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Original Article

Application of liver three-dimensional printing in hepatectomy for complex massive hepatocarcinoma with rare variations of portal vein: preliminary experience

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Abstract: Background: To discuss the role of Liver 3D printing in the treatment of complex massive hepatocarcinoma with rare variations of portal vein. Methods: Data of enhanced computed tomography (CT) were imported into the medical image three-dimensional visualization system (MI-3DVS) to create Standard Template Library (STL) files, which were read by 3D printer to construct life-size 3D physical liver model. The preoperative surgical planning was performed on the 3D model according to individualized segmentation, volume calculation, and virtual operation. Results: The 3D printing liver model was consistent with the model in MI-3DVS. The segment 4 portal vein (S4PV) was absent and variant S4PV originated from right anterior portal vein (RAPV). The preoperative surgical planning was designed according to the relationship between tumor and portal vein variation. Theoretically, the residual liver volume was 40.76%, if the right hemihepatctomy was carried out after the trunk of right portal vein (RPV) ligated. However, the actual residual volume was only 21.37% due to the variant S4PV originates from RAPV, thus, right trisegmentectomy would have to be performed. Interestingly, after optimization, the residual liver volume increased to 57.25% as narrow-margin right hemihepatectomy with the variant S4PV reserved were performed. The final resection was determined to be narrow-margin right hemihepatectomy. The actual surgical procedure was consistent with the preoperative surgical planning. Conclusion: Liver 3D printing may be a safe and effective technique to improve the success rate of surgery and reduce the operation risk for patients with complex massive hepatocarcinoma with variations of portal vein.

Keywords: Three-dimensional printing, three-dimensional reconstruction, hepatocarcinoma

Introduction

According to the World Cancer Report 2014 released by WHO last year [1], hepatocarcinoma among all categories of carcinomas is ranked at the first place by its prevalence and at the second place by its mortality across the world and at the second place by its prevalence and at the third place by its mortality in Chinese mainland, where it has more shockingly been sitting on the top as for its total number of new cases. Meanwhile, advances in recent three-dimensional (3D) visualization technology and more updated 3D printing technology allow more accessible approaches to hepatocarcinoma [2, 3]. In this research, we applied 3D printing into a successful diagnosis and operation on a complex massive hepatocarcinoma with rare variations of hepatic artery and portal vein, which had previously been misdiagnosed and even mistreated for the reasons of inaccessibility to the advanced technology.

Material and methods

Patients. A gentleman, aged 35 years, was admitted in the hospital on April 9, 2015, and then was diagnosed of massive hepatocarcinoma in the right liver. His hepatic function was assessed to be at class A by Child-Pugh grading, with HBsAg (+), HBeAg (+) and HBcAb (+). The AFP level of 76 ug/L.

3D visualization and 3D printing technology.

Enhanced CT data were collected by Philips Brilliance 256-MDCT scanner [4].

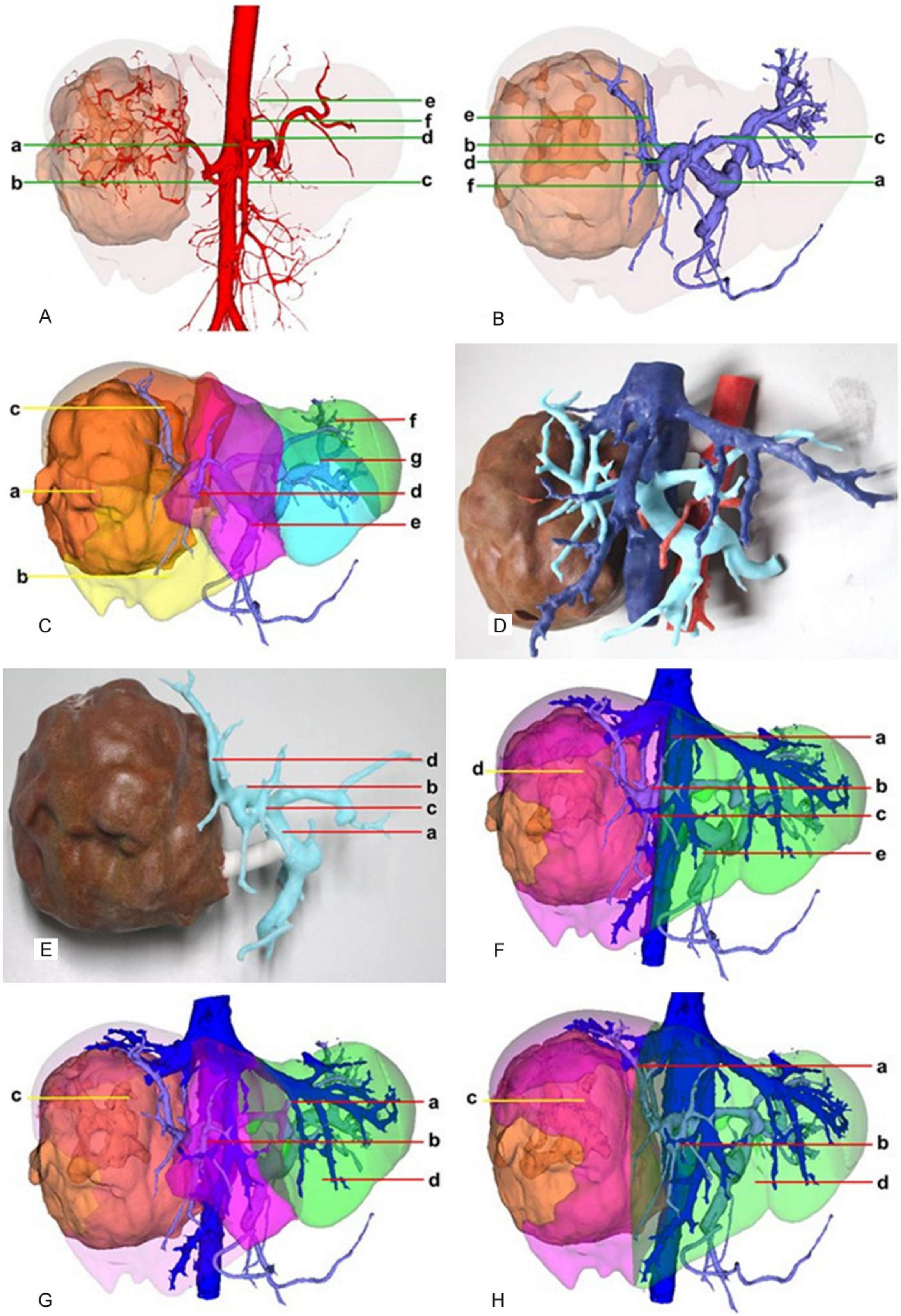

Figure 1. Preoperative surgical planning aided by the 3D visualization and 3D printing model. The 3D visualization model of celiac artery (A) a. gastroduodenal artery (GDA); b. replaced right hepatic artery (ReRHA); c. superior mes-

enteric artery (SMA); d. celiac trunk (CT); e. replaced left hepatic artery (ReLHA); f. left gastric artery (LGA). The 3D visualization model of portal vein (B) a. portal vein (PV); b. right portal vein (RPV); c. left portal vein (LPV); D. right anterior portal vein (RAPV); e. right posterior portal vein (RPPV); f. portal vein in the segment IV (S4PV). Individual hepatic segmentation (C) a. The carcinoma; b. segment V; (C) Segment VIII; d. S4PV; e. Segment IV; f. Segment II; g. Segment III. The 3D printed mode of liver (D). The carcinoma is in brown. The artery is in red. The portal vein is in light blue. The hepatic vein is in deep blue. The shortest distances from the carcinoma to the targeted blood vessels (E) a. PV; b. RPV; c. S4PV; d. portal vein in the segment VIII (S8PV). The virtual right semihepatectomy (F) a. The plane of resected live; b. RPV; c. S4PV; d. The resected liver (in red); e. The liver residuals (in green). The virtual right trihepatectomy (G) a. The plane of virtually resected liver; b. S4PV; c. The resected liver (in red); d. The live residuals (in green). The narrow margin right hemihepatectomy (H) a. The plane of virtually resected liver; b. S4PV; c. The resected liver (in red); d. The live residuals (in green).

Images segmentation and 3D reconstruction. The CT image data were imported to the Medical Imaging Three Divisional Visualization System (MI-3DVS, software copyright No.: 2008SR18798) to obtain 3D visualization models of liver, hepatocarcinoma, artery system in the abdomen, portal vein and hepatic veins, which were saved as files in the format of Standard Template Library (STL) [4]. Based on the 3D reconstructed models, the variations in celiac arteries and portal veins were analyzed and classified respectively according to Michels classification of hepatic artery and Atri Classification of portal vein and then the liver was segmented individually subject to the respective distributions of portal and hepatic veins in line with Couniaud classification.

3D printing technology. The files saved with STL format were run on Geomagic studio 2013 to design hepatic vascular fixation stents and then imported onto Z Edit TM, a desktop interface software for Spectrum ZTM 510 3D printer (Z Corporation, USA), on which the 3D models were reduced to thin-layer chromatographic data at the layer thickness of 0.0875 mm. With the reduced data sent to the 3D printer, the physical models of liver were printed with a composite material of ZP-150 layer by layer.

The preoperative planning and operations In the 3D model, the plan for the virtual hepatotectomy was carefully prepared according to the variations of the portal vein as well as the space between the hepatocarcinom and the vessels, with the resection plane delicately adjusted and the volume of would-be-resected liver accurately computed in the following equation: the volume to be resected = the volume of the residual/the volume of functional liver × 100%. The printed 3D physical model of liver and the laptop with MI-SDVS installed and run were taken into the operation chamber to direct surgical operation in real time.

Post operative treatment and follow-ups. On day 10 postoperatively, data were collected by Philips Brilliance 256-MDCT scanner and then treated for 3D visualization study in the same way to assess the accuracy of partial hepatic resection under the guidance of the printed 3D model [4].

Results

Diagnosis aided by the 3D visualization model. By 3D visualization analysis, we found the rare variations of abdominal blood vessels: the common hepatic artery (CHA) was congenitally absent, the gastroduodenal artery (GDA), the replaced right hepatic artery (ReRHA) and the replaced left hepatic artery (ReLHA) were respectively originated from the celiac trunk (CT), the superior mesenteric artery (SMA) and the left gastric artery (LGA), which was out of range of Michels' classification of hepatic artery (**Figure 1A**). Congenital absence of normal portal vein in the segment IV (S4PV), and varied S4PV originating from right anterior portal vein (RAPV), which was out of range of Atri Classification of portal vein (**Figure 1B**). The individualized hepatic segmentation indicated that the hepatocarcinoma invaded deep into the full segments VI, VII and the partial segments V, VIII and the right anterior branch of port vein played a role in supplying blood for the hepatic middle lobe (segments IV, V and VIII) (**Figure 1C**).

Surgical planning aided by the 3D printed liver model. The 3D printed physical model of liver was identical to the 3D visualization model (**Figure 1D**). The shortest distances from the hepatocarcinoma to the targeted blood vessels, e.g., the right anterior branch of portal vein and the branch of portal vein in segment VIII were 15.1 mm and 19.8 mm, respectively (**Figure 1E**). For the surgical planning of virtual hepatectemy, we prepared two options: For the

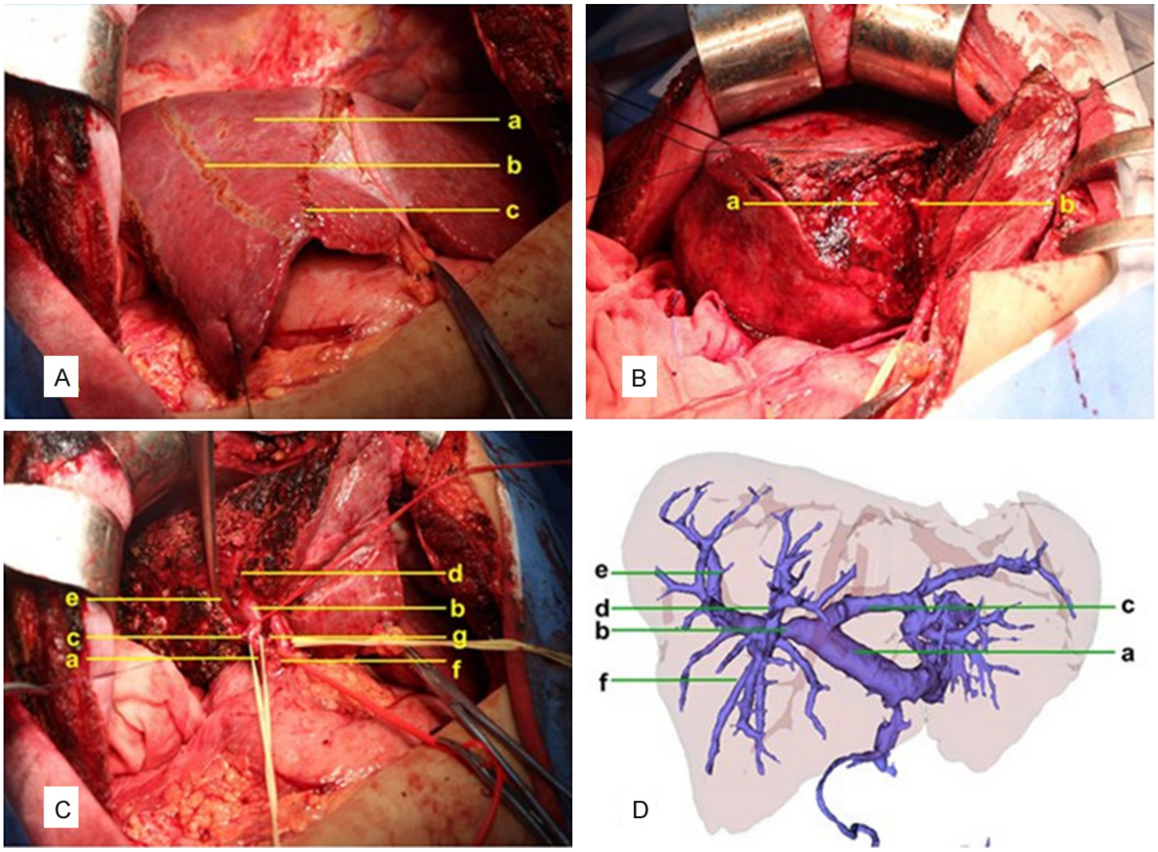

Figure 2. The real surgical results and the postoperative results in the 3D printed physical liver model. Ascertaining the ischemic boundary in the liver (A) a. The segment IV; b. The marker for right semihepatectomy; c. The marker for right trisegmentectomy. Resecting the hepatocarcinoma 1.5 cm to its boundaries (B) a. The carcinoma; b. The branches of portal vein in the carcinoma. Ligating and mutilating the posterior right branch of right hepatic artery and the posterior right branch of portal vein and meanwhile blocking the right hepatic artery and the posterior right branch of portal vein under the guidance of the 3D printed physical liver model (C) a. RPV; b. RAPV; c. The residual of RPPV; d. S4PV; e. S8PV; f. ReRHA; g. The residual of ReRHA; The postoperative 3D visualization model of portal vein (D) a. PV; b. RPV; c. LPV d. S4PV; e. S8PV; f. S5PV.

first, the right hemihepatctomy was performed with the resected volume of 599.50 ml (59.24%) and the residual of 412.50 ml (40.76%) once the right main branch of portal vein was ligated (**Figure 1F**); Supposed that ligating the right portal vein for the reason that the branch of portal vein in segment IV originated from the right anterior branch might lead to ischemic necrosis of segment IV, we intraoperatively had to resect the three right lobes with the resected volume of 795.74 ml (78.63%) and the residual of 216.26 ml (21.37%), which increased the postoperative risk of liver function failure (**Figure 1G**); For the second, the narrow-margin right hemihepatectomy was performed for the reserved branch of portal vein in segment IV with the resected volume of 432.63 ml (42.75% and the residual of 579.37 ml (57.25%) (**Figure 1H**). We made an ultimate vote to the latter surgical planning: the narrow-margin right hemihepatectomy.

The real surgical results. The real surgical processes accorded to that of the virtual ones. Intra operatively, the main right portal vein together with its anterior and posterior right branches were anatomically disassociated, followed by blocking the posterior right branch of portal vein and ascertaining the ischemic boundary in the posterior right lobe of liver. By blocking the anterior right branches of portal vein simultaneously, with its boundary only 0.5 cm to the right side of falciform ligament, the hepatic ischemia affected the three lobes of right liver, which verified origination of the branch of portal vein in segment IV from its anterior right branch (**Figure 2A**). Considering the variations, we succeeded in preserving the anterior right branch of portal vein, the branch of portal vein in segment IV and the main portal vein in segment VIII so that the narrow-margin right hemihepatectomy was completed within 280 min, with intraoperative blood loss of 180 ml (**Figure 2B**, **2C**). Postoperatively, the patient was discharged 10 days later. The pathological diagnosis confirmed that the resected tumor was a moderately differentiated hepatocellular carcinoma and the margin of reserved liver was carcinoma negative.

The postoperative results in the 3D visualization model. The carcinoma was seen with no residuals and the anterior right branch of portal vein and its branches in segments IV, V and VIII remained unchanged morphologically in contract with their preoperative forms (**Figure 2D**).

Discussion

The variations of celiac arteries, portal vein and hepatic veins are clinically common. Problematically, the 2D images by B ultrasounds, CTA and MRI are indirect in viewing so that it is grudging to surgeon to detect and even elaborate the rare variations of blood vessels. Similarly, without abundant experience in reading 2D images and clinical practice, a hepatobiliary surgeon may never make right diagnosis nor as rational operation planning [5]. The 3D visualization technology in recent decades contributes joyful advances to the medical sciences [3-7]. Our experience makes it certain that the 3D visualization mode might elaborate the spatial relations among celiac arteries, portal vein, hepatic vein, liver and the carcinomas in a real-time and stereo paradigm so as to reach an accurate diagnosis as well as a satisfactory operation planning preoperatively [3-5]. In this case, the rare variations in the celiac arteries and the portal vein in segment VI neglected by preoperative CTA and MRI were identified by 3D visualization so that the hepatobilliary surgeons avoided the possible mistakes of elaborating the variations of celiac arteries and portal vein and locating the space between the blood vessels and the carcinoma. No matter how smoothly the operations went on, however, the surgeons had to depend on the computer for an ideal approach or best surgical effect, which provided us the 2D or 3D images or videos [2]. Now that it has been used in orthopedic surgeries and research at present time, 3D printing technology is seldom reported in the disciplines of hepatobilliary surgery [2, 8, 9]. In our study, the 3D physical model derived from the authentic data of 3D visualization technology and CT scans, allows presentations of the real liver by a proportion of 1:1 before the surgeons and patient (**Figure 1D**, **1E**). Intraoperatively, we had to resect the three right lobes of liver only because the routine right hemihepaetctomy might result in ischemic necrosis in segment IV because of the main portal vein in segment IV originating from its anterior right branch. As a result, the residual liver might remain only at the rate of 21.37%, which made the risk of liver function failure amount steeply (**Figure 2G**). As a preservative method, the narrow-margin right hemihepatectomy with reservation of portal vein in segment IV achieved a residual liver at a rate of 57.25%, which evidently might prevent the postoperative secondary liver function failure (**Figure 2H**). The rational option attributed a lot to the 3D visualization and 3D printing technology. Specifically, the 3D physical model and the computer-aided 3D visualization virtual model in this case worked together to allow the surgeons to precisely evaluate and work out the deliberate operation plan, which was sure to have enhanced the safety in the hepatectomy and refrained from lower the surgical risk.

Routinely, our surgeons depend on ultrasonagraphy to ascertain the relations of a carcinoma with its adjacent blood vessels and then to make sure the range of hepatectomy [10]. In practical operations, however, this procedure includes the risk of being misled about the resection line because the view of the intrahepatic vessels differs depending on the angle between the ultrasonic probe and the hepatic surface and/or the surgeon's techniques [9]. Fortunately, the 3D printed physical model of liver is the representation of the real liver. In the model, the range of hepatectomy can be determined and the operation process can be simplified, which is not different from the intraoperative ultrasonography or even computer-aided 3D visualization model. We made the real-time contrast with the 3D printed physical model, adjusting the 3D printed mode and obtaining a best view point anatomically so as to steer visualized procedures during operation. Critically, it facilitated the fast identification and location of organs and tissues as well as the carcinoma (**Figure 2A-C**). The 3D visualization analyses postoperatively, there were no residuals of carcinoma in the model and no changes in the forms of the anterior right branch of portal vein and its branches in segments IV, V and VIII, which verifies that high possibility of 3D printed model may play a critical role in guiding the real surgical procedures (**Figure 2D**).

3D printing technology makes a leap from "human-brain-based 3D imaging", "computer-based 3D imaging" to "real 3D printed physical entity" and undoubtedly provides an ideal option for surgical treatment of hepatocarcinoma in digital surgery in that it is not only suitable for preoperative diagnosis and surgical planning of complex hepatocarcinom complicated with variations of hepatic arteries and portal vein, but beneficial for guiding intraoperative precise manipulations, improving the success rate of operation and lowering the rate of surgical risks.

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Disclosure of conflict of interest

None.

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