

The impact of using three-dimensional printed liver models for patient education

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Abstract

Objective: To investigate the impact of using a three-dimensional (3D) printed liver model for patient education.

Methods: Children with hepatic tumours who were scheduled for hepatectomy were enrolled, and patient-specific 3D liver models were printed with photosensitive resin, based on computed tomography (CT) images. Before surgery, their parents received information regarding liver anatomy, physiology, tumour characteristics, planned surgery, and surgical risks using these CT images. Then, parents completed questionnaires regarding this information. Thereafter, 3D printed models of each patient were presented along with an explanation of the general printing process, and the same questionnaire was completed. The median number of correct responses in each category before and after the 3D printed model presentation was compared.

Results: Seven children and their 14 parents were enrolled in the study. After the presentation of 3D printed models, parental understanding of basic liver anatomy and physiology, tumour characteristics, the planned surgical procedure, and surgical risks significantly improved. Parents demonstrated improvements in their understanding of basic liver anatomy by 26.4%, basic liver physiology by 23.6%, tumour characteristics by 21.4%, the planned surgical procedure by 31.4%, and surgical risks by 27.9%.

Conclusions: Using 3D printed liver models improved parental education regarding the understanding of liver anatomy and physiology, tumour characteristics, surgical procedure, and associated surgical risks.

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Keywords

Three-dimensional printing, hepatic surgery, hepatoblastoma, children

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Introduction

The influence of a patient's understanding of their medical condition on treatment outcomes has recently gained increasing attention.¹ Ideally, it is better for patients with hepatic tumours to understand the anatomy and physiology of the liver, the characteristics of tumours, the operative procedure, and associated risks. Generally, patient education is conducted via an explanation by the surgeon, or other medical professional, with the use of computed tomography (CT) or magnetic resonance images (MRI) when patients develop hepatic tumours that require surgical removal. However, it can be very difficult for a non-medical person to understand such complicated medical information and radiological images.¹ Furthermore, the plethora of available treatment strategies (ablation, excision, and transarterial chemoembolization) may further complicate patient understanding, given their specific risks of complications.

Novel technologies, such as three-dimensional (3D) printing, may play a role in the education of patients. Three-dimensional printing is a type of rapid prototyping that uses an additive manufacturing process, whereby a machine arranges successive layers of a thermoplastic material to build an object.² Three-dimensional printers allow fabrication of tangible anatomical and pathological structures from CT and MRI.³ As printing hardware becomes more readily available and affordable, the opportunities for use in the educational setting are numerous.^{4,5} One pilot study suggested that 3D printed

models of kidney and tumour anatomy can improve patient understanding of their medical condition and surgical procedures.¹

Three-dimensional printing has been widely used in a variety of medical teaching areas, and has been shown to be more effective than conventional methods.⁶ Three-dimensional printed models help to transfer complex anatomical information to clinicians, which results in increased usefulness in preoperative planning, as well as for intraoperative navigation and for surgical training purposes.⁷ However, 3D printing technology has not been tested in the arena of patient education and treatment satisfaction in patients with hepatic tumours. This current report describes an initial investigation using a 3D printed liver model for patient education.

Patients and methods

Study participants

This prospective study enrolled consecutive children with hepatic tumours scheduled for partial hepatectomy in the Department of Paediatric Surgery, Guangzhou Women and Children's Medical Centre, Guangdong Province, China between December 2016 and May 2017. All demographic and clinical data were collected prospectively.

The study was approved by the Institutional Review Board of Guangzhou Women and Children's Medical Centre, Guangzhou, Guangdong Province, China. Written informed consent was obtained from the patients' parents. Prior to analysis,

all patient records/data were anonymized and de-identified.

Study methods

Parents were given similar information regarding the anatomy and physiology of the liver, tumour characteristics, the planned surgery, and associated surgical

risks and outcomes through a face-to-face clinical consultation using CT images, which lasted approximately 20 min.

A questionnaire was designed to quantitatively assess the understanding of each participant. This questionnaire had 22 specific questions that covered five different knowledge areas, including liver anatomy, liver physiology, tumour characteristics, the

Table 1. Patient questionnaire that was distributed to the parents of the children enrolled in this study of the use three-dimensional printed liver models for patient education.

	True	False
1. What I know about the liver, generally speaking		
1.1 – The liver is not a paired organ		
1.2 – The liver has complex metabolic functions		
1.3 – The liver produces bile		
1.4 – The bile is drained through the biliary duct and stored in the gallbladder		
1.5 – The liver is a highly vascularized organ and a lot of blood flows through the hepatic vessels		
1.6 – The hepatic vessels can be described as an artery and veins		
1.7 – To work properly the liver needs blood coming through the hepatic artery and portal vein		
1.8 – When the liver is not working properly this leads to liver insufficiency		
1.9 – The liver is divided into five lobes and eight segments		
2. What I know about the disease	True	False
2.1 – The liver is bearing a tumour		
2.2 – The tumour is located in a part of the liver		
2.3 – The tumour is in close contact with hepatic vessels		
2.4 – The tumour is in close contact with the biliary tract		
2.5 – The tumour has dual blood supply and may metastasize through vessels		
3. What I understand about the planned surgery	True	False
3.1 – The surgeon will try to remove the tumour only		
3.2 – The surgeon will remove the entire liver In case of tumour only removal, the surgeon will have to cut the liver itself to separate the tumour from the surrounding healthy tissue. This may lead to:		
3.3 – bleeding with a risk of haemorrhage		
3.4 – damage of the biliary tract with a risk of bile leakage		
3.5 – To reduce the risk of haemorrhage at the time of tumour removal, the surgeon may need to clamp (i.e. interrupt blood flow) the hepatic artery and portal vein		
3.6 – Prolonged hepatic artery and portal vein clamping is known to alter liver function, so the surgeon will have to speed up the procedure to limit the length of clamping		
3.7 – In case of tumour only removal, the benefit is preservation of healthy liver tissue		
3.8 – Preserving healthy tissue from a tumour bearing liver decreases the risk of liver insufficiency		

surgical procedure, and associated surgical risks (Table 1). Since all patients were under the age of 18 years, both parents were chosen as the study participants.

The operating surgeon had a face-to-face discussion with each patient's father and mother the day before surgery, and information regarding liver anatomy, liver physiology, tumour characteristics, surgical procedure, and associated surgical risks was delivered using CT images (Figure 1). Parents were encouraged to raise questions during this process and were asked to complete the questionnaire immediately after this session. Thereafter, the 3D printed model of their own child was presented (Figure 2), and after a basic description of the 3D printing process, parents were again free to ask questions. Then, the parents immediately completed the questionnaire again.

3D printing process

The 3D printing process included reconstruction of the 3D image, digital preparation, 3D printing, and post-print finishing work. Enhanced multidetector CT (MDCT) data of all enrolled patients were prospectively collected using a Philips Brilliance 64 MDCT scanner (Philips, Eindhoven, the Netherlands). The MDCT

slices were 0.5 mm thick, yielding anisotropic voxels when viewed as 3D. The data were stored in Digital Imaging and Communications in Medicine (DICOM) files. The dataset of liver specimens was processed and edited using Mimics software version 14.01 (Materialise, Leuven, Belgium). Working together, radiologist and technologist digitally segmented anatomical structures (hepatic arteries, hepatic veins, and portal veins) from the optimal visualization phases of contrast-enhanced MDCT. Segmentation was completed with a combination of manual and 'region growing' techniques. Surface extraction of segmented data into the digital 3D model was performed automatically using the Mimics software. Once the models were rendered free of errors, the data were converted to .STL format, which is compatible with 3D printers. The .STL files from the final digital dataset were electronically delivered to a commercial printing company where the 3D printing was completed using a stereolithography rapid prototyping printer (RS6000; Shanghai Union 3D Technology Corp., Shanghai, China). Once printed, the models underwent post-manufacture processing, which included removal of the support structures with a pressured water jet

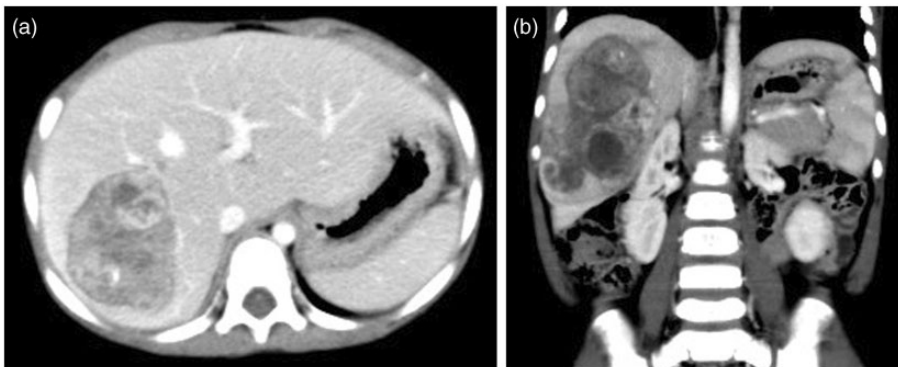


Figure 1. Representative computed tomography images of a hepatic tumour in a child: (a) axial view; and (b) coronal view.

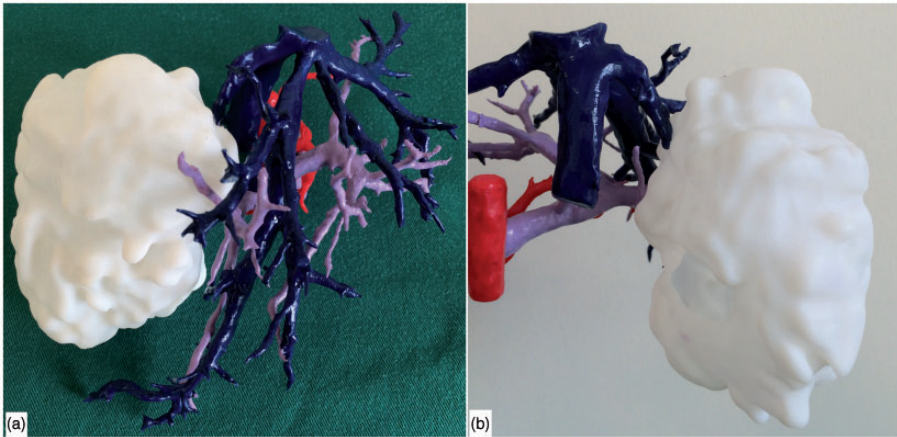


Figure 2. A representative three-dimensional (3D) printed model of a hepatic tumour in a child: (a) anterior view; and (b) posterior view. The tumour is shown in white, the hepatic vein in blue, the portal vein in purple, and the artery is shown in red. Anatomical structures were segmented from enhanced multidetector computed tomography data. Surface extraction of segmented data into a digital 3D model was then performed. Data were converted to .STL format files; the files were electronically delivered to a 3D printer, and then printed with photosensitive resin. Finally, the models underwent post-manufacture processing. The colour version of this figure is available at: <http://imr.sagepub.com>.

Table 2. Demographic and tumour characteristics of the paediatric patients ($n = 7$) who participated in this study of the use of three-dimensional printed liver models for patient education.

	Paediatric patients						
	1	2	3	4	5	6	7
Age, months	45	27	17	6	79	26	15
Sex	Female	Male	Female	Male	Female	Female	Female
Tumour location	Left media	Right lobe	Right lobe	Left lobe	Right lobe	Right lobe	Right lobe
Tumour size, cm	6.7 × 4.4 × 7.6	6.3 × 5.1 × 8.8	3.1 × 4.8 × 4.0	8.1 × 5.7 × 7.5	7.1 × 4.5 × 6.9	6.4 × 3.1 × 3.7	8.1 × 6.6 × 8.3

and painting. For this study, seven patient-specific 3D liver models were printed.

Statistical analyses

All statistical analyses were performed using the SPSS® statistical package, version 21.0 (IBM Corporation, Armonk, NY, USA) for Windows®. The number of correct responses on the patient questionnaire was used as an endpoint. The median number of correct responses for each category, both before and after the 3D printed

model presentation, was compared. χ^2 -test was used to compare the differences between groups and a P -value <0.05 was considered statistically significant.

Results

Seven children with hepatic tumours were enrolled in this study and their 14 parents completed the investigations (Table 2). None of the parents had medical or health professional training and the mean educational level

of all parents was 10 years. Table 3 shows a group analysis of the percentage of correct responses, reflecting parental level of understanding of each component both before and after the 3D printed model was presented to them. Parental understanding significantly improved for basic liver anatomy ($P < 0.001$), basic liver physiology ($P < 0.001$), tumour characteristics ($P < 0.001$), the planned surgical procedure ($P < 0.001$), and surgical risks ($P = 0.001$).

Figure 3 shows the level of improvement of parental understanding based on an individual analysis. In this analysis, the mean of both the father and mother's correct responses was used as the representative number for each child.

Figure 4 shows the mean improvement rate in parental understanding after viewing the 3D printed liver model. Parents demonstrated an improvement of 26.4% in their understanding of basic liver anatomy, 23.6% for basic liver physiology, 21.4% for tumour characteristics, 31.4% for the planned surgical procedure, and 27.9% for surgical risks. The overall improvement was 26.1%.

Discussion

This current study investigated the impact of using 3D printed liver models of the patient for patient (parent) education in

the field of paediatric liver surgery. The 3D model was used as an adjunct to the conventional preoperative consent process. In this current study, it was possible to quantify the impact of 3D printed liver models on patient (parent) education. The results suggested 3D printed liver models comprehensively improved patient (parent) education and understanding.

Three-dimensional printing technology is rapidly growing in many surgical fields and mostly focusses on surgical guidance,^{2,8} especially in the areas of maxillofacial reconstruction, orthopaedic surgery, and organ transplantation.^{9–11} The use of 3D printing technology is rapidly expanding, not only in surgical planning, but also in the area of medical education.¹²

Inspired by the versatile usage of 3D printing technology in surgical fields, this pilot study was conducted to examine the impact of 3D printed liver models on patient education. The most remarkable advantage of a 3D printed model is the straightforward exhibition of the liver organ, which it is not possible on CT images.³ The results were quite encouraging. Participants significantly improved their understanding of all aspects of research issues compared with conventional methods. Observing a physical representation of the liver did not make participants feel uncomfortable. On the contrary, all participants had positive comments about the

Table 3. Assessment of parental understanding before and after presentation of a three-dimensional (3D) printed liver model.

	Median (range) percentage of correct responses		
	Before 3D model presentation	After 3D model presentation	Statistical analysis ^a
Liver anatomy	50 (40–60)	80 (60–90)	$P < 0.001$
Liver physiology	50 (30–60)	70 (60–90)	$P < 0.001$
Tumour characteristics	60 (40–80)	80 (70–100)	$P < 0.001$
Surgical procedure	60 (40–70)	90 (80–100)	$P < 0.001$
Surgical risks	60 (40–70)	90 (70–100)	$P = 0.001$

^aBefore compared with after presentation of 3D model; χ^2 -test.

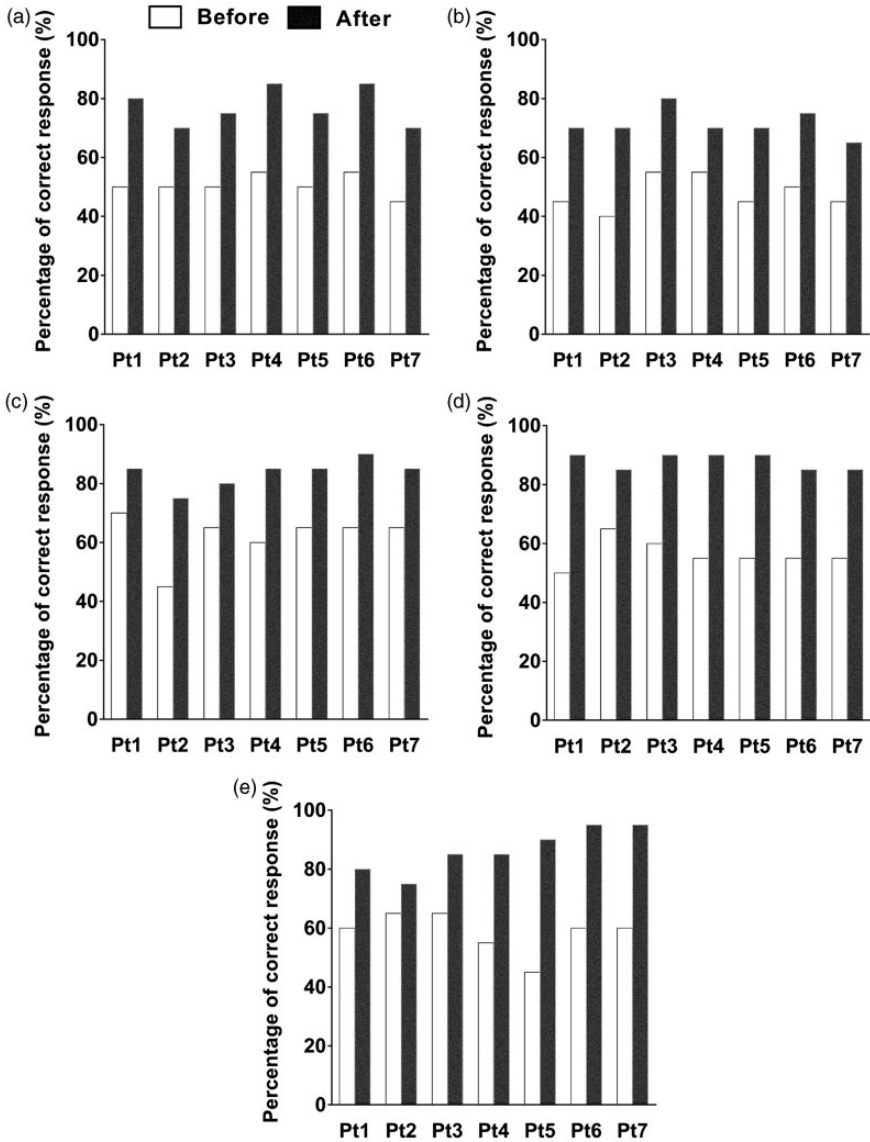


Figure 3. The percentage of correct responses per patient, before and after the three-dimensional printed model was presented to the parents of the patient. Individual analysis of improvements in understanding of the five educational components (the mean of the father’s and mother’s correct responses as the representative number for each child): (a) liver anatomy; (b) liver physiology; (c) tumour characteristics; (d) surgical procedure; (e) surgical risks. Pt: patient.

3D printed model. A previous study showed that 3D printed kidney models helped to improve patient understanding of the disease and surgical procedures compared with

MDCT.¹ The use of a 3D printed liver model in this current study gave participants a much better idea of what would happen during surgery, which reassured participants,

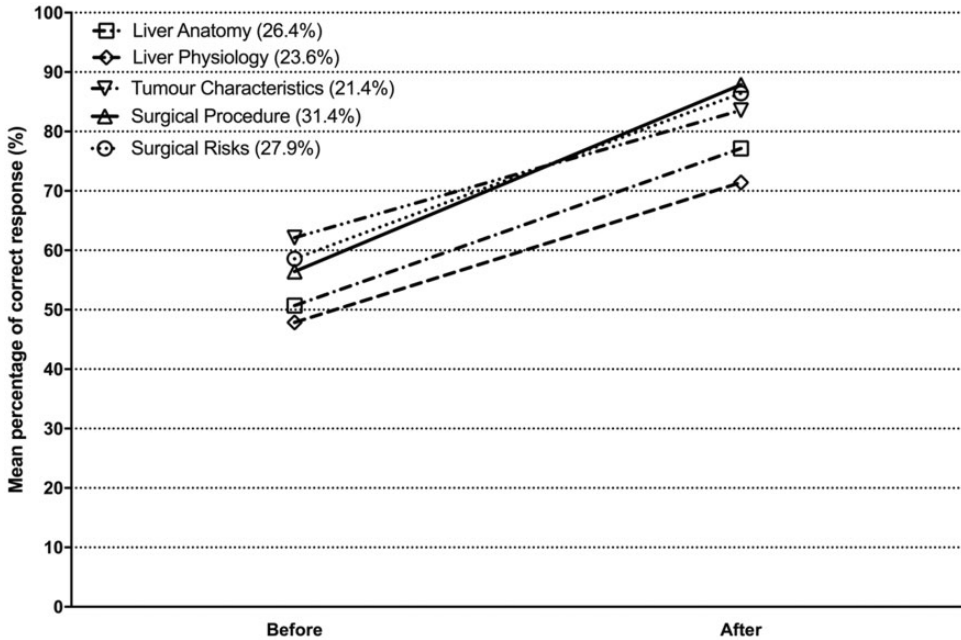


Figure 4. Mean percentage of correct responses per educational component, before and after a three-dimensional printed model was presented to the parents of the patient.

and the patients consequently felt more involved in the decision-making process. Using a 3D model is more straightforward compared with CT, which may explain why 3D printings were more effective than conventional methods. It would be interesting to see whether these positive responses had an impact on actual outcomes after surgery; however, this would require a larger study (or randomized trial) that included a formal assessment of validated outcome measures.

In this study, parents, rather than patients, were chosen as the study participants since all patients were under the age of 18 years. Both parents of each child were recruited for this study; thus, doubling the study population. In our opinion, both the father and the mother are representative in this situation; and we believe parental education can represent the child’s education.

The main limitation of 3D printing technology is that building a 3D model involves a 3D render and 3D printing, which are time-consuming and costly.^{2,13} In this current study, it took approximately 8 h for the model segmentation, which were then sent to a third-party company for 3D printing. The cost of each model was approximately 450 US dollars. In order to save costs, only vascular structures and tumours were printed in 1:1 scale, but no normal liver parenchyma. Of note, the cost varies depending on the 3D printer and printing materials used. However, with the development of newer printers and the broadening of printed materials, the time and cost may be reduced. As 3D printing technology progresses and costs fall, patient-specific 3D printing may become standard for both clinical and educational purposes.⁸ Advances in technology and multi-purpose use of models in treatment

planning, trainee education, and patient education may also help improve cost efficiency.

This study had several limitations. The explanations using the 3D printed models were the second time the parents heard the information, which likely caused bias. Receiving the educational information a second time may have inherently resulted in a better understanding, and therefore better scores after presentation of the 3D model. Furthermore, this study only enrolled seven paediatric patients and 14 parent participants, and small samples may also introduce bias.

In conclusion, the 3D printed liver model used in this study improved participant understanding of liver anatomy, physiology, tumour characteristics, the surgical procedures, and associated surgical risks. The impact of 3D printing on overall clinical outcomes may also be related; however, studies with larger sample sizes that include the assessment of other pathologies are needed to confirm these preliminary findings.

Declaration of conflicting interests

The authors declare that there are no conflicts of interest.

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