The comparison of 2-dimensional with 3-dimensional hepatic visualization in the clinical hepatic anatomy education

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Key words: *clinical hepatic anatomy; hepatic resection planning; computed tomography; 3-dimensional visualization; surgical education.*

Summary. *Objective. To determine whether 2-dimensional or 3-dimensional hepatic visualization is better for the medical students to be used while studying the clinical hepatic anatomy.*

Material and methods. Twenty-nine patients who underwent surgical intervention due to focal hepatic pathology at the Department of General Surgery, University of Heidelberg, and at Clinics of Santariškės, Vilnius University Hospital were included in the retrospective cohort study. Before the surgical intervention, the computed tomography (CT) liver scan and 3-dimensional (3D) hepatic visualization were performed. A total of 58 2-dimensional and 3-dimensional digital liver images, mixed up in random sequence not to follow each other with a specially designed questionnaire, were presented to the students of Faculty of Medicine, Vilnius University. Their aim was to determine tumor-affected liver segments, to plan which liver segments should be resected, and to predict anatomical difficulties for liver resection. Results were compared with the data of real operation.

Results. The students achieved better results for tumor localization analyzing 3D liver images vs. CT scans. This was especially evident determining the localization of tumor in segments 5, 6, 7, and 8 ($P<0.05$). Furthermore, the results of proposed extent of liver resection have been found to be better with 3D visualization (mean±SD – 0.794±0.175) in comparison with CT scans (mean±SD – 0.670±0.200), ($P<0.001$).

Conclusions. Computer-generated 3D visualizations of the liver images helped the medical students to determine the tumor localization and to plan the prospective liver resection operations more precisely comparing with 2D visualizations. Computer-generated 3D visualization should be used as a means of studying liver anatomy.

Introduction

Learning and identification of anatomy is known to be a fundamental component in any clinical specialty, particularly in surgical education, and especially, it plays a very important role in studying liver anatomy. Anatomic nomenclature is found to be different at each stage of medical training (1). Usually the first introduction to anatomical hepatic nomenclature begins in the first year of the medical studies learning human anatomy (2). Later on, students will be acquainted with the nomenclature of the Couinaud hepatic segmental anatomy. This model proposed by Couinaud in the 1960s was widely accepted in clinical practice and especially in the hepatic surgery (3). However, this is only an approximation of individually differentiated segment anatomy, and despite advantages in visualization technologies, this hepatic nomenclature remains difficult to be imagined in a nontransparent organ.

Technological advancement during the last de-

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cades had an enormous impact on the methods of studying, diagnosing, and treating hepatic diseases. New image-producing techniques (computed tomography (CT), magnetic resonance imaging (MRI), color Doppler ultrasound (US)) have been developed and integrated into the clinical workflow (4). However, in many cases images are usually difficult to understand and interpret for an inexperienced staff and especially for the students. In addition, there are unique educational challenges to overcome in hepatic surgical anatomy. The typical requirements in liver surgery are to localize the tumor and to determine its relations to the intrahepatic vascular and biliary systems (5, 6). Usually in clinical settings, this is achieved with the help of 2-dimensional (2D) image stacks (CT images), from which 3-dimensional (3D) images are reconstructed in thought. Recently, specialized computer software has been used to construct 3D spatial relationships of anatomical structures and to provide detailed information useful for hepatic surgery (Figs. 1 and 2) (7–12). 3D virtual reality of the liver results from converting 2D images (from CT stacks) into 3D virtual image. This new 3D visualization of the liver facilitates the visibility of their content and allows three new methods of perception to be used, such as immersion, navigation, and interaction (9). Virtual reality is particularly relevant to the analysis of the relationship between a tumor and the vascular anatomy of the liver to plan the limits of hepatic resections.

This study was designed to determine whether 2-dimensional or 3-dimensional hepatic visualization is better to use for medical students while studying the clinical hepatic anatomy.

Methods

Twenty-nine patients who underwent surgical intervention due to focal hepatic pathology at the Department of General Surgery, University of Heidelberg, and at Clinics of Santariškės of Vilnius University Hospital were included in a retrospective cohort study. Before the surgical intervention, the computed tomography (CT) liver scan and 3-dimensional (3D) hepatic visualization were performed for all the patients. 3D images were obtained with software designed at the Division of Medical and Biological Informatics, German Cancer Research Center (DKFZ).

Image data were acquired with a Somatom Plus 4 (Siemens AG, Erlangen) CT scanner at the Department of Radiology, Ruprecht-Karls-University of Heidelberg. A standard bi- or triphasic liver scan with an optimized portal venous phase was performed (contrast media dose – 130 mL Ultravist 370, Schering, Germany, flow rate 4–5 mL/s, collimation 2.5 mm, slice 3 mm, rec. increment 3 mm, dose 130 mAs.). At the Center of Radiology, Clinics of Santariškės of Vilnius University Hospital, data were gathered with a GE LightSpeed Pro 16 CT scanner. The liver scan as well were performed with an optimized arterial and portal venous phase (dose – 1 mL/kg Ultravist 370, Schering, Germany, flow rate 3–4 mL/s, collimation 10 mm, arterial phase slice thickness and interval 1.25 mm, portovenous and late phases – 2.5 mm, AutomA, SmartmA).

Imaging data sets were transferred to the Department of Medical and Biological Informatics of the German Cancer Research Center. 3D liver reconstructions were performed using software system embedded in the radiological workstation CHILI®. This task consisted of the following steps: 1) segmentation of the liver parenchyma and the tumor using manual and/or semiautomatical algorithm; 2) vessel segmentation using an automatic algorithm; 3) editing of the hepatic vessels to separate the portal system from the hepatic venous system; 4) visualization of 3D liver reconstruction with the help of the OrgaNicer (10, 13).

Estimating the sample volumes for the study, based on the data from medical literature, 3D images were expected to be helpful in increasing the precision of liver resection up to 31% (9). Minimum 3 respondents and 29 observations were computed in each group (CT and 3D), and this would be sufficient in order to get the expected results. This sample volume is sufficient to ensure the second rate deviation not higher than 20% with the first rate 5% deviation in order to check unilateral hypothesis.

Four digital data packages with different combinations of CT scans and 3D liver images were created. One data package set consisted of 29 CT scan stacks and 29 3D images, totally composing 58 clinical cases. Each case was presented as an individual clinical case. In order to avoid the results achieved analyzing the CT and 3D images as the common interrelated data of one and the same patient all CT and 3D images were randomized by the computer and presented in random numerical sequence so as to avoid following each other. For demonstration of the images in computer-generated random order, a special program was developed.

A specially designed questionnaire was developed. In the questionnaire, 58 cases were briefly described. The disease description of the same patient has been presented together with CT images and it has been different from disease description presented with 3D image in age and order of sentences without changing the etiology of the disease. Within the questionnaire, the segments invaded by the tumor and the segments intended for resection could be marked. The respondent in the questionnaire had the possibility to choose either a full or atypical segment resection. Additionally, the anatomical structures that could complicate the operation, such as hepatic and portal veins could be marked.

Four students of the Medical Faculty of Vilnius University who had completed courses of human anatomy, radiology, and abdominal surgery were randomly chosen and were asked to fill in the questionnaire.

The collected data from filled in questionnaires have been compared with the findings received during surgery and with the extent of liver resection. Moreover, the part of properly determined segments using CT scan images and the part of properly determined segments using 3D images for each case have been evaluated. The evaluations were made in such a way: if the student, according to the given image, planned to resect the segment and it was resected during real surgery or if he did not plan to resect it and the segment was not resected, the segment was found to be determined properly, otherwise it was considered to be wrong. The properly determined segments of one patient have been divided by 8, and it has been considered as a part of properly determined segments. The differences between determination of lesion localization according to segments, the extent of hepatic resections and the anatomical structures, the limiting the resection extents when analyzing 2D and 3D images were evaluated.

Statistical analysis

Statistical analysis was processed by SPSS statistical programs package (version 15.0 for Windows). As the data did not satisfy the normality precondition, the nonparametric tests were used: Mann-Whitney test to compare two groups, Kruskal-Wallis test in order to compare more than two groups. To analyze categorical variables, chi-square and Fisher's exact tests have been applied. The descriptive statistics has been presented in the form of mean ± standard deviation or frequency tables. The level of significance was set at ≤ 0.05. Two-sided P values are given.

Results

The patients' descriptive statistics and the etiology of focal hepatic lesions are presented in Tables 1 and 2.

The most commonly performed liver resection surgery was right hepatectomy, totally 11 operations

Table 1. **Patients' characteristics**

Characteristics		Patients (n=29)	Percentage (100%)
Gender	Female Male	13 16	44.8% 55.2%
Age, years		Average	Range
		59	25–81
Number of lesions per case	Number of lesions	Patients (n=29)	Percentage (100%)
	1 2 3 4 Multiple (>5)	18 4 4 2 1	62.06% 13.79% 13.79% 6.9% 3.46%
Location of lesion	Segments	Number of lesions	Percentage (100%)
	1 2 3 4 5 6 7 8	1 5 2 8 13 12 10 15	1.52% 7.58% 3.03% 12.12% 19.70% 18.18% 15.15% 22.73%

***Table 2.* The etiology of focal liver lesions**

Etiology	Number (n=29)	Percentage (100%)
Metastasis		
Metastasis of colon adenocarcinoma	17	58.61%
Metastasis of pancreatic adenocarcinoma	1	3.45%
Metastasis of ovary cancer	1	3.45%
Metastasis of breast cancer	2	6.9%
Tumors of undetermined etiology	1	3.45%
Primary liver cancer		
HCC	3	10.34%
Liver angiosarcoma	1	3.45%
Cholangiocarcinoma	1	3.45%
Benign tumors		
Focal nodular hyperplasia	1	3.45%
Hemangioma	1	3.45%

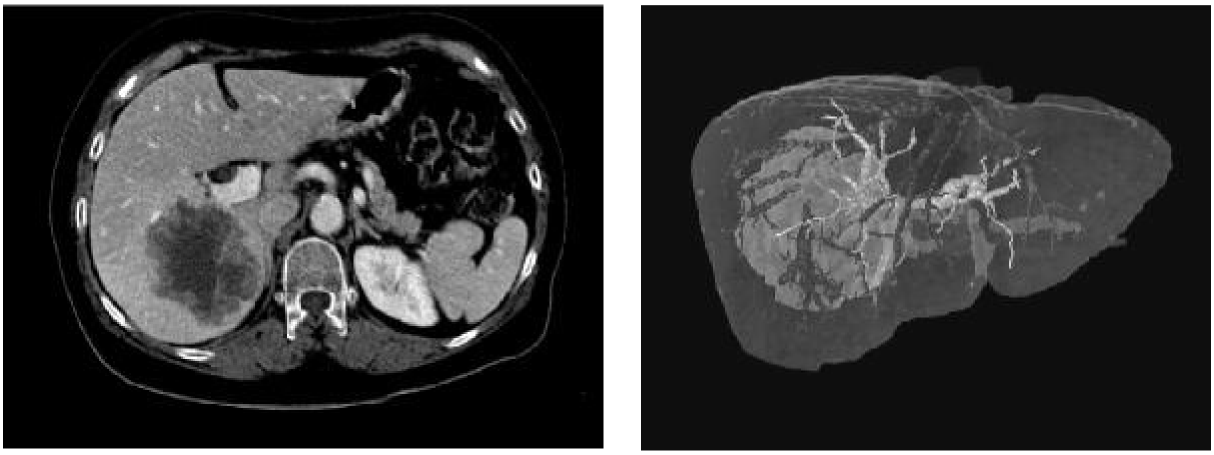

***Fig. 1.* 2-Dimensional CT scan on the left and 3-dimensional liver visualization on the right**
The tumor can be seen in segments 5, 6, and 8. Notice how clearly veins can be identified and followed.

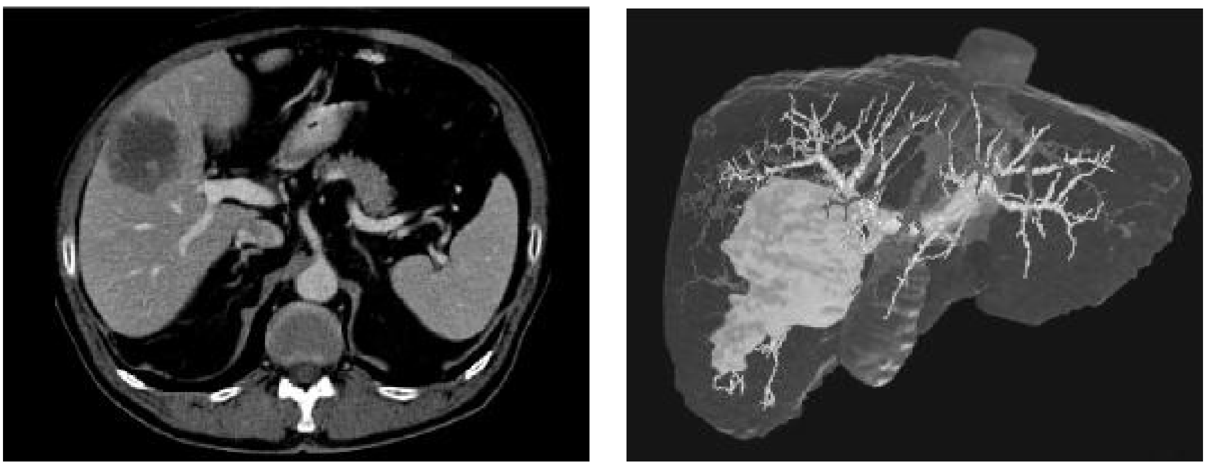

***Fig. 2.* 2-Dimensional CT scan on the left and 3-dimensional liver visualization on the right**
The tumor can be seen in segments 7 and 8.

(37.93%). Right hepatectomy with supplementary performed left lobe atypical resection was performed in three patients (10.34%). The atypical liver resections were performed on four patients (13.79%). One complicated central liver resection was performed, in addition to one right and one left expanded liver resections were performed (3.45% each). Other types of operations, such as anatomical segmental resection, left hepatectomy, left hepatectomy with atypical right lobe segmental resection were performed on the patients (3.45% each accordingly). The liver transplantation was performed on one non-operable patient with HCC (3.45%).

Four patients involved in the study did not undergo surgery (13.79%). Two of them were not operated on because of carcinomatosis, one patient due to a large non-operable tumor and the age limit and one patient due to multiple hepatic lesions. The patients did not undergo neoadjuvant therapy or any other procedures in order to devascularize the tumor or increase the hepatic tissue volume before the operation.

The compatibility of the proposed operation extent with the real operation data

In order to insure which of the operation planning method (CT scan or 3D visualization) is more similar to the real data of operations, the groups by the correctly selected segments of the liver have been compared. Our study showed that 3D visualization did help in naming correctly the affected segments of the liver for proper anatomical liver resections. The students correctly suggested a mean of 0.670±0.200 anatomical liver resections using CT 2D scans and a mean of 0.794±0.175 using 3D visualization. The difference has been found to be significant ($P<0.001$). We can assume the same tendency can be found in atypical resections as well. However, we could not get statistically significant difference (means of 0.875±0.159 using CT 2D and 0.908±0.141 using 3D visualization, respectively, $P=0.081$) (Fig. 3, 4).

We have analyzed the dependence between the accuracy of the classification and the method (CT scan or 3D visualization) in different liver segments using chi-square test (or Fisher's exact test). The results have shown the localization of the lesion in segment to be better using 3D visualization method in 4–8 segments. Having chosen segment, four students gave 93 (80.17%) correct answers using 3D visualization images and selected 76 (65.52%) true answers using CT scans. Additionally, students made 23 (19.83%) mistakes using 3D visualization and selected 40 (34.48%) wrong answers using CT scans. Those findings are statistically significant ($P=0.012$). Segment 5 was estimated similarly, as the students gave 79 (6.1%) correct answers using 3D visualization and chose 64 (55.17%) correct answers using CT scans. These differences are significant ($P=0.043$). The same tendency has been noticed after the evaluation of segments 6, 7, and 8 ($P=0.011$, $P=0.002$, and $P=0.002$, respectively) (Table 3).

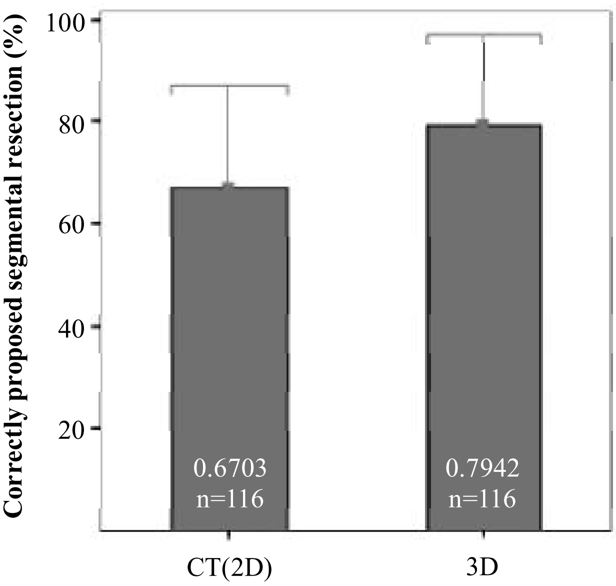

Fig. 3. **The comparison of CT scans and 3D visualization coincidence with real findings (segmental resections)**

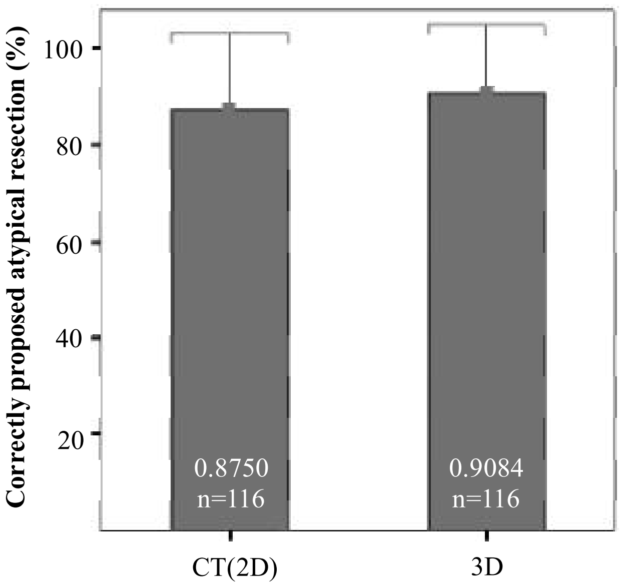

Fig. 4. **The comparison of CT scans and 3D visualization coincidence with real findings (atypical resections)**

Table 3. **The comparison of 2D (CT) and 3D in regard to correct segment classification**

Correctly defined segments			2D (CT)	3D	P value
Segment (1)	False	Number % in group	22 18.97%	13 11.21%	0.099
	True	Number % in group	94 81.03%	103 88.79%	
Segment (2)	False	Number % in group	18 15.52%	13 11.21%	0.335
	True	Number % in group	98 84.48%	103 88.79%	
Segment (3)	False	Number % in group	16 13.79%	11 9.48%	0.306
	True	Number % in group	100 86.21%	105 90.52%	
Segment (4)	False	Number % in group	40 34.48%	23 19.83%	0.012*
	True	Number % in group	76 65.52%	93 80.17%	
Segment (5)	False	Number % in group	52 44.83%	37 31.9%	0.043*
	True	Number % in group	64 55.17%	79 68.1%	
Segment (6)	False	Number % in group	57 49.14%	38 32.76%	0.011*
	True	Number % in group	59 50.86%	78 67.24%	
Segment (7)	False	Number % in group	55 47.41%	32 27.59%	0.002*
	True	Number % in group	61 52.59%	84 72.41%	
Segment (8)	False	Number % in group	46 39.66%	24 20.69%	0.002*
	True	Number % in group	70 60.34%	92 79.31%	

*A significant difference was detected.

Prediction of anatomical limitations

The next step in planning surgery was to foresee the probable challenges during the procedure. However, the unbiased index showing which method of operation planning is more advantageous has not been clearly stated. Consequently, it had to be found out if the same probable challenges during the operation could be noticed using CT scans and 3D visualization. This is a very problematic question. Two methods have been used, such as estimating the total difficulty (left hepatic vein + medium hepatic vein + right hepatic vein + left portal vein + right portal vein; the maximal score is six) and the comparison of methods, taking difficulties individually. There was found no statistically significant difference (P=0.786) between two methods (CT scans and 3D visualization) estimating the total difficulty, and no statistically significant difference was found comparing which method, either 3D visualization or 2D CT scans, was better in regard to possible/individual anatomical difficulties (Table 4).

***Table 4.* The comparison of 2D (CT) scans and 3D visualization in regard to prognosis of anatomical difficulties**

Prognosis of anatomical difficulties			2D(CT)	3D	P value
Left hepatic vein	False	Number % in group	95 81.9%	101 87.1%	0.277
	True	Number % in group	21 18.1%	15 12.9%	
Middle hepatic vein	False	Number % in group	54 46.6%	63 54.3%	0.237
	True	Number % in group	62 53.4%	53 45.7%	
Right hepatic vein	False	Number % in group	47 40.5%	39 33.6%	0.277
	True	Number % in group	69 59.5%	77 66.4%	
Left portal vein	False	Number % in group	90 77.6%	95 81.9%	0.414
	True	Number % in group	26 22.4%	21 18.1%	
Right portal vein	False	Number % in group	47 40.5%	47 40.5%	1.000
	True	Number % in group	69 59.5%	69 59.5%	
Other	False	Number % in group	96 82.8%	95 81.9%	0.863
	True	Number % in group	20 17.2%	21 18.1%	

The comparison of the proposed operation plans

The plans made using CT scans images with real operations in every segment paying attention to anatomical and atypical resection as well as the plans made using 3D visualization with real operations in every segment in regard to the anatomical and atypical resection have been compared. The difference comparing the proposals for liver resection using CT scans with the real operation has been found to be statistically significant. Students chose different operation plans for segments 5, 6, and 7 (P=0.044, P=0.035, and P=0.029, respectively) (Table 5). On the other hand, no statistically significant difference comparing proposals for liver resection using 3D visualization with the real operation has been found (Table 5).

Discussion

It is still under discussion, whether liver anatomy should be classified using portal system or some other one (3, 16, 17). However, the liver anatomy is variable and changes with tumor growth, the operations preceded, the regenerative growth (12). Therefore, a computer-based 3D segmental anatomy of the liver has been developed. A very high level of interest in this type of hepatic visualization is apparent from more than 100 quotations in the literature focused on 3D liver anatomy (18). During the past decade, the advancement of novel technological progress has outpaced the ability of medicine to put these achievements to practice. Image acquisition modalities have developed from early generation computed tomography scanners capable of simulating 3D reconstruction to the current day multidetector spiral computed tomography and magnetic resonance imaging (19). Parallel development has occurred in the fields, which use the modalities such as anatomy, operative planning, and hepatic lesion targeting (6, 9, 20). Hepatic surgery is considered a very challenging procedure and many aspects must be taken into consideration. Individual liver anatomy variations, the calculation of the liver

Table 5. **The comparison of 2D(CT), 3D visualizations, and real operations according to frequency**

Segment number	Properly proposed part	2D (P value)	3D (P value)	Performed resection
Segment (1)	Number % in group	18 15.50%	13 11.20%	1 3.40%
Segment (2)	Number % in group	14 12.10%	9 7.80%	3 10.30%
Segment (3)	Number % in group	12 10.30%	5 4.30%	3 10.30%
Segment (4)	Number % in group	38 32.80%	25 21.60%	5 17.20%
Segment (5)	Number % in group	44 37.93% (0.044)*	67 57.80%	17 58.60%
Segment (6)	Number % in group	43 37.07% (0.035)*	54 46.60%	17 58.60%
Segment (7)	Number % in group	35 30.20% (0.029)*	56 48.30%	15 51.70%
Segment (8)	Number % in group	61 53.00%	64 55.20%	15 51.70%

*Only significant P values are presented.

volumes can be quite easily achieved from standard radiological equipment (CT, US). However, definition of the devasculization zones, the relation of tumors and vessels, and the determination of the minimal resection volume have been found to be very problematic (21–27). The neophyte finds it to be even more complicated, particularly while studying hepatic anatomy and surgical procedures. The new revolutionary visualization technology provides interactive stereo viewing of the complex structures from the numerous real and theoretical vantage points correctly and in the way the viewer desires without the need of biological materials. These features may ensure a new, more efficient, educational framework that can be spread across the medical institutions (17).

All the standard radiological visualization methods are very complicated and focus on what can be computed, concentrating on the given images from a frequency or band-pass point of view. Alas, this is not the way the human being perceives the images. Human eyes can perceive stereo, perspective, depth, color, motion, and much more. The fact that 3D visualization may be accomplished on the computer screen and may help to create a user-friendlier environment, which has a high importance for a novice in analyzing and learning of hepatic anatomy, has been found to be advantageous. The image can be easily managed in virtual space being rotated and observed from different angles, magnified or reduced. One structure can be hidden and another can be highlighted using transparent function for any structure. In addition, structures are colored differently to help the user to identify the parts desired using less effort. 3D visualization gives even deeper perspectives in hepatic anatomy learning. Vessels (hepatic veins, portal veins, arteries and bile ducts) can be continuously observed in 3D space in contrast to CT, MRI standards, where vessels can be analyzed only using image by image in stacks. Therefore, it could be helpful in identifying the relationship of the vessels, their anatomical variations and Couinaud's liver segments more properly. Moreover, 3D visualization enables the integration of vascular system into semitransparent hepatic parenchyma.

Our study showed that the identification of the tumors and the proposals of resection increased significantly after introducing 3D visualization to the students. Presumably, 3D visualization improves the knowledge of the segmental anatomy and the precise localization of the pathology in the liver. Moreover, students have found 3D perspective to be user-friendlier, easier to master, and easier to see the liver and its alterations as a whole. 3D view has been found to be more visually expressive and interactive (28).

The students have achieved poorer results in tumor localization and resection proposals using 2D CT scans, as they lack deeper knowledge in radiology and the vascular system of the liver determining the correct liver segment. In addition, CT stacks must be viewed and analyzed separately without summarizing the views, which can be difficult for an inexperienced eye to follow (29, 30).

We found no evidence whether 3D visualization helps to choose atypical liver resection or not. Hypothetically, atypical liver resections are not very common in practice (this method was used only in 13.79% of 29 cases) because of its disputable indications and outcomes. Naming of atypical resection has been avoided by the students.

No proof that 3D visualization helps the students to suspect the resection challenges performing the operation has been found. There must have been no difference between both applied visualization methods clearly demonstrating intrahepatic structures and determining whether the liver vessel is affected. On the other hand, it can be suspected that the students having no clinical practice are likely to avoid surgical challenges and to mark as much anatomical limitations as possible despite the method used.

Our study showed that the 3D visualization assisted students in making better decisions while planning the liver surgery. Consequently, it can be assumed that 3D liver visualization can help in mastering surgical liver anatomy while studying.

To conclude, 3D liver visualization should take strong position in surgical practice and especially while studying surgical anatomy. It is highly important for every novice to learn the precise preoperative preparation such as the localization of the tumor and its boundaries, the defining extent of the liver resection, estimating the remaining and the functional tissue, etc (27). This study has shown that 3D liver visualization helps the students to deepen their knowledge in the complicated segmental liver anatomy, to determine the alteration processes more successfully and to suggest more precise liver resections. We hope that in the nearest future this method will become a part of the education process in every curriculum for medical student.

Conclusions

Our study has shown 3-dimensional liver visualization to be helpful to students naming the affected liver segments and localizing the tumors as well as finding more solid solutions in comparison with the data of the real operations on critical liver segments.

Dvimačio ir trimačio kepenų vizualizavimo palyginimas mokantis klinikinę kepenų anatomiją

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Raktažodžiai: klinikinė kepenų anatomija, kepenų rezekcijos planavimas, kompiuterinė tomografija, trimatis vizualizavimas, chirurgijos mokslas.

Santrauka. *Tyrimo tikslas*. Nustatyti, kuris iš vizualizavimo metodų – dvimatis ar trimatis tinkamesnis medicinos studentams mokantis klinikinę kepenų anatomiją.

Tyrimo medžiaga ir metodai. Į retrospektyvųjį kohortinį lyginamąjį tyrimą įtraukti 29 pacientai, kuriems nustatyta židininė kepenų patologija ir jiems Heidelbergo universiteto Chirurgijos klinikoje bei Vilniaus universiteto ligoninės Santariškių klinikose atliktos kepenų rezekcinės operacijos. Prieš operaciją visiems pacientams atlikta kompiuterinė tomografija ir trimatė (3D) kepenų vizualizacija. Dvimačiai ir trimačiai 58 kepenų skaitmeniniai vaizdai sumaišyti tarpusavyje, kad neitų vienas po kito, ir kartu su specialiai sudaryta anketa buvo pateikti Vilniaus universiteto Medicinos fakulteto ketvirtojo kurso studentams. Jie turėjo nustatyti naviko lokalizaciją, planuojamus rezekuoti segmentus bei anatominius rezekcijos sunkumus. Gauti rezultatai buvo palyginti su atliktų operacijų radiniais ir kepenų rezekcinių operacijų apimtimis.

Rezultatai. Studentai, nustatydami navikų lokalizaciją, geresnių rezultatų pasiekė naudodamiesi trimačiu kepenų vizualizavimu. Didžiausi skirtumai gauti 5, 6, 7 ir 8 segmentuose (p<0,05). Studentai, planuodami kepenų rezekciją, geresnių rezultatų pasiekė taip pat naudodamiesi trimačiu vizualizavimu. Palyginę su realiai atliktomis operacijomis, studentai tiksliau suplanavo rezekcinės operacijos apimtį, naudodamiesi trimačiu kepenų vizualizavimu (vidurkis±SN – 0,794±0,175) nei naudodamiesi kompiuterinės tomografijos vaizdu (vidurkis±SN – 0,670±0,200), (p<0,001).

Išvados. Trimatė kepenų vizualizacija padeda medicinos studentams tiksliau nustatyti naviko lokalizaciją kepenyse ir tiksliau suplanuoti kepenų rezekcines operacijas palyginus su dvimačiais kepenų vaizdais. Trimatė kepenų vizualizacija turėtų būti naudojama studijuojant kepenų anatomiją.

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