

Article

Application of 3D visualization combined with laparoscopic ultrasonography to guide indocyanine green fluorescence staining through portal vein puncture in anatomic segmentectomy

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Abstract: Objective: To investigate the feasibility and safety of 3D visualisation combined with laparoscopic ultrasound guidance for portal vein staining by portal vein puncture and injection of indocyanine green (ICG) in anatomic hepatectomy. **Methods:** A total of 41 patients with hepatocellular carcinoma (HCC) who underwent anatomical hepatectomy navigated by ICG fluorescent staining via the portal vein injection guided by 3D visualization combined with laparoscopic ultrasound technique were collected. 3D visualization software was used preoperatively to reconstruct 3D images of the patient's liver, occupancy and intrahepatic blood vessels, to analyze portal vein territory, to plan the route of portal puncture. Intraoperatively, The target portal vein branches were punctured using laparoscopic ultrasound guidance in conjunction with 3D visualization images and ICG was injected. laparoscopic hepatectomy was accomplished under ICG fluorescent imaging guidance. **Results:** Portal vein puncture staining was completed in all 41 patients, of which 40 cases (97.6%) had satisfactory staining results, one case (2.4%) had staining that did not meet the expected results. There were no intraoperative adverse events such as ICG allergy in all patients, and the median operation time of the patients was 230 (interquartile range, 180-370) min, the median estimated blood loss was 100 (interquartile range, 100-250) mL. The patients had no serious postoperative complications of grade III or higher, and the median postoperative hospital stay of 9 (interquartile range 7-11.5) days. Survival rates at 1, 2, and 3 years were 100%, 97.6%, and 97.6%, respectively, while PFS rates at 1, 2, and 3 years were 92.7%, 92.7%, and 85.0%, respectively. **Conclusion:** 3D visualization combined with laparoscopic ultrasound-guided ICG fluorescence staining via portal puncture is safely feasible, contributes to the precise performance of laparoscopic anatomic segmentectomy. Compared with historical controls, it helps to reduce surgical complications and shorten the length of stay following surgery, thereby promoting post-operative recovery and improving patients' health-related quality of life.

Keywords: three-dimensional visualization; laparoscopic ultrasonography; laparoscopic anatomic hepatectomy; portal branch puncture; postoperative recovery; quality of life; psychological distress

1. Introduction

Anatomical hepatectomy was defined as the complete removal of relatively

independent hepatic segment or subsegment that is supplied by the arbitrary Glissonian pedicles or portal veins[1]. It was accepted as an ideal method for the radical treatment of hepatocellular carcinoma (HCC) and was subsequently employed in other liver malignancies[2–4]. laparoscopic hepatectomy has been widely performed because of its advantages over open liver resection, such as less blood loss, quicker recovery, and shorter hospitalization[5–7]. Therefore, laparoscopic anatomical hepatectomy is currently the preferred option for various benign and malignant lesions.

Performing anatomical hepatectomy guided by demarcation lines after portal staining using injection of dye into the portal vein under intraoperative ultrasonography guidance was first reported by Makuuchi et al in 1985[1]. However, portal staining is not always successful as identification and puncture of the target portal vein under ultrasound guidance is technically difficult, and even more difficult in laparoscopic procedures. In addition, it was impossible to recognize the intersegmental plane during liver parenchyma division because the common dye disappeared rapidly after injection[8]. The 3D visualization technology not only enables the visualization of intrahepatic structures from multiple angles but also provides a clearer and more intuitive view than the traditional 2D imaging technology, which is more helpful for preoperative assessment, surgical planning, and guidance of precise hepatectomy[9]. Therefore, 3D visualization technology may be helpful in portal staining. Recently, indocyanine green (ICG) fluorescence imaging has been reported to allow clear and durable visualisation of segment or subsegment boundaries in liver surgery[10].

The aim of this study was to demonstrate the details and evaluate the feasibility and safety of portal staining via injecting ICG into the portal vein branches under the guidance of 3D visualization combined with laparoscopic ultrasound in anatomic hepatectomy.

2. Materials and methods

2.1. Materials

We enrolled 41 patients with HCC who underwent anatomical hepatic segmental resection navigated by ICG fluorescent staining via the portal vein injection guided by 3D visualization combined with laparoscopic ultrasound technique from June 2020 to December 2023 at the Second Affiliated Hospital of Nanchang University and from June 2022 to December 2023 at Mianyang Central Hospital. The clinical data of the above 41 patients were enrolled and analyzed, including 37 males and 4 females, with a median age of 61 (interquartile range, 51 ~ 66) years (**Table 1** lists detailed information about the baseline characteristics of all patients). We obtained written informed consent from all patients and their families before hepatectomy. This study received the ethics approval of an institutional review board and was conducted in accordance with the Declaration of Helsinki.

2.2. Inclusion and exclusion criteria

Inclusion criteria: (1) Preoperative liver function Child-Pugh classification grade A. (2) Laparoscopic anatomical segmental or subsegmental hepatectomy. (3) No contraindication to laparoscopic hepatectomy. (4) Complete clinical data.

Exclusion criteria: (1) Severe cardiac or pulmonary disease, unable to tolerate general anesthesia for surgery. (2) Patients with portal vein cancer embolism or extrahepatic metastasis on preoperative examination; (3) Patients with oversized

lesions and residual functional liver volume less than 40% of the standard liver volume; (4) Missing clinical data.

Table 1. Summary of characteristics of patients

Variables	Values
Age, median [IQR], years	61 [51;66]
Male, n (%)	37 (90.2)
Background liver	
Normal liver, n (%)	11 (26.8)
Chronic hepatitis, n (%)	30 (73.2)
Tumor size, median [IQR], mm	40 [30;49.5]
Tumor number	
Single, n (%)	33 (83.6)
Multiple (≤ 3), n (%)	8(16.4)

HCC: hepatocellular carcinoma, IQR: interquartile range.

2.3. Acquisition and processing of preoperative 3D visualization images

The patient's multiphase computed tomography (CT) images (plain scan phase, arterial phase, portal venous phase, and delayed phase) were acquired using a 256-slice spiral CT scanner (Brilliance iCT, Philips Medical Systems, Haifa, Israel) with a slice thickness of 1 mm and saved in DICOM format. The acquired DICOM data were segmented and 3D visualization images of the liver, tumors, portal vein, and hepatic vein were reconstructed using with 3D visualization software (Xudong Digital Medical Imaging Technology Co., Ltd., Shenzhen, China) (**Figure 1A**, **Figure 2A**). The volume calculation of any portal vein branch drainage area and individualized liver segmentation can be conducted using 3D visualization software[11] (**Figure 1B**, **Figure 2B**). After individualized hepatic segmentation and identification of the tumor-bearing portal vein based on the topological relationship of the portal vein blood flow, the surgeon determined the optimal virtual hepatectomy plan according to the location of the tumor and the spatial relationship between the tumor and segments or subsegments (**Figure 1C**, **Figure 2C**), so as to ensure complete removal of the tumor-bearing liver segment while ensuring that the predicted remnant liver volumes (PRLVs) reached more than 40% of the standard liver volume (SLV). The SLV was calculated based on the Urata formula[12]. Hepatectomy terminology was determined in accordance with the 2000 Terminology Committee of the International Hepato-Pancreato-Biliary Association[13].

After determining the hepatectomy plan, the surgeon formulates the staining plan and determines the puncture target based on the number, diameter, and location of the tumor-bearing portal vein: Injection of ICG into the tumor-bearing portal vein stains the tumor-bearing hepatic segment (positive staining) (**Figure 1**) or into the portal vein branch adjacent to the tumor-bearing portal vein stains the tumor-free hepatic segment (counter staining), or positive combined with counter staining(**Figure 2**). In addition to identifying preoperatively which portal vein to puncture and providing anatomical basis for finding the target portal vein branch under intraoperative ultrasound, the 3D visualization software can also slice the 3D visualization model in random planes. Anatomical structures such as tumors, blood vessels, and bile ducts

can be clearly displayed on the cut surface, and the image of this slice is very similar to an ultrasound image. Therefore, in order to rapidly identify and puncture the target portal vein under ultrasound guidance intraoperatively, we preoperatively performed several cuts of the 3D visualization model centered on the target portal vein and based on the plane in which the ultrasound was likely to be located at the time of the puncture of the portal vein, and saved the acquired planar images for intraoperative image matching(Figure 1D, G, Figure 2D, G, J).

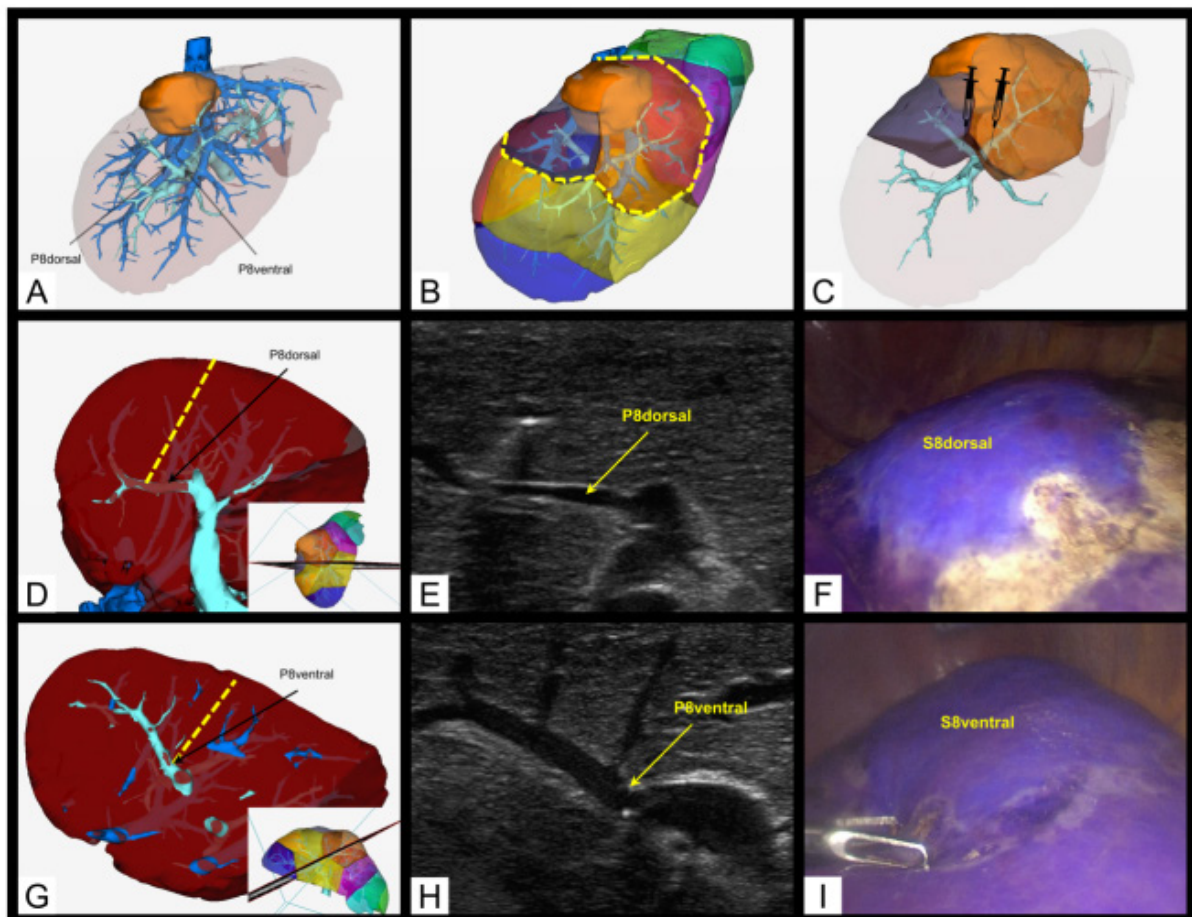


Figure 1. A patient with HCC underwent laparoscopic anatomical hepatectomy via positive staining is shown. (A) The 3D visual reconstruction model shows that the tumour is located at segment VIII (S8), lies between P8ventral and P8dorsal. (B) The S8dorsal and S8ventral within the yellow dotted line are planned for resection. (C) The Puncture of P8ventral and P8dorsal is planned. (D, G) The ultrasound images during intraoperative laparoscopic ultrasound-guided puncture of P8dorsal and P8ventral were simulated by planar cutting of the liver model with 3D visualisation software. (E, H) The ultrasound images during the puncture of P8dorsal and P8ventral under laparoscopic ultrasound guidance. (F, I) The ICG fluorescence image shows the boundary of S8dorsal and S8ventral on the surface of the liver after completion of portal vein puncture and injection of ICG.

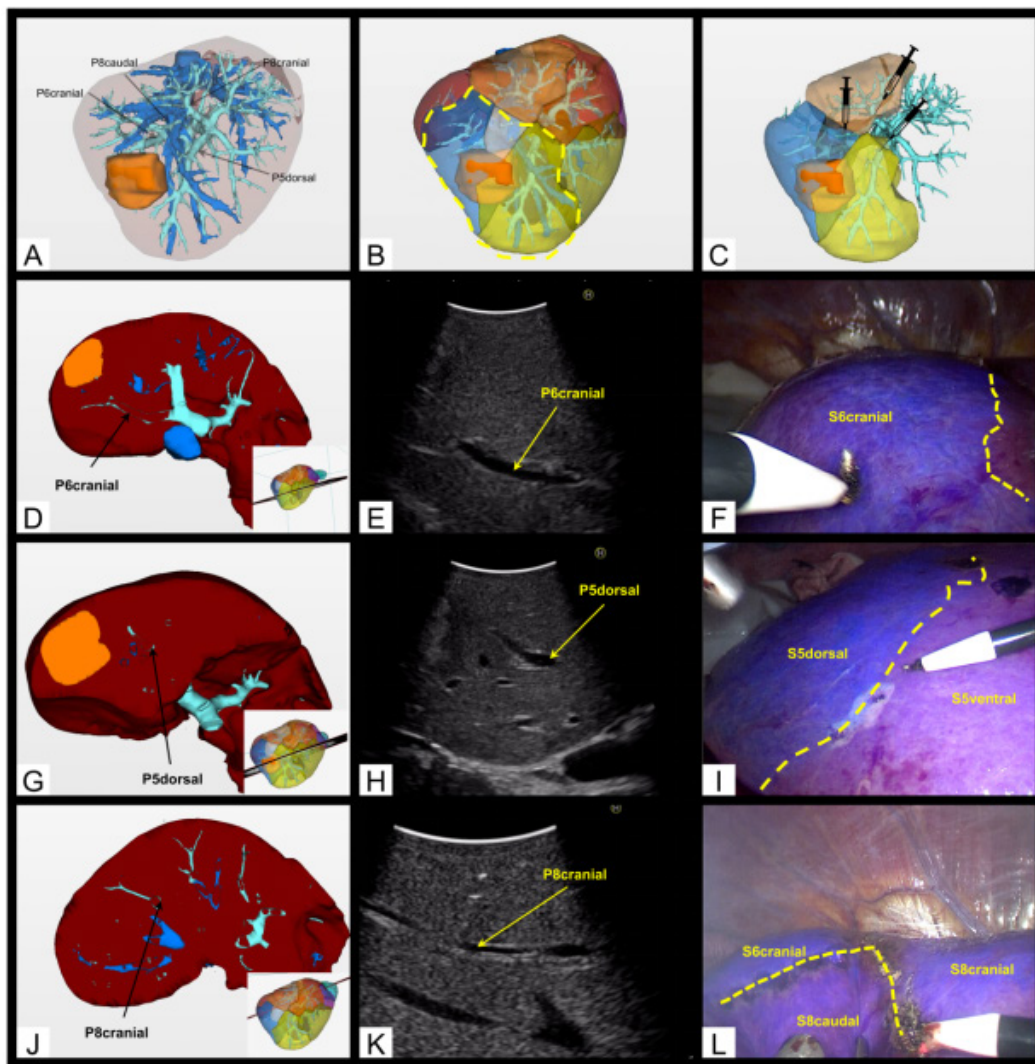


Figure 2. A patient with HCC underwent laparoscopic anatomical hepatectomy via positive staining combined with counter staining is shown. (A, B) The 3D visual reconstruction model shows that the tumour is located in the right lobe of the liver and that the tumor-bearing portal veins are P5dorsal, P6cranial and P8caudal branches. The S5dorsal, S6cranial and S8caudal within the yellow dotted line are planned for resection. (C) The Puncture of P5dorsal, P6cranial and P8cranial is planned. (D, G, J) The ultrasound images during intraoperative laparoscopic ultrasound-guided puncture of P5dorsal, P6cranial and P8cranial were simulated by planar cutting of the liver model with 3D visualisation software. (E, H, K) The ultrasound images during the puncture of P5dorsal, P6cranial and P8cranial under laparoscopic ultrasound guidance. (F, I, L) The ICG fluorescence image shows the boundary of S5dorsal, S6cranial and S8caudal on the surface of the liver after completion of portal vein puncture and injection of ICG. S5dorsal, S6cranial and S8cranial are displayed as fluorescent regions, and S8caudal is displayed as a fluorescence deficient region.

2.4. Staining of portal vein with 3D visualized images combined with laparoscopic ultrasound guidance

After a comprehensive exploration of the liver to clarify the location of the tumor and the presence of intrahepatic metastases using laparoscopic ultrasound, the target portal vein branches were searched for starting from the first hepatic hilum toward the tumor according to the surgical plan developed based on 3D visualization model, and the intraoperative laparoscopic ultrasound images were matched with the preoperative images of the sections to determine the proposed puncture portal vein branches and the puncture points. Without blocking blood flow into the liver, percutaneous transhepatic puncture of the target portal vein branch and subsequent injection of 5

to 10 mL of diluted ICG solution (25 mg/L) were performed using a 22-gauge Chiba needle (Neff Percutaneous Access Set; Cook Medical, Inc., Bloomington, IN) under intraoperative laparoscopic ultrasound guidance (Fig. 1E, H, Fig. 2E, H, K). The ICG fluorescence images at the liver surface can be observed, and the effective and persistent boundaries between the prospectively removed liver segment and the liver scheduled to be preserved can be determined by the fluorescence laparoscopy system (IMAGE1 S, Karl Storz SE & Co. KG, Tuttlingen, Germany) after completion of the targeted portal vein puncture and staining (Fig. 1F, I, Fig. 2F, I, L).

2.5. Laparoscopic anatomic segmental hepatectomy with ICG fluorescence guidance

Marking the resection line along the boundary of ICG fluorescence on the hepatic surface in the fluorescence mode of the laparoscopic system. The blood flow into the liver was intermittently blocked with Pringle's method, and the parenchyma was dissected along the border of the ICG fluorescence-stained hepatic segments with ultrasonic knife using the clamping method. The hepatic veins between the liver segments were naturally exposed, and the branches of the hepatic veins draining the tumor-bearing liver segments were ligated and dissected. The root of the Glisson pedicle of the resected liver segment is revealed, clamped closed, and then dissected.

The tumor-bearing hepatic segment was placed into a specimen bag and extracted from the subumbilical incision after complete resection. Following the cut surface of the liver was carefully processed, the abdominal cavity was washed using distilled water. The drainage tube was placed under laparoscopy and draw from the Trocar hole for observing postoperative hemorrhage and bile leakage.

2.6. Administration of the postoperative period and follow up

In order to assess the recovery and complications of all patients, the vital signs, blood routine, liver function, coagulation function, and other blood biochemistry were performed routinely in the postoperative period, and abdominal CT was reexamined approximately 3~5 days after the operation. Surgical complications were classified according to the Clavien-Dindo classification[14]. The postoperative CT data of the patients were imported into a 3D visualization software to reconstruct the 3D visualization image of the postoperative liver and the actual remnant liver volumes (ARLVs) was calculated. Correlation analysis and comparison of ARLV with PRLV were performed to assess the accuracy of the 3D visualization technique to predict the remaining liver. All patients were regularly followed up after discharge from the hospital for postoperative tumor recurrence, survival, and survival analysis via regular outpatient or telephone follow-up. The follow-up period ended in June 2024.

2.7. Statistical analysis

Continuous variables were presented as medians. Pearson's technique was used to study the correlation between ARLV and PRLV. The Statistical Package for Social Sciences, version 25.0 (IBM, Chicago, IL, USA), was used for all statistical analyses.

3. Results

3.1. Intraoperative situation

The successful rate of portal vein puncture using 3D visualization combined with laparoscopic ultrasound guidance was 100.0% in 41 patients. The tumor-bearing portal territory was identified through positive staining in 38 cases, counterstaining in one case, and positive staining with counterstaining in two cases. ICG fluorescence imaging could clearly show the boundaries of hepatic segments or subsegments

on the surface of the liver following injection of ICG into the portal vein branches. The boundaries of the preresected hepatic segments acquired according to ICG fluorescence were highly consistent with those obtained preoperatively with 3D visualisation techniques in 40 patients (97.6%). Staining result was not achieve the expected effect in one patient, with a small area of the tumor-bearing hepatic segment not being stained. We determined the boundary of the preresected hepatic segment by preoperative 3D visualization image and intraoperative laparoscopic ultrasound. Persistent and clearly visible ICG fluorescence appears at the borders of the stained liver segments when dissecting the liver parenchyma. Laparoscopic anatomical segmental hepatectomy was accomplished via gradual deeper dissection of the hepatic parenchyma along the border of the fluorescence, with natural exposure of the hepatic veins and the roots of the Glisson pedicle of the corresponding hepatic segment. Laparoscopic anatomical hepatectomy was ultimately completed in all cases, except for three cases in whom the conversion to laparotomy was abrogated due to massive intraoperative bleeding (**Table 2** summarizes the intraoperative and postoperative results of 3D visualization-guiding ICG fluoroscopic staining for LAH).None of the patients suffered intraoperative adverse events related to ICG or fluorescent staining procedures. The median operative time was 230 (interquartile range, 180-370) min, and the median estimated blood loss was 100 (interquartile range, 100-250) mL.

Table 2. Summary of patient data during the perioperative period.

Number	41
Fluorescence staining technique	
Positive staining technique, n (%)	38 (92.7)
Counter staining technique, n (%)	1 (2.4)
Positive staining with Counter staining technique, n (%)	2 (4.9)
Surgical procedure	
Mono-segmentectomy *, n (%)	28 (68.3)
Combined-segmentectomy *, n (%)	13 (31.7)
Operation time, median [IQR], min	230 [180;370]
Estimated blood loss,median [IQR], ml	100 [100;250]
Transfusion	
Concentrated red blood cell, median (range), U	0 (0-4)
Fresh frozen plasma, median (range), ml	0 (0-600)
postoperative length of stay, median [IQR], day	9 [7;11.5]

*Including the removal of portal vein territory smaller than Couinaud segment. IQR: interquartile range.

3.2. Postoperative situation

Pathological results in all patients showed negative resection margins. None of the patients had major postoperative complications, and all of them were successfully discharged from the hospital with a median postoperative hospital stay of 9 (interquartile range 7–11.5) days. Among the 41 patients, 33 patients underwent CT examination about 3~5 days after the operation, and the remaining 8

patients had postoperative abdominal CT review at a relatively long time from the operation. Therefore, the postoperative CT data of 33 patients were imported into 3D visualisation software and 3D model reconstruction of the liver was performed, and its volume was calculated. As shown in **Figure 3**, the ARLV and PRLV in 33 patients exhibited a robust correlation ($r^2 = 0.8925$, $p < 0.0001$).

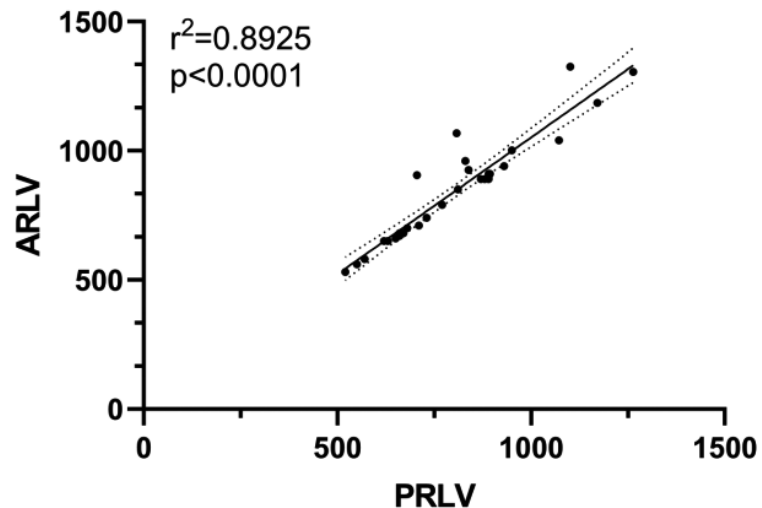


Figure 3. ARLV showed a strong correlation with the PRLV ($r^2 = 0.8925$, $p < 0.001$).
ARLV, predicted remnant liver volume; PRLV, actual remnant liver volumes.

3.3. Follow-up

The median follow-up for the all patients was 21 (interquartile range 15-28.5) months. Survival rates at 1, 2, and 3 years were 100%, 97.6%, and 97.6%, respectively, while PFS rates at 1, 2, and 3 years were 92.7%, 92.7%, and 85.0%, respectively (**Figure 4**).

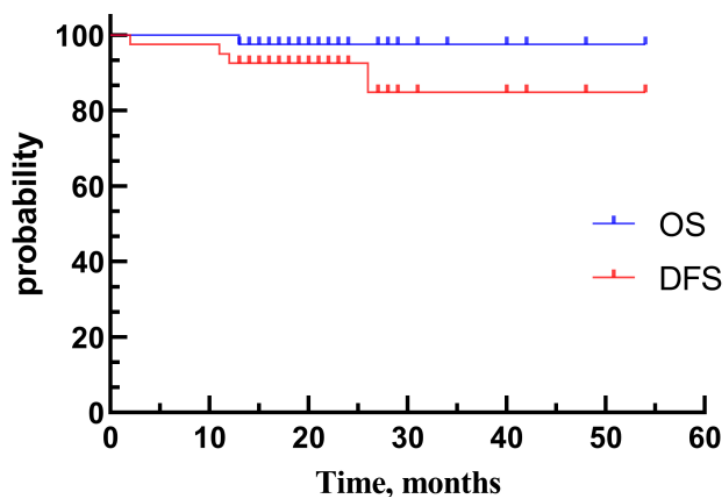


Figure 4. Kaplan-Meier curves for OS and PFS in all patients. OS, overall survival; PFS, progression-free survival.

4. Discussion

Anatomic hepatectomy is the most optimal surgical procedure for HCC determined by the characteristics of HCC spreading along the hepatic segmental portal vein branches in the tumor-bearing hepatic segments[15]. It has been shown that anatomic hepatectomy is associated with a reduced risk of intrahepatic

recurrence and improved overall survival for primary liver lesions below 5 cm in diameter[16]. In addition, each hepatic segment has its own Glisson pedicle branch, and the anatomical plane between segments is relatively avascular[17]. Performing anatomical hepatectomy requires precise transection of the hepatic parenchyma along the intersegmental plane, which not only naturally exposes the intersegmental vein and Glisson pedicle, but also contributes to the reduction of operative time, bleeding, and the risk of postoperative bile leakage, and avoids the formation of an abscess after ischaemia in the hepatic parenchyma leading to necrotic changes[10]. Therefore, anatomical hepatectomy is not only an ideal surgical procedure for HCC, but also a surgical procedure consistent with the concept of precision medicine.

During the treatment and the follow-up of hepatocellular carcinoma, patients may experience psychological issues to varying degrees, such as anxiety, depression, concerns about the long-term prognosis[18, 19]. These issues associated with poor health-related quality of life (HRQoL) that is a multidimensional concept encompassing physical, psychological and social functioning[20–22]. Surgical complications can increase the risk of negative emotions such as anxiety and depression, and an unfavourable psychological state can also hinder their smooth recovery[19, 23]. Conversely, a smooth recovery can reduce anxiety and improve HRQoL[24]. Laparoscopic anatomical liver resection employed in this study is currently the optimal treatment for hepatocellular carcinoma, offering reduced rates of postoperative complications, shorter hospital stays and faster patient recovery[25]. It helps prevent the onset or exacerbation of anxiety in patients and improve HRQoL.

Since laparoscopic hepatectomy was first reported in 1991, with the development of medical devices and surgical techniques, laparoscopic hepatectomy underwent tremendous progress in the past 30 years, and has become the most preferred surgical procedure for the treatment of a variety of benign and malignant lesions of the liver[5, 26, 27]. However, it remains to be explored how to accurately perform anatomical (sub)hepatic segmental resection laparoscopically. In this study, we performed portal vein staining by 3D visualisation combined with laparoscopic ultrasound guidance and identified hepatic segment boundaries and intersegmental planes using ICG fluorescence imaging. Results show that it is safe and feasible to use 3D visualisation combined with laparoscopic ultrasound to guide portal vein staining, and that laparoscopic anatomical liver resection can be performed accurately using ICG fluorescence imaging as a tool for intraoperative real-time navigation.

Identifying hepatic segment boundaries by superficial markings produced on the liver surface by dye staining of the portal vein branches under ultrasound guidance or interruption of the blood supply to the territory of planned resection are the most classical method of performing anatomical hepatectomy[1, 28]. However, these methods are unable to identify the planes between liver segments or subsegments during liver parenchyma dissections, surgeons must determine the 3D resection plane based on landmark vessels and educated guesses, and therefore it is often difficult to ensure the precise execution of anatomical hepatectomy. With the development of surgical instruments and techniques, ICG fluorescence imaging has made it possible for visualisation of the target hepatic segment boundaries in laparoscopic anatomical hepatectomy[29]. ICG is a safe and non-toxic near-infrared fluorescent dye, can excite longer wavelength near-infrared light under external light irradiation of wavelength 750 ~ 800 nm, with a tissue penetration depth of 5 ~ 10 mm[30]. When injected into the body, ICG immediately binds to plasma proteins

and is distributed throughout the body with blood circulation. Upon entering the liver it is 100% specifically taken up by hepatocytes and excreted through the biliary tract[31]. In recent years, ICG fluorescence imaging has been used for identification of liver tumours, visualisation of intra- and extra-hepatic bile ducts, and display of segmental boundaries[10]. Different from conventional dyes that are quickly washed out resulting in loss of the stained area, the fluorescent staining effect persisted for 6 ~ 8 h after ICG injection[29, 32]. Therefore, the ICG fluorescent imaging not only clearly shows the segmental boundaries on the liver surface, but also provides persistent and clear navigation during hepatic parenchyma division, which contributes to the precise anatomical hepatectomy implementation. The ICG fluorescent imaging staining technique involved positive staining or counter staining by injecting ICG solution into the target portal vein branches under ultrasound guidance, and negative staining by injecting ICG dye intravenously after clamping the segmental Glisson pedicles. Negative staining techniques seem to be easier to carry out in laparoscopic hepatectomy, as portal vein puncture under laparoscopic ultrasound guidance is technically considerable difficult. However, to perform negative staining requires incision of the hepatic parenchyma in cases where the Glisson pedicle of the target hepatic segment or subsegment is far away from the hilum and is located deep in the hepatic parenchyma, which is technically challenging and results in the massive loss of tumour-free hepatic parenchyma and intraoperative haemorrhage. In such cases, positive staining is safer and more convenient than negative staining.

Accurately puncturing the target portal vein is a critical step for accomplishment of positive staining. However, performing targeted portal vein puncture under ultrasound guidance is technically challenging and is made even more difficult under laparoscopic ultrasound guidance due to limitations in viewing and puncture angle. In addition, developing a scheme for positive staining requires accurate preoperative identification of the tumor-bearing portal vein. However, the branching pattern and course of the portal system is highly individualised and sometimes tumours are not confined to a single liver segment, but may involve multiple liver segments or subsegments with multiple tumour-bearing portal veins. It is difficult to accurately identify portal vein regions of (sub)hepatic segments preoperatively on conventional 2D planar images such as ultrasound or CT, therefore it is generally difficult to identify the tumor-bearing portal vein and develop a portal vein staining plan based on conventional 2D images. Compared with traditional imaging techniques, 3D visualisation not only provides a clearer, more intuitive, multi-angle view of structures such as the liver, tumour and intrahepatic vascular system, allowing the surgeon to have a detailed preoperative appreciation of the anatomy of the portal venous system and the topology of the tumour in relation to the intrahepatic vasculature, but also allows the determination of the hormonal portal vein by calculating the portal vein territory of each (sub)hepatic segment[9]. In addition, 3D visualisation techniques allow virtual surgery, which helps to plan the procedure, estimate the remaining liver volume, define the target portal vein to be punctured and guide the surgical strategy[33]. In this study, in order to accurately identify the target portal vein under intraoperative ultrasound, the entire liver (including the tumour, portal vein and hepatic vein) was cut according to the position and angle of possible intraoperative laparoscopic ultrasound placements after developing a surgical plan and portal vein staining protocol by virtual hepatectomy, and 2D images of the cutting plane were preserved. The success of the portal vein puncture and the success rate of portal vein staining were ensured by matching the ultrasound images with these

images to confirm the target portal vein during intraoperative examinations using laparoscopic ultrasound. In addition, the actual postoperative residual volume of the patients was analysed with the preoperative residual liver volume estimated based on virtual hepatectomy in this study, which showed a high level of correlation with each other. It demonstrates that anatomical hepatectomy using 3D visualisation combined with laparoscopic ultrasound-guided portal vein puncture ICG fluorescent staining navigation is essentially the same as virtual hepatectomy planned with preoperative 3D visualisation software.

Although 3D visualisation provides complete and accurate anatomical information preoperatively, allowing detailed surgical planning. However, it cannot navigate intraoperatively in real time for portal vein puncture guided by intraoperative ultrasound. Integration of 3D visualisation techniques with laparoscopic ultrasound may contribute to more rapid and precise guidance of portal vein puncture and laparoscopic anatomical hepatectomy performance. Another limitation of this study is the absence of a control group to show differences in clinical outcomes. Further studies are needed to investigate the differences in mortality, morbidity, operative time, blood loss and disease-free survival of anatomical hepatectomy with and without the guidance of 3D visualisation techniques. Furthermore, sufficient and detailed quality of life data were not collected in this study. Future research should incorporate quality of life data into research reports and use them as supporting evidence.

5. Conclusion

In conclusion, we have demonstrated that identification of (sub) hepatectomy using portal staining via injection of ICG into the portal branches of guided by 3D visualisation combined with laparoscopic ultrasound is safe and feasible and contributes to accurate laparoscopic anatomical hepatectomy. It helps to improve surgical outcomes, reduce their anxiety and enhance patients' quality of life following surgery.

Author contributions: Conceptualization, JG, YP and KW; methodology, XY and KW; software, JG and YP; validation, XY, RY, HW and ZH; formal analysis, ZH; investigation, BZ and YQ; resources, RY; data curation, JG and YP; writing—original draft preparation, JG, YP and KW; writing—review and editing, JG, YP and KW; visualization, JG and YP; supervision, XY; project administration, JG, RY and KW; funding acquisition, RY. All authors have read and agreed to the published version of the manuscript.

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Ethical approval: This study was reviewed and approved by Biomedical Research Ethics Committee of the Second Affiliated Hospital of Nanchang University (approval number:(2021) Medical Research Ethics Review No. (50)).

Informed consent statement: Informed consent was obtained from all subjects involved in the study.

Data availability statement: The data presented in this study are available from the corresponding author upon reasonable request.

Conflict of interest: The authors declare no conflict of interest.

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