Original Article

Multimodal transesophageal echocardiography in the surgical resection of patients with hepatocellular carcinoma and inferior vena cava tumor thrombus

Baochun Lai[1], Yonghuo Ye[2], Dimitrios Moris[3], Matteo Donadon[4,5], Zhensheng Ye[1], Jie Lin[1], Sanrong Lan[6]

[1]Department of Ultrasound, Fuzhou University Affiliated Provincial Hospital, Shengli Clinical Medical College of Fujian Medical University, Fuzhou, China; [2]Department of Cardiac Surgery, Fuzhou University Affiliated Provincial Hospital, Shengli Clinical Medical College of Fujian Medical University, Fuzhou, China; [3]MedStar Georgetown Transplant Institute, Washington, DC, USA; [4]Department of Health Sciences, University of Piemonte Orientale, Novara, Italy; [5]Department of Surgery, University Maggiore Hospital della Carità, Novara, Italy; [6]Department of Rheumatology, Fuzhou University Affiliated Provincial Hospital, Shengli Clinical Medical College of Fujian Medical University, Fuzhou, China

Contributions: (I) Conception and design: B Lai, S Lan; (II) Administrative support: Y Ye; (III) Provision of study materials or patients: B Lai, Y Ye, Z Ye; (IV) Collection and assembly of data: B Lai, S Lan, J Lin; (V) Data analysis and interpretation: B Lai, S Lan, Y Ye; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Sanrong Lan, MM. Department of Rheumatology, Fuzhou University Affiliated Provincial Hospital, Shengli Clinical Medical College of Fujian Medical University, 134 East Street, Gulou District, Fuzhou 350000, China. Email: lansanrong33@fjmu.edu.cn.

Background: The incidence and mortality rate of hepatocellular carcinoma (HCC) are increasing globally. HCC with inferior vena cava tumor thrombus (HCCIVCTT) represents an advanced stage of the disease. Research suggests that for patients with advanced HCCIVCTT, liver resection combined with thrombectomy is a safe and feasible option that can provide moderate survival benefit. The aim of this study was to evaluate the application value of multimodal transesophageal echocardiography (TEE) in the perioperative period for patients with HCCIVCTT.

Methods: TEE was used for routine intraoperative examination in 17 patients to determine the location and classification of tumor thrombi, guide the proper placement of the inferior vena cava occlusion band during surgery, and evaluate whether the tumor thrombus was completely removed postoperatively.

Results: Among the 17 patients with HCCIVCTT, tumor thrombi invaded the hepatic veins and extended into the inferior vena cava, with 3 cases of extension into the right atrium. The tumor thrombi varied in shape, size, and echogenicity, with high-velocity turbulent flow signals observed within the occluded vessels. There were 10 cases of type I, 4 cases of type II, and 3 cases of type III. Under the guidance of intraoperative TEE, preocclusion bands were successfully placed above the tumor thrombi in type I and II patients, with real-time dynamic monitoring showing no rupture or dislodgement of the thrombi, and postoperatively, the thrombi appeared to be completely removed.

Conclusions: TEE plays an important role in the perioperative management of HCCIVCTT. It can aid in deterring the type of tumor thrombus, selecting the suitable surgical method, and postoperatively assessing the completeness of tumor thrombus removal.

Keywords: Carcinoma; hepatocellular; thrombus; echocardiography; transesophageal

Submitted Sep 26, 2024. Accepted for publication Nov 08, 2024. Published online Dec 27, 2024.
doi: 10.21037/jgo-24-731
View this article at: https://dx.doi.org/10.21037/jgo-24-731

Introduction

The incidence and mortality rates of hepatocellular carcinoma (HCC) are increasing globally (1). HCC could metastasize and grow along the direction of blood flow, invading adjacent venous systems, with some tumor thrombi even entering the right cardiac system (2). HCC with inferior vena cava tumor thrombus (HCCIVCTT) represents an advanced stage of the disease (3) and was previously considered unsuitable for surgical treatment. Without aggressive treatment, the median survival time for patients with HCCIVCTT is only 2.7 to 4 months, indicating a poor prognosis (4,5). There is currently no global consensus regarding the diagnosis and treatment standards for patients with HCC and vascular invasion. A study has shown that for patients with advanced HCCIVCTT, liver resection combined with thrombectomy is a safe and feasible option that can provide moderate survival benefit (6).

With the development of surgical techniques and improvements in perioperative management, the significance of surgical treatment for HCCIVCTT has gradually been recognized. For cases with surgical indications, reasonable surgical treatment can not only remove the primary tumor but also eliminate the obstruction of hepatic veins and the inferior vena cava (IVC) caused by the tumor thrombus, preventing common complications such as pulmonary embolism and right-sided heart failure (7) and thus prolonging median survival time (8,9). Govalan *et al.* analyzed data from the National Cancer Database in the United States and found that surgical resection was superior to other treatment methods for treating HCC patients with vascular invasion (10).

According to computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound examinations, HCCIVCTT can be classified into three types (11,12), with each requiring different approaches for thrombus removal. In type I (subphrenic), the tumor thrombus is located above the renal veins and below the diaphragm (*Figure 1A*). It requires an abdominal incision for occluding the IVC subdiaphragmatically and removal of the thrombus. In type II (supradiaphragmatic), the tumor thrombus is located above the diaphragm but has not entered the right atrium (*Figure 1B*). It requires an abdominal incision through the diaphragm and the separation of the supradiaphragmatic IVC for thrombus removal. In type III (intracardiac), the tumor thrombus has entered the right atrium (*Figure 1C*), and completing thrombus removal requires opening of the right atrium and IVC via sternotomy and cardiopulmonary bypass.

The location of the thrombus determines the position for IVC control, with types I and II allowing for precise placement of a preocclusion band on the upper end of the thrombus. Previously devised surgical methods were limited by the lack of effective real-time monitoring methods, which adversely affected the surgical outcomes (7). In this study, we used transesophageal echocardiography (TEE) guidance to improve the surgical procedure. This study is the first to explore the real-time application of multimodal TEE in HCCIVCTT, filling the gap in the existing literature. This innovative approach has the potential to transform the decision-making process of clinicians in complex surgical Settings. We present this article in accordance with the SUPER reporting checklist (available

Highlight box

Key findings

- Transesophageal echocardiography (TEE) in the perioperative period of treating patients with hepatocellular carcinoma and inferior vena cava tumor thrombus (HCCIVCTT) is safe and feasible. TEE plays a crucial role in determining the type of tumor thrombus, selecting the surgical method, and assessing the completeness of tumor thrombus removal postoperatively.

What is known and what is new?

- For advanced HCCIVCTT, liver resection combined with thrombectomy is a feasible option that can provide moderate survival benefit. Rational surgical treatment can not only remove the primary tumor but also eliminate the obstruction of hepatic veins and the inferior vena cava (IVC) caused by the tumor thrombus, preventing common complications such as pulmonary embolism and right-sided heart failure.
- In this study, TEE has been innovatively used for real-time dynamic observation of thrombus position during surgeries for HCCIVCTT. It can further clarify the diagnosis and classification preoperatively, guide the accurate placement of the IVC occlusion band intraoperatively, and immediately evaluate whether the thrombus has been completely removed postoperatively. TEE helps to assess surgical outcomes, promptly reduce and detect surgical complications, monitor cardiac function in real time, and provide timely and reliable information for evaluating the patient's condition.

What is the implication, and what should change now?

- Liver resection combined with thrombectomy can remove the tumor and its associated thrombus, thereby improving the patient's prognosis and survival. We should actively pursue appropriate surgical interventions for these patients and emphasize the crucial role of TEE in the perioperative period. More in-depth, large-sample studies on this subject are warranted.

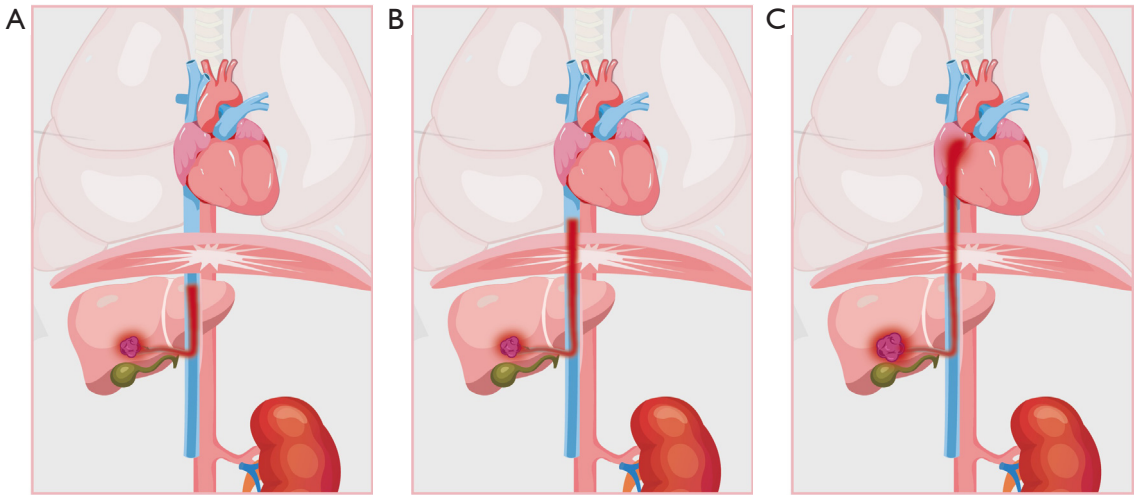

Figure 1 Classification of HCCIVCTT. (A) In type I (subphrenic), the tumor thrombus is located above the renal veins and below the diaphragm. (B) In type II (supradiaphragmatic), the tumor thrombus is located above the diaphragm but has not entered the right atrium. (C) In type III (intracardiac), the tumor thrombus has entered the right atrium. HCCIVCTT, hepatocellular carcinoma and inferior vena cava tumor thrombus.

at https://jgo.amegroups.com/article/view/10.21037/jgo-24-731/rc).

Methods

General information

In Fujian Provincial Hospital, to evaluate the application value of multimodal TEE in the perioperative period for patients with HCCIVCTT, intraoperative TEE has been innovatively used for real-time dynamic observation of thrombus position during surgeries. TEE can further clarify the diagnosis and classification preoperatively, guide the accurate placement of the IVC occlusion band intraoperatively, and immediately evaluate whether the thrombus has been completely removed postoperatively. In this study, TEE was used to assess surgical outcomes, reduce surgical complications and provide timely detection, monitor cardiac function in real time, and facilitate timely and reliable information for evaluating the patient's condition. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by Ethics Committee of Fujian Provincial Hospital (No. k2017-10-002) and informed consent was taken from all the patients.

From October 2012 to February 2024, 17 patients with HCCIVCTT who underwent surgical treatment in Fujian Provincial Hospital were selected. Fujian Provincial Hospital is a tertiary grade A hospital, and surgeries needed to be performed in an operating room with a cleanliness level of a class 10,000 clean operating room. The main surgical team included hepatobiliary surgeons, cardiac surgeons, and echocardiography physicians. The patient inclusion criteria were the following: diagnosed with HCC accompanied by IVCTT based on enhanced CT or MRI and confirmed by surgical resection and pathological results; intrahepatic lesions localized with no intrahepatic or extrahepatic metastasis; liver function classified as Child-Pugh A/B; and no severe dysfunction of critical organs such as the heart, lungs, or kidneys. Meanwhile, the exclusion criteria were as follows: incomplete case data; preoperative evidence of multiple intrahepatic or extrahepatic metastases; liver function classified as Child-Pugh C; severe cardiac, pulmonary, or renal insufficiency; and severe coagulation disorders.

Preoperative enhanced MRI scans were performed on 11 patients and enhanced CT scans on 14 patients. Multiangle comprehensive classification was conducted using coronal (*Figure 2A*,*2B*), transverse (*Figure 2C*), and sagittal (*Figure 2D*) planes to preliminarily determine the position of the tumor thrombus and the IVC obstruction (*Figure 1*).

Instruments and methods

A Vivid 7 ultrasound machine (GE HealthCare, Chicago, IL,

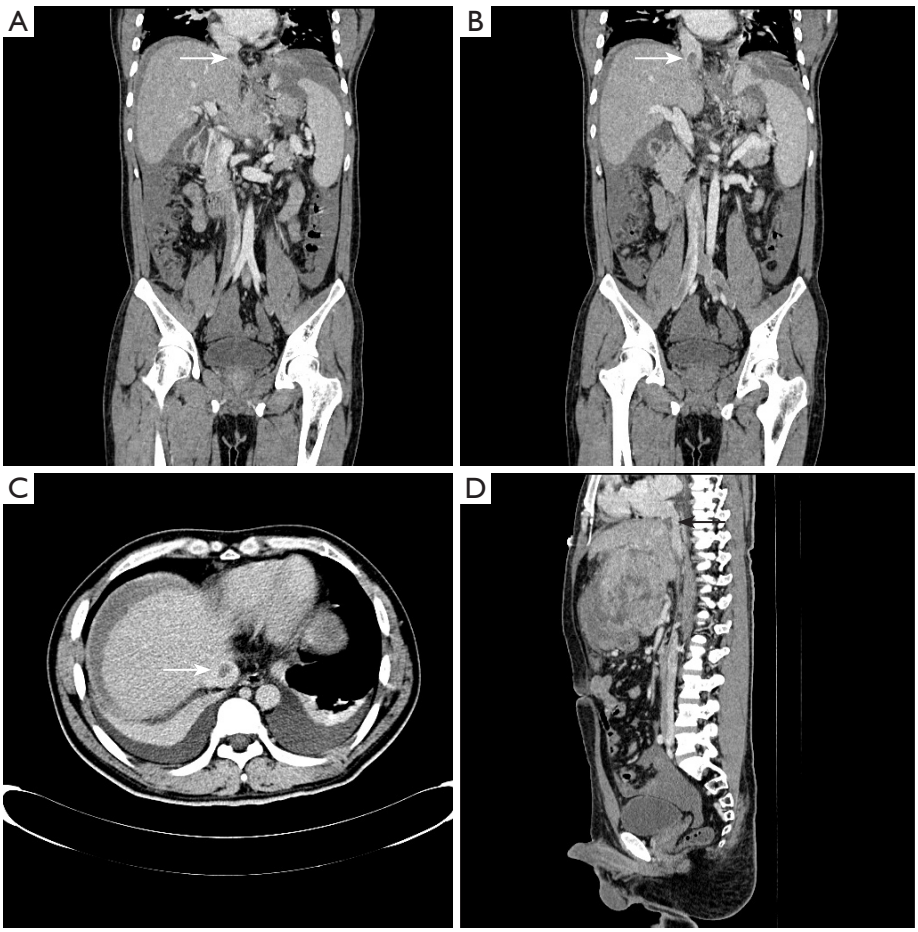

Figure 2 A 60-year-old male, patient with type II HCCIVCTT. Preoperative enhanced CT scan: (A,B) coronal views showed a large mass lesion in the hepatogastric space, closely related to the left lobe of the liver, which was suggestive of exophytic primary hepatocellular carcinoma with hemorrhage. Patchy tumor thrombus (arrow) was observed in the inferior vena cava, extending beyond the diaphragm level but not entering the right atrium. (C) Axial view showed patchy tumor thrombus (arrow) in the inferior vena cava. (D) Sagittal view showed patchy tumor thrombus (arrow) in the inferior vena cava, extending beyond the diaphragm level but not entering the right atrium. HCCIVCTT, hepatocellular carcinoma and inferior vena cava tumor thrombus; CT, computed tomography.

USA) with a multiplane TEE probe (frequency: 4–7 MHz) was used. After anesthesia, the TEE probe was inserted into the midesophagus, and a series of baseline cross-sectional scans were performed preoperatively to routinely evaluate the cardiac structure, determine whether there was any invasion of the heart chamber by the tumor thrombus, and assess any hemodynamic impacts. Based on the two-chamber heart view in the midesophagus, the probe was further inserted to trace the hepatic veins converging into the IVC, display the diaphragmatic arc echo, confirm the position of the tumor thrombus, and assess and classify the tumor thrombus.

Subsequently, the TEE probe was advanced to the patient's esophagus near the stomach and rotated clockwise toward the liver while the transducer angle was adjusted from 0° to 180° to fully evaluate the liver structure and display the diaphragmatic echo. Multiplane scanning aimed to show the tumor thrombus in each branch of the hepatic veins. The probe was bent forward and adjusted to display the hepatic veins. Rotation of the probe clockwise and adjustment of the transducer angle to 40° to 80° were completed to obtain the right hepatic vein image. The probe was gradually retracted to provide a long-axis view, showing the right hepatic vein entering the IVC and exposing the opening into the right atrium. Rotation of the probe counterclockwise and adjustment of the transducer angle to

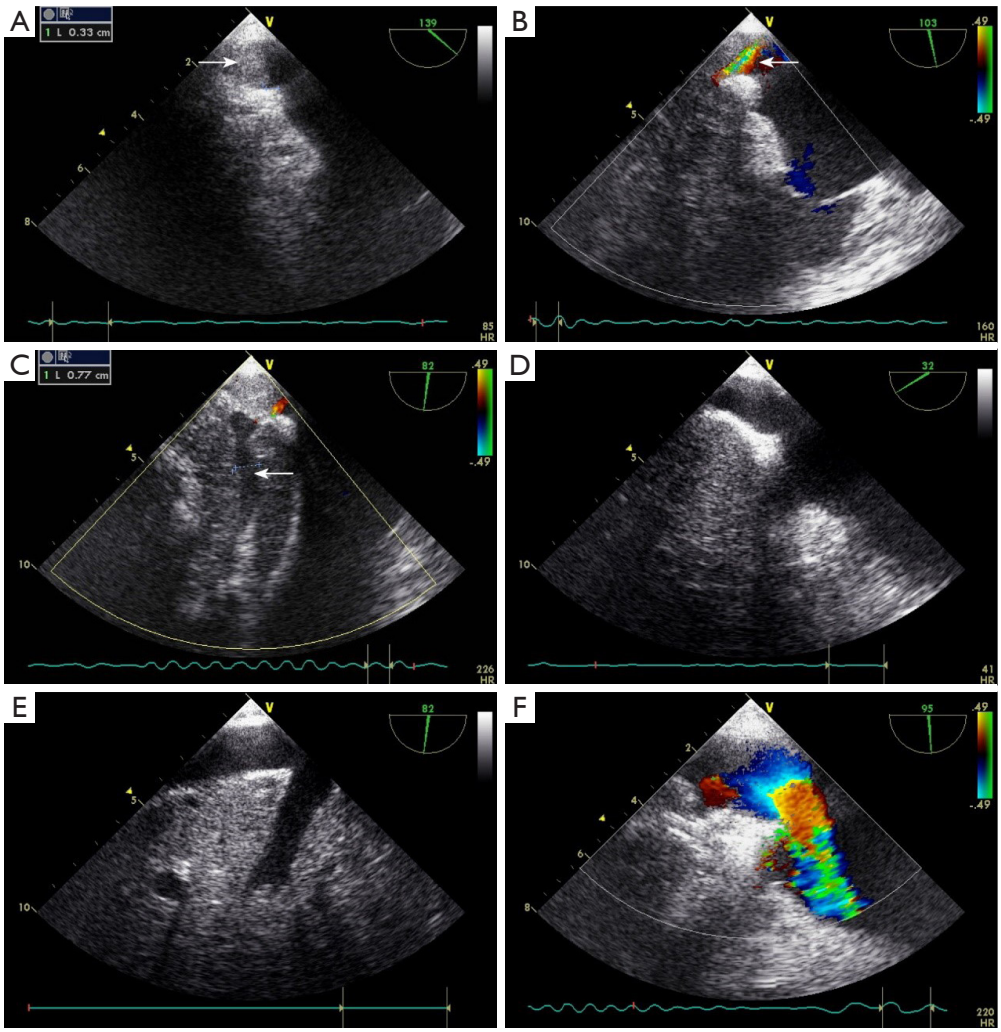

Figure 3 In the same patient as in *Figure 2* (60-year-old male), intraoperative TEE showed the status of the tumor thrombus in the inferior vena cava and was used for immediate postoperative evaluation of the complete removal of the tumor thrombus from the inferior vena cava and its tributaries. (A) Preoperative TEE showed an irregular, slightly hyperechoic tumor thrombus (arrow) in the inferior vena cava that was attached to the vessel wall. (B) The blood flow appeared to accelerate suddenly as it passed through the narrow segment between the thrombus and the vessel wall, displaying a colorful turbulent flow signal (arrow). (C) Hepatic venous flow stasis with a dilated internal diameter (arrow). (D,E) A comprehensive postoperative multiangle scan showed no significant tumor thrombus echo in the inferior vena cava and hepatic veins. (F) Postoperative TEE showed good blood flow filling in the inferior vena cava. TEE, transesophageal echocardiography.

50° to 90° was completed to display the middle hepatic vein, and further rotation of the probe counterclockwise and an increase in the angle to 30° to 80° provided the left hepatic vein image.

Continuous scanning along the IVC's long axis was performed to display the range and total length of the tumor thrombus and to evaluate its position and classification. Transverse scanning was conducted to obtain the IVC's short axis, displaying the extent of the tumor thrombus occupying the lumen and the residual diameter of the IVC (*Figure 3A*). Based on the 2D images, color and spectral Doppler ultrasound was applied to further observe the blood flow within and around the tumor thrombus (*Figure 3B*) and the morphology of the occluded vein and its branches (*Figure 3C*). For tumors entering the right atrium, a series of heart chamber cross-sectional views were

used to characterize the tumor thrombus's shape, size, echo characteristics, mobility, and relationship with adjacent heart structures.

Intraoperative procedures

The surgical approach was selected according to the classification of the tumor thrombus which was based on its position. Real-time monitoring of the tumor thrombus position accurately guided the placement of the IVC occlusion band at the upper end of the thrombus, ensuring surgical safety and reducing the occurrence of severe complications such as pulmonary embolism.

Postoperative procedures

Multiplane scanning immediately assessed whether the tumor thrombus in the IVC and its branches had been completely removed (*Figure 3D*,*3E*). Color and spectral Doppler ultrasound was used to further observe vascular filling (*Figure 3F*). During the surgery, cardiac structure and function were monitored to promptly detect any complications, such as right heart dysfunction. For patients with type III HCCIVCTT, the effects of extracorporeal circulation surgery on cardiac function and hemodynamic changes were also evaluated.

To ensure the quality of the surgery and consistency in diagnosis and treatment, we implemented standardized preoperative training, established a quality control team, and organized multidisciplinary consultations.

Statistical analysis

SPSS 26 statistical software (IBM Corp., Armonk, NY, USA) was used for analysis. Normally distributed measurement data are expressed as the mean ± SD.

Results

Preoperative TEE findings

The main symptom of the patient was dull pain in the upper abdomen. Among them, there were 15 males and 2 females, aged 33 to 69 years, with an average age of (49.76±11.80) years. All 17 cases showed primary HCC lesions in the liver, with tumor sizes ranging from 5.0 to 16.0 cm for an average size of 10.85±3.80 cm. The tumor locations were distributed as follows: a left liver location in 5 cases and a right liver location in 12 cases. All cases were solitary lesions with no intrahepatic metastasis. Tumor thrombi were found invading the hepatic veins in all cases, appearing as irregularly sized, heterogeneous echogenic masses, which were solid, strip-like, or nodular and were partially obstructing the venous lumen and extending into the IVC. The tumor thrombi were long-shaped in 3 cases, oval-shaped in 4 cases, and irregularly shaped in 10 cases. The distribution of locations of the tumor thrombi entering the IVC were as follows: the right hepatic vein in 10 cases, the left hepatic vein in 2 cases, the middle hepatic vein in 1 case, both the right hepatic vein and the middle hepatic vein in 2 cases, and both the left hepatic vein and the middle hepatic vein in 2 cases.

The veins and their branches in the occluded segment showed irregular widening, with some exhibiting spindle-shaped dilation. Color Doppler ultrasound revealed bright or multicolored mosaic turbulent flow signals between the tumor thrombi and the lumen, indicating high-velocity flow through the narrow segment. A significant stasis of blood flow was observed in some segments of the IVC and hepatic veins. In 3 cases, tumor thrombi were detected in the right atrium. Continuous ultrasound scanning tracked the tumor thrombi extending from the hepatic veins into the IVC and further into the right atrium, which appeared as oval-shaped or irregularly shaped slightly hyperechoic masses. In 2 cases, the tumor thrombi adhered to the side wall of the right atrium.

Classification and surgical outcomes

The HCCIVCTT cases were classified as follows: 10 cases of type I, 4 cases of type II, and 3 cases of type III. All 14 cases of type I and type II HCCIVCTT successfully had preocclusion bands placed above the tumor thrombi under TEE guidance. Postoperative TEE showed an unobstructed blood flow in the IVC, with no filling defects. Follow-up TEE with four-chamber views, left ventricular long-axis views, and basal short-axis views revealed normal blood flow in the main pulmonary artery and its branches, and normal systolic and diastolic movements of the left and right hearts.

The 3 type III patients underwent IVC and right atrial tumor thrombus removal under extracorporeal circulation. All 17 surgeries were successful, with total hepatic blood flow occlusion times ranging from 5 to 35 minutes. There were no intraoperative deaths, and intraoperative blood loss ranged from 400 to 2,100 mL. Real-time TEE monitoring showed no tumor thrombus fragmentation or detachment,

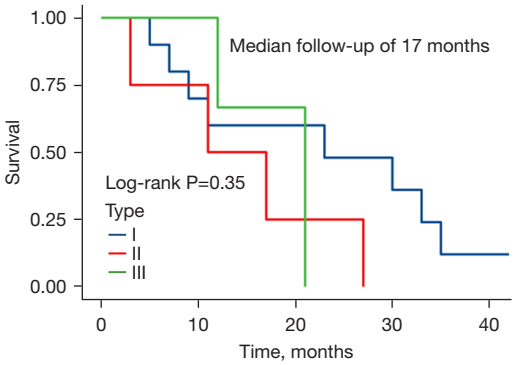

Figure 4 The postoperative survival time ranged from 3 to 45 months, with a median survival time of 17 months.

and there were no severe complications such as acute pulmonary embolism or cardiac tamponade. Postoperative pathology confirmed HCC in all cases.

After surgery, we will perform regular cardiac function assessments, including monitoring right ventricular function using TEE and assessing the patient's recovery. Long-term follow-up data were also collected to analyze long-term survival and complication rates. All patients were closely followed up, with the last follow-up date being February 5, 2024. Follow-up was conducted via telephone and outpatient visits. The main contents of the follow-up included survival time, tumor recurrence, metastasis, and treatment status. The postoperative survival time ranged from 3 to 45 months, with a median survival time of 17 months (*Figure 4*). At the time of writing, 2 patients are tumor free, with survival times of 13 and 19 months, respectively. Postoperatively, 11 patients experienced recurrence, with 3 cases of intrahepatic recurrence, 5 cases of extrahepatic recurrence, and 3 cases of both intrahepatic and extrahepatic recurrence. Among the intrahepatic recurrences, 2 cases received transarterial chemoembolization (TACE) treatment. Among the cases with concurrent intrahepatic and extrahepatic recurrence, 3 cases received TACE treatment; among these, one case with a solitary metastasis in the right upper lung was resected, and another case with multiple lung metastases was treated with apatinib.

Discussion

In the era of systemic therapy using molecular targeted drugs and immunotherapy, combining effective surgical procedures may be a viable means to improve the survival rate of patients with advanced HCC (13,14).

Choice of Treatment: Studies have shown that patients receiving combined therapies exhibit improved survival outcomes, given the complexity associated with HCCIVCTT, we prioritized surgical resection as the primary therapeutic intervention. Surgical resection has been established as an effective strategy to improve survival rates in patients with localized HCC (15,16). In our cohort, we did not administer sorafenib or thalidomide primarily due to the specific indications for these treatments not aligning with our patient population. Sorafenib is generally indicated for advanced HCC in systemic therapy contexts (17). Our subjects were undergoing surgical intervention specifically for localized tumor thrombus in the liver and IVC, which we believe makes timely surgical treatment more critical than systemic therapies at this stage. This approach is supported by literature indicating that early surgical intervention significantly improves prognosis (18). In this study, for certain cases of recurrence, we adopted a combined approach of surgical resection and TACE for patients with HCCIVCTT. This strategy aims to enhance treatment efficacy and improve patient outcomes. As the follow-up period extends, we may have more comprehensive treatment options, through ongoing clinical research and data accumulation, we aim to offer more personalized and effective treatment plans for patients.

The greatest risk in the surgical treatment of HCCIVCTT is the potential dislodgment of the tumor thrombus during the operation, which can be fatal for the patient (19). CT, MRI, and abdominal ultrasound are commonly used imaging modalities for evaluating HCCIVCTT, and each has its distinct advantages and disadvantages. For example, enhanced CT can accurately detect HCCIVCTT, but its effectiveness can vary due to factors such as the concentration, dosage, and injection speed of the contrast agent. Moreover, mixing of the contrast agent with blood and turbulence at vascular junctions can also lead to false positives. MRI can noninvasively determine the presence of IVC thrombus, showing the location of the tumor thrombus and whether the vessel wall is involved. Enhanced scans can help distinguish between tumor thrombus and blood clot. However, MRI is expensive and time-consuming, and the image quality can be compromised by patient movement, making it less suitable for critically ill patients.

Conventional transabdominal color Doppler ultrasound can promptly detect floating thrombi and dynamically observe them, providing some useful information for the diagnosis of HCCIVCTT (20,21). It can also assess the risk of the thrombus and, when combined with contrast-

enhanced ultrasound, can differentiate between the tumor thrombus and blood clot. However, due to the pulsation of the heart, it can often be difficult to accurately measure the blood flow spectrum around the tumor thrombus with transabdominal color Doppler ultrasound. Contrast-enhanced ultrasound can improve visualization of blood flow within the thrombus, but its accuracy heavily depends on the doctor's experience and is less effective in obese patients. Additionally, these imaging methods cannot be used intraoperatively and cannot monitor the position of the tumor thrombus in real time.

TEE, with its advantages of real-time imaging and noninvasiveness, has already been applied in the evaluation of liver structures and the diagnosis and treatment of diseases (22-24). It also holds considerable potential for use in the perioperative period of HCCIVCTT treatment. Comprehensive preoperative TEE examination after anesthesia induction is crucial, as TEE can further probe from behind the heart via the esophagus, verifying the results of preoperative routine transthoracic echocardiography to avoid omissions and correct any preoperative misdiagnoses. TEE was used in the perioperative period for all patients in this study, demonstrating significant advantages.

With the probe the placed in the esophagus, TEE can examine the tumor thrombus closely from behind the heart without affecting the sterile surgical field. Intraoperative TEE can clearly display the echogenicity and morphology of the tumor thrombus; comprehensively analyze the relationship between the tumor thrombus and the IVC wall, atrial, ventricular walls, and valves, and assess the activity of the tumor thrombus between the IVC and the right atrium.

Color Doppler and spectral Doppler can provide information on the direction and velocity of blood flow between the tumor thrombus and the IVC wall, determining if the tumor thrombus is causing obstruction and accurately assessing the degree of obstruction. Intraoperative TEE precisely locates the lesion, clarifies HCCIVCTT classification, and guides surgical operations under real-time monitoring throughout the procedure, significantly reducing the risk of tumor thrombus dislodgment and guiding the placement of preocclusion bands (25).

We combined TEE with traditional imaging methods (such as CT and MRI) to provide a comprehensive assessment perspective. This allows for the correction and refinement of preoperative diagnoses, timely detection of disease progression, and assists clinicians in formulating more personalized treatment plans. In this study, one case of tumor thrombus invading the IVC wall was detected, where the wall continuity was interrupted, and the tumor thrombus boundaries with surrounding tissues were unclear; in this case, TEE provided important reference value for the choice of surgical method, based on the detailed images from TEE, we found that the extent of invasion was relatively minor, requiring only partial resection of the IVC wall and the tumor thrombus, along with careful IVC reconstruction to restore vascular continuity. Another type III HCCIVCTT, as diagnosed by preoperative MRI, was found to be 1 cm away from the IVC valve during intraoperative ultrasound, and its detection led to timely adjustment of the surgical method and the ability to avoid extracorporeal circulation. Additionally, one patient diagnosed as type I HCCIVCTT by preoperative CT was identified as type II during intraoperative TEE, which in contrast to the CT scan, indicated progression of the disease and expansion of the tumor thrombus. Intraoperative ultrasound promptly corrected the diagnosis and facilitated adjustment of the surgical method, preventing tumor thrombus dislodgment due to inappropriate surgical method choice.

Postoperative TEE can further confirm if the tumor thrombus has been completely removed (26-28) and is safe, cost-effective, and repeatable (29). The use of TEE throughout the surgery is significant for monitoring the tumor thrombus, allowing for real-time observation of any dislodgment and ensuring the preocclusion band is placed above the tumor thrombus in patients with type I and II HCCIVCTT. Intraoperative TEE's real-time monitoring of cardiac structure and hemodynamics can quickly assess any volume deficiencies, cardiac dysfunction, or pulmonary embolism, aiding in anesthesia management, especially when the surgeon extracts the tumor thrombus from the IVC. Our study highlights the importance of postoperative monitoring, and early detection of potential problems can help improve patient outcomes, especially in HCC patients with tumor thrombosis. Our findings not only provide new ideas for the management of HCC patients, but also provide direction for future research, highlighting the potential value of integrating different imaging techniques in the clinic.

Strengths

In our study, we emphasized the application of multimodal TEE in the resection of HCCIVCTT. Specifically, the main contributions of our study are reflected in the

following aspects:

Innovative use of TEE

The study highlights the innovative application of multimodal TEE during surgeries for HCCIVCTT. TEE's real-time monitoring provides dynamic guidance, enabling precise surgical decisions, which is a significant contribution to the field.

Real-time intraoperative monitoring

TEE helps in accurately determining tumor thrombus location, guiding placement of occlusion bands, and evaluating tumor removal success during and after surgery, reducing risks of complications such as pulmonary embolism. By using the multimodal software, we were able to assess the contractile function and volume changes of the right ventricle in real time during the surgery, providing critical immediate feedback to the surgeons that helps in better adjusting surgical strategies. This dynamic monitoring capability has not been thoroughly explored in previous studies.

Method of comprehensive assessment

We combined TEE with traditional imaging methods (such as CT and MRI) to provide a comprehensive assessment perspective. Our study indicates that this integrative approach can enhance the accuracy of preoperative, intraoperative, and postoperative evaluations for patients with HCC, assisting clinicians in formulating more personalized treatment plans.

Impact on clinical decision-making

We found that the application of multimodal TEE not only helps improve postoperative outcomes but also reduces the occurrence of surgical complications. This finding, when integrated with current clinical practice, may offer new insights into the treatment of HCC with tumor thrombus.

Filling gaps in the literature

Although the use of TEE in HCC treatment has been previously studied, our prospective data collection and analysis further clarify its value in specific surgical scenarios. This provides a foundation for future research and clinical practice and offers new reference points for clinicians dealing with similar cases.

Comprehensive Multidisciplinary Approach: The study included collaboration between hepatobiliary surgeons, cardiac surgeons, and echocardiography physicians, ensuring well-rounded and accurate assessment and treatment.

Limitations

Small sample size

Due to the strict control of surgical indications for patients, the study included a limited number of cases. This restricts the generalizability of the findings. Nevertheless, larger sample studies are needed to better validate these results and confirm the effectiveness of TEE in similar cases. To improve the statistical power of the study, we plan to increase the sample size in future studies with the goal of including at least 50 patients. This will help improve the reliability of the results and make our findings more universally applicable. We will apply more rigorous statistical methods, including multivariate regression analysis and survival analysis, to comprehensively evaluate the effects of different treatment regimens.

Operator dependency

Compared with CT and MRI, TEE has the advantages of non-invasive, real-time and functional evaluation of cardiac structure. However, the operational dependencies and visualization limitations of TEE also need to be considered. Therefore, future research should explore the possibility of using these techniques in combination to achieve a more comprehensive diagnosis. We have ensured that proper training and standardization are implemented to achieve consistent results. This is essential for maintaining high-quality research and clinical practice. Such measures help reduce variability and improve the reliability and effectiveness of the data. As the research progresses, we will continue to reinforce these aspects to ensure the credibility of our findings.

Conclusions

We believe that the application of TEE in the perioperative period of HCCIVCTT is safe and feasible. TEE can play a crucial role in determining the type of tumor thrombus, selecting the surgical method, and assessing the completeness of tumor thrombus removal postoperatively. Future studies should look at expanding sample sizes and multi-center collaborations to validate our findings. In addition, the applicability of TEE in different clinical Settings should also be considered. Economic evaluation

of TEE in conjunction with other imaging methods will be an important next step to ensure that the diagnosis and treatment protocols adopted are economically viable and effective.

Acknowledgments

Funding: This study received funding from the Fujian Provincial Health Technology Project (No. 2021GGB002), the Fujian Provincial Natural Science Foundation Project (No. 2022J01403), and the Joint Funds for the Innovation of Science and Technology, Fujian Province (No. 2023Y9317).

Footnote

Reporting Checklist: The authors have completed the SUPER reporting checklist. Available at https://jgo.amegroups.com/article/view/10.21037/jgo-24-731/rc

Data Sharing Statement: Available at https://jgo.amegroups.com/article/view/10.21037/jgo-24-731/dss

Peer Review File: Available at https://jgo.amegroups.com/article/view/10.21037/jgo-24-731/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jgo.amegroups.com/article/view/10.21037/jgo-24-731/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by Ethics Committee of Fujian Provincial Hospital (No. k2017-10-002) and informed consent was taken from all the patients.

References

1. Singal AG, Kanwal F, Llovet JM. Global trends in hepatocellular carcinoma epidemiology: implications for screening, prevention and therapy. Nat Rev Clin Oncol 2023;20:864-84.
2. Pescatori LC, Galletto Pregliasco A, Derbel H, et al. Combination of intrahepatic TARE and extrahepatic TACE to treat HCC patients with extrahepatic artery supply: A case series. Res Diagn Interv Imaging 2024;9:100042.
3. Shukla A, Jain A. Hepatocellular Carcinoma with Hepatic Vein and Inferior Vena Cava Invasion. J Clin Exp Hepatol 2023;13:813-9.
4. Kinsey E, Lee HM. Management of Hepatocellular Carcinoma in 2024: The Multidisciplinary Paradigm in an Evolving Treatment Landscape. Cancers (Basel) 2024;16:666.
5. Lu J, Zhang XP, Zhong BY, et al. Management of patients with hepatocellular carcinoma and portal vein tumour thrombosis: comparing east and west. Lancet Gastroenterol Hepatol 2019;4:721-30.
6. Nishiwaki Y, Kusano T, Hiraiwa T, et al. Fifteen-year survival of a hepatocellular carcinoma extending into the right atrium treated by surgical resection with the heart-first approach under cardiopulmonary bypass: a case report and review of the literature. Clin J Gastroenterol 2024;17:118-29.
7. Yang J, Shui Y, Liu L, et al. Insights into treatment for hepatocellular carcinoma with tumor thrombus in the inferior vena cava or right atrium. Hepatobiliary Surg Nutr 2024;13:168-71.
8. Serper M, Parikh ND, Thiele G, et al. Patient-reported outcomes in HCC: A scoping review by the Practice Metrics Committee of the American Association for the Study of Liver Diseases. Hepatology 2022;76:251-74.
9. Kushiya H, Ambo Y, Takada M, et al. Right hepatectomy under cardiopulmonary bypass for hepatocellular carcinoma with inferior vena cava tumor thrombus: a case report. Surg Case Rep 2023;9:175.
10. Govalan R, Lauzon M, Luu M, et al. Comparison of Surgical Resection and Systemic Treatment for Hepatocellular Carcinoma with Vascular Invasion: National Cancer Database Analysis. Liver Cancer 2021;10:407-18.
11. Sakamoto K, Nagano H. Outcomes of surgery for

hepatocellular carcinoma with tumor thrombus in the inferior vena cava or right atrium. Surg Today 2018;48:819-24.
12. Chao WS, Shen CH, Luo SC, et al. Concomitant Hepatectomy and Atrial Thrombectomy under Cardiopulmonary Bypass versus Staged Hepatectomy in the Treatment for Hepatocellular Carcinoma with Large Right Atrial Tumor Thrombi. J Clin Med 2022;11:2140.
13. Kokudo N, Kokudo T, Hasegawa K. Role of Liver Resection for Hepatocellular Carcinoma with Vascular Invasion: Emerging Evidence from Western Countries. Liver Cancer 2021;10:404-6.
14. Han CL, Tian BW, Yan LJ, et al. Efficacy and safety of immune checkpoint inhibitors for hepatocellular carcinoma patients with macrovascular invasion or extrahepatic spread: a systematic review and meta-analysis of 54 studies with 6187 hepatocellular carcinoma patients. Cancer Immunol Immunother 2023;72:1957-69.
15. Fatehi Hassanabad A, Ball CG, Kidd WT. Inferior vena cava tumor thrombus: clinical outcomes at a canadian tertiary center. Perfusion 2024;39:1577-86.
16. Xia Y, Zhang J, Ni X. Diagnosis, treatment and prognosis of hepatocellular carcinoma with inferior vena cava/right atrium tumor thrombus. Oncol Lett 2020;20:101.
17. Uchikawa S, Kawaoka T, Murakami S, et al. Time trend of outcomes according to systemic therapy for patients with unresectable hepatocellular carcinoma: A single-institution study. Hepatol Res 2024. [Epub ahead of print]. doi: 10.1111/hepr.14130.
18. Tadokoro T, Tani J, Morishita A, et al. The Treatment of Hepatocellular Carcinoma with Major Vascular Invasion. Cancers (Basel) 2024;16:2534.
19. Zhang Y, Wu Z, Wang K, et al. Long-term survival after anterior approach right hepatectomy combined with inferior vena cava thrombectomy using trans-diaphragmatic intrapericardial inferior vena cava occlusion: a case report and review of the literature. BMC Surg 2019;19:122.
20. Tomita K, Shimazu M, Takano K, et al. Resection of recurrent hepatocellular carcinoma with thrombi in the inferior vena cava, right atrium, and phrenic vein: a report of three cases. World J Surg Oncol 2020;18:138.
21. Kolarich A, Frangakis C, Yarchoan M, et al. Transarterial Chemoembolization in Patients with Hepatocellular Carcinoma with Intra-atrial Tumor Extension: Imaging Response and Oncologic Outcomes. J Vasc Interv Radiol 2021;32:1203-1208.e1.
22. Seman MT, Alvord JM, Gorlin AW, et al. Nontraditional Transesophageal Echocardiographic Views to Evaluate Hepatic Vasculature in Orthotopic Liver Transplantation and Liver Resection Surgery. Transplant Direct 2020;6:e594.
23. Fadel BM, Kazzi B, Mohty D. Ultrasound Imaging of the Superior Vena Cava: A State-of-the-Art Review. J Am Soc Echocardiogr 2023;36:447-63.
24. Hansebout C, Desai TV, Dhir A. Utility of transesophageal echocardiography during orthotopic liver transplantation: A narrative review. Ann Card Anaesth 2023;26:367-79.
25. Abdelhady K, Karavites LC, Durgam S, et al. Metastatic right atrial hepatoma. J Card Surg 2017;32:368-9.
26. Thangaswamy CR, Manikandan R, Bathala Vedagiri SC. Role of transoesophageal echocardiography in renal cell carcinoma: a brief review. BMJ Case Rep 2017;2017:bcr2017221532.
27. Zacek P, Brodak M, Gofus J, et al. Renal cell carcinoma with intracardiac tumor thrombus extension: Radical surgery yields 2 years of postoperative survival in a single-center study over a period of 30 years. Front Oncol 2023;13:1137804.
28. Zlatanovic P, Koncar I, Jakovljevic N, et al. Transesophageal Echocardiography-Guided Thrombectomy of Level IV Renal Cell Carcinoma without Cardiopulmonary Bypass. Braz J Cardiovasc Surg 2019;34:229-32.
29. Russo A, Bergamini Viola E, Gambaro A, et al. Preoperative right ventricular strain as an early predictor of perioperative cardiac failure in patients undergoing mitral surgery: An exploratory study. Health Sci Rep 2024;7:e2172.

(English Language Editor: J. Gray)

Cite this article as: Lai B, Ye Y, Moris D, Donadon M, Ye Z, Lin J, Lan S. Multimodal transesophageal echocardiography in the surgical resection of patients with hepatocellular carcinoma and inferior vena cava tumor thrombus. J Gastrointest Oncol 2024;15(6):2588-2598. doi: 10.21037/jgo-24-731