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Comparative study on three-dimensional versus two-dimensional imaging using a computer-assisted surgery system for preoperative planning in pediatric middle hepatic tumors

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Abstract

Backgroud The study objective was to compare three-dimensional and two-dimensional imaging using computer-assisted systems (CASs) in clinical guidance for preoperative surgical planning for middle hepatic tumors in children.

Methods A retrospective analysis was performed on 23 children who underwent surgery for middle hepatic tumors in our hospital from January 2016 to June 2022. The surgical resection plan was formulated by the operator team using two-dimensional CT images before the operation. Then, the same qualified surgeons conducted an in-depth analysis and formulated the surgical resection scheme for the same pediatric patient using three-dimensional imaging of the middle hepatic tumor. The feasibility of the two schemes was compared and analyzed.

Result All the tumors were successfully removed according to the preoperative method developed using three-dimensional imaging. The postoperative short-term follow-up revealed that all patients were doing well. Preoperative plans were revised in 9 cases after evaluating the three-dimensional images due to the disparity between the original plans and the three-dimensional relationship between the tumor and blood vessels, vascular variation, and the volume of remnant liver.

Conclusions Three-dimensional imaging with a computer-assisted surgery system is superior to two-dimensional imaging in the preoperative planning of pediatric hepatoblastoma.

Keywords Middle hepatic tumor, Three-dimensional imaging, Computer-assisted surgery system, Preoperative plan

Introduction

Liver tumors are common solid tumors in pediatric patient [1]. The left inner and right anterior lobes of the liver are located in the central liver and are often collectively referred to as the middle lobe in the clinic. The middle lobe comprises segments IV, V and VIII according to the Couinaud classification system. Pediatric middle lobe liver tumors are often large and close to the hepatic vein, portal vein, bile duct, and the first and second hepatic

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hilum, complicating surgery. Traditional large-volume resection removes a substantial volume of normal liver tissue with the tumor, often causing complications such as liver failure [2, 3]. Preoperative assessment of mid-lobe liver tumors by computer-assisted surgical system (CAS) three-dimensional imaging to develop surgical plans significantly reduces the surgical risk after liver tumor resection [4, 5]. This study aimed to compare and analyze the effectiveness of computer-assisted surgical system 3D imaging with 2D imaging in preoperative surgical planning protocols for hepatic middle lobe tumors.

Data and methods

Clinical data

Enhanced CT data were collected from January 2016 to June 2022 from 23 children with hepatic middle lobe tumors who underwent surgery at the Affiliated Hospital of Qingdao University. The patient population comprised 16 males and 7 females, with a mean age at surgery of 22.3 months. The study was approved by the Ethics Committee of Qingdao University Hospital, and the parents were informed and signed informed consent documentation before the operation.

Research equipment and materials

The upper abdomen was scanned by GE 64-layer spiral CT; Philips MX4000 double-layer spiral CT and Siemens GEBRIGHTSPEEDELITE 16-layer CT.

CT 3D reconstruction was conducted using the Hisense Computer Assisted Surgery System (Hisense CAS), a surgical planning system jointly developed by Qingdao University Hospital and Qingdao Hisense Group under the support of the National 12th Five-Year Plan (No. 2013BAI01B03). The JIGEMI- MS model was used, and the system version was CAS-V3.01.4775.

Study methods

Upper abdominal enhancement CT examination method: After routine fasting for 4–6 h before the examination, children received a 10% chloral hydrate retention enema at a dose of 0.5 ml/kg. Intravenous access was established, and 1.5–2.0 ml/kg of iohexol was injected. The routine scanning range was from the top of the suprahepatic diaphragm to the lower edge of the pancreas; the arterial period was 25 s after the start of drug injection, and the intravenous period was 50 s. At the end of scanning, the image data were transmitted to the workstation at the end of the scan and stored in DICOM format.

Hisense CAS 3D reconstruction: The specific steps of the 3D reconstruction process have been described in detail in a previous report by our team. In this protocol, above 3D data are integrated, and the position relationship is adjusted so that the volume of the liver and tumor and the position relationship between intrahepatic vessels and tumor can be displayed three-dimensionally, clearly and accurately [6].

Surgical plan design, simulated liver resection methods and comparative analysis.

(1) The operator's team first developed the surgical resection plan through two-dimensional images and then performed three-dimensional imaging on the same child, and through a comprehensive observation, reformulated the surgical plan according to the size and location of the liver tumor and the relationship with the surrounding important blood vessels and bile ducts; some children had huge tumors after three-dimensional reconstruction and could not undergo one-stage surgery. Thus, the clinicians first performed preoperative chemotherapy and repeated the three-dimensional reconstruction after the tumor had shrunk significantly. The surgical plan was then evaluated.
(2) To simulate tumor resection under the guidance of CAS, one or several different liver resection planes can be selected to virtualize the liver tumor resection surgery plan, preserve the maximum volume of functional residual liver, and select the best surgical section.
(3) The differences between the surgical plans developed under the guidance of computer-aided 3D imaging and 2D imaging were compared and analyzed, including the impact of the techniques on surgical planning for middle-lobe liver tumors.

Surgical resection method for middle-lobe liver tumors.A right subcostal incision or an inverted "Y"-shaped incision in the upper abdomen was applied. The tumor size, specific location and relationship with surrounding organs was investigated and compared with the three-dimensional imaging data, and the ligaments around the liver were fully freed according to preoperative planning. The hepatic artery, portal vein and hepatic ducts of the lobe to be resected require ligation to prevent bile leakage and bleeding after surgery. Tumors in the middle lobe of the liver often involve all or part of segments IV, V, and VIII. Complete dissection and ligation of the associated short hepatic veins are performed for right hemihepatic, right and left trilobar resection, and enlarged left hepatic lobectomy. When dealing with the second hepatic hilar, the hepatic vein is dissected into the vena cava with fine dissection, and the invading hepatic vein is ligated and cut off. When separating the liver parenchyma from the tumor, a cutting line is drawn with an electric knife, and the tumor is removed by using an ultrasonic suction device CUSA and vascular clamp ligation. Hepatic portal blocking was performed as needed to reduce bleeding, and the duration was usually under 20 min [7].

Results

Comparative analysis of preoperative planning by computer-assisted surgical system 3D and 2D imaging

Among the 23 children, 13 had hepatoblastoma, 3 had hepatocellular carcinoma, 2 had hepatic sarcoma, 2 had hepatic teratoma, and 3 had mesenchymal malformation tumor. In 9 cases, the original surgical plan was revised after the surgeon observed the 3D reconstruction resection simulation (39.13% of the original surgical planning plans; Table 1). Patient 1 (Fig. 1) required the resection of a large liver volume to according to the 2D image, and the remaining liver volume was too small to meet the postoperative compensation requirements, thus risking liver failure. The surgical approach was remodified through 3D reconstruction to further reduce the resection area, and the tumor was successfully resected surgically. In Patient 2 (Figs. 2A, B), the tumor was large, invaded the middle hepatic vein and compressed the right hepatic vein; the remaining liver volume after simulated surgical resection would not meet the growth needs of the child. In Patient 3 (Fig. 3), preoperative tumor resection simulation revealed that left or right hepatectomy was feasible, requiring ligation of the corresponding vessels. In three other patients, the preoperative two-dimensional images suggested that the tumor in the middle lobe of the liver was huge and completely invaded segments IV, V and VIII of the liver (Figs. 4, 5 and 6), necessitating an enlarged right hemicolectomy as the patient presented substantial loss of normal liver tissue and a residual liver fraction under 25%. The right posterior lobe of the liver

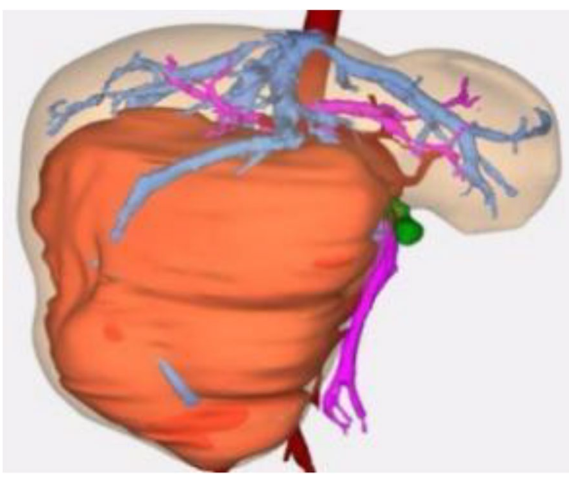

Fig. 1 Large liver tumor, clarification of the relationship between the tumor and blood vessels, reduction in the scope of resection, and retention of more residual liver volume

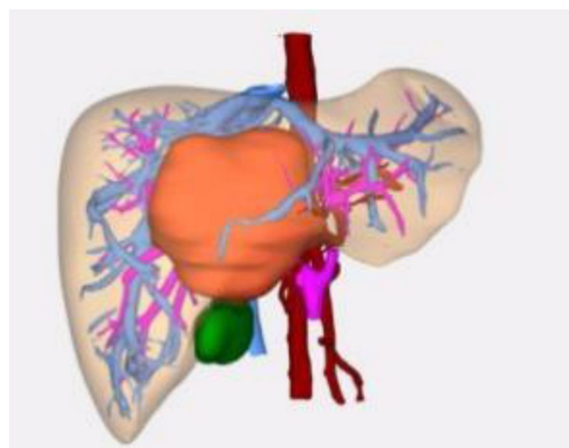

Fig. 3 Middle lobe tumor, resection of the middle hepatic tumor is performed avoiding damage to the portal vein, hepatic artery and bile duct and reducing postoperative stasis and ischemia

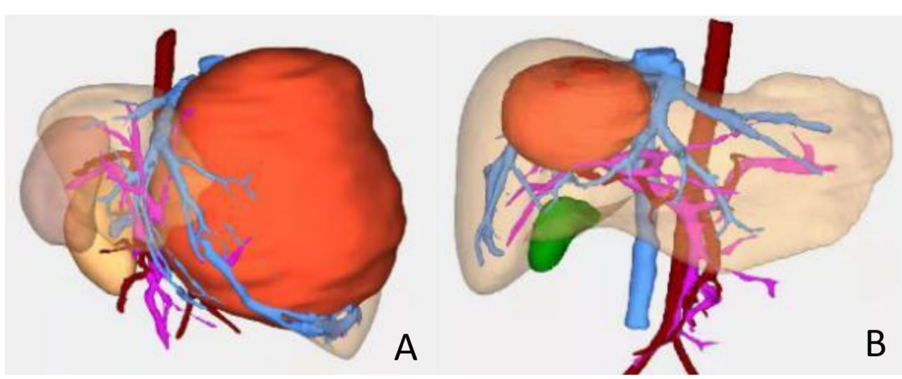

Fig. 2 **A**, **B** 3D reconstruction shows that the tumor is large, invades the middle hepatic vein, compresses the right hepatic vein. Chemotherapy was administered first; the tumor obviously reduced, and surgical resection was performed

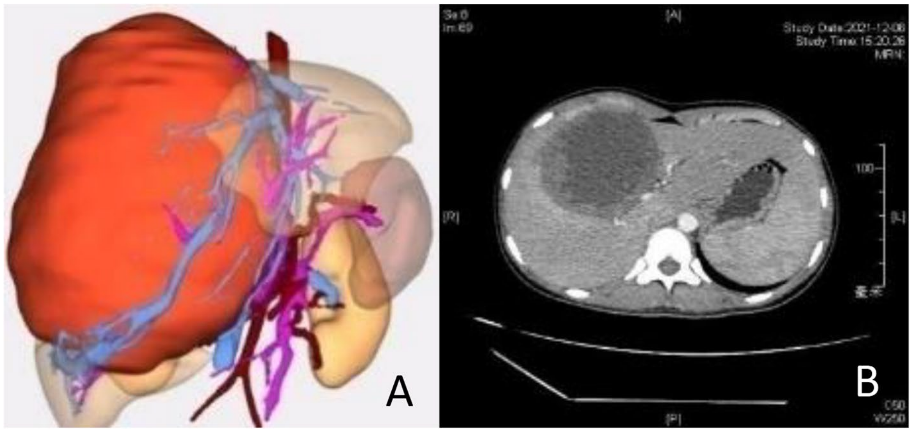

Fig. 4 **A**, **B** Huge tumor in the middle lobe of the liver with complete invasion of segments IV, V, and VIII, 3D imaging planning for middle lobe resection with preservation of the right hepatic vein

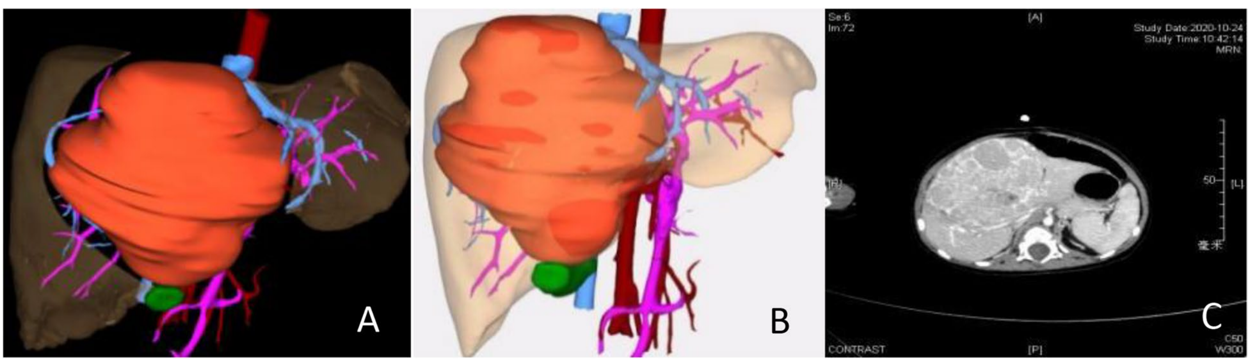

Fig. 5 **A**, **B**, **C** Huge tumor in the middle lobe of the liver with complete invasion of segments IV, V, and VIII, 3D imaging planning for middle lobe resection with preservation of the right hepatic vein

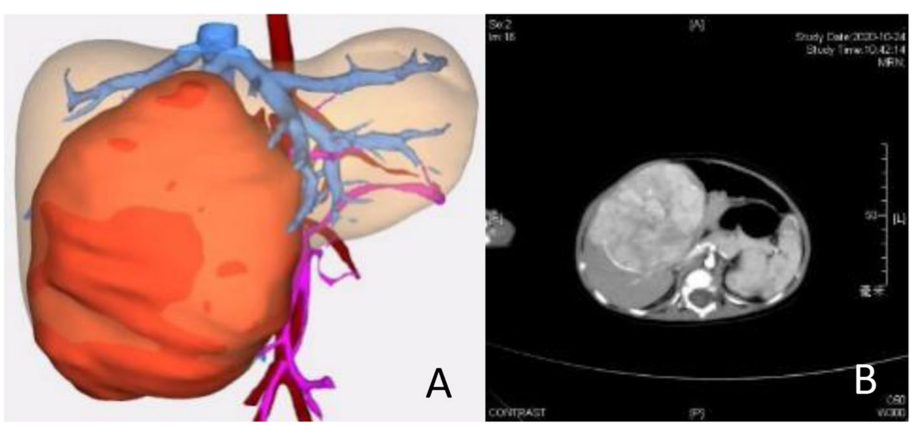

Fig. 6 **A**, **B** Huge tumor in the middle lobe of the liver with complete invasion of segments IV, V, and VIII, 3D imaging planning for middle lobe resection with preservation of the right hepatic vein

contained more normal liver tissue, and the right hepatic vein could be preserved intraoperatively with a residual liver volume ≥ 25%. The pediatric liver had a strong regenerative capacity and a good prognosis after 3D reconstructive surgery planning.

In one patient (Fig. 7), the right hepatic vein was invaded and could not be preserved, and a thicker short hepatic vein was seen in the return area of the residual liver in the 3D image; thus, trilobar resection was feasible to preserve more liver tissue and reduce the possibility of postoperative liver failure. In another patient (Fig. 8), preoperative planning for middle lobe resection was performed using 2D images. After observing the 3D images, the tumor was found to not invade hepatic segment VIII or the right or short hepatic vein; the upper and lower segments of the right posterior lobe of the liver were supplied by independent hepatic vessels that directly converged into the inferior vena cava. In one patient (Fig. 9), the tumor was close to the inferior vena cava and the middle hepatic vein on the 2D CT image, and the distance from the important vessels was less than 1 cm; thus, it was unclear whether the vessels were invaded, and the remaining liver volume could not be evaluated. The remaining liver volume after trilobar resection was calculated using CAS, the tumor size, location and relationship with surrounding vessels were observed in three dimensions, and the surgical plan was considered comprehensively before surgical resection. Figures 7, 8 and 9 have given a comparison between 2 and 3D images. 3D can show the short hepatic veins that are not easily observed in 2D and determine the close relationship between the tumor and the major blood vessels more accurately, and more liver volume can be preserved.

Surgical method and postoperative situation

All children underwent successful resection in accordance with three-dimensional reconstructive surgery planning. There were 9 cases of middle lobe resection, 5 cases of right hepatectomy, 2 cases of enlarged right hepatectomy, 2 cases of IV and V segment resection, 3

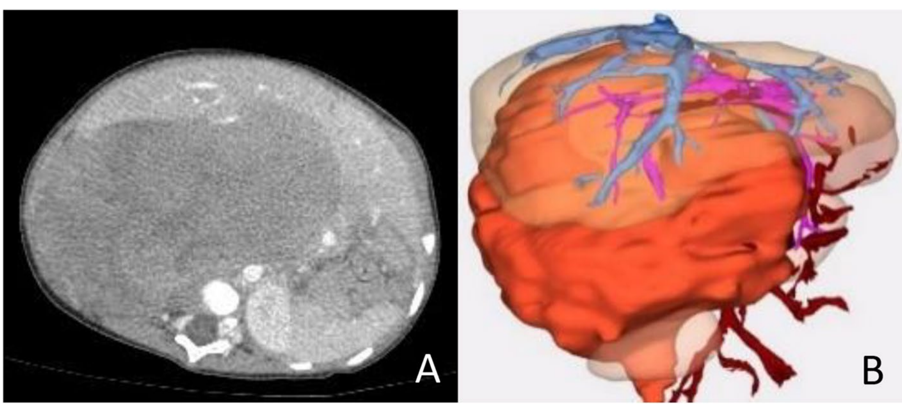

Fig. 7 **A**, **B** The right hepatic vein is invaded, and a thicker short hepatic vein is seen; thus, it is feasible to resect the middle lobe of the liver to preserve more liver tissue

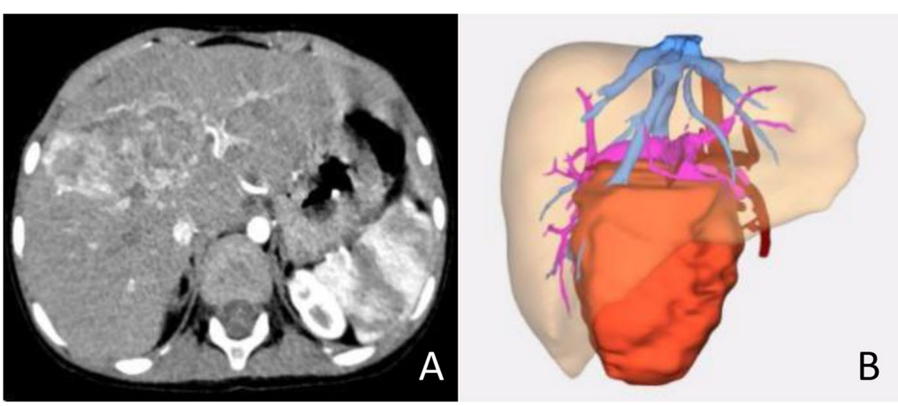

Fig. 8 **A**, **B** The three dimensional image shows that the tumor did not invade hepatic segment VIII, and the right posterior lobe of the liver has independent hepatic blood vessels supplying blood; thus, it is possible to resect hepatic segments IV and V

cases of left hepatectomy, and 2 cases of enlarged left hepatectomy (Table 2). There was one case of postoperative bile leak. The average hospital stay was (11 ± 2) d. The average operation time was (147 ± 18) min, and the intraoperative bleeding was (85 ± 24) ml; 3 patients received 200 ml of intraoperative red blood cells via transfusion. The children were routinely treated with chemotherapy after surgery, and all were alive without recurrence at the final follow-up.

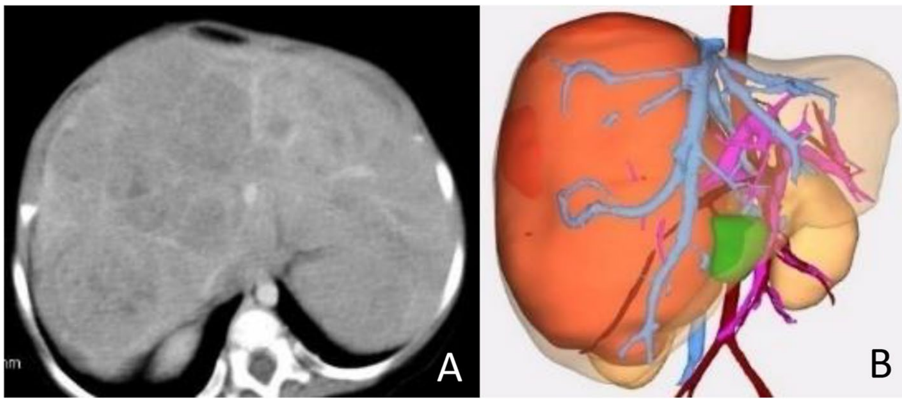

Fig. 9 **A**, **B** In the two-dimensional CT images, it is unclear whether the blood vessels are invaded, and the remaining liver volume cannot be assessed

Table 1 Revision of surgical liver volume parameters in 9 children

Surgical method	Volume				
	TLV(cm^3)	FLV(cm^3)	RLV1(cm^3)	RLV2(cm^3)	ΔRLV(cm^3)
1 Surgery method (IV,V,VIII)	485.4	250.3	113.6	157.8	44.2
	410.5	300.6	203.1	274.9	71.8
	217.5	182.5	108.7	131.1	22.4
2 Right hemicolectomy (V-VIII)	494.1	233.9	87.6	102.3	14.7
	372.5	201.4	118.4	160.7	42.3
3 Enlarged righthemicolectomy (IV-VIII)	452.3	220.7	102.5	146.4	43.9
	412.5	170.2	96.5	120.6	24.1
	386.8	133.6	85.6	112.7	27.1
4 Hepatic segment resection	440.5	255.7	132.1	183.7	51.6

TLV Total liver volume, *FLV* Functional liver volume, *RLV1* Residual liver volume after the first surgical planning of liver resection, *RLV2* Residual volume of liver resected again after modification of surgical approach after prognostic evaluation of 3D images; ΔRLV = RLV2 - RLV1, increased residual liver volume

Table 2 Surgical resection and pathological findings in 23 children with hepatic mesoblastoma

Scope of surgical excision	Pathology					
	Hepatoblastoma	Live cancer	Hepaticsarcoma	Teratoma of the liver	Mesenchymal malformation tumor	Total
Mesolobectomy of the liver	5	1	1	1	1	9
Right hemicolectomy	2	1	1		1	5
Enlarged Right hemicolectomy	1			1		2
Hepatic segment resection	2					2
Left Hepatic hemicolectomy	2				1	3
Enlarged left hemicolectomy	1	1				2

Discussion

Pediatric hepatic middle lobe tumors, which are often very large, are most commonly known as hepatoblastomas. The location in the middle lobe determines the complexity of the tumor resection, with complex intrahepatic vascular and biliary tract structures, large variants, high surgical risks, and high postoperative complication rates [8]. Therefore, reasonable preoperative surgical planning is crucial. Preoperative clarification of the relative spatial structure of the tumor and blood vessels directly affects the planning, implementation, and prognosis of the surgical plan. Due to the complexity of the internal liver system, it is difficult to clearly analyze the specific location of liver tumors in relation to surrounding vessels and bile ducts with two-dimensional images, and the preoperative assessment often cannot fully and accurately guide the smooth execution of surgery. In recent years, 3D reconstruction technology based on CT data has been applied to the segmental reconstruction of the liver, blood vessels, and tumors, providing a more intuitive 3D model for the surgeon to achieve preoperative simulated surgical planning.

Computer-aided 3D imaging can provide images of areas that are difficult to assess in 2D, accurately display the precise location of the tumor and the spatial anatomical relationship of the hepatic vascular system, and even demonstrate the precise alignment and adjacent relationship of the blood vessels supplying the liver tumor. The liver parenchyma, liver tumor, and different vascular systems can be displayed in different colors and dynamically observed from all angles, and the spatial relationship of the tumor and intrahepatic vessels can be displayed in all directions [8]. Preoperative liver tumor resection is simulated according to these data, and a better surgical planning plan is designed. The 3D reconstruction can display the hepatic artery, portal vein and hepatic vein branches up to and exceeding three levels, clearly showing the 3D morphology of the individualized intrahepatic vascular system and its spatial adjacent relationship with the tumor, allowing the formulation of a reasonable surgical plan according to the type of vascular variation, carefully handling the hepatic artery, hepatic vein, short hepatic vein and bile duct, reducing intraoperative vascular collateral damage, preventing postoperative bile leakage and bleeding, and maximizing the preservation of the remaining liver tissue to reduce the likelihood of postoperative liver failure [9–11]. Lamada et al. [12] performed 2D CT image acquisition and 3D CT image reconstruction in patients with hepatocellular carcinoma. The images were then assessed by surgeons with different levels of seniority. The accuracy of tumor localization was increased by 37% when using 3D reconstructed images versus 2D CT images. Our case study showed that the success or failure of the surgery and the patient prognosis could be determined by the accurate assessment of preoperative 3D reconstruction data, the reserve function of the liver, the location of the tumor, whether it invaded the surrounding vital vessels, whether the residual liver volume was sufficient for patient compensation, and whether there was bruising after liver tumor resection.

The pediatric liver has a strong regenerative and compensatory capacity. If the surgeon cannot accurately assess the relationship between the liver and blood vessels and the residual liver volume before surgery, especially for complex giant liver tumors, the common surgical approach is hemihepatectomy or enlarged hemihepatectomy. The residual liver volume is often not compensated, and the incidence of postoperative liver dysfunction is high. In contrast, mid-liver resection can prevent a low residual liver tissue level; however, the surgical risk is higher due to the need to free the liver on both sides of the tumor. Computer-assisted three-dimensional imaging can minimize such surgical complications by allowing the accurate assessment of the paraneoplastic vessels and bile ducts [13–15]. Surgical resection of the tumor is an important treatment tool for hepatoblastoma, and whether complete resection is possible is a key factor in imaging prognosis. Multidisciplinary diagnosis and treatment based on surgery combined with chemotherapy is currently the standard approach for hepatoblastoma treatment in children [16]. Hepatoblastoma in children can be treated with chemotherapy first and surgery after effective reduction of the tumor volume, which can reduce surgery risks; chemotherapy can also be given after surgery. In one of the children, the liver tumor invaded the middle and right hepatic veins, and the residual liver volume that would have remained after tumor resection risked liver failure. After six courses of chemotherapy, the child's tumor was significantly reduced, the tumor was clearly demarcated from the veins, and liver tumor resection was feasible as the residual liver volume was significantly increased. The treatment standard for pediatric hepatoblastoma indicates that the residual liver volume should exceed 35% after resection [17]. Three pediatric liver tumor patients had a residual liver volume $\geq$ 25% in our study. They recovered well after surgery, which may be related to the strong regenerative ability of the pediatric liver and good liver function reserve capacity [18, 19]. For children with huge middle lobe liver tumors, two-dimensional images suggested that enlarged hemihepatectomy was performed, and the remaining liver volume was small, which had a greater impact on the children's later stages. After three-dimensional reconstruction to reassess the surgical plan, some children's middle lobe liver tumors did not completely encroach on the right hepatic vein or the short hepatic vein, and the blood vessels and the corresponding hepatic tissue could be preserved, which reduced the volume of the liver to be resected. For children whose right hepatic vein is invaded and cannot be preserved, if there is a thicker short hepatic vein within the residual hepatic reflux, the right hepatic volume should be actively preserved as much as possible to prevent postoperative liver failure. For some children with an unclear demarcation between the right hepatic vein and the tumor or when this vein is suspected to be invaded and encapsulated by the tumor, it is often found intraoperatively that the vein is completely compressed by the tumor and bounded by the tumor envelope, which can often be detached from the tumor and completely preserved in hepatic segment resection. Shen et al. [20] concluded after a border study and follow-up of 28 children who underwent surgery for hepatoblastoma that solid tumors less than 1 cm from major vessels can also be subjected to more aggressive radical surgery. Hepatoblastoma is covered with an envelope in which the tumor grows. The impact on the surrounding vessels is often results from compression and pushing from the tumor, and the vessels closely related to the tumor are rarely invaded by the envelope; thus, the surrounding vessels can often be completely separated and preserved outside the envelope.

Preoperative assessment of tumor size, site and relationship with surrounding vessels is needed for middle-lobe liver tumors. 3D reconstruction is performed for different individuals, and precise liver tumor resection ensures the integrity of the remaining liver anatomy and maximizes functional volume, allowing the complete removal of the target lesion while maximizing surgical bleeding control and enabling surgical patients to obtain the best treatment outcome [21].

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Authors' contributions
Nan Su contributed to data curation, formal analysis, funding acquisition, investigation, methodology, and writing of original draft,resources, investigation, methodology, reviewing and editing. Kaiyue Cui contributed to formal analysis, methodology, reviewing, editing and language.Jing Zhao contributed to project administration, supervision,validation, reviewing and editing. Xiongwei Wu,Yuhe Duan,Huanyu Zhang,Peng Zhang,contributed to data curation, investigation and project administration. Xiwei Hao contributed to conceptualisation,resources, reviewing and editing. Qian Dong contributed to conceptualization,funding acquisition, project administration, resources,reviewing and editing. All the authors approved the final version of the manuscript. The first named author had ensured that all authors have read and approved the contents of the manuscript.

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Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of the Affiliated Hospital of Qingdao University(approval No.QYFY-WZLL-28841).

Informed consent statement
This is a retrospective study article, and all guardians of the patients signed the informed consent forms before treatment and surgery. The patient's identity information was not disclosed and will not cause any harm to the patient.

Competing interests
The authors declare no competing interests.

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