)	112 (69.1)	<0.001*
Students	27 (41.5)	44 (67.7)	0.003*
Residents	51 (52.6)	68 (70.1)	0.012*
Overall 2D and 3D scores, *n (%)*			
< 2			
Students	44 (67.6)	19 (29.2)	<0.001*
Residents	55 (56.7)	29 (29.8)	<0.001*
> 2			
Students	21 (32.3)	46 (70.7)	<0.001*
Residents	42 (43.2)	68 (70.1)	<0.001*
Score, *mean (95% CI)*	2.3 (1.1-2.4)	3.07 (2.90-3.24)	<0.001†
Response time, sec, *mean (± SD)*	276.6 ± 175.5	225.8 ± 112.9	<0.001‡

*The 2 groups of percentages were compared using the Chi-Squared test.

†Means of scores were compared using ANOVA test.

‡Means of response time were compared using Paired Samples t-test.

Abbreviations: CI, confidence intervals; SD, standard deviation; CT, computed tomography; 3DVT, three-dimensional visualization technology.

atlases in teaching anatomy. The authors surveyed students who had experience using both traditional and 3D atlases and reported that by combining 3D and 2D atlases, the identification of anatomical structures could be more effective. Furthermore, research has demonstrated that 3D printed models and virtual 3D images outperform traditional 2D imaging.[5] However, one of the main obstacles in utilizing 3D printed models is their expensive cost and the time-intensive production procedures.[19] One solution to this issue is utilizing 3DVT, which involves displaying 3D models on a computer's standard screen. The current study is important because

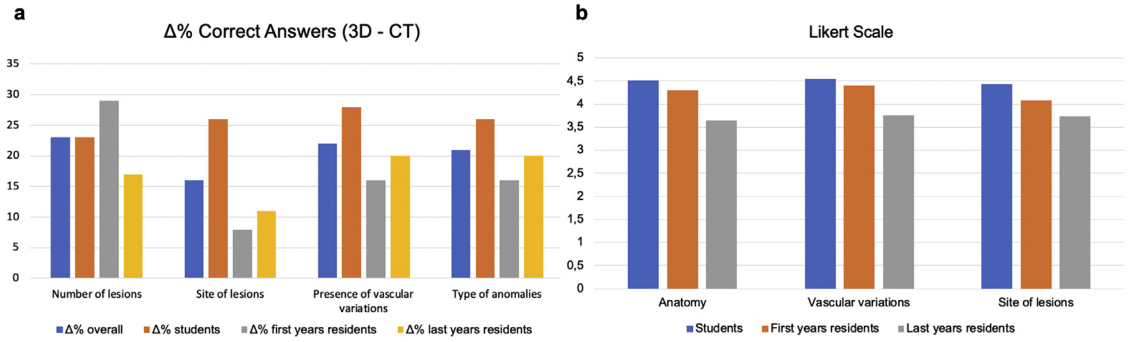

FIGURE 4. Variations in the percentage of correct answers between CT scan and 3DVT (a) and mean results of the Likert scale questionnaire (b) between subgroups of participants.

compared the effectiveness of 3DVT and traditional CT scans in understanding liver anatomy and tumor characteristics among medical students and surgical residents. Specifically, all participants agreed that 3DVT facilitated a precise preoperative understanding of liver anatomy and tumor characteristics. As such, the number and location of lesions as well as the presence of vascular variations were identified more accurately when using 3DVT compared with CT scans.

Several authors demonstrated that utilizing 3DVT offers an advantage in comprehending liver anatomy compared to conventional CT imaging.[9,10] In fact, trainees face a difficult task in developing the skills needed to convert 2D images into 3D mental reconstructions due to limited learning opportunities and the complicated, asymmetrical, and variable nature of internal hepatic anatomy. As such, Crossingham et al.[9] successfully utilized interactive 3D models of the liver to aid trainees in comprehending the intricate spatial anatomy of the organ. Jurgaitis et al.[10] further confirmed that using 3DVT to display liver anatomy can assist medical students in understanding clinical hepatic anatomy better than 2D visualization. Hence, the authors have stated that utilizing computer-generated 3D models is an effective approach to studying and teaching the anatomy of the liver. In the current study, although participants defined tumor location more accurately when evaluating the 3DVT compared with CT scans (80.9% vs. 64.8%, $p = 0.001$), 3DVT answers were significantly more accurate among medical students only (86.2% vs. 60.0%, $p < 0.001$). Notably, the difference between the 2 methods was not statistically significant among the residents (77.3% vs. 68.0%, $p = 0.147$). Likely, failure to reach the statistical significance of some questions by participants with more experience is mainly attributable to their excellent performances by using CT scans. As such, although these participants performed better with 3D methods, they showed no significant improvement. Conversely, identifying the number of lesions and the presence of any vascular variations was more challenging using the CT scans than 3DVT among all participants ($p < 0.05$). Furthermore, current surgical training heavily relies on the operating room for teaching technical and cognitive surgical skills as well as for learning surgical anatomy. It has been shown that the ability to make sense of visual cues during surgery is learned in the operating room. The 3D models can serve as an additional tool for residents with less operating room experience.[20]

In addition, Marconi et al.[21] conducted a study to evaluate the CT scans and 3D model interpretation skills of 30 individuals with different levels of expertise in radiological imaging, including medical students, surgeons, and radiologists. The authors discovered noticeable and statistically significant differences among participants who had no prior experience in hepatobiliary surgery, while the differences in interpretation of the images tend to lose their significance for those who frequently used liver CT images.[21] Similarly, the findings of the current study revealed the inverse proportionality relationship between the improvement in results when switching from CT scans to 3DVT and participant experience in hepatobiliary surgery. Specifically, 3DVT led to an increase in the accuracy of the definition of the number of lesions compared with CT scans with a better performance among PGY1 to 2 residents (medical students 23.1% vs. PGY1-2 residents 29.4% vs. PGY3-5 residents 17.4%), while medical students benefitted most from using 3DVT relative to the increase in the correctness of tumor location (medical students 26.2% vs. PGY1-2 residents 7.8% vs. PGY3-5 residents 10.9%) and definition of vascular variations (medical students 27.7% vs. PGY1-2 residents 15.7% vs. PGY3-5 residents 19.6%). As such, the results indicated that residents had higher abilities to assess tumor number and location as well as vascular variations compared with medical students regardless of the presentation method (CT scans vs. 3DVT). This finding may be primarily attributed to the fact that when a 3D object is projected on a 2D screen, depth perception is lost. However, surgical residents with more experience rely on extra visual aids to better understand nonstereoscopic depth cues. This compensates for the absence of the third dimension. Hence, the use of 3DVT in the comprehension of hepatobiliary anatomy and planning of surgery showed improvement on various levels. The 3DVT has been shown to enhance comprehension of liver anatomy among students and surgical residents, thereby augmenting the baseline knowledge of the next generation of surgeons.[7-10] Among expert surgeons, the use of 3DVT can help plan surgery more precisely, identify critical intraoperative conditions, and indicate the need for more demanding and challenging procedures during surgery. This information may lead to a change in the surgical plan.[5] Visual-spatial ability is crucial for accurately interpreting radiological images and learning anatomy. Several authors have investigated various methods to improve the learning process of students/trainees in understanding individual anatomy from imaging methods.[22-23] Special training can improve visual-spatial ability, as well as teaching anatomy using 3D, tangible models.[24]

Studies have shown that playing video games can improve people ability to navigate and orient themselves in virtual environments.[25-27] In theory, this could be advantageous when navigating and interpreting clinical imaging. The current study did not show any association between playing video games and the skill to comprehend and explain images. The observed differences were likely attributed to random variations. Specifically, the group of participants in this study who identified themselves as "gamers" had varying levels of video game usage, ranging from half an hour to 5 hours per week. As a result, it is possible that the group was too diverse to draw conclusive findings regarding the benefits of video games. It would be beneficial for future larger studies to investigate how video games can enhance the interpretation of anatomical images.

The current study should be interpreted in light of several limitations. First, the questionnaires were completed by the participants independently. This could have introduced bias related to any distractions that may have changed the correctness of the answers provided or altered the time measurement. Second, even though we provided instructions for the questionnaire and how to visualize the CT scans and 3D model, some participants who were not familiar with 3DVT may have spent more time on the 3D model. This could have affected the measurement of the time taken. Third, although the clinical data collected had a sufficient number of samples, with each participant observing 5 different cases, the small number of participants may have negatively influenced the results.

In conclusion, 3DVT can be a useful tool for those who are not experienced in hepatobiliary surgery to better comprehend both normal and pathological liver anatomy. Although 3DVT serves as a helpful tool for education and training in hepatobiliary surgery, medical students can benefit the most. However, all participants agreed that utilizing 3DVT is easier than relying on conventional 2D images. As a result, it is anticipated that this approach might soon become a standard practice in hepatobiliary surgery training.

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